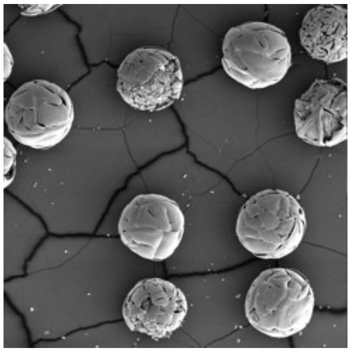
Environmental Services Association of Alberta

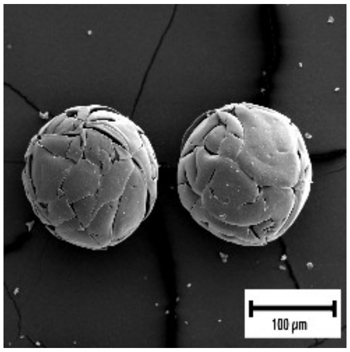
ESAA

Nanotechnology in the Environment Industry: Opportunities and Trends



Final Report and Bibliography
for the Nano-Environmental
Cross-Sector Initiative

March 4, 2005



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www.dk3.ca www.synchrocomm.ca www.chi3.ca

Supporters of the Nano-Environmental Cross-Sector Initiative

Alberta Economic Development
www.alberta-canada.com/aed

Alberta Environment
www3.gov.ab.ca/env

Alberta Innovation and Science
www.innovation.gov.ab.ca

Environment Canada
www.ec.gc.ca

Environmental Services Association of Alberta
www.esaa.org

Industry Canada
www.ic.gc.ca

NRC National Institute for Nanotechnology
www.nint.ca

Western Economic Diversification Canada
www.wd.gc.ca

The photos on the cover of this report are of sub-millimetre sized but nanostructured oxide beads. These are made by loading metal precursors onto ion exchange resin beads and then oxidizing the beads at low temperatures. The oxide beads are composed of oxide nanoparticles with excellent absorbent properties, but the approximate overall form of the original resin beads is retained. This makes the products large enough for practical industrial applications. Photos are courtesy Dr. Allen Apblett (Department of Chemistry, Oklahoma State University).

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Executive Summary

New technologies are needed by Alberta industry to help remediate existing environmental contamination and to reduce or prevent future pollution problems. Nanotechnology will likely be of great benefit to the environmental industry, especially in the areas of soil remediation, water purification, desalination, and high-sensitivity chemical sensors for field applications. The development and adoption of new approaches by industry will be accelerated if nanotechnology researchers are informed of relevant application opportunities and if the environmental industry is familiarized with nanotechnology solutions.

The Nano-Environmental Cross-Sector Initiative was established to facilitate these activities in Alberta. The partners in this Initiative were Alberta Economic Development, Alberta Environment, Alberta Innovation and Science, Environment Canada, Industry Canada, the National Institute for Nanotechnology (NINT), and Western Economic Diversification. The project was coordinated by the Environmental Services Association of Alberta (ESAA). The consulting firms DK^3 Scientific Ltd., SynchroComm Inc., CHI 3 Consulting Inc., and the Sekrijer Group were retained to deliver the project objectives:

- search the US patent database for relevant nanotechnologies,
- review the primary scientific literature,
- develop an industry survey,
- organize two major workshops, and
- write a final report.

The core areas chosen for all reviews and searches were soil and water remediation, water desalination, and field-based sensors, since these areas were considered to be of the most immediate interest to Alberta industry. The world literature searches and the US patent searches were designed to provide a reasonably representative selection of the information available, since a comprehensive search of either data set was well beyond the scope of the project. As it was, over 2000 electronic search hits were individually reviewed in the world literature search alone.

The US databases for both patents and patent applications were examined for records that were simultaneously relevant to both nanotechnology and one of these core areas, and a total of 711 patents and applications were found. All of these records are listed in an appendix and their full content may be freely accessed on line; full abstracts have been included for the most environmentally relevant entries. Patents and patent applications on the subjects of water purification and sensors were far more numerous than those on water desalination and soil remediation, indicating that the first two fields are further advanced.

A search of the scientific literature from 1995 to 2004 ultimately yielded 195 publications that combined nanotechnology with water desalination, water purification or soil remediation, and 263 that linked nanotechnologies with possible environmental sensor applications. The most popular subject for remediation was water, accounting for 104 out of 143 remediation publications, with the most common contaminants being water-soluble organics, halogenated compounds, and salts. Nanofiltration predominated in the techniques explored for remediation. In the area of sensors, four broad classifications of sensor types were seen: (i) chemical spectroscopy or electrochemistry, (ii) chemical separations, (iii) changes to micromechanical devices such as cantilevers, and (iv) biologically based systems. The most popular environmental analytes were gases, organic compounds, and biological materials. The literature search results are listed in bibliographies with a full reference and an abstract for each publication, as well as keywords and web links (some to the full text of the publication) for many entries. The literature review database is also available in the ProCite® (version 5) file format. Graphical analyses are presented of the groupings and trends found in the results of the literature and patent searches.

Many useful review articles were also located. Searches in the areas of purification and remediation found reviews of nano-scale iron for dehalogenation, nanoparticles for oxidation, nanofiltration to remove pollutants, and catalysts for remediation. Searches relevant to environmental nanotechnology sensors found reviews on topics such as nanomaterials for sensor construction, bioMEMS, biosensors, electrochemical sensors, molecular recognition, MEMS, nanowires, carbon nanotubes, biological pathogens, nanofluidics, optical sensors, metal oxides, self-assembly, and nanolithography.

A selection of environmental nanotechnology vendors is included, along with website references to more extensive listings.

Forty-five ESAA members responded to the industry survey. Only 6% of the respondents considered their organizations to possess a high level of knowledge of nanotechnology, while just 4% had either purchased or commercialized nanotechnology products or services. Only 9% were involved in R&D activities in this area. Overall, 51% of those who responded could not judge the potential for nanotechnology in their industry. The results confirmed that the level of nanotechnology awareness and application could be much improved in the environmental industry of Alberta.

Fifty participants attended the Calgary edition of the workshop “Environmental Applications of Nanotechnology”, and 45 were present at the identical workshop in Edmonton. These half-day workshops included a one-hour introduction to the field by a keynote speaker (Terry McIntyre, Environment Canada), a review of the literature search results (Ken Schmidt, DK^3 Scientific), and presentations by noted nanotechnology researchers on nanosensors (Steve Dew, University of Alberta) and on remediation using nanomaterials (Allen Apblett, Oklahoma State University). Brief overviews of the workshop presentations are included in this report. The workshops were also recorded on video, and have been edited into a DVD presentation available from ESAA. The slide presentations of the speakers are available on a CD from ESAA as Adobe PDF files.

The body of the report concludes with the following recommendations to the Alberta environmental industry:

1. Pursue upcoming opportunities in the area of micro- and nanotechnology sensors, whose applications may range from rapid and accurate mapping of site contamination to detecting pipeline leaks (with a methane gas sniffer). The small size of such sensors will allow their use in portable field devices and unmanned aerial vehicles. The experts at the University of Alberta (Dr. Steven Dew and others) are at the forefront of nanosensor research. The Alberta Research Council also has an active sensor group.

2. Pursue opportunities in the rapidly maturing technology of nanofiltration for water purification. Field applications will continue to evolve.

3. Pursue opportunities in remediation technologies based on nanotechnology. In particular, pursue opportunities in soil remediation. This area is growing slowly, but there is a high demand for better methods in Alberta and a potential for good returns on well-executed nanotechnology solutions. Field studies using nanocrystalline iron have been reported in Western Canada, and oxide-based solids are also showing promise. The platform technology developed by Dr. Allen Apblett (Department of Chemistry, Oklahoma State University) should be more closely examined as a possible solution for various remediation problems in Alberta.

4. Search the electronic versions of this report for relevant keywords or phrases (using the tools available in Microsoft Word® or Adobe Acrobat Reader®) to locate useful patents and literature references in Appendices B and C.

5. Explore the resources of Appendix D, including full-text reviews and websites relating to environmental nanotechnology. The Small Times and the NINT websites link to electronic newsletters that cover environmental nanotechnology events and developments. A link to a Canadian nanotechnology job website is also included.

6. Attend future nanotechnology workshops and forums, especially those including sessions on the environment.

7. Partner with nanotechnology researchers to shorten the learning curve and to decrease product development times.

8. Organize an industrial special interest group to pursue the development of environmental nanotechnology at the pre-commercial level. Successful examples of such groups may be found in the IT industry. NINT, ESAA, and various government agencies and departments may wish to participate.

Nanotechnology in the Environment Industry: Opportunities and Trends

1. Introduction

1.1 Background

Intensive oil and gas production has left Alberta with contaminated soil at several thousand well sites, and the petrochemical infrastructure and industrial development has contributed other site contamination problems.[1]

In addition, oil companies are being forced to consider alternatives to water injection for extracting oil and gas from depleting wells; water usage by oilsands projects is also an ongoing issue. A related environmental concern is the global consumption of water, which is increasing twice as fast as population growth. Many areas of the province depend upon irrigation for agricultural production, and intensive feedlot methods place strains on water resources and waste disposal practices. Water shortages have been worsened both by contamination problems and by the permanent removal of water from the ground supply.[2] Resolving these environmental challenges will have a multi-billion dollar price tag using current technologies.

Nanotechnology is a new and quickly expanding field, and will show its first commercial successes in the development of materials engineered on the nanoscale to provide useful properties that cannot be obtained by traditional manufacturing processes. Some of these new nanomaterials will have properties that will be of great benefit to the environmental industry in the areas of membrane technologies for filtration and desalination.

Effective pollution prevention and remediation strategies depend upon reliable and inexpensive chemical analyses to help to develop and implement programs in a timely and cost-effective manner. Traditional sample collection and lab analysis methodologies have limitations, and onsite real-time chemical measurements would be extremely useful if they were robust, cost-effective and scientifically valid.[3] Nanotechnologies are already being applied to the development of a growing number of new high-sensitivity chemical sensors for use in field applications.

The adoption of these cutting-edge instruments, methods and materials by the environmental industry will be accelerated if interactions can be enhanced: industry must be made aware of the developments in new nanotechnologies, and researchers must be made aware of the needs of the environmental industry to help tailor their research and development activities. This is the mandate of the Nano-Environmental Cross-Sector Initiative and this document is the final report for the project.

1.2 The Nano-Environmental Cross-Sector Initiative

A cross-sector team was established to examine issues that could be addressed with the use of nanotechnology in the environmental sector and to open up new opportunities for Alberta industry. The supporters of the Nano-Environmental Cross-Sector Initiative are

- Alberta Economic Development
- Alberta Innovation and Science
- Alberta Environment
- Environment Canada
- Industry Canada
- Western Economic Diversification
- NRC National Institute for Nanotechnology (NINT)

To enhance the interactions between the Alberta environmental industry and nanotechnology vendors and researchers, the initiative contracted the Environmental Services Association of Alberta (ESAA) to coordinate the project. The consulting firm of DK^3 Scientific Ltd. was retained to run the project, and SynchroComm Inc., CHI 3 Consulting Inc. and the Sekrijer Group were subcontracted to provide expert services to the project.

DK^3 Scientific Ltd. was asked to deliver a multi-component project that examined the potential for nanotechnology to impact environmental problems in Alberta. Relevant nanotechnology research results were to be obtained from the international scientific literature, from the US patent database, and from current researchers; the findings would then be summarized for the benefit of nanotechnology researchers and of environmental manufacturing and service companies. The complete project comprised the following eight components:

1. The international scientific literature was reviewed. The primary areas of focus were water purification, water desalination, soil remediation, and sensors for field-based chemical analysis. A search of US patents was also done to identify research that is close to the commercialization stage of development. These literature and patent searches were designed to provide a reasonably representative selection of the information available, since a comprehensive search of either data set was well beyond the scope of the project. As it was, over 2000 electronic search hits were individually reviewed in the world literature search alone. A short survey of industrial offerings was also performed to identify current products that utilize nanotechnology.

2. The most interesting results obtained from the literature and patent searches were presented in a 30-minute presentation given at environmental nanotechnology workshops organized on behalf of the Initiative.

3. A draft survey of the Alberta environmental industry (ESAA members) was prepared to identify companies interested in nanotechnology, their particular areas of interest, and their levels of nanotechnology expertise. The final survey was prepared in conjunction with the cross-sectoral team and was conducted by ESAA.

4. A short presentation was prepared for delivery at the ESAA RemTech 2004 conference in Banff to raise awareness of this project and to promote the subsequent workshops. A final presentation on the results of this project is scheduled to be delivered by DK^3 Scientific Ltd. at the ESAA RemTech 2005 conference.

5. Interviews were conducted with several nanotechnology researchers at major Alberta research centres such as the Alberta Research Council, the University of Alberta, the University of Calgary and NINT. Interviews were also conducted with appropriate experts in the environmental industry.

6. Researchers with expertise in water purification, soil remediation and chemical sensors were recruited to provide talks at two environmental nanotechnology workshops. One workshop was organized in Calgary and one in Edmonton. ESAA was primarily responsible for promoting industrial participation at the workshops, while DK^3 Scientific and NINT were responsible for organizing the program. These half-day workshops included a one-hour introduction to the field by a keynote speaker, a review of the literature results by DK^3 Scientific, and presentations by two noted nanotechnology researchers.

7. The workshop presentations were videotaped and professionally edited to provide a portable DVD presentation that will be useful to those in industry who were unable to attend in person.

8. This final report presents the results of the literature searches, the patent searches, and the industry survey along with a summary of the environmental nanotechnology workshops.

2. Results and Discussion

2.1 Introduction to Nanotechnology

Nanotechnology is a new and rapidly expanding field which crosses traditional boundaries of the sciences and engineering. Many definitions of nanotechnology have been formulated, as might be expected given the many different backgrounds and points of view of the researchers in this multidisciplinary field. Most definitions agree that nanotechnology involves objects or structures that are formed with a length-scale of 1 to 100 nanometres (nm) or billionths of a metre. At this size, materials often have properties that are different from those of similar bulk materials, and possessing these size-dependent novel properties and functions is the determining factor in defining something as nanotechnology.[4] This does not mean that the final objects need to be microscopic in size, as nanomaterials may be of normal dimensions, but they must be composed of building blocks (such as grain size or polymer fillers) that owe their useful properties to their nanometre length scales.

Another way of looking at this question is to consider the surface atom to interior atom ratio of nanomaterials versus regular materials. Atoms are exceedingly tiny; 10 hydrogen atoms lined up side by side are only 1 nm across. In a normal material, the number of surface atoms is insignificant as compared to number of atoms in the bulk, so the properties of the material are dominated by the properties of the bulk material. In a nanomaterial, however, the surface atoms make up a large fraction or even the majority of the atoms in the material. This causes surface atom properties and quantum mechanical effects within these small clusters of atoms to become of much greater important to the overall material, leading to the novel “nanoproperties” seen in these new materials.

This might be only of academic interest except that many of our most useful technologies rely on the surface-, electronic- and micro-structures of materials to function efficiently. Examples include catalysts, electronic circuits, optoelectronic devices such as lasers and LEDs, magnetic materials, absorbents, and high-technology materials of all kinds. Furthermore, biomaterials are also almost always nanostructured to provide exceptional strength-to-weight ratios (bones), electrical conductivity (nerves), or optical properties (corneas).[4]

2.2 Survey of the Environmental Services Industry

A survey of ESAA members was conducted to determine the current state of nanotechnology awareness and implementation within the Alberta environmental industry. Twelve questions were asked in an online survey that was emailed to all members of ESAA. Responses were obtained from 45 organizations. The survey and the analysis of the responses are presented in Appendix A.

Only 6% of the respondents considered their organizations to posses a high level of knowledge of nanotechnology, while just 4% had either purchased or commercialized nanotechnology products or services. Only 9% were involved in R&D activities in this area. Overall, 51% of those who responded did not know what the potential for nanotechnology would be in their industry.

These data serve to reinforce the mandate of this project: it is clear from this sample that the environmental industry in Alberta is still at the beginning of the learning curve regarding nanotechnology.

2.3 Current Products and Precommercialization of Nanotechnology for the Environmental Industry

2.3.1 Overview of the Size of the Environmental Market

There will be up-front costs to becoming involved with either developing or using nanotechnology-based environmental products. These will include at least the time required for the companies who are offering these products to educate themselves in this novel area. Will it be worth the necessary investment of time and money? A complete answer to this question requires an examination of the chances that nanotechnology will open up new market opportunities by solving environmental problems more cheaply or easily. It is conceivable that this will happen in the not too distant future, especially in the areas of focus for this study: soil and water remediation, water desalination, and field-based sensors.

Since it seems likely that new markets can be exploited using nanotechnology, what is the total size of the environmental market? The US Environmental Protection Agency (EPA) has estimated that the costs of complying with US Federal environmental regulations in the late 1990s were approximately 2.6% of GDP, or over US$200 billion.[5] Alberta numbers for soil remediation alone are in the multi-billion dollar range.[1] Chemical analysis requirements are conservatively estimated to be at least 20% of total costs, and therefore this represents a huge potential market for sensors. If the use of nanotechnology leads to a larger market share for Alberta companies in either of these areas, the potential size of these markets should easily compensate for the up-front investment costs.

2.3.2 Nanotechnology Vendors for the Environmental Market

This is a newly emerging field, and few information sources are currently available. The best leads are given in the *Small Times Directory* and the *Unofficial EPA List of Nanotechnology Products.* Some local product vendors and developers have also been found.

2.3.2.1 The Small Times Directory

The Small Times Directory is a very large web-based business directory developed by Small Times Media, “the first media company devoted entirely to the fast-growing industry that includes MEMS (microelectromechanical systems), microsystems, and nanotechnologies.” This directory is freely accessible at www.SmallTechDirectory.com. Representative companies in this area that sell products useful to the environmental industry are listed below. Their contact data are presented in Table 1.

Applied Nanotech Inc. (Austin, TX, USA)

- Sensors and nanomaterials:
  - H_2 and other gas sensors
  - Biosensors for chemical and bio warfare agents (CBWAs)
  - Remote detection of CBWAs
  - Silicon nanocrystals (quantum dots)
  - Catalysts for fuel cells
- CNT composites
- CNT electron sources:
  - Field emission displays
  - High intensity light sources
  - RF devices for radar
  - Miniature X-ray tubes
  - Portable X-ray instruments

Holographix LLC (Hudson, MA, USA)

Holographix offers nano-replication: a full spectrum of surface relief replication capabilities. Structures include diffraction gratings, moth-eyes, micro-lens arrays, and microfluidic channels ranging in feature size from 100 microns down to less than 10 nm. These can be reproduced in prototype or production volumes with high fidelity.

Hyper-Therm High-Temperature Composites, Inc. (Huntington Beach, CA, USA)

Hyper-Therm High-Temperature Composites, Inc. is a world leading producer of state-of-the-art high-temperature refractory composite materials, engineered coatings and thermostructural components using patented chemical vapour infiltration and deposition (CVI/CVD) process technology. Hyper-Therm HTC's nanolayering process enables the production of highly uniform microstructures with grain sizes ranging from about one molecular monolayer (~1 nm) to a thickness beyond the upper limit of grain refinement achievable from current state-of-the-art materials processing techniques (>150 nm). Available materials include $W\text{-}W_XC$ (patents pending), $Nb–NbB_2$, Nb–NbC, SiC–BN, and $SiC–Si_3N_4$.

Millennial Net, Inc. (Burlington, MA, USA)

Millennial Net delivers a platform that helps our customers build ultra-efficient, highly scalable, self-organizing wireless sensor networks. Millennial Net's components and software can be used to create reliable, low-power, ad-hoc wireless networks that can

- monitor environmental conditions and process-control variables;
- monitor machine activity and status;
- track assets, work in progress (WIP), inventory, and goods in transit;
- conserve energy and resources; or
- monitor and protecting personnel.

Applicable industries and markets include:

- industrial automation and process control;
- commercial building automation and facilities management systems;
- security and access control systems;
- defence, homeland security, and crisis management;
- automatic meter reading;
- home automation and appliance control;
- supply-chain management;
- telemetry and remote sensing; and
- medical and athletic performance monitoring.

Nanophase Technologies Corporation (Romeoville, IL, USA)

Nanophase Technologies is an industry-leading nanocrystalline materials innovator and manufacturer with an integrated family of nanomaterial technologies. The entire focus of Nanophase is nanotechnology, with two distinct and patented processes for the preparation and commercial manufacturing of nanopowder metal oxides; i.e. aluminum oxide, zinc oxide, cerium oxide, titanium dioxide, and several others. Nanophase Technologies Corporation has developed a process, Discrete Particle Encapsulation, to coat the surface of its nanoparticles with a thin polymeric shell that enables compatibility of the particles with a wide variety of fluids, resins and polymers. Also, Nanophase has developed technology to permit the dispersion of its nanoparticles in water and a variety of polar and non-polar organic fluids. This allows Nanophase to supply concentrated, ready-to-use nanoparticle dispersions, eliminating the need for customers to disperse the nanoparticles themselves. Nanophase’s family of integrated technologies economically produces nanocrystalline materials, and then engineers those materials to fit a customer need.

An enhanced capability of Nanophase is the ability to process complex multi-component materials. This process has demonstrated the ability to produce homogeneous mixed metal oxide nanopowders where the component materials form solid solutions with well-defined single crystalline phases. Nanocrystalline metal oxides having up to four metallic elements have been successfully produced. Nanophase has the capability to produce a wide variety of single-phase pure and mixed rare earth oxides, as well as pure and mixed transition metal oxides and main group metal oxides. The materials produced by this process have application in ultrafine polishing and chemical-mechanical planarization (CMP), catalysis, fuel cells, electronic materials, and advanced imaging.

The use of nanomaterials based on rare earth metal oxides allows for the preparation of thinner active layers, which can mean less precious metal usage in catalysis applications. These nanomaterials also allow for the preparation of higher solids dispersions that are very stable, minimizing the number of coating steps and losses due to flocculated dispersions. Automotive catalytic converters are a key focus area for catalyst performance. While government regulations continue to drive lower acceptable emissions levels of carbon monoxide, hydrocarbons and nitrogen oxides, automotive companies are attempting to lower the use of precious metals (such as platinum, palladium and rhodium) in the catalytic converter, thereby lowering costs while still meeting more stringent performance standards. Diesel engines are beginning to be subject to regulations similar to those of gasoline engines.

One way to achieve lower emissions in a cost-effective manner is to utilize co-catalysts that provide good oxygen storage capability and thermal stability in thinner layers. NanoArc^{TM} ceria and mixed-rare-earth metal oxides meet the criteria necessary to enhance catalytic converter performance when properly incorporated into a catalyst system. Because they are dense, single phase individual crystals, there is nothing to collapse during thermal cycling. The same materials can be used in other types of environmental catalysts, such as exhaust converters for stationary and large internal combustion engines, for chemical scrubbers, and for other gaseous products and waste streams.

QuantumSphere, Inc. (Costa Mesa, CA, USA)
QuantumSphere, Inc. is a leading manufacturer of metallic nanopowders for aerospace, defence, energy, automotive and other markets demanding advanced material applications. QuantumSphere produces large volumes of the world's highest quality nanonickel for applications that improve the efficiencies of storing and generating new sources of power. It also produces nanoaluminum for breakthrough propellants, munitions and other energetic applications. QuantumSphere's nanonickel and nanoaluminum powders are being used and evaluated in numerous applications, including as components for fuel cells and membranes such as energy catalysts, platinum metal group replacement, and filtration membranes. Other uses include as additives for plastics or sealants, as high-performance surface coatings, and as electromagnetic frequency (EMF) shielding.

Sensicore (Ann Arbor, MI, USA)
Sensicore’s innovative micro-sensor development has successfully produced lab-on-chip multi-parameter water analyzers for measuring pH, ORP, conductivity, TDS, free and total chlorine, monochloramine, hardness, alkalinity and ammonium simultaneously in less than 4 minutes. This is suitable for a wide variety of water and wastewater applications from process control to environmental monitoring. The technology is based on a disposable silicon chip (the size of a small button) that incorporates chemical selective sensors and physical measurement devices to chemically profile a sample as small as a single drop. Micralyne Inc. of Edmonton, Alberta (www.micralyne.com) recently announced that it has renewed and expanded an agreement for the development and manufacture of Sensicore's multi-sensor chip systems. Micralyne will manufacture Sensicore's disposable silicon chip system as the ramp-up to commercial volume production begins. (Micralyne Inc. is listed in Appendix D).

SouthWest NanoTechnologies (Norman, OK, USA)
SWeNT is dedicated to being the world's leader in the production of high-quality single-wall carbon nanotubes and for enabling and enhancing commercial applications in the areas of electronics, structural composites, fuel cells, catalysts, and coatings.

Texas Instruments Inc. - DLP Products (Plano, TX, USA)
This division of Texas Instruments produces the DMD Discovery 1100-DLP technology developers kit. This technology is designed to enable non-projector applications of Texas Instruments' Digital Micromirror Device (DMD) components, which is the same light modulation technology used in DLP projectors and TVs. DMD Discovery products enable the system developer to load binary data into the DMD and create light patterns with high update rates. Discovery products are flexible (by design) to facilitate exciting new products based on DLP technology. The kit includes an easy-to-use interface along with comprehensive data sheets and schematics.

Table 1. Contact information for selected companies in the Small Times Directory

Applied Nanotech Inc.	3006 Longhorn Boulevard, Suite 107 Austin, TX 78758 USA Tel: 512-339-5020 Fax: 512-339-5021 E-mail: zyaniv@appliednanotech.net Website: www.appliednanotech.net
Holographix LLC	577 East Main Street, Suite 260 Hudson, MA 01749-3054 USA Tel: 978-562-4474 Fax: 978-562-4182 E-mail: info@holographix.com Website: www.holographix.com
Hyper-Therm High-Temperature Composites, Inc.	18411 Gothard St., Units B&C Huntington Beach, CA 92648 USA Tel: 714 375-4085 Fax: 714 375-4087 E-mail: info@htcomposites.com Website: www.htcomposites.com
Millennial Net, Inc.	2 Fourth Avenue Burlington, MA 01803 USA Tel: 1 781-222-1030 Fax: 1 781-222-1039 E-mail: info@millennial.net Website: www.millennial.net
Nanophase Technologies Corporation	1319 Marquette Drive Romeoville, IL 60446 USA Tel: 630-771-6700 Fax: 630-771-0825 Sales e-mail: sales-marketing@nanophase.com Research Materials e-mail: products-inquiries@nanophase.com Tech Support e-mail: techsupport@nanophase.com Website: www.nanophase.com

QuantumSphere, Inc.	1041 West 18th Street, Suite B102 Costa Mesa, CA 92627 USA Tel: 949-574-3000 Fax: 949-574-3010 E-mail: info@qsinano.com Website: www.qsinano.com
Sensicore Inc.	755 Phoenix Drive Ann Arbor, MI 48108 USA Tel: 734-528-6300 Fax: 734-528-6301 E-mail: sales@sensicore.com Website: www.sensicore.com
SouthWest NanoTechnologies (SWeNT)	2360 Industrial Blvd Norman, OK 73069 USA Tel:405-217-8388 E-mail: info@swnano.com Website: www.swnano.com
Texas Instruments DLP Products	6550 Chase Oaks Blvd Plano, TX 75023 USA Tel: 1-888-DLP-by-TI (1-888-357-2984) Website: www.dlp.com

2.3.2.2 The Unofficial EPA List of Nanotechnology Products

The Unofficial EPA List of Nanotechnology Products, generated by the US Environmental Protection Agency (EPA), is an unofficial list of products based on nanotechnologies that were of interest to the EPA. It was distributed at a dialogue on nanotechnology at the Woodrow Wilson International Center for Scholars in Washington, DC, held on May 18, 2004. It is freely available at www.etcgroup.org/documents/nanoproducts_EPA.pdf. Representative examples from this listing are given below:

- Catalysts in the petroleum industry
- Carbon black in tires
- Superlattices in optoelectronic devices
- Plasma spray of nanostructured coatings
- Nanocrystalline titanium dioxide in sunscreens
- Silver nucleation in photographic film
- Chemical mechanical polishing (CMP) slurries in the electronics industry
- Sunscreening agents

2.3.2.3 Canadian Developers or Suppliers of Environmental Nanotechnology

A few local companies are involved in this area; two examples are shown here.

Artsinteg Corporation (Edmonton, AB)

Artsinteg Corporation is an Edmonton-based developer of nanosensors. Its mission is to be an innovative provider of biodetection systems by applying the most recent advances in the nanotechnology, bioMEMS, and information technology fields. Its ultimate business model is to develop and commercialize cost-effective, user- and environment-friendly integrated systems for various applications that will enhance the health, safety, and welfare of the public in a socially responsible manner. The company's focus is on the development and commercialization of miniaturized (from micro to nano) real-time diagnostic integrated devices (MEMS, fluidics, optronics, and software) for applications in the oil and gas, veterinary, medical, environmental, and biochemical testing industries. The company can also provide industrial partners with the cost-effective technical solutions by integrating functionalities and miniaturizing subsystems.

BI PureWater (Canada) Inc. (Surrey, BC Canada)

BI Pure Water (Canada) Inc. is a BC company with an Alberta presence, and is a vendor of systems that filter drinking water to less than 1 micron. A major goal of the company is to provide mobile water treatment plants capable of providing potable water, no matter what the source. Currently they design, manufacture, and commission custom water-treatment plants. They produce small resort to small community potable water treatment plants from 20gpm to 15mgpd. The company focuses are on chlorination, filtration, and Giardia and Cryptosporidium removal. Nanofiltration product information is available at www.bipurewater.com/html_product_harmsco_one_micron_absolute_cartridges.html and www.bipurewater.com/html_product_all_poly_filter_cartridges.html.

Table 2. Contact information for selected Canadian vendors of nanotechnology.

Artsinteg Corporation	5008 - 122A Street Edmonton, AB Canada T6H 3S7 Tel: 780-443-5881 Fax: 780-456-8594 Email: huy@artsinteg.com Website: www.artsinteg.com
BI PureWater (Canada) Inc.	#255, 19358 - 96th Ave. Surrey, BC Canada V4N 4C1 Tel: 604-882-6650 Alberta Tel: 403-720-6696 Toll Free: 1-888-901-3111 Fax: 1-888-882-6659 E-Mail: info@bipurewater.com Website: www.bipurewater.com

2.3.3 Review of the Patent Literature

A useful indication of precommercial interest in new technologies is the patent literature, as many researchers and organizations patent new processes and products for protection before they reach the market. Even newer findings show up in the patent application database, which contains public records of inventions are so recent that they are still in the review stage and have not yet been granted patents.

For legal and market reasons, US patents are often applied for first, even if other patents such as European and Canadian may eventually be obtained as well. We therefore searched the US patent literature for both patents and patent applications in our target areas of nanotechnology applications of water desalination, soil and water remediation, and field-based sensors. The results and the search strategies used to obtain them are given in Appendix B. The most promising items with respect to environmental applications have the complete patent abstract included in the tables, while the less interesting results include only the titles. All the results include the patent number or patent application number so that the full record can be obtained readily on line.

Figure 1 shows a summary of the results obtained from the patent search. Judging from the number of entries in the patent database, water purification using nanotechnology is a more mature area than the others, with 196 patents and 225 patent applications found. This is likely due to the natural progression in filtration technology over time, with microfiltration having given way to ultrafiltration over the last twenty years, which is in turn now being augmented by nanofiltration using novel nanoporous filter media. Nanotechnology and water desalination is a more specific area than purification, and thus shows a lesser number of entries with 38 patents and 19 patent applications. Nanotechnology as applied soil remediation is also only beginning to provide results, with 13 patents and 2 patent applications. In contrast, nanosensors are an active area, with 125 patents and 93 patent applications. Overall, 711 patents and patent applications in all four areas of interest were found in the database searches. The patents and patent applications most relevant to the environmental area are plotted against the year of publication in Figures 2 and 3. As before, sensors are revealed to be the most active research area.

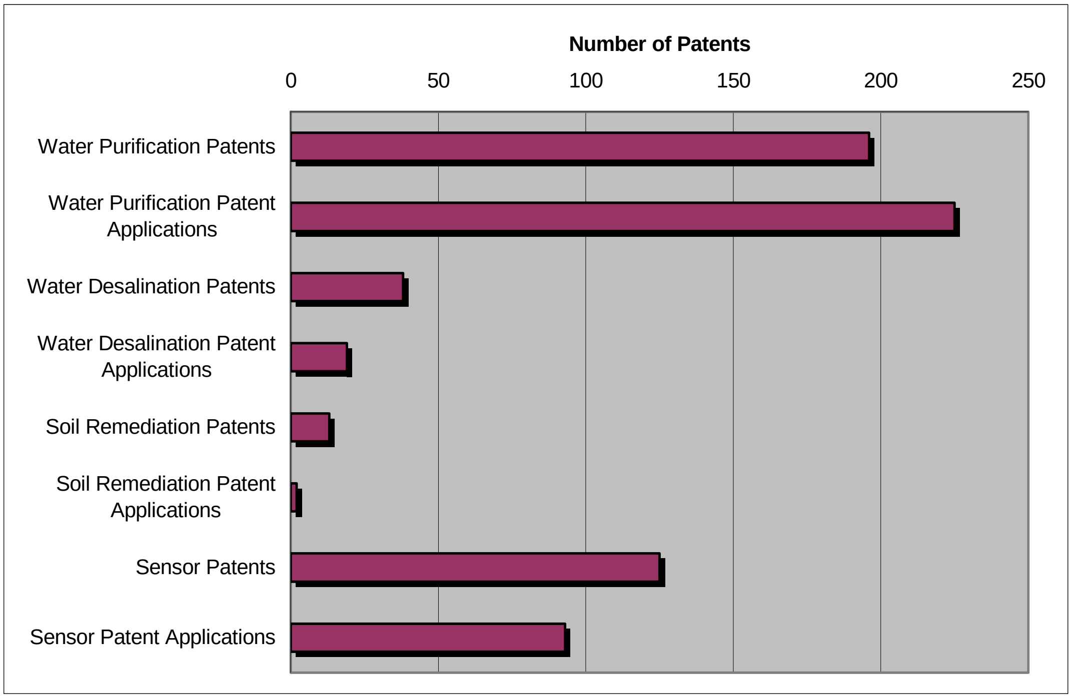


Figure 1. Nanotechnology patents and patent applications by area as found in a search of the US Patent Database. See Appendix B for search strategies, titles and abstracts.

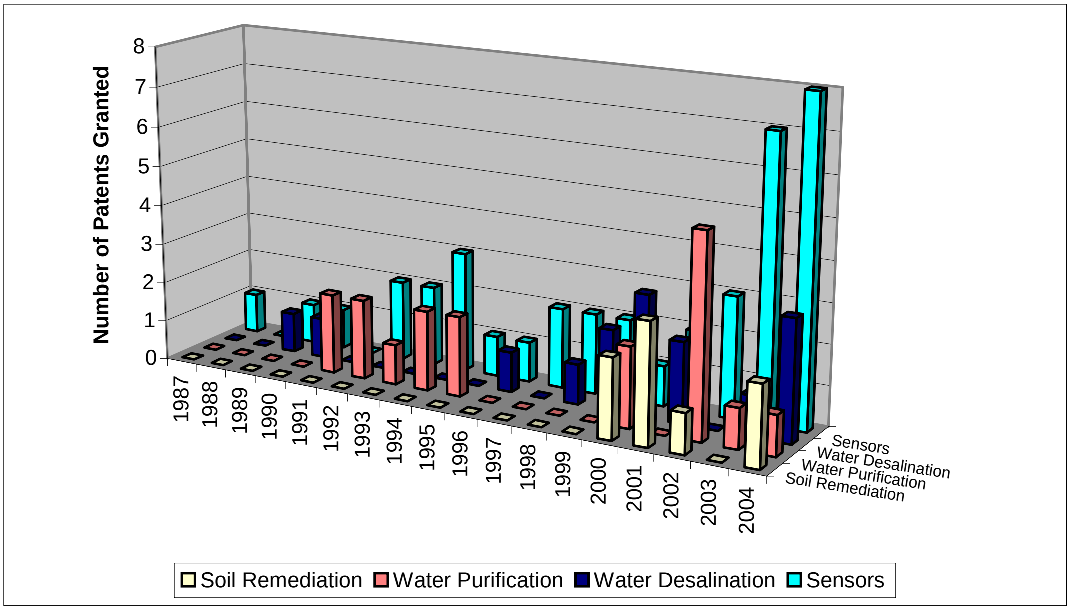


Figure 2. Relevant US nanotechnology patents by year. These are only the patents for which abstracts are included in Appendix B.

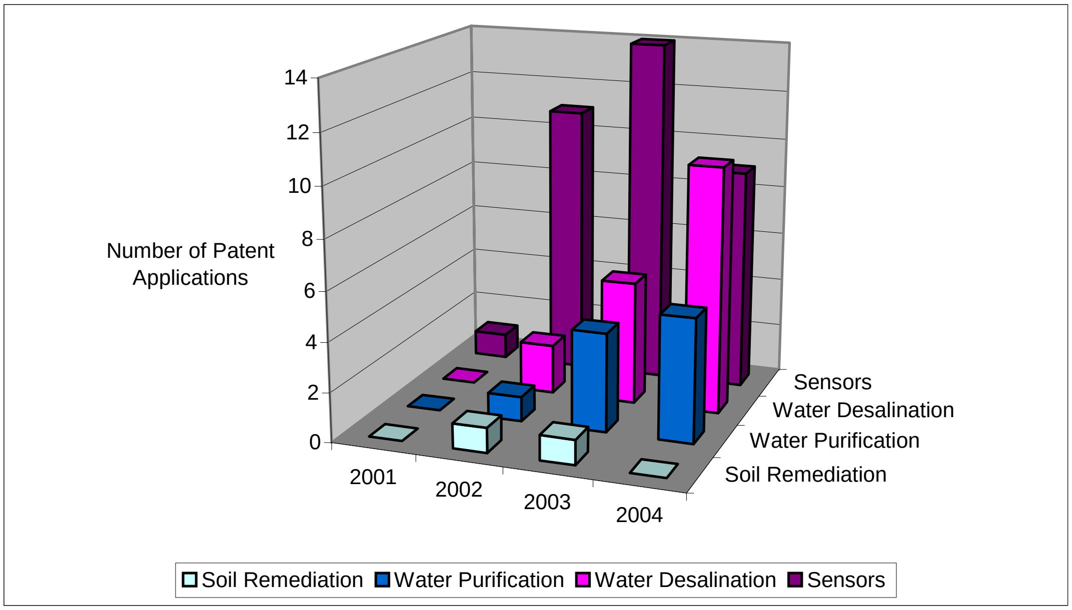


Figure 3. Relevant US nanotechnology patent applications by year. These are only the patent applications for which abstracts are included in Appendix B.

2.4 Review of the Scientific Literature

Environmental nanotechnology is a new area that is evolving at a rapid pace, and therefore a review of the primary scientific literature is essential. Topics that can be found only in scientific journals at present may become new commercial processes or products in the near future. Access to a survey of the literature will help to properly position Alberta industry for nanotechnology advancements soon to come.

As with the patents searches, the focus of the literature review was nanotechnology research into soil and water remediation, water desalination, and sensors for environmental analysis. Up to five different databases were used for each search: Compendex 1995+, AS&TA 1996+, NTIS 1995+, ScienceDirect 1995+, and the Internet, generating over 2000 hits that were individually reviewed. The publications selected from the electronic searches were entered into a database and further classified into smaller groups to provide additional details on the areas of research. The resulting literature review database is available in the ProCite® (version 5) file format, but full bibliographies of the database contents (together with the search parameters) are also presented in Appendix C. These bibliographies include titles and full abstracts, which may be searched for key words and phrases within the electronic versions of this report using standard tools available in both Microsoft Word® and Adobe Acrobat Reader®.

The searches for primary scientific literature also identified a variety of focused review papers and news articles relevant to nanotechnology: 36 in the area of soil and water remediation and water desalination and 82 relating to sensors. These publications are listed in Appendix C, as sections C1 and C3 respectively.

Searches in the areas of purification and remediation found reviews of nanoscale iron for dehalogenation,[6,7] nanoparticles for oxidation,[8,9,10,11] nanofiltration to remove pollutants[12,13] and catalysts for remediation.[14] Searches relevant to environmental nanotechnology sensors found reviews on topics such as nanomaterials for sensor construction,[15,16] BioMEMS,[17] biosensors,[18,19] electrochemical sensors,[20,21] molecular recognition,[22] MEMS,[23] nanowires,[24] carbon nanotubes,[25,26] biological pathogens,[27,28] nanofluidics,[29] optical sensors,[30] metal oxides,[31] self-assembly,[32] and nanolithography.[33]

The primary research papers and reports in the corresponding areas are presented separately in Appendix C as sections C2 and C4, with the former containing 159 records for remediation and desalination and the latter 184 records for sensors. Summary graphs and analysis of the search results are presented on the following pages. These publications frequently dealt with more than one subject and hence were assigned to more than one category in many cases.

Figure 4 shows the year-by-year increase in the total number of environmental nanotechnology publications seen in the scientific literature in all areas that were investigated for this study. The number of publications has been almost doubling each year since 2000, which indicates a research area that is undergoing a rapid expansion in interest and effort.

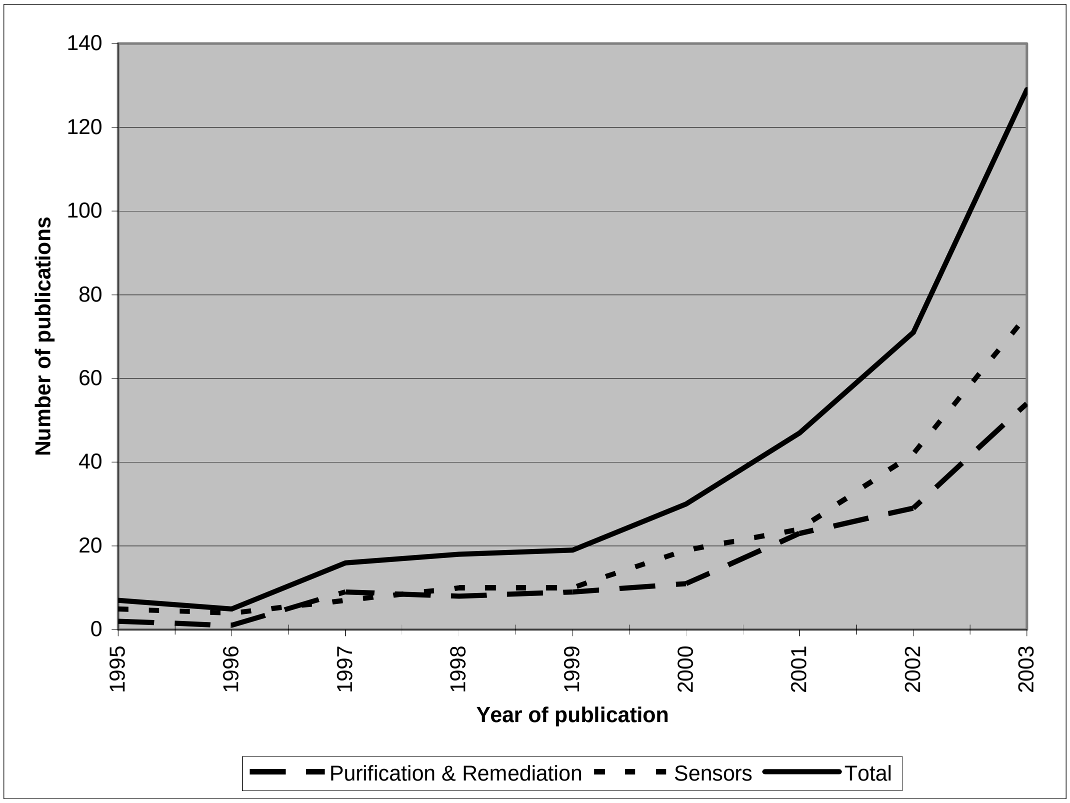


Figure 4. The number of nanotechnology publications found on soil and water remediation topics, on sensor topics, and the total data set plotted versus year of publication.

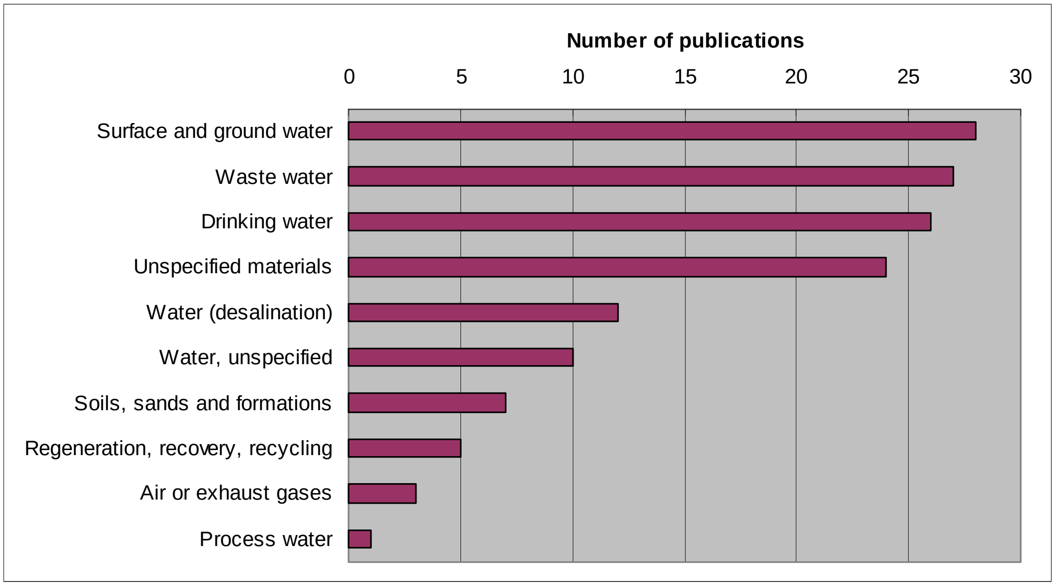
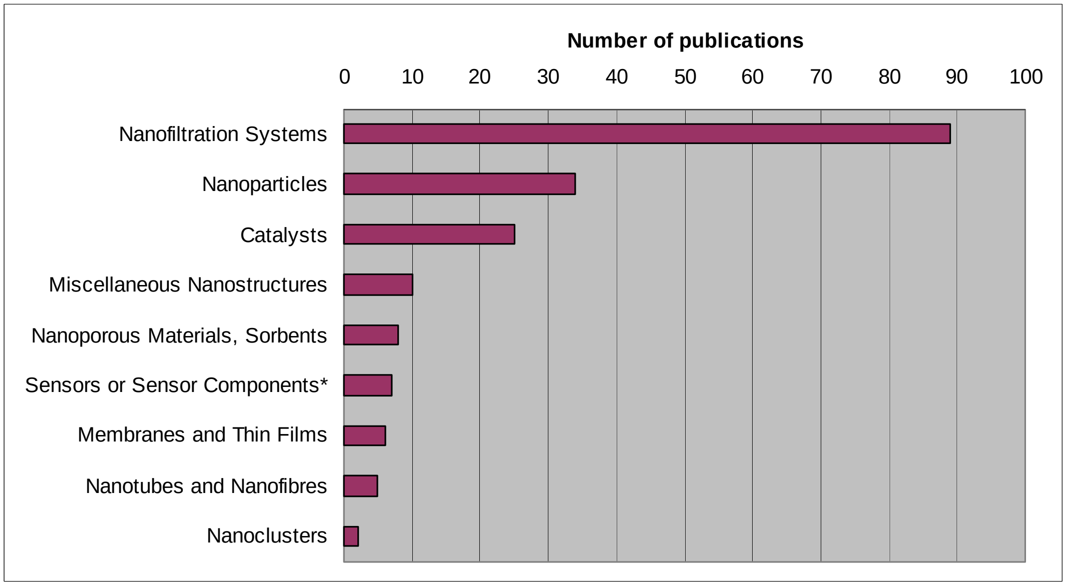


Figure 5. Subject categories found for soil and water remediation publications.



* These are sensor records that were found in searches for articles referring to nanotechnology as well as either soil remediation, water purification or water desalination. They were recorded separately from those listed the two bibliographies on sensors in appendix sections C2 and C4.

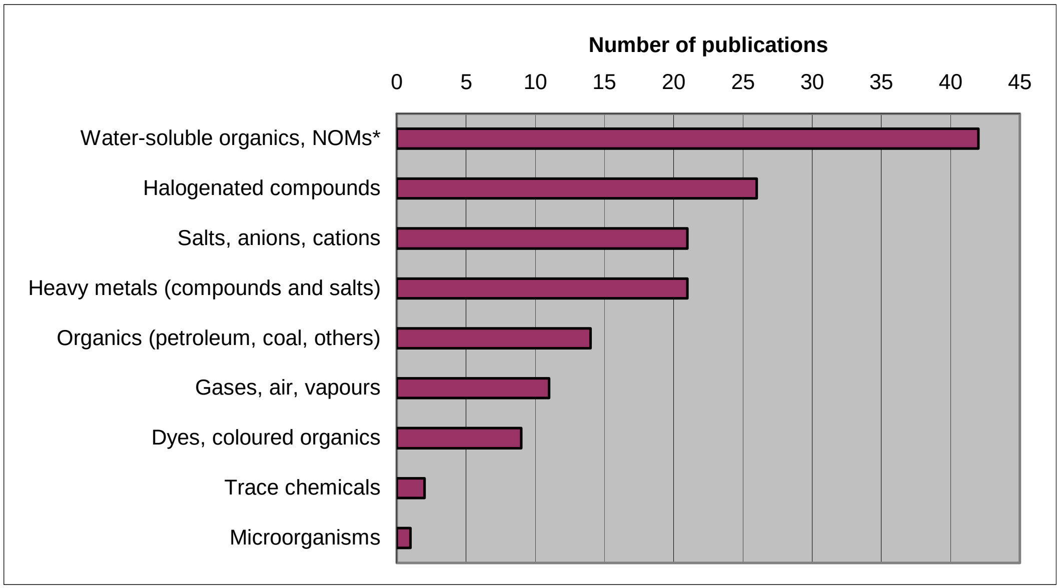
Figure 6. Soil and water remediation publications categorized by type of nanotechnology.

There were 195 purification and remediation publications found, as well as 263 sensor publications, giving 458 environmental nanotechnology publications in total. Bibliographic data for all of these are presented in Appendix C.

Figure 5 provides an outline of nanotechnology remediation publications broken down by area of interest. Water in various forms is by far the most common subject for purification and remediation, accounting for 104 entries out of the 143 publications found.

Figure 6 depicts the search results for remediation and purification by nanotechnology type. As was seen for the patents, nanofiltration systems predominate in this area. Since filtration of all types is a well understood and often-used technology, the extension of this technology down to nanofiltration is not surprising. Nanoparticles, nanocatalysts, and nanostructures all derive their reactive properties from their size, and are important nanotechnology research areas, while nanoporous materials and sorbents are similar to nanofilters in their properties. Membranes and thin films are one-dimensional nanomaterials (in thickness), and can act as selective migration barriers to chemical compounds. Finally, nanotubes, nanofibres and nanoclusters are all novel nanomaterials that can have interesting conducting properties useful in electrochemical cells for remediation and desalination. There were 186 publications in total in this analysis.

Figure 7 displays the variety of chemical compounds that are currently being investigated as candidates for nanotechnology-based remediation strategies. Research is progressing primarily on water-soluble organic compounds, water-insoluble and halogenated organic compounds, and on dyes. These make up the largest fraction of publications reported, at 91 out of a total of 147 publications. Inorganic salts and heavy metals form another substantial grouping, at 42 publications in total.



* Natural organic materials.

Figure 7. Soil and water remediation publications categorized by industrial application.

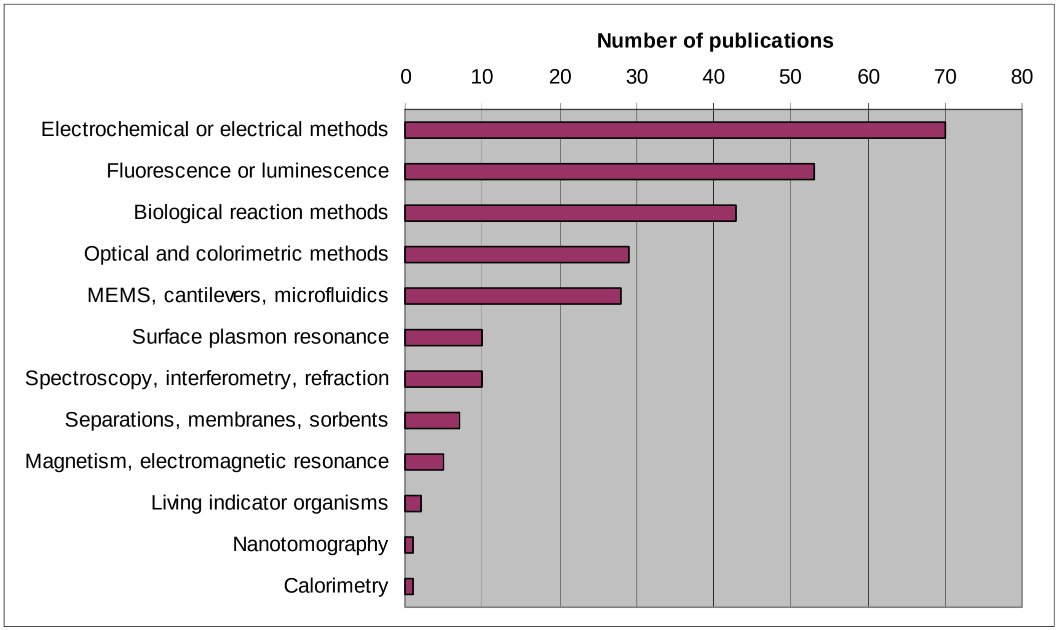


Figure 8. Sensor publications categorized by sensing method.

Figure 8 details the types of sensing methods currently under investigation for use with environmental nanosensors. Four broad classifications can be seen, (i) chemical spectroscopy or electrochemistry, (ii) chemical separations, (iii) changes to mechanical devices such as cantilevers, and (iv) biologically based systems. The first classification predominates to some degree, but all areas are well represented in the total of 259 publications that were found.

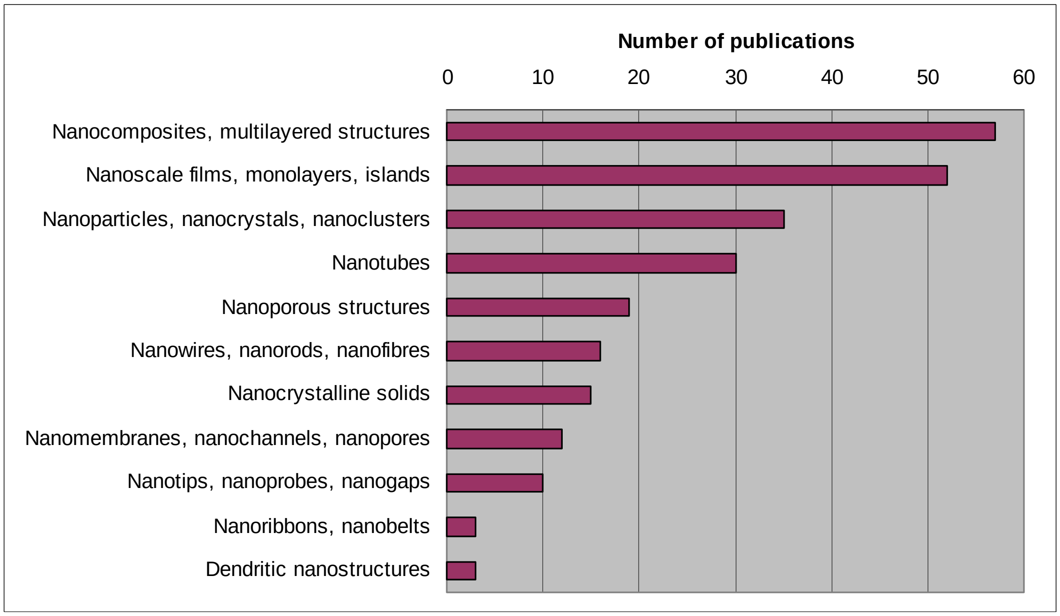


Figure 9. Sensor publications categorized by type of nanotechnology.

Many different types of nanotechnology can be used to develop nanosensors for environmental applications, as can be seen in Figure 9. Two major groups are represented in this graph. The first is nanomaterials with separation properties: nanoporous structures, nanomembranes, nanochannels, nanopores and films. These can be used to selectively allow only certain environmental analytes to react with the nanosensors, thereby providing chemical discrimination to the device. The other group includes nanomaterials with novel chemical, electrical or optical properties due to their small size, and these properties are used to form the active elements of the nanosensors. A total of 252 publications provided the data for this figure.

No one type of determination predominates among the various environmental analytes currently being investigated in the scientific literature, as can be seen in Figure 10. Gases, vapours, and nerve agents represent a large fraction of the compounds under investigation, likely due to both their ease of sampling and to homeland security concerns regarding the quick and easy determination of airborne toxins. Biological compounds are also well represented, as befits the current level of interest in genomics and proteomics. The remaining analytes are quite evenly distributed among the total number of 245 publications displayed in this plot.

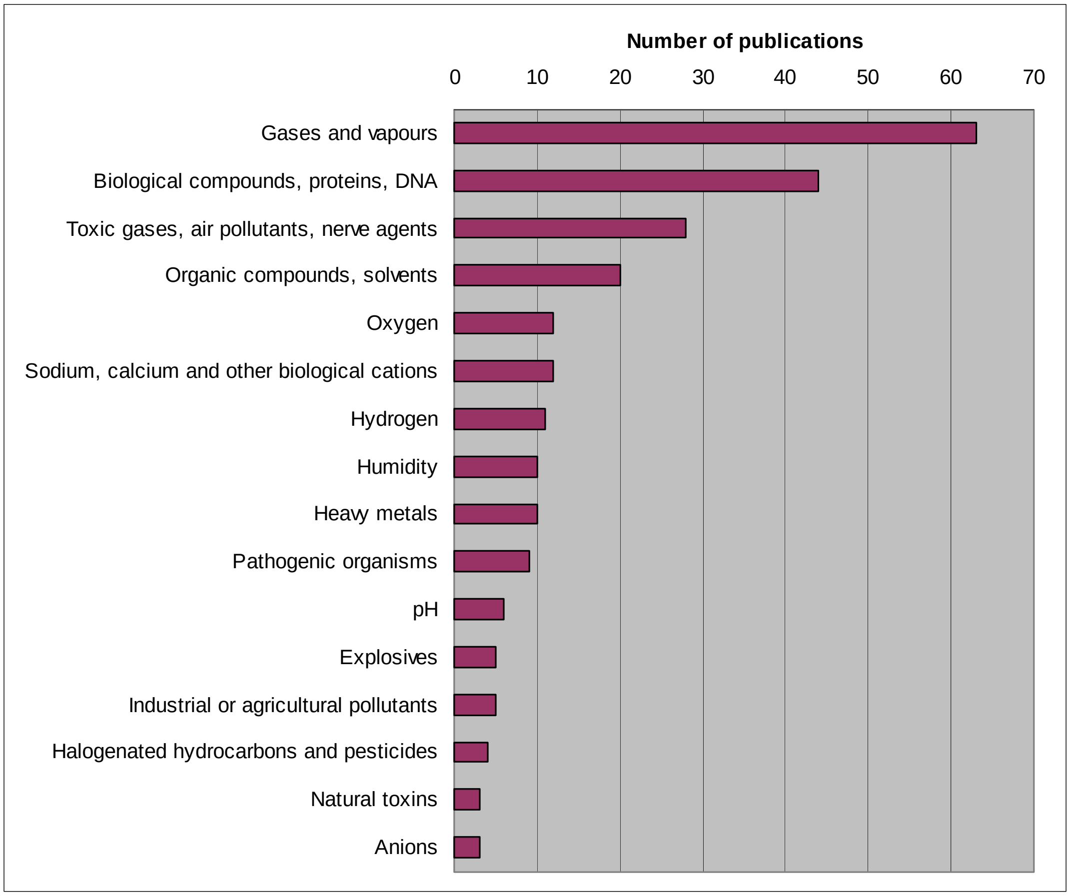


Figure 10. Sensor publications categorized by industrial application.

In addition, several recent reviews and a number of important nanotechnology websites are listed in Appendix D.

2.5 Presentation at RemTech 2004

A presentation to raise awareness of this project was prepared by DK^3 Scientific Ltd. and delivered by Norm Jede (Alberta Economic Development) at the ESAA RemTech 2004 conference in Banff, AB (October 13–15, 2004). A final presentation on the results of this report is scheduled to be given by DK^3 Scientific Ltd. at the ESAA RemTech 2005 conference.

2.6 Interviews with Nanotechnology Researchers and with the Environmental Industry

Interviews were conducted with nanotechnology researchers at NINT, the University of Alberta, the University of Calgary, NASA Ames Research Center, Oklahoma State University, CANMET Devon, Alberta Environment, and Alberta Research Council, as well as members of ESAA, vendors of environmental equipment, and interested parties in several other organizations. Their consultations were used to plan the workshops, to advance this project and to provide input for this report.

2.7 Workshops in Calgary and Edmonton

Nanotechnology Solutions and Opportunities
for the Environmental Industry
December 8 and 9, 2004

Identical workshops were held on December 8 in Calgary and on December 9 in Edmonton to provide Alberta industry with a solid introduction to environmental applications of nanotechnology. Approximately 50 people were present at the Calgary workshop, while the Edmonton presentations attracted about 45 participants the following day. The workshop proceedings were videotaped and this video has been converted into DVD format (see section 2.8). In addition, the PowerPoint presentations have been converted to a printer-friendly format and saved on a CD for distribution by ESAA. Since detailed records of the workshops are available from ESAA, only a brief overview of the workshops will be presented in this report. The complete program for the workshops, including presentation abstracts and speaker's biographies, is reproduced in Appendix E. DK^3 Scientific Ltd. and Rick Brommeland of NINT organized the content of the workshops, while SynchroComm Inc., DK^3 Scientific Ltd. and The Sekrijer Group provided the written and video documentation. ESAA organized the facilities and promoted the events.

2.7.1 Presentation: An Overview of Nanotechnology

Dr. Terry McIntyre
Environment Canada

As the keynote speaker at the workshops, Dr. McIntyre provided an excellent overview of nanotechnology. He provided definitions, background information, an overview of global efforts in the area, and projections on the potential for nanotechnology in the environmental sector to provide enabling technologies for the purification of water, wastewater and hazardous waste, as well as in resource recovery, pollution prevention, green manufacturing and energy efficiency. For example, nanotechnology-based quantum dot phosphors hold the promise of more economical white-light LED lighting, which could cut the electricity used for illumination by as much as 50 percent by for 2025. A second example is given in Figure 11, where metallic nanoparticles were used in a groundwater cleanup trial. A comprehensive list of information sources was also provided by Dr. McIntyre.

The topic of the environmental stewardship and due diligence of nanotechnologies was discussed in detail, and it was found to be a new area which had many opportunities for research (as outlined below) since many more questions than answers currently exist:

- What is the toxicity or potential toxicity of manufactured nanomaterials?
- Can similar nanomaterials be grouped with respect to their bioactivity?
- What are the health effects associated with nanomaterial mixed exposures or multiple exposure routes?
- What are the dose-response characteristics of nanomaterials?
- What are appropriate testing procedures, models, and biomarkers to evaluate the potential toxicological effects of nanomaterials in humans and/or other species in natural ecosystems?
- What extrapolation models are needed to evaluate or predict toxicity?
- What is the mode of action and mechanism of toxicity?
- What effects may occur in exposed wildlife populations, and are some subpopulations more sensitive to nanomaterials?
- Do nanoparticles impact ecological (animal/plant) receptors?
- By what means do (can) manufactured nanomaterials enter the environment?
- What are the modes of dispersion for nanomaterials in the environment?
- Do manufactured nanoparticles undergo transformation in the environment?
- Do manufactured nanoparticles bioaccumulate through the food chain?
- How and to what degree are humans exposed to nanomaterials in the environment and workplace?
- What effects may occur in exposed human populations and occupations?
- Are some subpopulations more vulnerable to nanomaterial exposure?
- What are the exposure pathways for humans?
- What releases might occur from the manufacturing processes of nanomaterials?
- At what stage in the product lifecycle might exposure occur?

- How will changes from current processes to nanotechnology processes affect material flows of hazardous substances?
- What are the lifecycle impacts from the manufacturing processes for nanomaterials?
- What are the effects of nanomaterials and mixtures on engineering controls and personnel protective equipment?

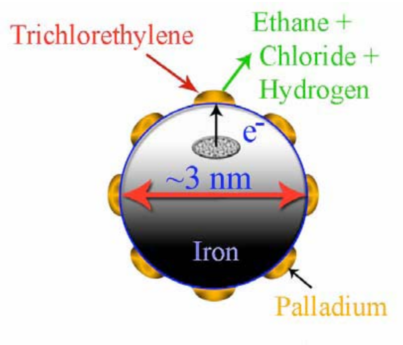


Figure 11(a). Palladium-iron nanoparticles for groundwater cleanup.

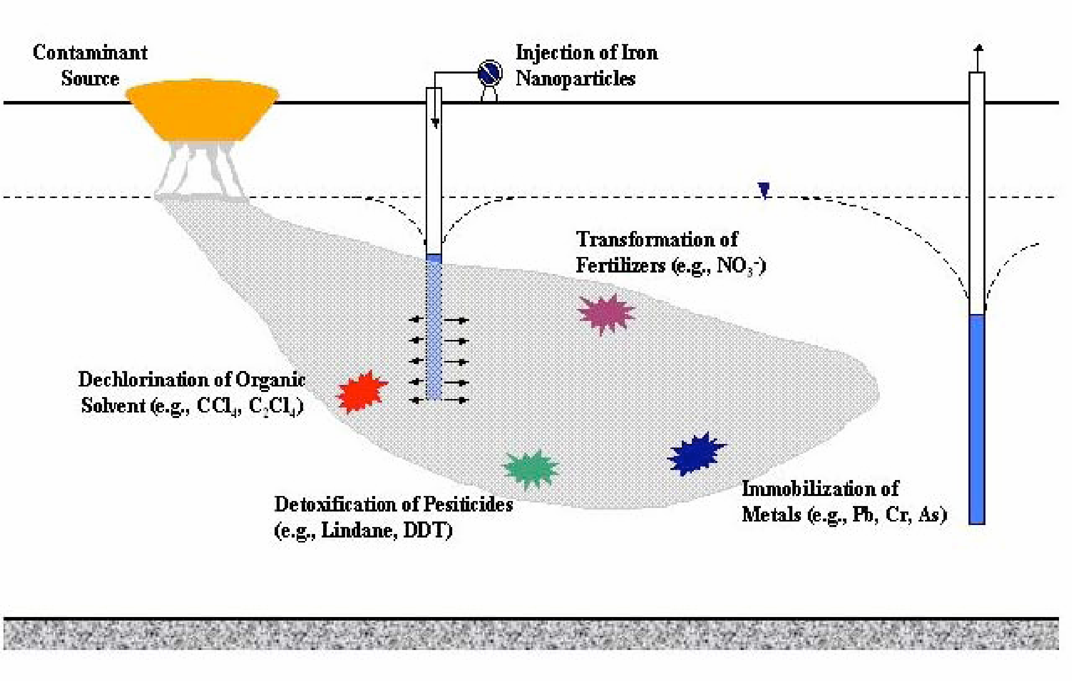
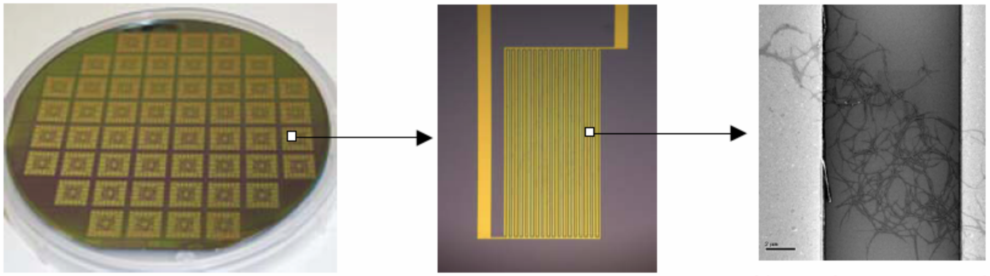


Figure 11(b). Field demonstration that iron nanoparticles can remove up to 96% of a major contaminant—trichloroethylene—from groundwater at an industrial site. (Courtesy W. Zhang, Lehigh University).

2.7.2 Presentation: Environmental Nanotechnology Literature Review

Dr. Ken Schmidt
DK^3 Scientific Ltd.

Dr. Ken Schmidt's presentation was a review of the results of the literature and patent searches undertaken for this project. These will not be gone over here in detail as they are already covered elsewhere in this report. The search strategies focused on four major areas of environmental activities: water desalination, water purification, soil remediation and sensors for field-based chemical analysis. Both the primary scientific literature and the US patent system were searched using these criteria to provide insight into current research trends as well as identify technologies close to commercialization. Several examples of relevant technologies were provided, including a new commercial product presented here in Figure 12. References were provided to help participants find commercial products relevant to their own interests.



54 Sensor Chips on a 4" wafer
12 sensors array on each chip

A sensor contains ~µm wide
IME arrays (Au, Pt, etc.)

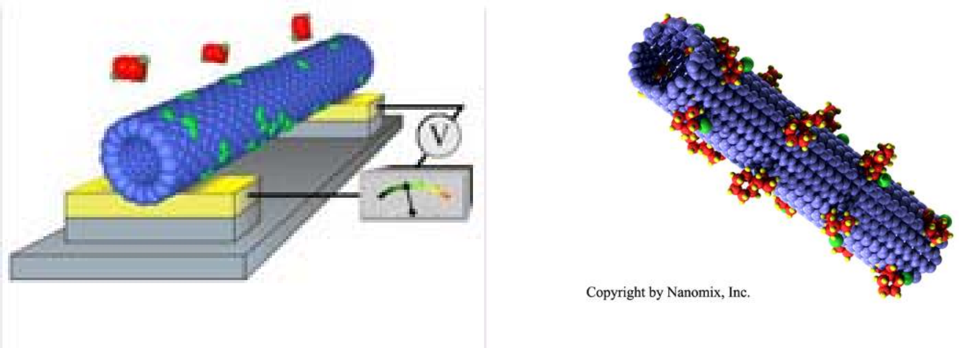
Nanotubes or nanowires
form network on the IME

Figure 12. Nanocomb Sensor Technology from INI (Integrated Nanosystems, Inc.: www.intnano.com). This is a patent-pending comb electrode chip with arrays of nanotubes and nanowires for producing low-power chemical sensors, with applications in portable rapid sensors for gases and organic analytes such as nitrogen dioxide, methane, acetone, nitrotoluene and benzene.

2.7.3 Presentation: Nanotechnology and Sensors for the Environment

Dr. Steve Dew
University of Alberta

Dr. Dew's talk provided a detailed review of the nanotechnologies and associated devices that will be important in the area of sensors, focusing on those that will have environmental applications. A variety of platform nanotechnologies will aid in the development of nanosensors: self assembled monolayers, micro- and nanofluidics, MEMS/NEMS, nanoparticles, quantum dots, carbon nanotubes and nanostructured materials. Two general methods, "top-down nanofabrication", or "bottom up self-assembly" can be used to produce these sensors. Due to their small size, nanosensors can be extremely fast, portable and low power, and require exceeding small sample sizes. They can be made to be highly selective, and also fabricated as arrays to perform many simultaneous analyses. Detectors for gases and organic compounds will be the first nanosensors to be commercialized, but many biological sensors are also under development. Figure 13 shows a gas nanosensor that is close to market, while Figure 14 shows the brightness and colour selectivity available through the use of quantum dots.



Copyright by Nanomix, Inc.

Figure 13. A functionalized single wall carbon nanotube as an H_2 gas sensor by Nanomix (www.nano.com).

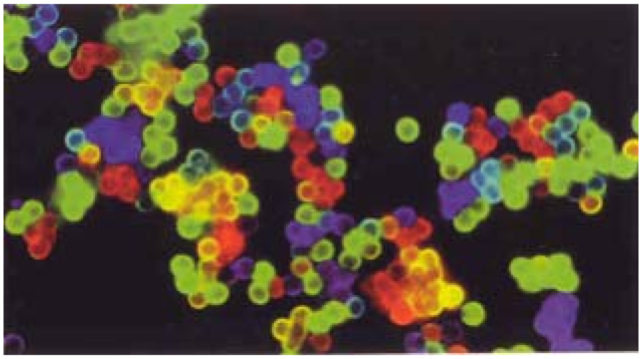


Figure 14. Quantum dot tags shown imbedded in latex spheres. The individual dots can also be used as molecular tags. (Image from www.qdots.com).

2.7.4 Presentation: Water and Soil Remediation Using Nanoparticulate Metal Oxides

Dr. Allen Apblett
Oklahoma State University

Dr. Apblett's presentation explored a variety of uses of nanoparticles in the areas of soil and water remediation. Nanomaterials were shown to be more efficient than the same material in bulk form at removing heavy metals such as arsenic from water and removing organic pollutants from the ground. Several strategies were presented to prevent the particles from escaping during use. These included (i) forming the nanoparticles into larger aggregate spheres of macro dimensions, and (ii) using magnetic extractants to recover the nanoparticles once they have collected the pollutants. Nanoparticles show great promise as advanced absorbents for a variety of pollutants, but a central practical problem is how to take advantage of them in the field without significant loss of particles due to their small size and without having them clog retaining filters. Dr. Apblett's solution to this problem is to use ion-exchange resins as a manufacturing template to form metal oxide particles into macro-sized spheres, while still retaining the nano-crystalline structure and chemical activity. Figure 15 shows SEM images of ZnO spheres produced in this manner. Figure 16 illustrates the use of magnetic extractants to purify water.

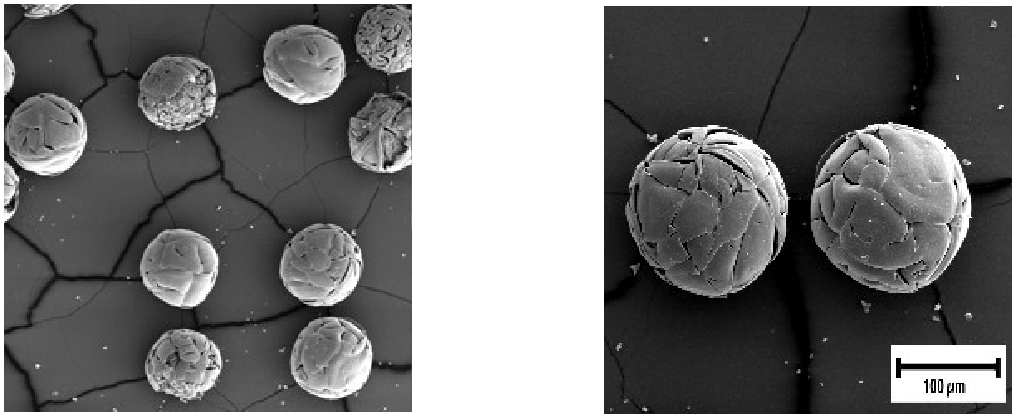


Figure 15. The photos are of sub-millimetre sized but nanostructured oxide beads. They are composed of oxide nanoparticles with excellent absorbent properties, but the approximate overall form of the original resin beads is retained.

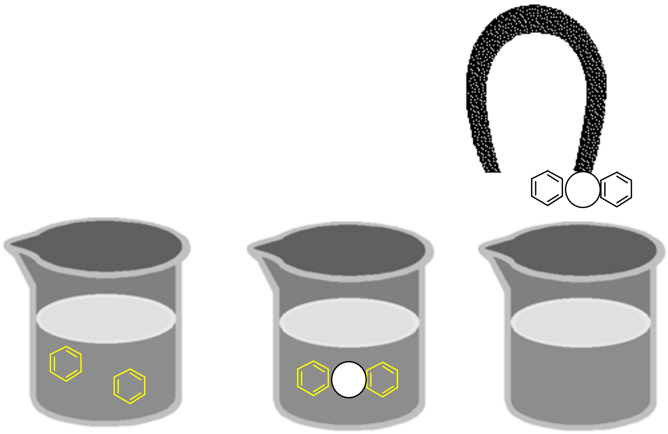


Figure 16. Magnetic extractants used to remove 99.995% of the benzene originally present in a sample of water (left). The extractant contains a non-polar group that binds to the contaminant (middle), and the extractant and the bound contaminant are then removed using a magnet (right).

2.7.5 Presentation: Panel Discussions in Calgary and Edmonton

The speakers formed a panel at the end of each workshop. The panel discussion and the questions-and-answers session with the audience are included in the video recording of the workshops.

2.8 DVD and CD of the Workshops

The Calgary and Edmonton “Nanotechnology Solutions and Opportunities for the Environmental Industry” workshops of December 8 and 9, 2004 were both videotaped. This video recording has been edited into a single presentation that includes the panel discussions of both workshops and converted into DVD format. It has been included with this report and is available from ESAA.

The workshop program and the complete PowerPoint slide presentations of the speakers were converted to Adobe Acrobat PDF files and placed on a companion CD for distribution by ESAA to all participants in the workshops.

The electronic versions of this report (in both Microsoft Word® and Adobe Acrobat® PDF file formats) are also included on this CD.

3. Recommendations

The purpose of this project was to facilitate the application of nanotechnology in the environmental industry in Alberta. To this end, the following recommendations are directed towards members of this industry:

1. Pursue upcoming opportunities in the area of micro- and nanotechnology sensors, whose applications may range from rapid and accurate mapping of site contamination to detecting pipeline leaks (with a methane gas sniffer). The small size of such sensors will allow their use in portable field devices and unmanned aerial vehicles. The experts at the University of Alberta (Dr. Steven Dew and others) are at the forefront of nanosensor research. The Alberta Research Council also has an active sensor group.

2. Pursue opportunities in the rapidly maturing technology of nanofiltration for water purification. Field applications will continue to evolve.

3. Pursue opportunities in remediation technologies based on nanotechnology. In particular, pursue opportunities in soil remediation. This area is growing slowly, but there is a high demand for better methods in Alberta and a potential for good returns on well-executed nanotechnology solutions. Field studies using nanocrystalline iron have been reported in Western Canada, and oxide-based solids are also showing promise. The platform technology developed by Dr. Allen Apblett (Department of Chemistry, Oklahoma State University) should be more closely examined as a possible solution for various remediation problems in Alberta.

4. Search the electronic versions of this report for relevant keywords or phrases (using the tools available in Microsoft Word® or Adobe Acrobat Reader®) to locate useful patents and literature references in Appendices B and C.

5. Explore the resources of Appendix D, including full-text reviews and websites relating to environmental nanotechnology. The Small Times and the NINT websites link to electronic newsletters that cover environmental nanotechnology events and developments. A link to a Canadian nanotechnology job website is also included.

6. Attend future nanotechnology workshops and forums, especially those including sessions on the environment.

7. Partner with nanotechnology researchers to shorten the learning curve and to decrease product development times.

8. Organize an industrial special interest group to pursue the development of environmental nanotechnology at the pre-commercial level. Successful examples of such groups may be found in the IT industry. NINT, ESAA, and various government agencies and departments may wish to participate.

Appendix A. Survey of the Environmental Industry

ESAA administered the environmental industry survey and compiled the results. The following pages display the output from the web-based analysis provided by ESAA.

1.	What is the overall level of knowledge in fundamental or applied nanotechnology in your organization?		
		Number of Responses	Response Ratio (%)
New to area		21	47
Low		15	33
Moderate		6	13
High		2	4
Expert		1	2
	Total	45	100

2.	Is your organization currently developing or providing environmental products or services that utilize nanotechnology?		
		Number of Responses	Response Ratio (%)
No, jump to question #4			
		39	87
Research and Development Stage			
		4	9
Purchasing Nanotechnology Products and Services		0	0
Commercialization of 1 to 3 products or services		0	0
Commercialization of more than 3 products or services		2	4
	Total	45	100

3.	If yes, what areas of the environmental products and services industry within your organization are currently using nanotechnology? (Check all that apply.)		
		Number of Responses	Response Ratio (%)
Water Desalination		2	17
Water Purification		3	25
Soil Remediation		1	8
Sensors for Field-Based Chemical Analysis			
		4	33
Other (Please Specify)			
		6	50

Relevant responses to “Other (Please Specify)” in question 3:
5. Polymer nanocomposites
6. MEMS

4.	How much potential do you see in using nanotechnology to improve or expand the environmental products or services offered by your organization?		
		Number of Responses	Response Ratio (%)
Don’t Know		23	51
Little or No Potential		0	0
Some Potential		10	22
Good Potential		8	18
Excellent Potential		4	9
	Total	45	100

5.	What areas of the environmental products and services industry are of particular interest to your organization for future application of nanotechnology? (Check all that apply.)		
		Number of Responses	Response Ratio (%)
Water Desalination		16	36
Water Purification		22	49
Soil Remediation		28	62
Sensors for Field-Based Chemical Analysis			
		23	51
Other (Please Specify)			
		11	24

Responses to "Other (Please Specify)" in question 5:
1. Vapour phase purification, environmental analysis
2. Health and safety of the workers involved
3. Wastewater purification
4. Ambient air and water monitoring
5. Improving polymer properties
6. Air quality control
7. All
8. Laboratory analysis
9. Air quality analysis
10. Heavy metals, process control
11. Gov't, involved in all aspects

6.	Are you aware that the National Research Council (NRC) has established the National Institute for Nanotechnology (NINT) at the University of Alberta?		
		Number of Responses	Response Ratio (%)
Yes		31	69
No		14	31
	Total	45	100

7.	Do you want to receive more information on NINT?		
		Number of Responses	Response Ratio (%)
Yes		28	62
No		17	38
	Total	45	100

Corporate Information (Optional)

8.	How much of the total output of your organization currently goes to providing products or services (directly or indirectly) to the environment industry in Canada?		
		Number of Responses	Response Ratio (%)
0 to 20%		11	31
21 to 40%		3	8
41 to 60%		7	19
61 to 80%		4	11
81 to 100%		11	31
	Total	36	100

9.	What is your primary product or service to the environment industry in Alberta? (Check all that apply.)		
		Number of Responses	Response Ratio (%)
Hardware		4	12
Software		0	0
Consulting		10	30
Consumables			
		7	21
Other (Please Specify)			
		17	52

Responses to “Other (Please Specify)” in question 9:
1. Calibration gas, purge gases, gas detection tubes
2. Regulatory
3. Power and water
4. Analytical services
5. Education
6. Regulatory
7. Chemical analysis
8. Analytical services
9. Regulation and enforcement
10. Research and development
11. Applied research, commercialization, training
12. All of the above, and technical services
13. Not in the environmental field directly
14. NRC-IRAP
15. Education
16. Laboratory analytical services
17. Gov't, review and applicability of technology

10.	How many employees in your organization are involved in providing products and services to the environment industry and currently do this work in Alberta?		
		Number of Responses	Response Ratio (%)
0		2	6
1 to 5		5	15
6 to 20		11	32
21 to 100		4	12
101 to 500		6	18
Over 500		5	15
Other (Please Specify)		1	3
	Total	34	100

Response to “Other (Please Specify)” in question 10:
1. All regional and some central staff.

11.	Contact Information (Optional)		
	Number of non-blank responses	19	42%

There were varying amounts of contact information given in the responses received to question 11. This information is in the possession of ESAA.

12.	Any additional comments. (For example, are there environmental problems or sensing issues in the field that have not been adequately addressed by current technologies? How might nanotechnology provide suitable solutions?)		
	Responses	2	4%

Responses to question 12:
1. I am interested in the potential for vapour phase purification and flue gas cleaning.
2. Membrane technology related to salts and hydrocarbons, in situ remediation.

Appendix B. US Patent Searches

B1. US Patents and US Patent Applications for Soil Remediation

B1.1 Results of a US Patent Search for “nano$” AND “soil remediation”: 13 Patents

This is a search of all fields in the US patents database from 1976 to the present.
The search returned hits only when both of the following were found anywhere in an entire patent record: (i) the prefix “nano” followed by any sequence of characters and (ii) the exact phrase “soil remediation”. Abstracts are included only for those patents with apparent environmental applications.

To read the entire patent, visit the website at http://patft.uspto.gov/netahtml/srchnum.htm and enter the desired patent number (Pat. No.).

	Pat. No.	Title
1	6,802,805	**Method for recombining soil** A method for recombining and then solidifying groups of soil particles by utilizing changes in the status and properties of soil particles which comprises a combination (in an adhering state) between soil particles and groups polymers (humin) in an aqueous solution (solvent). By using specified solvents, the preliminary treatment of separating soil particles and polymers is initiated. Secondarily, each structure of groups of soil particles is observed microscopically as a metal complex, and the combining method is accomplished by utilizing substitution based on various reactions (i.e. SN, SE, and SEAr type reactions) along with electron transfer in a solvent made of specified solutes. The substitution includes the rock forming function through the substitution of the hydrogen atom within the hydroxyl group of clay minerals as molecular components and the dehydration and dissociation function resulted from the binding structure of oxygen molecule O^{-2} and Al^{+3} as components of aluminum oxide.
2	6,689,485	**Powerful reductant for decontamination of groundwater and surface streams** The disclosed invention relates to a composite material for use in recovery of radionuclides, metals, and halogenated hydrocarbons from aqueous media. The material has very high surface area, and includes ***nanometer*** sized, zero-valent iron on a support. The material can be used to remediate aqueous media which have contaminants such as radionuclides, metals and halogenated hydrocarbons from aqueous media.

3	6,586,583	**Soybean peroxidase gene family and an assay for detecting soybean peroxidase activity**
4	6,569,416	**Compositions containing synthetic soil-extract materials and medicaments based thereon**
5	6,387,276	**Immobilization of inorganic arsenic species using iron** A method for the remediation of arsenic is presented, comprising providing an aqueous solution of inorganic arsenic species, and passing the solution of inorganic arsenic species over a substrate comprising zero valent iron under anaerobic conditions, thereby reducing the arsenic species and forming arsenic-metal co-precipitates. Preferably, the metal is iron in the form of iron filings, and a source of sulfate ions is also present, resulting in the precipitation of arseno-pyrites.
6	6,280,601	**Electrolytic method for sterilization of microorganisms and/or mineralization of organic and/or inorganic substances in ground soil** This invention relates to a method for sterilizing microorganisms and/or decomposing organic and inorganic pollutants in a region of ground soil by passing a specified direct current through the contaminated soil region with a controlled voltage applied between at least one pair of electrodes incorporated into the ground soil. For decomposition of the organic and inorganic pollutants, it is postulated that the applied electric field increases the natural capacitance of the individual soil particles to over capacitance sufficient to cause the soil particles to discharge electrons. This electric discharge, in turn, provides the reaction energy to promote the redox reactions which effects decomposition of the pollutants. The voltage is preferable controlled to optimize the amplitude and frequency of the electric discharges emitted by the soil particles which have become subject to over capacitance. Preferably, the applied electric field is aligned with the natural electric field of the soil particles being treated. A voltage of at least 0.4 V to 2 V per meter of electrode distance for each pair of electrodes is required.
7	6,242,663	**Powerful reductant for decontamination of groundwater and surface streams** The disclosed invention relates to a composite material for use in recovery of radionuclides, metals, and halogenated hydrocarbons from aqueous media. The material has very high surface area, and includes ***nanometer*** sized, zero-valent iron on a support. The material can be used to remediate aqueous media which have contaminants such as radionuclides, metals and halogenated hydrocarbons from aqueous media.
8	6,193,867	**Management of soil conditions and electroosmotic flow in electrokinetic remediation** Methods for controlling electroosmotic flow through a porous medium by applying an electric field between a plurality of electrodes positioned in a porous medium, supplying an acid solution to at least one of the electrodes and/or the soil, and supplying a zeta potential modifying compound to at least one of the electrodes is disclosed. The methods can be used to separate organic

		as well as inorganic contaminants from porous mediums.
9	6,145,244	**Methods for enhancing phytoextraction of contaminants from porous media using electrokinetic phenomena** The present invention relates to a method of remediating soil, water, and other porous media contaminated with organic and/or inorganic contaminants using plants in conjunction with an electric field applied through the medium to control movement of the contaminants and enhance removal of the contaminants from the medium. Applying an electric field in soil induces electromigration (movement of ions in the pore fluid), as well as electroosmosis (movement of pore water) and electrophoresis (movement of charged particles in soil such as colloids). In the present invention these phenomena are beneficially utilized to control the transport of charged and/or non-charged contaminants in soil within the plant root zone (rhizosphere) and to bring contaminants into the root zone, perhaps from a contaminated zone located deeper in the soil than the root zone. The effectiveness of the phytoremediation is also enhanced by preventing the soil from becoming so strongly acidic or basic as to kill the plants. The present invention significantly extends the utility of phytoremediation to cleanup of soils with deeper contamination plumes than are typically accessible to the roots of plants.
10	6,132,623	**Immobilization of inorganic arsenic species using iron** In a method for the remediation of inorganic arsenic species, a solution of inorganic arsenic is passed over zero valent iron under abiotic and anaerobic conditions, thereby removing the inorganic arsenic species and forming arsenic-metal co-precipitates. The metal is preferably in the form of iron filings, and is provided together with sand.
11	5,945,446	**Process for preparing synthetic soil-extract materials and medicaments based thereon**
12	5,866,695	**Soybean peroxydase gene family and an assay for detecting soybean peroxidase activity**
13	5,847,825	**Apparatus and method for detection and concentration measurement of trace metals using laser induced breakdown spectroscopy**

B1.2 Results of a Search of US Patent Applications in the PGPUB Production Database for “soil remediation” AND “nano$”:
2 Patent Applications

This is a search of all fields in the US patent *applications* database from 2001 to 2004. The search returned hits only when both of the following were found anywhere in a patent application record: (i) the prefix “nano” followed by any sequence of characters and (ii) the exact phrase “soil remediation”. Abstracts are included below only for patent applications with apparent environmental applications.

To read the entire patent application, visit the website at http://appft1.uspto.gov/netahtml/PTO/srchnum.html and enter the published application number (Pub. App. No.).

	Pub. App. No.	**Title**
1	20030134409	**Delivery vehicles for environmental remediants** The invention provides novel environmental remediants and methods for remediating contaminated soils, earth, ground, or groundwater, particularly subsurface sites. The environmental remediants comprise a chemically or biologically active material, in the form of a particles which are on average less than about one micron, and a carrier which is interactive with an environmentally acceptable solvent. The carrier is capable of maintaining the particles in a persistent suspension which can permeate soil pores due to it small size, thereby delivering the remediant to the subsurface contamination. Significant advantages over prior art methods, particularly for metallic ***nanoparticles,*** are avoiding agglomeration, ease of application, and delivery to subsurface sites. Methods are provided which comprise selecting an appropriate environmental remediant and contacting a subsurface soil or water with the remediant; by applying the remediant in a composition with a carrier, wherein the remediant transits to the subsurface site.
2	20020006867	**Powerful reductant for decontamination of groundwater and surface streams** The disclosed invention relates to a composite material for use in recovery of radionuclides, metals, and halogenated hydrocarbons from aqueous media. The material has very high surface area, and includes ***nanometer*** sized, zero-valent iron on a support. The material can be used to remediate aqueous media which have contaminants such as radionuclides, metals and halogenated hydrocarbons from aqueous media.

B2. US Patents and US Patent Applications for Water Purification

B2.1 Results of a Patent Search for “nano$” AND “water” AND “purif$”: 20 Patents

This is a search of the abstract fields (only) in the US patents database from 1976 to the present. The search returned hits only when all three of the following were found in a patent abstract: (i) the prefix “nano” followed by any sequence of characters, (ii) the exact word “water”, and (iii) the root “purif” followed by any sequence of characters.

To read the entire patent, visit the web page http://patft.uspto.gov/netahtml/srchnum.htm and enter the desired patent number (Pat. No.).

	Pat. No.	Title
1	6,841,068	**Domestic nanofiltration membrane based water purifier without storage tank** A domestic ***nanofiltration*** membrane based ***water purifier*** without a storage tank. The ***water purifier*** according to the present invention uses a ***nanofiltration*** membrane filter as a main filtering section and does not have a storage tank for containment of ***purified water***. Although conventional reverse osmosis membrane based ***water purification*** systems provide good quality ***water,*** they have problems in that installation of the storage tanks due to insufficient flow rate results in the increased volumes of ***water purifiers,*** and at the same time, secondary pollution may be caused by microorganism propagation upon prolonged storage. In this regard, the present invention provides a domestic ***nanofiltration*** membrane based ***water purifier*** without a storage tank, in which a ***nanofiltration*** membrane filter with a pore size of approximately 0.1 to 10 nm is used as a main filtering section.
2	6,838,005	**Nanosize electropositive fibrous adsorbent** Aluminum hydroxide fibers approximately 2 ***nanometers*** in diameter and with surface areas ranging from 200 to 650 m^2/g have been fount to be highly electropositive. When dispersed in ***water*** they are able to attach to and retain electronegative particles. When combined into a composite filter with other fibers or particles they can filter bacteria and ***nano*** size particulates such as viruses and colloidal particles at high flux through the filter. Such filters can be used for ***purification*** and sterilization of ***water,*** biological, medical and pharmaceutical fluids, and as a collector/concentrator for detection and assay of microbes and viruses. The alumina fibers are also capable of filtering sub-micron inorganic and metallic particles to produce ultra pure ***water***. The fibers are suitable as a substrate for growth of cells. Macromolecules such as proteins may be separated from each other based on their electronegative charges.

3	6,833,073	**Composite nanofiltration and reverse osmosis membranes and method for producing the same** The present invention relates to ***nanofiltration*** and reverse osmosis membranes that may be used in a number of commercial applications in which a contaminant, such as salt, must be separated from a feed fluid, such as brackish ***water,*** to yield a ***purified*** product fluid, as well as a method for manufacturing such membranes. According to embodiments of the invention, an aqueous amine solution including an amine, an organic acid (e.g., propionic acid) and a non-amine base is applied to the surface of a porous substrate. A second solution containing an acyl halide and an organic solvent immiscible in ***water*** is then applied to the aqueous amine solution to cause interfacial polymerization to occur. The resulting membranes exhibit superior salt rejection and flux properties.
4	6,638,918	**Chitosan compositions** Compositions comprising chitosan in the form of a network of ***nano-sized*** fibres. There is also provided a process for making such compositions. The compositions have improved solubility and activity. The compositions are useful in hair care, skin care, odour control, wound care, blood management, sanitary compositions, oral care, film formation, hard surface treatment, fabric treatment, release of hydrophobic or hydrophilic materials, plant care, ***water purification*** and drug delivery.
5	6,462,935	**Replaceable flow-through capacitors for removing charged species from liquids** A free-standing flow-through capacitor (FTC) is constructed by concentrically winding two electrodes and two dividers into a hollow-center roll. A liquid-feeding pipe is inserted to the central opening for delivering fluids to the FTC. ***Nanoparticles*** of hydrated iron compound with Fe_3O_4 as the main component or its composite powders are used as the active materials for the electrodes. With channels crated by the dividers assembled in the roll, fluids injected from the feed pipe are confined inside the FTC, and flow outwardly and transversely through the entire length of the electrodes. Under an application of a low DC voltage to the electrodes, charged species are adsorbed and removed from the treated liquids as soon as they are in contact with the electrodes. Capacitive deionization using FTC of the present invention is applicable to waste-streams reduction, ***water purification*** and desalination at low costs and easy operation.
6	6,451,209	**Method and a system for the treatment of water** According to a method and a system for ***purifying*** bathing ***water*** for a swimming pool (1), ***water*** is passed through a filter (2) for filtration of the ***water***. A subflow (6) of the filtered ***water*** on the downstream side of the filter is passed through a UV system (3) for photochemical treatment. A second subflow (7) of photochemically treated ***water*** is withdrawn from the first subflow (6) for ***nanofiltration*** or reverse osmosis treatment in a membrane filter device (4). The invention makes it possible to remove carcinogenic substances, such as THM and AOX from the ***water***. A method according to the invention may also be used for removing biocides, pesticides and peroxides, in

		order to prepare ***water*** for drinking.
7	6,426,312	**Air purifying matrix for the oxidation of air-borne particulate and gases** The present invention is an air ***purifying*** matrix to remove, reduce or detoxify organic pollutants. The matrix has an inert substrate, a photoreactive semiconductor material, and aqueous particles. The inert substrate is ***water*** absorbent, transparent to ultraviolet light, able to withstand extended periods of exposure to all wavelengths of ultraviolet light side of the spectrum without decomposing or altering the structure thereof, able to withstand high concentrations of hydroxyl radicals without decomposing or altering the structure thereof, and in the form of an expanded granular type with spaces therein. The photoreactive semiconductor material is crystallized within the spaces. And the aqueous particles are within the spaces to form photoreactive metal semiconductor material ***nano-reactors*** within the matrix. These ***nano-reactors*** generate high concentrations of hydroxyl radicals which surround and diffuse through the matrix, and remove, reduce or detoxify organic pollutants within and surrounding the matrix. Moreover, the ultraviolet light is at a wavelength which the semiconductor material photoreacts.
8	6,416,668	**Water treatment process for membranes** This invention discloses a cost-effective process for separating contaminants and a wide-range of fouling material from surface ***water,*** ground ***water*** and from industrial effluents. Having undergone effective pre-treatment, the ***water*** can be ***purified*** further by using high-surface area spirally wound micro-filtration (MF), ultra-filtration (UF), ***nano-filtration*** (NF) or reverse osmosis (RO) membranes. High-quality potable ***water*** free from pathogen and other contaminants is thus produced at low-cost from the pre-treated surface ***water*** and ground-***water***. Conversely, pre-treated industrial effluents are further ***purified*** at a relatively low-cost using NF or RO membranes, thus producing ***water*** suitable for recycle or surface discharge. The process of this invention uses cationic inorganic and/or polymeric flocculants to coagulate and flocculate the ***water***-borne colloidal matter (e.g. clays, iron hydroxides, naturally occurring matter (NOM's), etc.), followed by filtration using a multi-media filter, charge neutralization and reversal and final filtration using a 5-micron cartridge filter. These pre-treatment steps provides a good quality ***water*** having a low Silt Density Index and a significant negative zeta potential, thereby ensuring against irreversible chemical fouling of the spirally-wound membranes.
9	6,383,282	**Pseudophasic extraction method for the separation of ultra-fine minerals** An improved aqueous-based extraction method for the separation and recovery of ultra-fine mineral particles. The process operates within the pseudophase region of the conventional aqueous biphasic extraction system where a low-molecular-weight, ***water*** soluble polymer alone is used in combination with a salt and operates within the pseudo-biphase regime of the conventional aqueous biphasic extraction system. A combination of low molecular weight, mutually immiscible polymers are used with or without a salt. This method is especially suited for the ***purification*** of clays that are useful as rheological

		control agents and for the preparation of ***nanocomposites***.
10	6,132,618	**System and method for waking a computer having a plurality of power resources from a system state using a data structure** A method for ***purifying*** commercial alkali metal silicate solutions involves passing the alkali metal silicate solution through a ***nanofiltration*** device having a membrane with a molecular weight cutoff of between about 400 to about 3,000 daltons. Preferably, the molecular weight cutoff is between about 400 and about 1,000 daltons and, more preferably, between about 400 and about 800 daltons. In this way, a large portion of impurities in alkali metal silicate solutions, which tend to become associated with higher molecular weight silicates, can be removed. A pressure differential may be used to drive the solution across the device, from which a permeate is withdrawn as a ***purified*** alkali metal silicate solution. The retentate from the device is preferably recycled to the feed alkali metal silicate solution to form a mixture, and the mixture is introduced to the ***nanofiltration*** device. Two or more devices, of decreasing molecular weight cutoff, may be used in series to obtain a more concentrated form of a ***purified*** silicate solution. When two devices are used, the second device has a molecular weight cutoff sufficient to allow ***water*** molecules to pass but to retain most of the remaining molecules. In order to achieve this, a molecular weight cutoff of approximately 100 to 600 daltons and, preferably, from about 150 to about 400 daltons, is suitable.
11	6,080,317	**Process and apparatus for the purification of waste water** A process and apparatus for the ***purification*** of waste ***water*** includes a ***nano-filtration*** stage (19) which returns a stream of retained substance (20) in a cycle (15, 16, 17, 18) in order to effect a concentration of the content substances. Concentrate (29) is taken out of the cycle and is introduced into a physical and/or chemical treatment stage. At least a part of the treated concentrate (47) is returned into the cycle of the ***nano-filtration*** stage (19).
12	5,476,591	**Liquid treatment system and method for operating the same** A treatment system for removing metal ions from liquids. A metal ion-containing liquid (e.g. ***water*** or an acidic mining leachate) is first passed through a ***nanofiltration*** membrane system to produce a metal ion-rich retentate and a permeate. The retentate may be saved for metal recovery or discarded. To ***purify*** the permeate and remove residual metal ions therefrom, it may thereafter be passed through one or more columns containing metal ion-extracting materials. Specifically, the permeate is passed through at least one and preferably multiple columns filled with porous polymer beads having metal ion extracting agents therein (e.g. biomass materials). As a result, ***purified*** liquid is produced. When saturated with metal ions, each bead-containing column is successively cleaned with acid solutions.
13	5,405,532	**Process for the purification of industrial waste-waters** The invention relates to a process for treating industrial waste ***water*** which comprises either: (a) pre-treating the waste ***water*** with at least two different pre-treatments selected from adsorption, membrane filtration and oxidation and then, biologically ***purifying*** the waste ***water*** or, (b) neutralizing and

		biologically ***purifying*** the waste ***water*** and then after-treating the waste ***water*** either by membrane filtration in combination with adsorption or oxidation or, by oxidation optionally in combination with adsorption or filtration on a ***nanofiltration*** membrane or, by filtration on a ***nanofiltration*** membrane.
14	5,310,486	**Multi-stage water treatment system and method for operating the same** A treatment system for removing metal ions from ***water***. Contaminated ***water*** is first passed through a ***nanofiltration*** membrane system, and then through one or more columns having ion-extracting materials therein. The ***nanofiltration*** membrane system involves at least one and preferably multiple ***nanofiltration*** membrane units which are capable of removing metal ions from ***water***. To remove any residual metal ions from the permeate generated by the ***nanofiltration*** membrane system, the permeate is passed through at least one and preferably multiple columns filled with porous polymer beads having metal ion extracting agents therein (e.g. biomass materials). As a result, highly ***purified water*** is produced. When saturated with ions, each bead-containing column is successively cleaned with acid solutions.
15	5,308,492	**Process for the purification of industrial waste-waters by nanofiltration** The invention relates to a process for treating industrial waste ***water*** which comprises either: (a) pretreating the waste ***water*** with at least two different pretreatments selected from adsorption, membrane filtration and oxidation and then, biologically ***purifying*** the waste ***water*** or, (b) neutralizing and biologically ***purifying*** the waste ***water*** and then after-treating the waste ***water*** either by membrane filtration in combination with adsorption or oxidation or, by oxidation optionally in combination with adsorption or filtration on a ***nanofiltration*** membrane or, by filtration on a ***nanofiltration*** membrane.
16	5,254,257	**Reclaiming of spent brine** The method of ***purifying*** spent brine from the regeneration of ion exchange resin, for example resin in ***water*** softeners. The method comprises acidifying the spent brine to a pH of less than 3 with an acid other than sulfuric acid, which acid is preferably chosen from at least one acid which forms a calcium salt that is more ***water*** soluble than calcium sulfate. One passes the brine through a ***nanofiltration*** membrane to ***purify*** the brine by separating from it a waste stream which comprises the majority of the polyvalent ions present, so that the ***purified*** brine has most of its contaminating polyvalent ions removed.
17	5,158,681	**Dual membrane process for removing organic compounds from the water** An apparatus and process for treating ***water*** contaminated with hydrocarbons utilizes a dual membrane apparatus wherein contaminated ***water*** is first treated by a cellulose based membrane to produce a permeate fraction that is clarified and has a reduced content of hydrocarbons. The clarified permeate fraction is then treated with a reverse osmosis or ***nanofiltration*** membrane to produce a ***purified*** permeate ***water*** having an additionally lowered content of hydrocarbons.
18	5,112,483	**Slow sand/nanofiltration water treatment system** A ***water*** treatment device comprising a slow sand filter in fluid flow

		combination with a ***nanofilter for water*** pretreatment purposes. The ***nanofilter*** is surrounded by a housing spacedly arranged thereto which housing is capped at each end and axially aligned with and connected to a T-shaped pipe fitting at each end thereof. A pipe is arranged to extend axially through the T-shaped fittings, the caps and the ***nanofilter*** which pipe is apertured along that portion thereof in said ***nanofilter***. ***Water*** fed from the slow sand filter into one T-shaped fitting is directed inwardly and laterally through the ***nanofilter with the purified water*** flowing through the apertures of the pipe with a discarded portion of the ***water*** being conducted through the second T-shaped pipe fittings out of the device for disposal purposes.
19	5,039,416	**Process for the purification of industrial waste-waters** The invention relates to a process for treating industrial waste ***water*** which comprises either: (a) pre-treating the waste ***water*** with at least two different pre-treatments selected from adsorption, membrane filtration and oxidation and then, biologically ***purifying*** the waste ***water*** or, (b) neutralizing and biologically ***purifying*** the waste ***water*** and then after-treating the waste ***water*** either by membrane filtration in combination with adsorption or oxidation or, by oxidation optionally in combination with adsorption or filtration on a ***nanofiltration*** membrane or, by filtration on a ***nanofiltration*** membrane.
20	4,981,594	**Waste water purification system** A ***purification*** system for cooling tower ***water*** where no antiscalent chemicals need be added when the ***water*** is provided from a municipal source. The ***water*** is continually filtered and disinfected, and its TDS is kept at acceptable levels, by the use of ***nanofiltration*** in combination with ionization. ***Water*** discharge form the tower is reduced by 80 percent or more.

B2.2 Results of a Search of US Patent Applications in the PGPUB Production Database for “nano$” AND “water” AND “purif$”: 11 Patent Applications

This is a search of the abstracts fields (only) in the US patent *applications* database from 2001 to 2004. The search returned hits only when all three of the following were found in the same abstract: (i) the prefix “nano” followed by any sequence of characters, (ii) the word “water”, and (iii) the root “purif” followed by any sequence of characters.

To read the entire patent application, visit the web page at http://appft1.uspto.gov/netahtml/PTO/srchnum.html and enter the published application number (Pub. App. No.).

	Pub. App. No.	Title
1	20050016907	**Electro-optical water sterilizer** The present invention relates to a ***water purifier*** and more particularly, it relates to an electro-optical ***water purifier*** which employs ultraviolet light with the wavelength of 253.7 ***nanometers*** and provides a spiral circulation for influent ***water*** to achieve disinfection of drinking ***water*** wherein said circuitry having an ability to adapt power source of alternate current (AC). A quartz bushing prevents fault electricity discharge from said UV tube, which is interchargeably connected with power source, therefore assure user's safety and ensure UV's complete emission.
2	20040226872	**Apparatus for the purification of water** An apparatus for ***purifying water,*** comprising an ion exchanger with a ***water*** inlet and a product outlet, connected to an inlet of a first filtration step, which comprises one or more ***nano***- and/or RO-filtration membranes and is provided with a first permeate outlet and a first concentrate outlet. According to a first embodiment, the apparatus comprises a subsequent filtration step in which an inlet is connected with the first concentrate outlet, which subsequent filtration step comprises one or several subsequent ***nano***- and/or RO-filtration membranes, and which is provided with a second permeate outlet and second concentrate outlet, which second concentrate outlet is optionally connected with an inlet of a subsequent filtration step.
3	20040211726	**Membrane-assisted fluid separation apparatus and method** This present invention relates to a fluid separation module adapted to separate a given fluid mixture into permeate and retentate portions using bundles of hollow fiber membranes. The membranes may be composed of different kinds of membranes depending on the application being used to separate the fluid mixture. The fluid separation module may be used to separate fluid mixtures by a number of different processes, including but not limited to, pervaporation, vapour permeation, membrane distillation

		(both vacuum membrane distillation and direct contact membrane distillation), ultra filtration, microfiltration, ***nanofiltration,*** reverse osmosis, membrane stripping and gas separation. The present invention also provides an internal heat recovery process applied in association with those fluid separation applications where separation takes place by evaporation through the membrane of a large portion of the feed into permeate. Desalination and contaminated ***water purification*** by means of vacuum membrane distillation are just two examples where the internal heat recovery process may be applied. In these two examples, large portions of the feed are separated by membranes into a high purity ***water*** permeate stream by evaporation through the membranes and into a retentate stream containing a higher concentration of dissolved components than present in the feed. In this process the permeate vapour that is extracted from the fluid separation module is compressed by an external compressor to increase the temperature of the vapour higher than the temperature of the feed entering the separation module. Heat from the permeate vapour at the elevated temperature is transferred back to the incoming feed fluid mixture entering the fluid separation module in a condenser/heat exchange.
4	20040055955	**Production of purified water and high value chemicals from salt water** Sodium chloride and ***purified water*** are recovered by treating salt ***water*** that contains sodium chloride with an integrated reverse osmosis and electrodialysis system, which includes an efficiency-enhancing feature that is one or more of the following: the use of univalent anion and univalent cation selective membranes in the electrodialysis unit; the addition of a ***nanofiltration*** unit to process the diluate from the electrodialysis unit; or operation of the electrodialysis unit at an elevated pressure. Magnesium and bromine can optionally be produced when the salt ***water*** contains these materials.
5	20040026320	**Method and device for purifying water** This invention relates to a method and a device for ***purifying water*** by means of inverted osmosis, ultra or ***nanofiltration*** or the like. The device comprises a raw ***water*** inlet (10) which via a pressurizing pump (15) is connected to a filter housing (24) in order to achieve an increased pressure of the ***water*** in the filter housing. The filter housing comprises a filter inlet (23), an outlet conduit (27) for ***purified water*** and a reject outlet (29) which is connected to a first branched off conduit (20) connected to the filter inlet (23) in order to form a circulation circuit (19) for concentrated unpurified ***water***. The circulation circuit comprises a circulation pump (21) and a second branched off conduit (31) connected to a sewage drain (32) or the like for tapping off unpurified ***water***. The device also comprises means for flushing (12, 18, 30), which when the pumps (15, 21) are not activated operates such that the raw ***water*** inlet is connected to the circulation circuit (19) and thereby forces the raw ***water*** in the direction towards and through the filter inlet (23) in order to expel a major part of the ***water not purified***

		in the circulation circuit through the sewage (32).
6	20040007526	**Pumping arrangement for a household water purifier** This invention relates to a device for a household ***water purifier*** in which raw ***water*** is pressurized and is filtered by means of inverted osmosis, ultra or ***nanofiltration*** or the like. The device is provided with a central unit having a first part (10) comprising a vane pump (12) with a pump housing (16) and a second part (11) comprising a filter connected to the first part. The first part (10) is shaped of plastic or the like and the pump housing is (16) at least partly surrounded by a liner (17), which consists of a material which differs from the material of the pump housing, and the liner (17) is at least partly surrounded by the first part (10).
7	20030127393	**Nanosize electropositive fibrous adsorbent** Aluminum hydroxide fibers approximately 2 ***nanometers*** in diameter and with surface areas ranging from 200 to 650 m^2/g have been fount to be highly electropositive. When dispersed in ***water*** they are able to attach to and retain electronegative particles. When combined into a composite filter with other fibers or particles they can filter bacteria and ***nano*** size particulates such as viruses and colloidal particles at high flux through the filter. Such filters can be used for ***purification*** and sterilization of ***water,*** biological, medical and pharmaceutical fluids, and as a collector/concentrator for detection and assay of microbes and viruses. The alumina fibers are also capable of filtering sub-micron inorganic and metallic particles to produce ultra pure ***water***. The fibers are suitable as a substrate for growth of cells. Macromolecules such as proteins may be separated from each other based on their electronegative charges.
8	20030104020	**Chitosan compositions** Compositions comprising chitosan in the form of a network of ***nano***-sized fibres. There is also provided a process for making such compositions. The compositions have improved solubility and activity. The compositions are useful in hair care, skin care, odour control, wound care, blood management, sanitary compositions, oral care, film formation, hard surface treatment, fabric treatment, release of hydrophobic or hydrophilic materials, plant care, ***water purification*** and drug delivery.
9	20030066796	**Composite nanofiltration and reverse osmosis membranes and method for producing the same** The present invention relates to ***nanofiltration*** and reverse osmosis membranes that may be used in a number of commercial applications in which a contaminant, such as salt, must be separated from a feed fluid, such as brackish ***water,*** to yield a ***purified*** product fluid, as well as a method for manufacturing such membranes. According to embodiments of the invention, an aqueous amine solution including an amine, an organic acid (e.g., propionic acid) and a non-amine base is applied to the surface of a porous substrate. A second solution containing an acyl halide and an organic solvent immiscible in ***water*** is then applied to the aqueous amine solution to cause interfacial polymerization to occur. The resulting

		membranes exhibit superior salt rejection and flux properties.
10	20030024884	**Method for removing oil, petroleum products and/or chemical, pollutants from liquid and/or gas and/or surface** The invention relates to the field of ecology, in particular to the struggle against pollution of the environment with oil, petroleum products, cyclic and aromatic hydrocarbons, other chemical pollutants, i.e. to ***purification of a water*** area, waste waters, industrial machinery, polluted soil and grounds etc., and also to the field of objects used to satisfy the vital requirements of humans and to medicine. A method for removing chemical pollutants includes preparing a carbonaceous mixture of an expanded graphite and carbonaceous ***nanocrystals*** of a graphite-containing feedstock, dispersing it onto the surface and/or into a liquid and/or placing on a surface and/or passing a liquid or gas through a filter, and collecting the carbonaceous mixture saturated with the pollutants. The method is used for collecting oil and petroleum products from the surface of ***water,*** for filtering drinking ***water,*** is used for removing volatile fractions of petroleum products or gaseous condensate from free basins of storage reservoirs, for neutralizing exhaust gases of internal combustion engines as the base of a matrix of a neutralizer of exhaust gases, for filtering cigarette smoke, for ***purifying*** blood plasma, for external use in the case of skin integument diseases characterized by discharges. The invention makes it possible to enhance the effectiveness of the removal of oil and petroleum products and also to ensure the removal of other chemical pollutants.
11	20020185439	**Process for the removal of organic substances (TOC), pesticides, or other substances from a salt solution** A process is provided for the removal of organic substances (TOC), pesticides or other specific compounds from an aqueous salt solution, for example from a regenerate derived from ***water purification***. The TOC-containing aqueous salt solution is treated in a desalination membrane according to the dead-end principle, wherein neither longitudinal flow over the membrane with air and/or ***water,*** nor continuous concentrate discharge takes place, after which the obtained permeate is reused, and the concentrate obtained after flushing is discharged. The TOC-containing aqueous salt solution is introduced at the feed side of the membrane module at a flux of 5-75 $L/m^2 \cdot h$, a feed pressure of 4-12 bars for 30-40 minutes, while the obtained TOC-depleted permeate is discharged. Preferably, operation takes place at a flux of 15-25 $L/m^2 \cdot h$, a pressure of approximately 8 bars, and the duration of treatment is approximately 30 minutes. The membrane used is tubular, capillary, hollow fiber or helically wound, and is usually of the ***nanofiltration*** or reverse osmosis type.

B2.3 Results of a US Patent Search for “nano$” AND “water” AND “purif$”: 176 Patents

This is a search of all fields in the US patents database from 1976 to the present. The search returned hits only when all of the following were found: (i) the prefix “nano” followed by any sequence of characters (in any field of the patent), (ii) the word “water” (in the abstract field only), and (iii) the root “purif” followed by any sequence of characters (in the abstract field only). Many of the hits are only peripherally relevant to the present study.

To read an entire patent, visit the web page http://patft.uspto.gov/netahtml/srchnum.htm and enter the desired patent number (Pat. No.).

	Pat. No.	Title
1	6,778,378	Flow-through capacitor and method
2	6,776,970	Getter materials for deoxygenating ammonia/oxygen gas mixtures at low temperature
3	6,773,487	Process for refining silver bullion with gold separation
4	6,764,601	Method for granulating powders
5	6,722,314	Method for improving conditions in closed circuit fish farming
6	6,712,947	Water purifying apparatus with electric field generator
7	6,699,827	Method for manufacturing an active component of surfactant, surfactant and a method for using the surfactant
8	6,692,734	N,O-amidomalonate platinum complexes
9	6,679,988	Apparatus for producing USP or WFI purified water
10	6,669,851	Water purification by polymer colloids
11	6,660,875	Ion exchange purification of dielectric condensate precursor fluids and silicate esters such as tetraethylorthosilicate (TEOS)
12	6,646,097	Method for purifying 1,1-bis(4'-hydroxy-3'-methylphenyl)cyclohexane and methods of producing polycarbonates therefrom
13	6,638,918	Chitosan compositions
14	6,635,177	Reclaiming water and usable brine concentrate from domestic sewage
15	6,623,635	Assembly for purifying water
16	6,623,603	Method and apparatus for water purification
17	6,592,763	Method and device for treating aqueous flows in a bioreactor, an ultrafiltration unit and a membrane filtration unit
18	6,567,492	Process and apparatus for production of F-18 fluoride
19	6,524,447	Apparatus and method for photocatalytic purification and disinfection of water and ultrapure water
20	6,518,067	Automated chemical synthesis apparatus

21	6,503,401	Effluent purifying system
22	6,491,740	Metallo-organic polymers for gas separation and purification
23	6,479,081	Method for obtaining grape tannin, resulting tannin and uses
24	6,464,884	Portable water treatment unit
25	6,462,935	Replaceable flow-through capacitors for removing charged species from liquids
26	6,461,514	High water recovery single stage membrane process
27	6,451,209	Method and a system for the treatment of water
28	6,447,721	Drinking water UV disinfection system and method
29	6,426,312	Air purifying matrix for the oxidation of air-borne particulate and gases
30	6,423,212	Microbial resistant water purification and collection system
31	6,416,668	Water treatment process for membranes
32	6,406,626	Composite semipermeable membrane, process for producing the same, and method of purifying water with the same
33	6,405,387	Sanitized jetted bathing facility
34	6,399,022	Simplified ozonator for a semiconductor wafer cleaner
35	6,395,182	Method for purifying water, in particular ground water, under anaerobic conditions, using a membrane filtration unit, a device for purifying water, as well as drinking water obtained by using such a method
36	6,387,850	Pesticide composition and method
37	6,387,409	Composition and method of preparing microparticles of water-insoluble substances
38	6,383,282	Pseudophasic extraction method for the separation of ultra-fine minerals
39	6,379,518	Electrodeionization apparatus and pure water producing apparatus
40	6,363,656	Apparatus and method for germinating grain
41	6,342,154	Assembly for purifying water
42	6,322,702	Solvent and process for recovery of hydroxide from aqueous mixtures
43	6,299,771	Composite adsorbent element
44	6,296,775	Apparatus and method for UV wastewater purification in septic tank systems
45	6,277,349	Tridymite-based processing for high purity quartz
46	6,268,607	UV purification of air and water in dental operatories
47	6,218,505	Chemical process for preparing amide derivatives of antibiotic A 40926
48	6,203,709	Iron (III)-doped calcium alginate gel sorbents for sorption of arsenate and selenite
49	6,187,917	Process for the purification of caprolactam obtained from the depolymerization of polyamide-containing carpet
50	6,172,121	Process for preparing organoclays for aqueous and polar-organic systems
51	6,171,568	Method for the purification of exhaust air and/or effluents by contact with moulded bodies containing dealuminated zeolite Y

52	6,153,789	Purification of aqueous dye solutions
53	6,153,724	Preparation of cross-linked 2-dimensional polymers with sidedness from alpha, beta-lactones
54	6,136,853	Sordarin derivatives
55	6,132,618	System and method for waking a computer having a plurality of power resources from a system state using a data structure
56	6,126,834	High resistivity water production with controlled water temperatures
57	6,113,797	High water recovery membrane purification process
58	6,099,735	Counter top reverse osmosis water purification system
59	6,080,317	Process and apparatus for the purification of waste water
60	6,080,316	High resistivity water production
61	6,080,313	Point-of-use water purification system with a cascade ion exchange option
62	6,074,551	Automatic cleaning system for a reverse osmosis unit in a high purity water treatment system
63	6,050,509	Method of manufacturing polymer-grade clay for use in nanocomposites
64	6,046,324	Process for preparation of macrocyclic chelants and the chelates thereof with paramagnetic metal ions
65	6,042,810	Process for the preparation of macrocyclic chelants and the chelates thereof with paramagnetic metal ions
66	6,027,649	Process for purifying water using fine floc and microfiltration in a single tank reactor
67	6,016,820	Aqueous cleaning system
68	6,015,840	Process for producing emulsifiers, and emulsified compositions
69	5,990,306	Process for the purification of caprolactam obtained from the depolymerization of polyamide-containing carpet
70	5,925,752	Process for the preparation of macrocyclic chelants and the chelates thereof with paramagnetic metal ions
71	5,904,854	Method for purifying water
72	5,868,851	Process for production of solid glucose
73	5,858,702	Isolation, cloning and expression of transmembrane water channel Aquaporin 5 (AQP5)
74	5,858,246	Method of water purification with oxides of chlorine
75	5,858,199	Apparatus and method for electrocoriolysis the separation of ionic substances from liquids by electromigration and coriolis force
76	5,831,081	Process for the purification of water-soluble cyclodextrin derivatives
77	5,766,479	Production of high purity water using reverse osmosis
78	5,741,671	Isolation cloning and expression of transmembrane water channel aquaporin 1(AQP1)
79	5,731,471	Process for the preparation of 2,3-pentanedione
80	5,730,181	Mass flow controller with vertical purifier

81	5,728,305	Waste water purification system
82	5,726,164	Nanosuspensions for intravenous administration
83	5,716,588	Getter materials for deoxygenating ammonia/oxygen gas mixtures at low temperature
84	5,711,887	Water purification system
85	5,670,053	Purification of gases from water using reverse osmosis
86	5,665,428	Preparation of peptide containing biodegradable microspheres by melt process
87	5,635,071	Recovery of carboxylic acids from chemical plant effluents
88	5,626,745	Waste water purification system
89	5,616,595	Process for recovering water insoluble compounds from a fermentation broth
90	5,614,206	Controlled dissolution pellet containing calcium sulfate
91	5,597,487	Water purification and dispensing system
92	5,587,089	Water purification and dispensing system
93	5,578,213	Fluid treatment process
94	5,547,590	UV-based water decontamination system with dimmer-control
95	5,545,335	Water purifier
96	5,536,400	Apparatus for purifying fluids with UV radiation and ozone
97	5,532,163	Process for refining oil and fat
98	5,531,971	Process for purifying semiconductor process gases to remove Lewis acid and oxidant impurities therefrom
99	5,518,624	Ultra pure water filtration
100	5,512,648	Polyamide resin-protide conjugate, preparation and uses
101	5,500,127	Purification process
102	5,500,124	Process for the purifying working-up of reaction media and/or wash media obtained during preparation of cellulose ethers
103	5,494,576	System and method for treating water
104	5,480,665	Apparatus and method for removing compounds from a solution
105	5,476,591	Liquid treatment system and method for operating the same
106	5,473,102	Process for recovery of aromatic acid and dihydric alcohol from waste polyester resins
107	5,447,635	Process of concentration and purification of organic compounds
108	5,443,739	Water purification and dispenser with uncontaminated mineral addition
109	5,433,866	System and method for treating water
110	5,427,682	Water purification and dispensing system
111	5,405,532	Process for the purification of industrial waste-waters
112	5,385,689	Process and composition for purifying semiconductor process gases to remove Lewis acid and oxidant impurities therefrom
113	5,376,281	Water purification system

114	5,374,356	Fluid treatment process using dynamic microfiltration and ultrafiltration
115	5,328,825	Nucleic acid probe, test kit and diagnostic and purification methods
116	5,320,755	Method and apparatus for purifying water
117	5,310,486	Multi-stage water treatment system and method for operating the same
118	5,308,492	Process for the purification of industrial waste-waters by nanofiltration
119	5,296,572	Large pore polyamide resin and method of preparation thereof
120	5,292,499	Method of preparing medical aerosol formulations including drug dissolved in reverse micelles
121	5,272,091	Water purification method and apparatus
122	5,269,850	Method of removing organic flux using peroxide composition
123	5,266,201	Process for the purification of aqueous solutions polluted by nitrate ions
124	5,259,936	Purified ion exchange resins and process
125	5,254,257	Reclaiming of spent brine
126	5,227,053	Water purification system
127	5,211,823	Process for purifying resins utilizing bipolar interface
128	5,196,134	Peroxide composition for removing organic contaminants and method of using same
129	5,174,901	Liquid purifying system
130	5,158,681	Dual membrane process for removing organic compounds from the water
131	5,116,509	Electrodeionization and ultraviolet light treatment method for purifying water
132	5,112,483	Slow sand/nanofiltration water treatment system
133	5,098,993	Method for removing alkali metal compound from crude high-molecular weight substance
134	5,093,009	Process for purifying water using a polymer flocculating agent
135	5,039,584	Charge transport layers containing purified polycarbonates
136	5,039,416	Process for the purification of industrial waste-waters
137	5,037,524	Apparatus for treating liquids with high-intensity pressure waves
138	5,030,749	Method for producing purified trimesic acid
139	5,026,484	Continuous flow method for processing liquids using high-energy discharge
140	5,024,766	Point of use deionized water purification unit
141	4,990,260	Method and apparatus for removing oxidizable contaminants in water to achieve high purity water for industrial use
142	4,981,641	Inhibition of nuclear-reactor coolant-circuit contamination
143	4,981,594	Waste water purification system
144	4,975,199	Water reclamation process
145	4,970,074	Fluorophores for encapsulation into liposomes
146	4,957,606	Separation of dissolved and undissolved substances from liquids using high energy discharge initiated shock waves

147	4,929,313	Amperometric electrochemical ion sensors and method for determining ion concentration
148	4,921,940	Process for the purification of Ti containing polycarbonate with solvent, complexing agent and water
149	4,917,785	Liquid processing system involving high-energy discharge
150	4,913,827	Process for purifying and de-pyrogenating water
151	4,912,208	Fluorophores for encapsulation into liposomes
152	4,791,234	Substantially pure spirobiindane bisphenols and method for their preparation
153	4,655,933	System of ionized oxygen allotrope gas water purification and method and apparatus therefor
154	4,623,467	Water purifying and vending apparatus
155	4,595,498	Water-polishing loop
156	4,574,075	Purification of alkali metal nitrates
157	4,563,286	System of ionized oxygen allotrope gas water purification and method and apparatus therefor
158	4,508,688	Method of regenerating acetate in a metal removal process
159	4,496,520	Field detection of 2,4,6-trinitrotoluene in water by ion-exchange resins
160	4,455,301	Antihemophilic factor concentrate
161	4,386,068	Antihemophilic factor concentrate and method for preparation
162	4,384,956	Waste water purification
163	4,282,196	Method of preparing optical fibers of silica
164	4,247,473	Method for producing bis-[4-(diphenylsulfonio)phenyl] sulfide bis-MX_6 photoinitiator
165	4,247,472	Method for producing bis-[4-(diphenylsulfonic)phenyl]sulfide bis-MF_6 photoinitiator
166	4,204,956	Water purification system
167	4,201,640	Method for producing bis-[4-(diphenylsulfonio)phenyl] sulfide bis-MX_6
168	4,197,174	Method for producing bis-[4-(diphenylsulfonio) phenyl] sulfide bis-MX_6
169	4,126,544	Process and apparatus for removing impurities dissolved in water
170	4,075,280	Preparation of improved zeolites
171	4,047,989	Method for the recovery of blasting oil from effluents from the production of nitroglycerine-containing explosives
172	4,021,535	Reagents used in the radioimmunoassay of digoxin
173	4,017,734	Water purification system utilizing ultraviolet radiation
174	4,008,161	Treatment of pulp mill effluents
175	3,955,318	Waste purification system
176	3,940,332	Treating waste water containing nitriles and cyanides

B2.4 Results of a Search of US Patent Applications in the PGPUB Production Database for "water purification" AND “nano$”: 214 Patent Applications

This is a search of all fields in the US patent *applications* database from 2001 to 2004. The search returned hits only when both of the following were found in an abstract: (i) the prefix “nano” followed by any sequence of characters and (ii) the exact phrase “water purification”. Many of the hits are only peripherally relevant to the present study.

To read an entire patent application, visit the web page at http://appft1.uspto.gov/netahtml/PTO/srchnum.html and enter the corresponding published application number (Pub. App. No.).

	Pub. App. No.	**Title**
1	20040168989	System and method for water purification
2	20040166592	Method of immobilizing membrane-associated molecules
3	20040164029	Water treatment compositions with masking agent
4	20040164018	Water filter materials, water filters and kits containing particles coated with cationic polymer and processes for using the same
5	20040163941	Method for purification of poisonous gas
6	20040161610	Method of identifying chemical compounds having selected properties for a particular application
7	20040161504	Mineral fortification systems
8	20040159596	Water filter materials, water filters and kits containing silver coated particles and processes for using the same
9	20040152145	Assay for detecting, measuring and monitoring the activities and concentrations of proteins and methods of use thereof
10	20040149655	Methods and systems for purifying fluids and regenerating purification media
11	20040149571	Electrolysis cell for generating halogen (and particularly chlorine) dioxide in an appliance
12	20040147397	Magnetic activated carbon particles for adsorption of solutes from solution
13	20040140269	Ultraviolet-and-ozone disinfection apparatus having improvement on disinfection effect
14	20040132195	Method of monitoring membrane cleaning processes
15	20040129639	Extraction methodology for suspended and dissolved material from fruit and vegetable wastewater
16	20040129617	Water filter device
17	20040121070	Connect diamond powders by cycloaddition reactions

18	20040120100	Composite electrode and current collectors and processes for making the same
19	20040118776	Method of monitoring membrane separation processes
20	20040115757	Method of monitoring biofouling in membrane separation systems
21	20040115278	Method for eliminating potentially toxic and/or harmful substances
22	20040110714	Stabilized naked DNA compositions
23	20040110220	Nanoparticles having oligonucleotides attached thereto and uses therefor
24	20040108270	Method and apparatus for treatment of a fluid system
25	20040106741	Nanofilm compositions with polymeric components
26	20040104171	Method of monitoring membrane separation processes
27	20040104169	Method of monitoring membrane separation processes
28	20040104161	Module for purifying a fluid, in particular water
29	20040101835	Direct multiplex characterization of genomic DNA
30	20040092607	Water purification by polymer colloids
31	20040092393	Photocatalytic rutile titanium dioxide
32	20040091620	Surfaces with gradients in surface topography
33	20040086885	Magnetic nanomaterials and methods for detection of biological materials
34	20040086445	Synthesis method for carbon material based on $Li_xM_{1-y}M'_y(XO_4)_n$
35	20040084365	Solvent-resistant microporous polybenzimidazole membranes and modules
36	20040072231	Nanoparticles having oligonucleotides attached thereto and uses therefor
37	20040072158	Electrochemical detection of nucleic acid sequences
38	20040060808	Advective solar collector for use in multi-effect fluid distillation and power co-generation
39	20040058034	Mineral fortified water
40	20040054127	Water-soluble block copolymer and production method therefor
41	20040052746	Multi-purpose polymers, methods and compositions
42	20040050761	Apparatus for producing USP or WFI purified water
43	20040049230	Biomimetic membranes
44	20040045932	Method of manufacturing a spectral filter for green and shorter wavelengths
45	20040034223	Amphiphilic molecular modules and constructs based thereon
46	20040029211	Method for locating hidden microorganism contaminated surfaces in industrial water systems
47	20040020978	Biologically safe mail box
48	20040020858	Method for controlling the integrity of a nanofiltration or reverse osmosis module, or module system
49	20040020840	Low-level boron detection and measurement
50	20040018583	Method of monitoring biofouling in membrane separation systems

51	20040018530	In vitro evolution of functional RNA and DNA using electrophoretic selection
52	20040012913	Fringe-field capacitor electrode for electrochemical device
53	20040009726	Multi-functional protective textiles and methods for decontamination
54	20040007529	Method for modifying membrane rejection characteristics
55	20040007521	Polysulfonamide matrices
56	20040005700	Poroplasts
57	20040004779	Spectral filter for green and shorter wavelengths
58	20030232335	Minicell-based screening for compounds and proteins that modulate the activity of signalling proteins
59	20030230522	Portable high-pressure washing and rinsing system producing and using ultrapure ultrasoft reverse osmosis water
60	20030228727	Stress-induced bandgap-shifted semiconductor photoelectrolytic/photocatalytic/photovoltaic surface and method for making same
61	20030224444	Antibodies to native conformations of membrane proteins
62	20030224369	Reverse screening and target identification with minicells
63	20030220502	Fluorescent labeling complexes with large stokes shift formed by coupling together cyanine and other fluorochromes capable of resonance energy transfer
64	20030219888	Minicell-based bioremediation
65	20030219408	Methods of making pharmaceutical compositions with minicells
66	20030217967	Processes for manufacturing water filter materials and water filters
67	20030217963	Water filter materials and water filters and processes for using the same
68	20030215914	Structure for presenting desired peptide sequences
69	20030211626	Pulsed-flow total organic carbon analyzer
70	20030211599	Minicell-based delivery agents
71	20030211086	Minicell-based selective absorption
72	20030211022	Method and apparatus for decontaminating water or air by a photolytic and photocatalytic reaction
73	20030209501	Fluid purification and disinfection device
74	20030209495	Mixtures of adsorber materials
75	20030207833	Pharmaceutical compositions with minicells
76	20030207296	Nanoparticles having oligonucleotides attached thereto and uses therefor
77	20030205509	Method and system for monitoring water treatment and water quality
78	20030203481	Conjugated minicells
79	20030203471	Bacterial small-molecule three-hybrid system
80	20030203411	Methods of minicell-based delivery
81	20030202937	Minicell-based diagnostics
82	20030201225	Organic slurry treatment process

83	20030199688	Macrocyclic module compositions
84	20030199100	Method and system for detecting and recording submicron sized particles
85	20030199089	Membrane to membrane delivery
86	20030199088	Minicell-based gene therapy
87	20030199005	Solid supports with minicells
88	20030198996	Minicell libraries
89	20030198995	Forward screening with minicells
90	20030196966	Reactive compositions for fluid treatment
91	20030196955	Membrane based fluid treatment systems
92	20030194798	Minicell compositions and methods
93	20030194714	Minicell-based transformation
94	20030194039	Process and apparatus for production of F-18 fluoride
95	20030192664	Use of vinyl amine polymers with ionic, organic, cross-linked polymeric microbeads in paper-making
96	20030190749	Minicell-producing parent cells
97	20030190683	Minicell-based rational drug design
98	20030190601	Target display on minicells
99	20030190254	Method for ultra-violet disinfecting of compressed air
100	20030183575	Method of monitoring membrane separation processes
101	20030180946	Site-specific cell perforation technique
102	20030180783	Nanoparticles having oligonucleotides attached thereto and uses therefor
103	20030175321	Inorganic shaped bodies and methods for their production and use
104	20030173307	Assembly and method for purifying water at a point of use and apparatus and method for testing same
105	20030173297	Methods for the on-line, on-demand preparation of sterile, water-for-injection grade water
106	20030173296	High recovery reverse osmosis process and apparatus
107	20030170906	Conductive diamond spectrographic cells and method of use
108	20030166279	Minicell-based transfection
109	20030166099	Minicells comprising membrane proteins
110	20030160005	Enhanced air and water purification using continuous breakpoint halogenation with free oxygen radicals
111	20030159980	Solvent-resistant microporous polybenzimidazole membranes
112	20030157732	Self-assembled metal colloid monolayers
113	20030155308	Process for treating industrial wastewaters
114	20030154865	Nano coupling magnetoadsorbent
115	20030153636	Mesoporous carbons and polymers from hydroxylated benzenes
116	20030151819	Optical filters comprising solar blind dyes and UV-transparent substrates

117	20030150707	Apparatus and method for photocatalytic purification and disinfection of fluids
118	20030148282	Nanoparticles having oligonucleotides attached thereto and uses therefor
119	20030146099	Method for removing inorganic compounds from a section of soil
120	20030144467	Matrix solid-phase organic synthesis
121	20030143538	Nanoparticles having oligonucleotides attached thereto and uses therefor
122	20030141242	Polysulfonamide matrices
123	20030139517	Aqueous silica-containing composition
124	20030138473	Composite shaped bodies and methods for their production and use
125	20030136534	Aqueous silica-containing composition
126	20030135032	Methods and compositions for bioremediation
127	20030132167	Potable water treatment system, apparatus and method of operation thereof
128	20030127381	Apparatus for producing USP or WFI purified water
129	20030124528	Nanoparticles having oligonucleotides attached thereto and uses therefor
130	20030121842	Encapsulated filter unit, system and method for filtering fluids
131	20030108985	Structure for presenting desired peptide sequences
132	20030108460	Method for surface corona/ozone making, devices utilizing the same and methods for corona and ozone applications
133	20030104386	Methods for the specific detection of redox-active tags and the use thereof for capillary gel electrophoresis and DNA sequencing
134	20030104020	Chitosan compositions
135	20030102269	Pulsed blackbody radiation flux enhancement
136	20030100617	Water purification by polymer colloids
137	20030098247	Waste fluid or waste water treatment method and its apparatus
138	20030091647	Controlled dispersion of colloidal suspensions via nanoparticle additions
139	20030091641	Antimicrobial polymeric surfaces
140	20030089609	Apparatus for fluid purification and methods of manufacture and use thereof
141	20030087242	Nanoparticles having oligonucleotides attached thereto and uses therefor
142	20030080068	Apparatus and method for combined use of ultraviolet and ozone in appliances
143	20030080058	Method of bacteriostasis or disinfection for permselective membrane
144	20030068622	Nanoparticles having oligonucleotides attached thereto and uses therefor
145	20030059777	Nanoparticles having oligonucleotides attached thereto and uses therefor
146	20030054358	Nanoparticles having oligonucleotides attached thereto and uses therefor
147	20030052064	Method and system for controlling biofilm
148	20030049631	Nanoparticles having oligonucleotides attached thereto and uses therefor
149	20030049630	Nanoparticles having oligonucleotides attached thereto and uses therefor
150	20030044855	Microarrays and their manufacture by slicing

151	20030044805	Nanoparticles having oligonucleotides attached thereto and uses therefor
152	20030042201	Medical grade water production system
153	20030042134	High efficiency electrolysis cell for generating oxidants in solutions
154	20030029274	SERS substrates formed by hydroxylamine seeding of colloidal metal nanoparticle monolayers
155	20030024884	Method for removing oil, petroleum products and/or chemical, pollutants from liquid and/or gas and/or surface
156	20030022169	Nanoparticles having oligonucleotides attached thereto and uses therefor
157	20030019818	Method and apparatus for preparing pure water
158	20030013401	Water reuse in food processing
159	20030007588	Process and apparatus for production of F-18 fluoride
160	20020197467	Process for the surface modification of a polymeric substrate
161	20020195331	Treatment of dental-unit water lines
162	20020187082	Photocatalyst coated magnetic composite particle
163	20020185439	Process for the removal of organic substances (TOC), pesticides, or other substances from a salt solution
164	20020185417	Apparatus for the treatment of domestic water
165	20020182613	Nanoparticles having oligonucleotides attached thereto and uses therefor
166	20020182611	Nanoparticles having oligonucleotides attached thereto and uses therefor
167	20020180082	Preparation of microporous films from immiscible blends via melt processing and stretching
168	20020179493	Production and use of a premium fuel grade petroleum coke
169	20020172953	Movement of biomolecule-coated nanoparticles in an electric field
170	20020165620	Assay for detecting, measuring and monitoring the activities and concentrations of proteins and methods of use thereof
171	20020164605	Nanoparticles having oligonucleotides attached thereto and uses therefor
172	20020162969	Ultraviolet radiated water treatment tank
173	20020159951	Novel targeted compositions for diagnostic and therapeutic use
174	20020155462	Nanoparticles having oligonucleotides attached thereto and uses therefor
175	20020155461	Nanoparticles having oligonucleotides attached thereto and uses therefor
176	20020155459	Nanoparticles having oligonucleotides attached thereto and uses therefor
177	20020155458	Nanoparticles having oligonucleotides attached thereto and uses therefor
178	20020155442	Nanoparticles having oligonucleotides attached thereto and uses therefor
179	20020146720	Nanoparticles having oligonucleotides attached thereto and uses therefor
180	20020144955	Method and system for purifying water contained in a vessel
181	20020140137	Inorganic shaped bodies and methods for their production and use
182	20020137072	Nanoparticles having oligonucleotides attached thereto and uses therefor
183	20020137071	Nanoparticles having oligonucleotides attached thereto and uses therefor

184	20020137070	Nanoparticles having oligonucleotides attached thereto and uses therefor
185	20020130069	Water quality monitoring and transmission system and method
186	20020127574	Nanoparticles having oligonucleotides attached thereto and uses therefor
187	20020110924	Water contamination concentration apparatus and process
188	20020108846	Photocatalytic degradation of organic compounds
189	20020100715	Microbial resistant water purification and collection system
190	20020092613	Method of utilizing sol-gel processing in the production of a macroscopic two or three dimensionally ordered array of single wall nanotubes (SWNTs).
191	20020091225	Ion-conducting sulfonated polymeric materials
192	20020090430	Food processing method and system
193	20020088945	Apparatus and method for simultaneously germicidally cleansing both air and water
194	20020077249	Contact and adsorbent granules
195	20020076714	Spatially encoded analyte detection
196	20020074292	Adsorption vessels
197	20020070172	Contact and adsorbent granules
198	20020066368	Magneto adsorbent
199	20020063954	UV portal-based appliances and containers
200	20020056634	Capacitive electrostatic process for inhibiting the formation of biofilm deposits in membrane-separation systems
201	20020053547	Contact and adsorbent granules
202	20020047551	High efficiency solid state light-emitting device and method of generating light
203	20020036461	Discharge device having cathode with micro hollow array
204	20020023866	Assembly for purifying water
205	20020015952	Microarrays and their manufacture by slicing
206	20020014410	Amperometric sensor probe for an automatic halogen control system
207	20020005385	Water treatment systems and methods
208	20010042842	Hand-held germicidal lamp with safety features
209	20010042708	Assembly for purifying water
210	20010041339	Microarrays and their manufacture
211	20010040130	Detection of pyrogen and other impurities in water
212	20010040122	Assembly for purifying water
213	20010031798	Free radical polymerization method
214	20010012537	Dry deposition of materials for microarrays using matrix displacement

B3. US Patents and US Patent Applications for Water Desalination

B3.1 Results of a US Patent Search for “nano$” AND "water desalination": 38 Patents

This is a search of all fields in the US patents database from 1976 to the present.
The search returned hits only when both of the following were found anywhere in an entire patent record: (i) the prefix “nano” followed by any sequence of characters and (ii) the exact phrase “water desalination”. Abstracts are included only for those patents with apparent environmental applications.

To read the entire patent, visit the web page http://patft.uspto.gov/netahtml/srchnum.htm and enter the desired patent number (Pat. No.).

	Pat. No.	Title
1	6,814,865	**Ion exchange membranes, methods and processes for production thereof and uses in specific applications** The invention includes novel anion exchange membranes formed by in situ polymerization of at least one monomer, polymer or copolymer on a woven support membrane and their methods of formation. The woven support membrane is preferably a woven PVC membrane. The invention also includes novel cation exchange membranes with or without woven support membranes and their methods of formation. The invention encompasses a process for using the membranes in electrodialysis of ionic solutions and in particular industrial effluents or brackish water or seawater. The electrodialysis process need not include a step to remove excess ions prior to electrodialysis and produces less waste by-product and/or by-products which can be recycled.
2	6,787,235	**Consolidated amorphous carbon materials, their manufacture and use**
3	6,783,682	**Salt water desalination process using ion selective membranes** The invention is directed to an improved desalination process to produce potable water. The process represents an improvement of hybrid of membrane and desalination technologies. The improvement of the invention comprises the operation of an ion selective membrane at a variable pressure as a function of the cost of electricity to form a softened salt water that is blended in variable proportions, to increase the top operating temperature of the desalination system and increase recovery of potable water, with untreated salt water.
4	6,761,809	**Alternating-polarity operation for complete regeneration of electrochemical deionization system**
5	6,699,391	**Biofilm reduction in crossflow filtration systems** Systems and methods for reducing biofilms are described. The systems and methods are particularly suitable for use with conventional aqueous crossflow

		filtration systems, such as reverse osmosis systems. The addition of the enzyme/surfactant compound has been found to enhance the effectiveness of conventional crossflow filtration processes by decreasing or inhibiting the growth of biofilms and other contaminants.
6	6,544,648	**Consolidated amorphous carbon materials, their manufacture and use**
7	6,511,645	**Consolidated amorphous carbon materials, their manufacture and use**
8	6,508,936	**Process for desalination of saline water, especially water, having increased product yield and quality** A desalination process is disclosed which combining two or more substantially different water treatment processes in a unique manner to desalinate saline water, especially sea water, to produce a high yield of high quality fresh water, including potable water, at an energy consumption equivalent to or less than much less efficient prior art desalination processes. In this process a ***nanofiltration*** step is synergistically combined with at least one of sea water reverse osmosis, multistage flash distillation, and multieffect distillation of vapor compression distillation to provide an integrated desalination system by which sea water can be efficiently and economically converted to high quality potable water in yields which are at least 70%-80% greater than the yields available from the prior art processes. Typically a process of this invention using the ***nanofiltration*** initial step will produce, with respect to sea water feed properties, calcium, magnesium, sulfate and bicarbonate ion content reductions of 63%-94%, pH decreases of about 0.4-0.5 units and total dissolved solids content reductions of 35%-50%.
9	6,506,305	**Methods of isolating urea, urea compositions and methods for producing the same**
10	6,375,847	**Method for operating a cross-flow filtration installation**
11	6,350,520	**Consolidated amorphous carbon materials, their manufacture and use**
12	6,346,187	**Alternating-polarity operation for complete regeneration of electrochemical deionization system**
13	6,309,532	**Method and apparatus for capacitive deionization and electrochemical purification and regeneration of electrodes**
14	6,289,853	**Water injection system for an internal combustion engine of a marine propulsion system**
15	6,277,265	**Apparatus and method for electrocoriolysis, the separation of ionic substances from liquids in the electrodynamic mode** An apparatus and method for electrocoriolysis, the separation of ionic substances from liquids in the electrodynamic mode. The method maximizes centrifugal forces on a fluid contained in a chamber having oppositely polarized electrodes. A feed fluid is fed into the chamber. Spacing of the electrodes can be minimized for enhancement of the process. A constant voltage can be applied. Centrifugal force and the electric potential across the chamber create enhanced separation. Concentrated solution can be removed from a location in the chamber and depleted solution from another location.

16	6,187,200	**Apparatus and method for multistage reverse osmosis separation** This invention relates to an apparatus and method for a multistage reverse osmosis separation which comprises reverse osmosis membrane module units arranged at multistage with a booster pump provided in the concentrate flow channel between reverse osmosis membrane module unit, wherein the total effective reverse osmosis membrane area of a module unit is in the range of 20-80% of that of the preceding module unit. The object of this invention is to provide apparatus and separation method that produce low-concentration solution from high-concentration solution with a high recovery ratio, small energy requirements, and high stability.
17	6,161,435	**Method and apparatus for determining the state of fouling/cleaning of membrane modules** The fouling state of a polymeric membrane within the high pressure housing of a spiral wound or a hollow fiber membrane module is determined. An ultra sonic transducer positioned with its emitting face in physical engagement with the outer surface of the housing is pulse energized by a pulser / receiver device. A membrane echo signal is detected by a receiver of the pulser / receiver device. A reference echo signal indicative of a fouled or an unfouled state of the membrane is compared to the echo signal to determine the membrane fouling state. The echo to reference comparing step can be based upon comparing amplitude domain signals, comparing time-domain signals, comparing combinations of amplitude domain and time-domain signals, and comparing transformations of amplitude domain and time-domain signals. A clean or a fouled reference echo can be provided from a clean or a fouled membrane and then stored for use during a liquid separation process, or a clean reference echo signal can be obtained on-line from a second transducer whose echo signal is derived from an area of the membrane known to remain relatively unfouled during the liquid separation process, or a clean or fouled reference echo signal can be provided for later use during a cleaning process or during a liquid separation process. Multiple transducers and a switching network can sample the fouling state at different positions within the membrane module.
18	6,103,125	**Zero waste effluent water desalination system** A ***water desalination*** and softening system that can be used in a home or commercial environment which recirculates water past a membrane filter element in a manner to self clean the membrane and to prevent a buildup of salts and minerals on the membrane surface. The system conserves water so as to result in near zero waste by recirculating water from a reservoir tank past the membrane. The system can operate in conjunction with a building's water supply and can operate without problems in either a zero or low effluent mode or when water usage is frequent.
19	6,080,315	**Process for the partial desalination of water** In a process for the partial desalination of water, especially of drinking water, with a mixture of weakly acid cation exchangers and strongly basic anion exchangers, whereby the charged ion exchangers are regenerated by CO_2-

		containing water, if required, with the addition of $CaCO_3$, $CaCO_3$/MgO, $Ca(OH)_2$ or the like. Simultaneous with the partial desalination, the organic carbon compounds present in the water are reduced, whereby the charged ion exchangers are intermittently regenerated with HCl, NaCl, NaOH, or a mixture of NaCl and NaOH.
20	5,961,835	**Process and installation for the separation of heavy and light compounds by extraction using a supercritical fluid and nanofiltration** A process and installation for the separation of heavy and light compounds is provided. According to the process, a solid or liquid phase containing the compounds to be separated is contacted with a supercritical fluid in an extractor, after which the supercritical fluid containing compounds leaving the extractor undergo ***nanofiltration*** for recovering a permeate flow containing the light compounds and a retentate flow containing the heavy compounds. The invention has particular utility for separating fats in food stuffs such as butter or fish oil.
21	5,954,937	**Method and apparatus for capacitive deionization and electrochemical purification and regeneration of electrodes**
22	5,858,199	**Apparatus and method for electrocoriolysis the separation of ionic substances from liquids by electromigration and coriolis force** An apparatus and method for separating and removing ionizable components dissolved in fluids, such as for example, water, by separating said ionizable substances into fractions by the action of electric current and of coriolis force. Liquid containing ionizable components is continuously fed in and the purified solvent and the solute in a concentrated solution are continuously removed while the liquid is rotated. Compound centrifugal force or coriolis force causes the concentrated solution to move to a location where it can be effectively and continuously removed as well as causes the depleted liquid to move to a separate location where it also can be effectively and continuously removed. The invention can operate in several modes, the modes being electrolytic and electrostatic. The invention allows for almost universal application to removal of ionizable components and provides a cost effective and energy efficient continuous process to do so.
23	5,783,079	**Composite hollow fiber membrane and process for its production**
24	5,736,050	**Currents in narrow pores** Current fluctuations typical of those observed with biological channels which are ion selective and inhibited by divalent cations and protons have been observed in synthetic membranes, and a process for controlling permeability of a synthetic membrane to ions and uncharged molecules may be used in a switch or sensor, for example to monitor the content of a solution, to trigger macroscopic events by local microscopic changes and to alter the ionic content of a solution e.g. desalination.
25	5,626,752	**Device for separating biologic-organic flow media with filter elements in the form of membrane cushions**

26	5,545,320	**Device for filtering and separating flow media with filter elements that are in the form of membrane cushions**
27	5,520,816	**Zero waste effluent desalination system** The present invention is directed to a ***water desalination*** system that can be used in a home or commercial entity which uses a reverse osmosis or ***nanofilter*** membrane element in a unique flow configuration which promotes self cleaning of a membrane element to prevent a buildup of salts and minerals on the membrane surface. The systems use the dynamics of water usage in a water service line, not connected to the membrane to flush a recirculation/reservoir tank that feeds the reverse osmosis or ***nanofilter*** membrane periodically. The systems also produce little or no waste effluent that must be dumped into a waste system, thereby wasting water and causing an environmental problem.
28	5,435,969	**Monitoring water treatment agent in-system concentration and regulating dosage**
29	5,425,858	**Method and apparatus for capacitive deionization, electrochemical purification, and regeneration of electrodes**
30	5,411,889	**Regulating water treatment agent dosage based on operational system stresses**
31	5,246,593	**Silica scale deposition control**
32	5,233,027	**Copper complexes of sulpho groups containing disazo dyestuffs**
33	4,948,506	**Physicochemically functional ultrathin films by interfacial polymerization**
34	4,897,193	**Device for mass transport and separation through selective barriers** The present invention relates to a new technique and device for mass transport operation and physical separation, being substantially quantitative and involving selective barriers. According to the new technique, the mass transport through the selective barrier and physical separation are carried out in the same device. The device consists of a mixing-reservoir into which is fitted snugly a mixer-separator, having a channel in the vertical axis of the mixer-separator, the mixer-separator being provided with means for accumulating a gas pocket to decrease the pressure exerted on the barrier. The completely solid-free liquid passing through the selective barrier is removed by pushing in the mixer-separator, said liquid being accumulated in a collecting container. Typical examples of such selective barriers are: membrane, bed of adsorbent material, paper, plastic, glass and metal filters or any other porous material, and hollow fibers. The new technique and device can be successfully utilized in any operation involving separation of solids from liquids and particularly useful in immunoassay, sterilization, ultra-filtration, desalination by reverse and osmosis.
35	4,832,850	**Method and device for mass transport and separation through selective barriers** The present invention relates to a new technique and device for mass transport operation and physical separation, being substantially quantitative and involving selective barriers. According to the new technique, the mass

		transport through the selective barrier and physical separation are carried out in the same device. The device consists of a mixing-reservoir into which is fitted snugly a mixer-separator, having a channel in the vertical axis of the mixer-separator, the mixer-separator being provided with means for accumulating a gas pocket to decrease the pressure exerted on the barrier. The completely solid-free liquid passing through the selective barrier is removed by pushing in the mixer-separator, said liquid being accumulated in a collecting container. Typical examples of such selective barriers are: membrane, bed of adsorbent material, paper, plastic, glass and metal filters or any other porous material, hollow fibers etc. The new technique and device can be successfully utilized in any operation involving separation of solids from liquids and particularly useful in immunoassay, sterilization, ultra-filtration, desalination by reverse osmosis, etc.
36	4,246,092	**Method and apparatus for the performance of selective electrodialysis** The invention provides a method for the performance of selective electrodialytic separation of a first group of charged ions from a solution containing other charged ions having the same sign and optionally the same valence as said first group comprising applying a current to an electrodialysis unit comprising at least one thin, dense, non-porous charged electrodialysis membrane made of water-insoluble hydrophobic polymeric material, containing covalently bound ionizable groups, wherein said membrane separates at least one diluting compartment from at least one concentrating compartment in said unit and wherein said membrane is in the form of a polymeric matrix optionally supported on a porous support and having a preselected dielectric constant and composition adapted to induce selective ion disassociation of said first group of charged ions whereby there is achieved a substantial ion migration of said selected ion group and its preferential transference across said membrane at a fraction larger than its relative concentration in said solution. The invention also provides a selective electrodialysis unit per carrying out said method.
37	4,102,827	**Novel polyelectrolytes**
38	4,036,808	**Conductive hydrogel containing 3-ionene**

B3.2 Results of a Search of US Patent Applications in the PGPUB Production Database for “water desalination” AND “nano$”: 19 Patent Applications

This is a search of all fields in the US patent *applications* database from 2001 to 2004. The search returned hits only when both of the following were found anywhere in an entire patent application record: (i) the prefix “nano” followed by any sequence of characters and (ii) the exact phrase “water desalination”. Abstracts are included below only for patent applications with apparent environmental applications.

To read an entire patent application, visit the website at
http://appft1.uspto.gov/netahtml/PTO/srchnum.html and enter the published application number
(Pub. App. No.).

	Pub. App. No.	**Title**
1	20050016922	**Preferential precipitation membrane system and method** A system and method for desalinating a feed solution containing a high level of sparingly soluble solutes, such as calcium sulfate, in which a high percentage of the water content of the feed solution is recovered as purified water. The method and system comprise introducing a sufficient quantity of nucleation crystals on the low pressure side of a first-pass membrane separation unit so that the sparingly soluble solutes precipitate on the suspended nucleation crystals, instead of on the surface of the first-pass semi-permeable membrane barrier. The permeate from the first-pass membrane separation unit is then sent to the high pressure side of a second-pass membrane separation unit. The second-pass semi-permeable membrane barrier rejects additional dissolved solutes, some of which can be recycled back to the first-pass membrane, so that permeate with a low level of dissolved solutes is produced on the low pressure side of the second-pass membrane barrier.
2	20050011832	***Water desalination* process using ion selective membranes** The invention is directed to an improved desalination process to produce potable water. The process represents an improvement of hybrid of membrane and desalination technologies. The improvement of the invention comprises the operation of an ion selective membrane at a variable pressure as a function of the cost of electricity to form a softened salt water that is blended in variable proportions, to increase the top operating temperature of the desalination system and increase recovery of potable water, with untreated salt water.
3	20040245177	**Method and apparatus for parallel desalting** Parallel desalting (PDS) includes a hybrid membrane softening (MS) system for de-mineralizing water for residential and commercial use.

		Parallel desalting produces "soft" water without the use of salt, or any other liquid chemical reagent normally used to carry out pH adjustment in industrial membrane and precipitation processes. The PDS process balances the operation of a RO (potable water) membrane unit with the operation of a tubular MF (wastewater) membrane unit, thereby providing a highly efficient and regenerative water treatment technology: (1) The optimum operation for the PDS system transforms roughly 90 percent of a potable, slightly brackish water supply into <50 mg/L TDS water with <1-grain (10-15 mg/L as calcium carbonate)-water hardness; and (2) The operation of the PDS system produces, in salinity terms, in a 100 percent reusable effluent for downstream recycling. Virtual prototype results suggest that with Colorado River Aqueduct source water (570-620 mg/L TDS and 16-grain water hardness), parallel desalting can produce an effluent with a TDS 40-70 mg/L lower than the originating supply (excluding TDS contributed directly by the particular type of use of the soft water).
4	20040217052	**Biofilm reduction in crossflow filtration systems** Systems and methods for reducing biofilms are described. The systems and methods are particularly suitable for use with conventional aqueous crossflow filtration systems, such as reverse osmosis systems. The addition of the enzyme/surfactant compound has been found to enhance the effectiveness of conventional crossflow filtration processes by decreasing or inhibiting the growth of biofilms and other contaminants.
5	20040211726	**Membrane-assisted fluid separation apparatus and method** This present invention relates to a fluid separation module adapted to separate a given fluid mixture into permeate and retentate portions using bundles of hollow fiber membranes. The membranes may be composed of different kinds of membranes depending on the application being used to separate the fluid mixture. The fluid separation module may be used to separate fluid mixtures by a number of different processes, including but not limited to, pervaporation, vapour permeation, membrane distillation (both vacuum membrane distillation and direct contact membrane distillation), ultra filtration, microfiltration, *nanofiltration,* reverse osmosis, membrane stripping and gas separation. The present invention also provides an internal heat recovery process applied in association with those fluid separation applications where separation takes place by evaporation through the membrane of a large portion of the feed into permeate. Desalination and contaminated water purification by means of vacuum membrane distillation are just two examples where the internal heat recovery process may be applied. In these two examples, large portions of the feed are separated by membranes into a high purity water permeate stream by evaporation through the membranes and into a retentate stream containing a higher concentration of dissolved components than present in the feed. In this process the permeate vapour that is extracted from the fluid separation module is compressed by an external compressor to increase the

		temperature of the vapour higher than the temperature of the feed entering the separation module. Heat from the permeate vapour at the elevated temperature is transferred back to the incoming feed fluid mixture entering the fluid separation module in a condenser/ heat exchange.
6	20040188246	**Alternating-polarity operation for complete regeneration of electrochemical deionization system** An electrically regeneratable battery of electrochemical cells for capacitive deionization (including electrochemical purification) and regeneration of electrodes is operated at alternate polarities during consecutive cycles. In other words, after each regeneration step operated at a given polarity in a deionization-regeneration cycle, the polarity of the deionization step in the next cycle is maintained. In one embodiment, two end electrodes are arranged one at each end of the battery, adjacent to end plates. An insulator layer is interposed between each end plate and the adjacent end electrode. Each end electrode includes a single sheet of conductive material having a high specific surface area and sorption capacity, preferably a sheet formed of carbon aerogel composite. The battery further includes a plurality of generally identical double-sided intermediate electrodes that are equidistantly separated from each other, between the two end electrodes. As the electrolyte enters the battery of cells, it flows through a continuous open serpentine channel defined by the electrodes, substantially parallel to the surfaces of the electrodes. By polarizing the cells, ions are removed from the electrolyte and are held in the electric double layers formed at the carbon aerogel surfaces of the electrodes. As the electrodes of each cell of the battery are saturated with the removed ions, the battery is regenerated electrically at a reversed polarity from that during the deionization step of the cycle, thus significantly minimizing secondary wastes.
7	20040154979	**Composite semipermeable membrane** The present invention relates to a composite semipermeable membrane, which is useful as a reverse osmosis membrane or a ***nano***-filtration membrane and comprises a polysulfone porous support membrane and a polyamide ultrathin layer formed on one of the surfaces of the porous support membrane, the composite membrane having the characteristic that in the infrared absorption spectrum obtained from the surface of a polyamide ultrathin layer of the composite semipermeable membrane, the ratio T (=Aa/As) of absorption intensity Aa at the absorption peak revealing C=O of polyamide in the region of 1600-1700 cm^{-1} to absorption intensity As at the absorption peak revealing polysulfone at a wavenumber around 1586 cm^{-1} is at least 0.05 and not higher than 3. The composite semipermeable membrane thus obtained can attain conversion of sea water into fresh ***water, desalination*** of brackish water, recovery of valuable matter in aqueous solutions, treatment of waste water, and particularly removal of impurities (e.g., organic substances) from water.
8	20040113291	**Diffusion driven desalination apparatus and process** A diffusion driven desalination apparatus and related method includes

		structure for receiving a heated water stream and creating at least one region having a thin film of water and structure for forcing a low humidity air stream over the thin film of water, wherein water from the thin film of water evaporates and diffuses into the air stream to create a humidified air stream. A diffusion tower including at least one plenum can be used to create and transfer the humidified air stream. At least one condenser, such as a direct contact condenser, condenses the humidified air stream, wherein purified water is produced. Waste heat from a power plant can be used to provide the heated water stream and power plants can use the waste heat generated to inexpensively provide purified water.
9	20040084384	**Microbicidal separation systems** The invention relates to microbicidal separation systems using antimicrobial polymers, and to their production and use.
10	20040055955	**Production of purified water and high value chemicals from salt water** Sodium chloride and purified water are recovered by treating salt water that contains sodium chloride with an integrated reverse osmosis and electrodialysis system, which includes an efficiency-enhancing feature that is one or more of the following: the use of univalent anion and univalent cation selective membranes in the electrodialysis unit; the addition of a ***nanofiltration*** unit to process the diluate from the electrodialysis unit; or operation of the electrodialysis unit at an elevated pressure. Magnesium and bromine can optionally be produced when the salt water contains these materials.
11	20040016699	**Systems and methods for ultrasonic cleaning of cross-flow membrane filters** This document discusses, among other things, systems and methods for ultrasonic-assisted cleaning of cross-flow membrane filters, both within and removed from a filtration system. In one example, an applied vacuum reduces a cavitation threshold, avoiding damage to certain sensitive filter membranes. In another example, the ultrasonic-assisted cleaning is used in conjunction with backflushing. In another example, different levels of ultrasound are applied to different portions of the filtration system.
12	20040012913	**Fringe-field capacitor electrode for electrochemical device** The invention features an electrochemical device which includes at least two capacitor electrodes 16, each of which includes a conductive material characterized in that at least ten percent (10%) of the overall surface area of the conductive material is an edge plane. In contrast to a basal plane, the electric field along an edge plane is distorted so as to exhibit an edge effect or fringe effect. Capacitor electrodes 16 with many edges, points, corners, or fractal surfaces exhibit greater capacitance per unit volume or mass amount of capacitor electrode material, than do materials in which the surface area of the material is predominately basal plane. An electrochemical device of the invention can be, for example, an electrochemical cell, e.g., a battery, a capacitor, or a flow-through capacitor.

13	20030230535	**Downhole desalination of aquifer water** A method and well is disclosed for desalinating saline aquifer water, wherein saline aquifer water flows from a subsurface aquifer layer directly into a downhole aquifer inflow region of a desalinated water production well in which a downhole assembly of one or more desalination and/or purification membranes is arranged, which separate the saline aquifer water into a primary desalinated water stream which is produced through the well to surface and a secondary concentrated brine reject stream, which can be disposed into a subsurface brine disposal zone.
14	20030228727	**Stress-induced bandgap-shifted semiconductor photoelectrolytic/photocatalytic/photovoltaic surface and method for making same** Titania is a semiconductor and photocatalyst that is also chemically inert. With its bandgap of 3.0, to activate the photocatalytic property of titania requires light of about 390 nm wavelength, which is in the ultra-violet (UV), where sunlight is very low in intensity. A method and devices are disclosed wherein stress is induced and managed in a thin film of titania in order to shift and lower the bandgap energy into the longer wavelengths that are more abundant in sunlight. Applications of this stress-induced bandgap-shifted titania photocatalytic surface include photoelectrolysis for production of hydrogen gas from water, photovoltaics for production of electricity, and photocatalysis for detoxification and disinfection.
15	20030136727	**Composite semipermeable membrane** The present invention relates to a composite semipermeable membrane, which is useful as a reverse osmosis membrane or a ***nano***-filtration membrane and comprises a polysulfone porous support membrane and a polyamide ultrathin layer formed on one of the surfaces of the porous support membrane, the composite membrane having the characteristic that in the infrared absorption spectrum obtained from the surface of a polyamide ultrathin layer of the composite semipermeable membrane, the ratio T (=Aa/As) of absorption intensity Aa at the absorption peak revealing C=O of polyamide in the region of 1600-1700 cm^{-1} to absorption intensity As at the absorption peak revealing polysulfone at a wavenumber around 1586 cm^{-1} is at least 0.05 and not higher than. The composite semipermeable membrane thus obtained can attain conversion of sea water into fresh ***water, desalination*** of brackish water, recovery of valuable matter in aqueous solutions, treatment of waste water, and particularly removal of impurities (e.g., organic substances) from water.
16	20030104208	**Consolidated amorphous carbon materials, their manufacture and use** A carbon based material produced from the consolidation of amorphous carbon by elevated temperature compression. The material having unique chemical and physical characteristics that lend themselves to a broad range of applications such as in electrical, electrochemical and structural fields.
17	20030047510	**Biofilm reduction in crossflow filtration systems** Systems and methods for reducing biofilms are described. The systems and

		methods are particularly suitable for use with conventional aqueous crossflow filtration systems, such as reverse osmosis systems. The addition of the enzyme/surfactant compound has been found to enhance the effectiveness of conventional crossflow filtration processes by decreasing or inhibiting the growth of biofilms and other contaminants.
18	20020185439	**Process for the removal of organic substances (TOC), pesticides, or other substances from a salt solution** A process is provided for the removal of organic substances (TOC), pesticides or other specific compounds from an aqueous salt solution, for example from a regenerate derived from water purification. The TOC-containing aqueous salt solution is treated in a desalination membrane according to the dead-end principle, wherein neither longitudinal flow over the membrane with air and/or water, nor continuous concentrate discharge takes place, after which the obtained permeate is reused, and the concentrate obtained after flushing is discharged. The TOC-containing aqueous salt solution is introduced at the feed side of the membrane module at a flux of 5-75 1/m^2·h, a feed pressure of 4-12 bars for 30-40 minutes, while the obtained TOC-depleted permeate is discharged. Preferably, operation takes place at a flux of 15-25 1/m^2·h, a pressure of approximately 8 bars, and the duration of treatment is approximately 30 minutes. The membrane used is tubular, capillary, hollow fiber or helically wound, and is usually of the ***nanofiltration*** or reverse osmosis type.
19	20020084188	Alternating-polarity operation for complete regeneration of electrochemical deionization system An electrically regeneratable battery of electrochemical cells for capacitive deionization (including electrochemical purification) and regeneration of electrodes is operated at alternate polarities during consecutive cycles. In other words, after each regeneration step operated at a given polarity in a deionization-regeneration cycle, the polarity of the deionization step in the next cycle is maintained. In one embodiment, two end electrodes are arranged one at each end of the battery, adjacent to end plates. An insulator layer is interposed between each end plate and the adjacent end electrode. Each end electrode includes a single sheet of conductive material having a high specific surface area and sorption capacity, preferably a sheet formed of carbon aerogel composite. The battery further includes a plurality of generally identical double-sided intermediate electrodes that are equidistally separated from each other, between the two end electrodes. As the electrolyte enters the battery of cells, it flows through a continuous open serpentine channel defined by the electrodes, substantially parallel to the surfaces of the electrodes. By polarizing the cells, ions are removed from the electrolyte and are held in the electric double layers formed at the carbon aerogel surfaces of the electrodes. As the electrodes of each cell of the battery are saturated with the removed ions, the battery is regenerated electrically at a reversed polarity from that during the deionization step of the cycle, thus significantly minimizing secondary wastes.

B4. US Patents and US Patent Applications for Sensors

B4.1 Results of a US Patent Search for “nano$” AND “sensor$”: 125 patents

This is a search of the abstract fields (only) in the US patents database from 1976 to the present. The search returned hits only when both of the following were found anywhere in the abstract of the patent record: (i) the prefix “nano” followed by any sequence of characters and (ii) the root “sensor” followed by any sequence of characters. Abstracts are included only for those patents with apparent environmental applications.

To read the entire patent, visit the website at http://patft.uspto.gov/netahtml/srchnum.htm and enter the desired patent number.

	Patent No.	Title
1	6,829,941	**Tunnel effect nanodetector of mechanical vibrations and method for preparation thereof**
2	6,828,786	**Method and apparatus for nanomagnetic manipulation and sensing** The invention combines (A) capabilities in fabrication, characterization, and manipulation of single domain magnetic ***nanostructures,*** with (B) the use of binding chemistry of biological molecules to modify the magnetic ***nanostructures*** into magnetic ***sensors*** and magnetically controllable ***nanoprobes***. A biological characterization scheme is realized by combining ***nanomanipulation*** and observation of small magnetic structures in fluids. By coating ***nanomagnets*** with biological molecules, ultra-small, highly sensitive and robust biomagnetic devices are defined, and molecular electronics and spin electronics are combined. When these ***nano-sensors*** are integrated into microfluidic channels, highly efficient single-molecule detection chips for rapid diagnosis and analysis of biological agents are constructed.
3	6,828,039	**Magnetoresistive sensor and manufacturing method therefor**
4	6,826,021	**Spin valve sensor having ultra-thin free layers including nickel-iron, ruthenium, and a cobalt-iron nanolayer**
5	6,825,161	**Multi component controlled delivery system for soap bars** The present invention relates to an improved controlled delivery system that can be incorporated in soap bars to enhance deposition of active ingredients and ***sensory*** markers onto skin. The carrier system also provides controlled release or prolonged release of these actives from the skin over an extended period of time. The controlled delivery system of the present invention comprises substantially free-flowing, powder formed of solid hydrophobic, positively charged, ***nanospheres*** of encapsulated active ingredients that are encapsulated in moisture sensitive microspheres. The high cationic charge density of the ***nanosphere*** improves deposition of active ingredients onto skin.

		The high cationic charge density on the ***nanosphere*** surface is created by incorporating a cationic conditioning agent into the solid hydrophobic matrix of the ***nanospheres,*** by incorporating a cationic charge "booster" in the moisture sensitive microsphere matrix, or by using a cationic conditioning agent in the ***nanosphere*** matrix in conjunction with a cationic charge "booster" in the microsphere matrix. The invention also pertains to soap products comprising the controlled release system of the present invention.
6	6,815,706	**Nano optical sensors via molecular self-assembly**
7	6,803,840	**Pattern-aligned carbon nanotube growth and tunable resonator apparatus**
8	6,790,460	**Biodegradable bioadhesive controlled release system of nano-particles for oral care products**
9	6,786,950	**High purity fine metal powders and methods to produce such powder** Methods of producing metal and alloy fine powders having purity in excess of 99.9%, preferably 99.999%, more preferably 99.99999% are discussed. Fine submicron and ***nanoscale*** powders discussed include various shapes and forms including spheres, rods, whiskers, platelets and fibers. The use of surfactant, emulsifying agents and capping dispersants in powder synthesis are presented. Compositions taught include nickel, copper, iron, cobalt, silver, gold, platinum, palladium, tin, zirconium, aluminum, silicon, antimony, indium, titanium, tantalum, niobium, zinc and others from the periodic table. The fine powders are useful in various applications such as biomedical, ***sensor,*** electronic, electrical, photonic, thermal, piezo, magnetic, catalytic and electrochemical products.
10	6,781,690	**Sensors employing nanoparticles and microcavities**
11	6,778,316	**Nanoparticle-based all-optical sensors**
12	6,773,950	**Method of forming dual exposure glass layer structures**
13	6,773,515	**FeTa nano-oxide layer as a capping layer for enhancement of giant magnetoresistance in bottom spin valve structures**
14	6,762,025	**Single-molecule selection methods and compositions therefrom** Single-molecule selection methods are provided for identifying target-binding molecules from diverse sequence and shape libraries. Complexes and imprints of selected target-binding molecules are also provided. The subject selection methods are used to identify oligonucleotide and nonnucleotide molecules with desirable properties for use in pharmaceuticals, drug discovery, drug delivery, diagnostics, medical devices, cosmetics, agriculture, environmental remediation, smart materials, packaging, microelectronics and nanofabrication. Single oligonucleotide molecules with desirable binding properties are selected from diverse sequence libraries and identified by amplification and sequencing. Alternatively, selected oligonucleotide molecules are identified by sequencing without amplification. Nonnucleotide molecules with desirable properties are identified by single-molecule selection from libraries of conjugated molecules or nucleotide-encoded nonnucleotide molecules. Alternatively, target-specific nonnucleotide molecules are prepared by

		imprinting selected oligonucleotide molecules into nonnucleotide molecular media. Complexes and imprints of molecules identified by single-molecule selection are shown to have broad utility as drugs, prodrugs, drug delivery systems, wilfully reversible cosmetics, diagnostic reagents, sensors, transducers, actuators, adhesives, adherents and novel multimolecular devices.
15	6,756,795	**Carbon nanobimorph actuator and sensor**
16	6,746,791	**Nano-ionic products and devices** An ionic conducting device comprising a nanostructured material layer. The nanostructured layer has a microstructure confined to a size less than 100 nm. The ion conductivity of the nanostructured layer is higher than the ion conductivity of a layer of equivalent composition and size having a micron-sized microstructure. Nano-ionic compositions taught include ceramics, polymers, lithium containing compounds, sodium containing compounds, ion defect structures, silver containing compounds, Applications of nano-ionics to fuel cells, sensors, batteries, electrochemical devices, electrocatalysts are taught.
17	6,737,286	**Apparatus and method for fabricating arrays of atomic-scale contacts and gaps between electrodes and applications thereof** A method for forming atomic-scale contacts and atomic-scale gaps between two electrodes is disclosed. The method provides for applying a voltage between two electrodes in a circuit with a resistor. The applied voltage etches metal ions off one electrode and deposits the metal ions onto the second electrode. The metal ions are deposited on the sharpest point of the second electrode, causing the second electrode to grow towards the first electrode until an atomic-scale contact is formed. By increasing the magnitude of the resistor, the etching and deposition process will terminate prior to contact, forming an atomic-scale gap. The atomic-scale contacts and gaps formed according to this method are useful as a variety of nanosensors including chemical sensors, biosensors, hydrogen ion sensors, heavy metal ion sensors, magnetoresistive sensors, and molecular switches.
18	6,724,064	**Photoelectric conversion element and photoelectric conversion device**
19	6,723,388	**Method of depositing nanostructured films with embedded nanopores**
20	6,709,558	**Gas sensor** Disclosed herein is a gas sensor and a method of making a gas sensor comprising disposing a reference electrode on an inner surface of an electrolyte; sputtering a sensing electrode on an outer surface of the electrolyte; sputtering a zirconia layer on a side of the sensing electrode opposite the electrolyte, wherein the zirconia layer has a thickness of about 20 nanometers to about 1 micrometer, and disposing a protective layer on a side of the zirconia layer opposite the sensing electrode.
21	6,705,152	**Nanostructured ceramic platform for micromachined devices and device arrays** The present invention discloses a type of ***nanostructured*** ceramic platform for gas ***sensors and sensor*** arrays. These ***sensors*** comprise micromachined anodic

		aluminum oxide films, which contains extremely high density (e.g., 10^{11} cm^{-2}) ***nanoscale*** pores. Sensing materials deposited inside this self-organized network of ***nanopores*** have ultra-high surface area and ***nanometer*** grain structure, therefore enabling high sensitivity. Refractory nature of alumina ceramic enables the desired robustness, long lifetime and stability in harsh environment. This ***sensor*** platform can be used for both chemical gas and physical (humidity, temperature) ***sensors and sensor*** arrays.
22	6,691,554	**Nanocrystalline films for gas-reactive applications** A gas ***sensor*** for detection of oxidizing and reducing gases, including O_2, CO_2, CO, and H_2, monitors the partial pressure of a gas to be detected by measuring the temperature rise of an oxide-thin-film-coated metallic line in response to an applied electrical current. For a fixed input power, the temperature rise of the metallic line is inversely proportional to the thermal conductivity of the oxide coating. The oxide coating contains multi-valent cation species that change their valence, and hence the oxygen stoichiometry of the coating, in response to changes in the partial pressure of the detected gas. Since the thermal conductivity of the coating is dependent on its oxygen stoichiometry, the temperature rise of the metallic line depends on the partial pressure of the detected gas. ***Nanocrystalline*** (<100 nm grain size) oxide coatings yield faster ***sensor*** response times than conventional larger-grained coatings due to faster oxygen diffusion along grain boundaries rather than through grain interiors.
23	6,675,654	**Pressure sensing device with moisture filter**
24	6,658,597	**Method and apparatus for automatic recovery of microprocessors/ microcontrollers during electromagnetic compatibility (EMC) testing**
25	6,652,967	**Nano-dispersed powders and methods for their manufacture**
26	6,627,157	**Dual manifold system and method for fluid transfer**
27	6,616,734	**Dynamic filtration method and apparatus for separating nano powders** A method and apparatus for separating ***nanometer-sized*** particles of a powder. The method includes (a) feeding the powder particles into a pressurized gas stream which carries the particles into a first stage filter device of a multiple-stage separator system; (b) operating the first stage filter device to remove and collect coarse particles and a filter device in at least another stage to remove and collect finer particles of the powder; the filter device having a dynamic filter which is composed of (b1) a mesh of a multiplicity of openings with the opening size at least two times larger than the average size of the particles, (b2) vibration devices or shakers to shake off the particles that may otherwise clog up the mesh openings, (b3) size ***sensors*** to measure the sizes of the particles collected by the filter devices, and (b4) a controller to regulate the operations of the shakers and ***sensors*** in order to form desired dynamic mesh holes for the purpose of filtering out the coarse particles in the first stage or the finer particles in another stage; and (c) operating a dust collector to exhaust the residual gas, allowing the finest particles of the powder to be separated and collected.
28	6,614,084	**Magnetic materials**

29	6,611,140	**Magnetic sensing unit for detecting nanometer scale displacements or flections**
30	6,610,355	**Nanostructured deposition and devices** Ion-conducting solid electrolytes are constructed from ***nanoscale*** precursor material. ***Nanocrystalline*** powders are pressed into disc structures and sintered to the appropriate degree of densification. Metallic material is mixed with 0 to 65 vol % ***nanostructured*** electrolyte powders to form a cermet mix and then coated on each side of the disc and fitted with electrical leads. The electrical conductivity of a Ag/YSZ/Ag cell so assembled exhibited about an order of magnitude enhancement in oxygen ion conductivity. As an oxygen-sensing element in a standard O_2 /Ag/YSZ/Ag/N_2 set up, the ***nanocrystalline*** YSZ element exhibited commercially significant oxygen ion conductivity at low temperatures. The invention can be utilized to prepare ***nanostructured*** ion conducting solid electrolytes for a wide range of applications, including ***sensors,*** oxygen pumps, fuel cells, batteries, electrosynthesis reactors and catalytic membranes.
31	6,592,825	**Microvolume liquid handling system**
32	6,589,562	**Multicomponent biodegradable bioadhesive controlled release system for oral care products**
33	6,569,687	**Dual manifold system and method for fluid transfer**
34	6,569,397	**Very high purity fine powders and methods to produce such powders**
35	6,565,873	**Biodegradable bioadhesive controlled release system of nano-particles for oral care products**
36	6,563,132	**Conductive polymer materials and methods for their manufacture and use**
37	6,562,424	**Photochemical sensors and method for the production thereof** The invention provides an indicator dye ***nanoporous*** photochemical ***sensor*** composite glass film, comprising a multiplicity of polyacrylate chains intertwined with a multiplicity of cross-linked networks of silica and doped with an indicator dye, wherein the film is formed with a plurality of ***nanopores*** sized in the range between 20 and 200 angstrom for the entry of analytes to be detected thereby.
38	6,537,498	**Colloidal particles used in sensing arrays** Chemical ***sensors*** for detecting analytes in fluids comprising a plurality of alternating nonconductive regions (comprising a nonconductive material) and conductive regions (comprising a conductive material). In preferred embodiments, the conducting region comprises a ***nanoparticle***. Variability in chemical sensitivity from ***sensor to sensor*** is provided by qualitatively or quantitatively varying the composition of the conductive and/or nonconductive regions. An electronic nose for detecting an analyte in a fluid may be constructed by using such arrays in conjunction with an electrical measuring device electrically connected to the conductive elements of each ***sensor***.
39	6,528,020	**Carbon nanotube devices**

		This invention provides an assembly of novel ***nanotube*** devices that can be employed in a variety of applications. In particular, the ***nanotube*** devices of the present invention provide a new class of versatile chemical and biological ***sensors***. The present invention describes methods for growing individual ***nanotubes*** in a controlled fashion and for manipulating and integrating the ***nanotubes*** into functional devices. It further provides methods for modifying the ***nanotubes*** such that their sensitivity to a wide range of chemical and biological species can be achieved.
40	6,515,749	**Sensitive and selective chemical sensor with nanostructured surfaces** A chemical ***sensor*** is provided which includes an optical resonator including a ***nanostructured*** surface comprising a plurality of ***nanoparticles*** bound to one or more surfaces of the resonator. The ***nanoparticles*** provide optical absorption and the ***sensor*** further comprises a detector for detecting the optical absorption of the ***nanoparticles*** or their environment. In particular, a selective chemical interaction is provided which modifies the optical absorption of the ***nanoparticles*** or their environment, and an analyte is detected based on the modified optical absorption. A light pulse is generated which enters the resonator to interrogate the modified optical absorption and the exiting light pulse is detected by the detector.
41	6,513,362	**Low-cost multi-laminate sensors** ***Sensors*** for monitoring environmental variables such as chemical composition are disclosed. These low-cost ***sensors*** comprise multiple layers in a laminated stack. Very high numbers of sensing layers (e.g., 500) may be incorporated into a single laminated ***sensor*** device. The ***sensors*** may be produced from ***nanostructured*** materials. Additionally, multilayer magnetic, optical, photonic, thermal and biomedical ***sensors*** are disclosed.
42	6,491,902	**Controlled delivery system for hair care products**
43	6,489,626	**Wafer orientation sensor for GaAs wafers**
44	6,458,327	**Electronic device, especially chemical sensor, comprising a nanoparticle structure** Disclosed is an electronic device comprising a ***nanoparticle*** structure and configured such that, when driven by a power source, a current path is defined through said ***nanoparticle*** structure, wherein the ***nanoparticle*** structure comprises a substrate and metal and/or semiconductor ***nanoparticles, wherein the nanoparticles*** are linked to each other and/or to the substrate by bifunctional or polyfunctional ligands. The invention especially relates to an electronic device in the form of a ***sensor*** for detecting one or more analytes in a liquid or a gas phase.
45	6,452,763	**GMR design with nano oxide layer in the second anti-parallel pinned layer**
46	6,433,760	**Head mounted display with eyetracking capability**
47	6,433,310	**Assembly suitable for reading/writing/erasing information on a media based on thermal coupling**
48	6,432,176	**Device for storing compressed gas**

49	6,426,505	**Phase-modulation fluorometer and method for measuring nanosecond lifetimes using a lock-in amplifier**
50	6,419,340	**Method for automatically forming ink and media-dependent color transforms for diverse colored inks and ink types, validating color gamut, and applying said inks**
51	6,417,507	**Modulated fibre Bragg grating strain gauge assembly for absolute gauging of strain**
52	6,406,805	**Method for storing purged hydrogen from a vehicle fuel cell system**
53	6,389,877	**Double-headed mass sensor and mass detection method** There is provided a double-headed mass ***sensor*** (25) in which between a first connecting plate (22A) joined to a first diaphragm (21A) at respective sides and a second connecting plate (22B) joined to a second diaphragm (21B) at respective sides, a first sensing plate (41A), on which a main element (44) is provided on at least one plane surface, is bridged, and a resonating portion comprising the diaphragms (21A), (21B), the connecting plates (22A), (22B), the first sensing plate (41A) and the main element (44) is joined to a ***sensor*** substrate (27). Change in the mass of each of the diaphragms (21A), (21B) is measured by measuring change in the resonant frequency of the resonating portion accompanying the change in the mass of the diaphragms (21A), (21B). The mass ***sensor*** of the present invention enables the easy and highly accurate measurement of a minute mass of a ***nanogram*** order including microorganisms such as bacteria and viruses, chemical substances, and the thickness of vapor-deposited films.
54	6,387,560	**Nanostructured solid electrolytes and devices**
55	6,386,053	**Mass sensor and mass detection method** A mass ***sensor*** (30) in which a connection plate (33) and a diaphragm (31) are joined together at their respective sides; a sensing plate (32) is joined to the connection plate (33) at their respective sides in the direction perpendicular to the direction where the diaphragm (31) is joined to the connection plate (33); a piezoelectric element (35) consisting of a piezoelectric film and an electrode is installed on at least either one of plate surfaces of the sensing plate (32); and a resonating portion consisting of the diaphragm (31), the sensing plate (32), the connection plate (33), and the piezoelectric element (35) is joined to a ***sensor*** substrate (34). Change in the mass of the diaphragm (31) is measured by measuring change in the resonant frequency of the resonating portion accompanying the change in the mass of the diaphragm (31). The mass ***sensor*** of the present invention enables the easy and accurate measurement of a minute mass of a ***nanogram*** order including microorganisms such as bacteria and viruses, chemical substances, and the thickness of vapor-deposited films.
56	6,379,955	**Optical fiberless sensors**
57	6,353,317	**Mesoscopic non-magnetic semiconductor magnetoresistive sensors fabricated with island lithography**
58	6,344,271	**Materials and products using nanostructured non-stoichiometric substances**

59	6,339,958	**Adhesion strength testing using a depth-sensing indentation technique**
60	6,326,563	**Mass sensor and mass sensing method** A mass ***sensor*** includes a diaphragm, a sensing plate having a piezoelectric element arranged on at least a part of at least one surface joining respective sides, a connecting plate sandwiched by the diaphragm and the sensing plate, wherein the diaphragm, the sensing plate, the piezoelectric element, and the connecting plate form a resonating portion. The connecting plate is bridged across the side surfaces of a concave portion formed in a ***sensor*** substrate, and the sensing plate is joined to at least the bottom portion of the concave portion. Change in the mass of the diaphragm is measured by measuring change in the resonant frequencies of the resonating portion accompanying the change in the mass of the diaphragm. The mass ***sensor*** enables the easy and accurate measurement of a minute mass of a ***nanogram*** order including microorganisms such as bacteria and viruses, or chemical substances, or the thickness of vapor-deposited films.
61	6,323,660	**Integrated device for capacitive measuring of nanometer distances**
62	6,295,873	**Ultrasonic sensor and method of use**
63	6,289,717	**Micromechanical antibody sensor**
64	6,286,226	**Tactile sensor comprising nanowires and method for making the same**
65	6,270,591	**Amorphous and nanocrystalline glass-covered wires**
66	6,267,005	**Dual stage instrument for scanning a specimen**
67	6,260,795	**Oya computerized glider**
68	6,246,543	**Textured data storage disk having a brittle nonmetallic substrate**
69	6,232,879	**Sensor and method for remote detection of objects**
70	6,208,252	**Low intensity flame detection system** A smoking detection device comprising a smoke ***sensor*** for generating an electrical signal in response to the detection of smoke, and an optical ***sensor*** for generating an electrical signal in response to the detection of ultraviolet radiation in a prescribed range. The smoking detection device may further comprise an alarm unit which is electrically connected to the smoke and optical ***sensors*** for generating an alarm signal in response to any one of the electrical signals generated by the smoke and optical ***sensors***. The optical ***sensor*** is configured to sense ultraviolet radiation in a spectral range of from about 185 ***nanometers*** to about 260 ***nanometers,*** and of an intensity in a range of about 1 picowatt per square centimeter to about 1 ***nanowatt*** per square centimeter.
71	6,143,558	**Optical fiberless sensors for analyzing cellular analytes**
72	6,143,412	**Fabrication of carbon microstructures**
73	6,134,946	**Nano-crystalline porous tin oxide film for carbon monoxide sensing** A tin oxide sol is deposited on platinum electrodes (12) of a ***sensor*** (10). The sol is calcined at a temperature of 500 to 800 C to produce a thin film of tin oxide with a thickness of about 150 nm to 2 μm and having a ***nano-crystalline*** structure with good stability. The ***sensor*** rapidly detects reducing gases, such

		as carbon monoxide, or hydrocarbons and organic vapors. ***Sensors*** using films calcined at around 700 C have high carbon monoxide selectivity with a response time of around 4 minutes and a recovery time of 1 minute, and therefore provide good detection systems for detection of trace amounts of pollutants such as toxic and flammable gases in homes, industrial settings, and hospitals.
74	6,118,208	**Film tensioning apparatus**
75	6,111,407	**Method of producing a magnetic field sensor, and sensor with a sensor wire press-fitted into spaced-apart conductors**
76	6,104,297	**Corona discharge detection system**
77	6,096,559	**Micromechanical calorimetric sensor**
78	6,084,231	**Closed-loop, daylight-sensing, automatic window-covering system insensitive to radiant spectrum produced by gaseous-discharge lamps**
79	6,078,706	**Quasi-static fiber pressure sensor**
80	6,040,077	**Catalyst for membrane electrode assembly and method of making**
81	6,036,298	**Monochromatic optical sensing system for inkjet printing**
82	6,018,390	**Integrated optics waveguide accelerometer with a proof mass adapted to exert force against the optical waveguide during acceleration**
83	6,016,686	**Micromechanical potentiometric sensors**
84	6,013,919	**Flame sensor with dynamic sensitivity adjustment**
85	6,002,488	**Compact spectrophotometer**
86	5,948,972	**Dual stage instrument for scanning a specimen**
87	5,947,601	**Thermometer based on CB tunnelling**
88	5,905,000	**Nanostructured ion conducting solid electrolytes** Ion conducting solid electrolytes are constructed from ***nanoscale*** precursor material. ***Nanocrystalline*** powders are pressed into disc structures and sintered to the appropriate degree of densification. Metallic material is mixed with 0 to 65 vol % ***nanostructured*** electrolyte powders to form a cermet mix and then coated on each side of the disc and fitted with electrical leads. The electrical conductivity of a Ag/YSZ/Ag cell so assembled exhibited about an order of magnitude enhancement in oxygen ion conductivity. As an oxygen-sensing element in a standard O_2 /Ag/YSZ/Ag/N_2 set up, the ***nanocrystalline*** YSZ element exhibited commercially significant oxygen ion conductivity at low temperatures. The invention can be utilized to prepare ***nanostructured*** ion conducting solid electrolytes for a wide range of applications, including ***sensors,*** oxygen pumps, fuel cells, batteries, electrosynthesis reactors and catalytic membranes.
89	5,883,591	**Ultra-wideband impedance sensor**
90	5,879,827	**Catalyst for membrane electrode assembly and method of making** ***Nanostructured*** elements are provided for use in the electrode of a membrane electrode assembly for use in fuel cells, ***sensors,*** electrochemical cells, and the like. The ***nanostructured*** elements comprise acicular microstructured support

		whiskers bearing acicular ***nanoscopic*** catalyst particles which may comprise alternating layers of catalyst materials, which may comprise a surface layer that differs in composition from the bulk composition of the catalyst particles, and which may demonstrate improved carbon monoxide tolerance.
91	5,877,589	**Gas discharge devices including matrix materials with ionizable gas filled sealed cavities**
92	5,831,181	**Automated tool for precision machining and imaging**
93	5,814,281	**Resistive gas sensing** A resistive gas ***sensor*** has a porous semiconducting oxide body in which the pore surfaces are decorated with a precious metal. The ***sensor*** operates at ambient temperatures for detection and measurement of target gases, especially carbon monoxide. The porous ***sensor*** body is formed of primary crystallites agglomerated together, the agglomerate size being less than 10 times the primary crystallite size, and the primary crystallite size having an average diameter of less than 5 micrometer. From 0.05 to 80% of the pore surfaces are covered by the metallic phase, the metallic phase consisting of particles having an average size of less than 50 ***nanometers***. Presence of the target gas is indicated by a change in electrical resistance of the ***sensor***.
94	5,793,230	**Sensor readout detector circuit**
95	5,773,270	**Three-layered membrane for use in an electrochemical sensor system**
96	5,730,165	**Time domain capacitive field detector** A capacitive field ***sensor,*** which may be used for the control of a water supply valve in a basin or fountain, employs a single coupling plate to detect a change in capacitance to ground. The apparatus comprises a circuit for charging a sensing electrode and a switching element acting to remove charge from the sensing electrode and to transfer it to a charge detection circuit. The time interval employed for the charging and discharging steps can vary widely. Usually at least one of the charge or discharge pulses is on the order of a hundred ***nanoseconds,*** and is shorter in duration than a characteristic conduction time for a body of water disposed about the sensing plate. Thus, the ***sensor*** can detect the presence of a user near a controlled faucet without being subject to measurement artefacts arising from standing water. In a controller for a water basin, a short charge or discharge pulse duration may be used when the controlled valve is closed, and a longer duration, which allows conduction through the water, may be used when the valve is open. The long duration measurement can detect the continued presence of the user as long as the user's hand remains in the stream of water.
97	5,677,978	**Bent probe microscopy** A general purpose force ***sensor*** for measuring ***nanometer*** scale surface topography and other characteristics includes a hollow micropipette having an inner diameter of about 7.5 ***nanometers*** at its tip. The probe includes a cantilevered structure obtained by heating it near the tip to bend it. A reflective coating is then applied to the outer surface of the micropipette.
98	5,670,031	**Electrochemical sensor**

		The invention relates to an electrochemical ***sensor*** with interdigital micro-electrodes (1) with structure widths in the sub-µm range. With a twin or multi-pair array of the interdigital micro-electrodes on a substrate (8), the electrochemical detection of molecules with high sensitivity is made possible and further uses for the detection of chemical reaction cycles are made available. The electrodes may be arranged in a micro-channel applied to the substrate having a constant small volume of a few ***nanoliters***. The electrochemical ***sensor*** of the invention is suitable for the multiple measurement of the same species of molecule or as a multi-sensitive ***sensor*** in chemical analysis and process control in various fields such as biotechnology, environmental protection or health.
99	5,591,978	**All wavelength ultraviolet intensity monitor**
100	5,581,256	**Range gated strip proximity sensor**
101	5,569,808	**Method for regulating a process for the separation of isomers of aromatic hydrocarbons having from 8 to 10 carbon atoms** A monochromatic light signal of a wavelength of between 400 and 1300 ***nanometers*** is simultaneously passed by a source 1, a beam splitter 2 and optical fibers 3, 3a to at least two points of a zone 9 for the separation of a mixture of isomers and aromatic hydrocarbons having from 8 to 10 carbons atoms. A polychromatic signal is recovered corresponding to the Raman effect between 400 and 3500 cm^{-1} by optical receiving fibers 5, 5a connected to ***sensors*** 4 at the locations of said points. The chemical composition of the mixture is determined from the Raman spectra obtained by a spectrometer 6. The analysis sequence is repeated, the profiles with respect to the concentration of the isomers in the mixture are reconstituted and by comparison with reference concentration profiles, action is taken on at least on operational variable 11, 12 of the separation process. Application of this process to the regulation of simulated mobile beds, a distillation operation or a crystallization process for obtaining paraxylene or orthoxylene are also provided.
102	5,446,286	**Ultra-fast detectors using doped nanocrystal insulators**
103	5,391,913	**Semiconductor device** In the present invention, for the purpose of precluding defective image caused by stains adhering on the surfaces of a semiconductor device and a color filter of a solid-state color image ***sensor,*** a semiconductor device excellent in the water and oil repellence, anti-soiling property and durability is provided, by forming on the each surface a uniform water- and oil-repellent protective film with a thickness on the order of ***nanometer,*** by treating with a nonaqueous solvent containing a chlorosilane surface treating agent having a fluoroalkyl.
104	5,345,816	**Integrated tip strain sensor for use in combination with a single axis atomic force microscope** An integrated tip strain ***sensor*** is combination with a single axis atomic force microscope (AFM) for determining the profile of a surface in three dimensions. A cantilever beam carries an integrated tip stem on which is

		deposited a piezoelectric film strain ***sensor***. A high-resolution direct electron beam (e-beam) deposition process is used to grow a sharp tip onto the silicon (Si) cantilever structure. The direct e-beam deposition process permits the controllable fabrication of high-aspect ratio, ***nanometer-scale*** tip structures. A piezoelectric jacket with four superimposed elements is deposited on the tip stem. The piezoelectric ***sensors*** function in a plane perpendicular to that of a probe in the AFM; that is, any tip contact with the linewidth surface will cause tip deflection with a corresponding proportional electrical signal output. This tip strain ***sensor,*** coupled to a standard single axis AFM tip, allows for three-dimensional metrology with a much simpler approach while avoiding catastrophic tip "crashes". Two-dimensional edge detection of the sidewalls is used to calculate the absolute value or the linewidth of overlay, independent of the AFM principle. The technique works on any linewidth surface material, whether conductive, non-conductive or semiconductive.
105	5,338,430	**Nanostructured electrode membranes**
106	5,329,808	**Atomic force microscope** This invention is an atomic force microscope having a digitally calculated feedback system which can perform force spectroscopy on a sample in order to map out the local stiffness of the sample in addition to providing the topography of the sample. It consists of a three-dimensional piezoelectric scanner, scanning either the sample of a force ***sensor***. The force ***sensor*** is a contact type with a tip mounted on a cantilever and a ***sensor*** to detect the deflection of the lever at the tip. The signal from the ***sensor*** goes to an A-D converter and is then processed by high-speed digital electronics to control the vertical motion of the sample or ***sensor***. In operation, the digital electronics raise and lower the piezoelectric scanner during the scan to increase and decrease the force of the tip on the sample and to use the ***sensor*** signal to indicate the change in height of the tip to measure the which is the spring constant of the sample. This constant can be determined with ***nanometer*** spatial resolution. At the same time, the instrument can determine the topography of the sample with ***nanometer*** resolution. In an alternate embodiment, the lever is connected to a separate piezoelectric driver to vary the force on the tip. This improved AFM can also be used to periodically reset the force at which the tip contacts the sample and quickly replace the tip on the sample in the event that the tip loses contact with the surface.
107	5,321,977	**Integrated tip strain sensor for use in combination with a single axis atomic force microscope** An integrated tip strain ***sensor*** is combination with a single axis atomic force microscope (AFM) for determining the profile of a surface in three dimensions. A cantilever beam carries an integrated tip stem on which is deposited a piezoelectric film strain ***sensor***. A high-resolution direct electron beam (e-beam) deposition process is used to grow a sharp tip onto the silicon (Si) cantilever structure. The direct e-beam deposition process permits the controllable fabrication of high-aspect ratio, ***nanometer-scale*** tip structures. A piezoelectric jacket with four superimposed elements is deposited on the tip

		stem. The piezoelectric ***sensors*** function in a plane perpendicular to that of a probe in the AFM; that is, any tip contact with the linewidth surface will cause tip deflection with a corresponding proportional electrical signal output. This tip strain ***sensor,*** coupled to a standard single axis AFM tip, allows for three-dimensional metrology with a much simpler approach while avoiding catastrophic tip "crashes". Two-dimensional edge detection of the sidewalls is used to calculate the absolute value or the linewidth of overlay, independent of the AFM principle. The technique works on any linewidth surface material, whether conductive, non-conductive or semiconductive.
108	5,278,435	**High responsivity ultraviolet gallium nitride detector**
109	5,237,859	**Atomic force microscope** This invention is an atomic force microscope having a digitally calculated feedback system which can perform force spectroscopy on a sample in order to map out the local stiffness of the sample in addition to providing the topography of the sample. It consists of a three-dimensional piezoelectric scanner, scanning either the sample or a force ***sensor***. The force ***sensor*** is a contact type with a tip mounted on a cantilever and a ***sensor*** to detect the deflection of the lever at the tip. The signal from the ***sensor*** goes to an A-D converter and is then processed by high-speed digital electronics to control the vertical motion of the sample or ***sensor***. In operation, the digital electronics raise and lower the piezoelectric scanner during the scan to increase and decrease the force of the tip on the sample and to use the ***sensor*** signal to indicate the change in height of the tip to measure the which is the spring constant of the sample. This constant can be determined with ***nanometer*** spatial resolution. At the same time, the instrument can determine the topography of the sample with ***nanometer*** resolution. In an alternate embodiment, the lever is connected to a separate piezoelectric driver to vary the force on the tip. This improved AFM can also be used to periodically reset the force at which the tip contacts the sample and quickly replace the tip on the sample in the event that the tip loses contact with the surface.
110	5,224,376	**Atomic force microscope** This invention is an atomic force microscope having a digitally calculated feedback system which can perform force spectroscopy on a sample in order to map out the local stiffness of the sample in addition to providing the topography of the sample. It consists of a three-dimensional piezoelectric scanner, scanning either the sample or a force ***sensor***. The force ***sensor*** is a contact type with a tip mounted on a cantilever and a ***sensor*** to detect the deflection of the lever at the tip. The signal from the ***sensor*** goes to an A-D converter and is then processed by high-speed digital electronics to control the vertical motion of the sample or ***sensor***. In operation, the digital electronics raise and lower the piezoelectric scanner during the scan to increase and decrease the force of the tip on the sample and to use the ***sensor*** signal to indicate the change in height of the tip to measure the which is the spring constant of the sample. This constant can be determined with ***nanometer*** spatial resolution. At the same time, the instrument can determine the

		topography of the sample with ***nanometer*** resolution. In an alternate embodiment, the lever is connected to a separate piezoelectric driver to vary the force on the tip. This improved AFM can also be used to periodically reset the force at which the tip contacts the sample and quickly replace the tip on the sample in the event that the tip loses contact with the surface.
111	5,151,110	**Molecular sieve sensors for selective detection at the nanogram level** The invention relates to a selective chemical sensor for selective detection of chemical entities even at the ***nanogram*** level. The invention further relates to methods of using the ***sensor.*** The ***sensor*** comprises: (a) a piezoelectric substrate capable of detecting mass changes resulting from adsorption of material thereon; and (b) a coating applied to the substrate, which selectively sorbs chemical entities of a size smaller than a preselected magnitude.
112	5,133,842	**Electrochemical cell having electrode comprising gold containing electrocatalyst** The disclosed electrocatalyst material is useful in electrodes, especially in cathodes for the reduction of oxygen or peroxide to water or hydroxide. The electrocatalyst typically comprises 0.1 to 20 weight%, based on the weight of the material, of a supported particulate elemental gold wherein the particles are apparently crystalline in nature, apparently with exposed (100) faces, but smaller in size than 5 ***nanometers*** (<Angstrom). These tiny monocrystals of gold are supported on carbon black or particulate conductive ceramic-like compounds having a B.E.T. surface area of at least 50 m^2/g. The supported gold monocrystals appear to be selective for the reductions described above, and performance in air or O$_2$ cathodes is outstanding, e.g. >0.7 volts vs. RHE at 200 mA/cm^2, generally indicating a substantial proportion of four-electron change reactions when oxygen is being reduced. The electrodes (which are also useful as anodes in acid electrolytes) are made by impregnating the support material with a reducible gold compound dissolved in a polar solvent, gently evaporating the solvent, and chemically reducing the gold compound in situ at a moderate temperature with a flowing reducing gas (e.g. H$_2$) then applying the resulting supported gold to a porous backing material. Typical gold content levels at the electrode surface are <2 mg/cm^2. Cathodes of this invention are useful in various types of air or oxygen-depolarized cells, alkaline fuel cells, metal/air cells, metal/H$_2$ O$_2$ cells, oxygen ***sensors,*** electrochemical caustic concentrators, etc.
113	5,036,437	**Vehicle lamp control sensor**
114	5,006,846	**Power transmission line monitoring system**
115	4,967,094	**Film detection apparatus**
116	4,963,747	**Ionizing radiation detector** An ionizing radiation detector is provided which is based on the principle of analog electronic integration of radiation ***sensor*** currents in the sub-pico to ***nano*** ampere range between fixed voltage switching thresholds with automatic voltage reversal each time the appropriate threshold is reached. The thresholds are provided by a first NAND gate Schmitt trigger which is coupled with a

		second NAND gate Schmitt trigger operating in an alternate switching state from the first gate to turn either a visible or audible indicating device on and off in response to the gate switching rate which is indicative of the level of radiation being sensed. The detector can be configured as a small, personal radiation dosimeter which is simple to operate and responsive over a dynamic range of at least 0.01 to 1000 R/hr.
117	4,803,370	**Infrared light generation** To measure the amount of carbon dioxide in a mixture of gases, a source of infrared light includes a porous getter emitted formed of an inner tungsten heater with a layer of sintered together zirconium and carbon powder covered with spectrographic grade carbon over at least 50 percent of its surface serving as a getter and an emitter of infrared light. It is mounted within a vacuum and emits light in a strong spectrum including light having a bandwidth of at least 150 ***nanometers*** with a center point of substantially 4.2 micrometers. The light is transmitted through reference and sample flow cells each including a corresponding one of a reference gas and a sample gas onto a photosensor. The light source includes a reflector located within a range of no more than 1 centimeter from the emitter getter for reflecting heat back to said emitter getter at least 50 percent of its surface and has a window aligned with said infrared light ***sensor*** with an opening of area of between 0.05 to 20 square millimeters. The heater heats the emitter getter to a temperature in the range of 600 K to 2,000 K.
118	4,788,466	**Piezoelectric sensor Q-loss compensation**
119	4,746,816	**Spike detector circuitry**
120	4,687,987	**Beam current sensor**
121	4,687,344	**Imaging pyrometer** An imaging radiometer for high temperature measurements has a ***sensor*** head comprised of a solid-state video camera operated in fixed gain mode, preferably one with a charge injection device detector, an infrared filter, and a lens system to image a radiating object on the detector array. Spectral response of the system is limited to 700 to 1100 ***nanometers*** or a smaller portion of this near-infrared band. The video signal output of the ***sensor*** is processed and object temperature is displayed on a television monitor; alternatively the video signal is presented to a digital frame grabber and converted to a temperature map.
122	4,666,554	**Method of manufacturing a sensor having a magnetic field sensitive element**
123	4,568,906	**Sensor having a magnetic field-sensitive element with accurately defined weight and thickness dimensions in the nanometer range**
124	4,086,555	**Photoconductive sensor**
125	4,000,502	**Solid state radiation detector and process** A radiation detector that combines the characteristics of high quantum efficiency in the UV spectrum with good IR transmission characteristics so

		that it may be used in association with an IR ***sensor*** to produce a coaxial transducer suitable for use in association with unfiltered, high-resolution optics. The detector is a solid state photovoltaic Schottky barrier semi-conductor junction comprising a thin platinum layer laid over single-crystal cadmium sulfide. Processing, including lapping, polishing, and chemical etch, produces a surface suitable for providing radiation sensitivity which drops off sharply outside of the ultraviolet spectrum beyond 550 ***nanometers***. The platinum layer is approximately 35 angstroms in thickness and is therefore transparent both to ultraviolet and infrared radiation. The infrared radiation passes through the cadmium sulfide wafer and through a window in the indium ohmic contact surface on the second surface of the cadmium sulfide crystal. An infrared ***sensor*** positioned in association with this window will be exposed to up to 85% of the incident infrared radiation.

B4.2 Results of a Search of US Patent Application Abstracts in the PGPUB Production Database for “nano$” AND “sensor$”:
93 Patent Applications

This is a search of the abstract fields (only) in the US patent *applications* database from 2001 to 2004. The search returned hits only when both of the following were found anywhere in a patent application abstract: (i) the prefix “nano” followed by any sequence of characters and (ii) the root “sensor” followed by any sequence of characters. Abstracts are included below only for patent applications with apparent environmental applications.

To read the entire patent application, visit the website at http://appft1.uspto.gov/netahtml/PTO/srchnum.html and enter the published application number
(Pub. App. No.).

	Pub. App. No.	Title
1	20050019849	**Nanoparticles for optical sensors** The present invention concerns a polymer layer for a ***sensor,*** wherein the polymer layer has ***nanoparticles*** embedded therein which impart to the polymer layer recognizing properties as well as transducer properties, a ***sensor*** comprising such layer and the use of the ***sensor*** for detecting and/or quantifying a target analyte.
2	20050018274	**Nanoparticle-based all-optical sensors** The present invention provides a ***sensor*** that includes an optical device as a support for a thin film formed by a matrix containing resonant ***nanoparticles***. The ***nanoparticles*** may be optically coupled to the optical device by virtue of the geometry of placement of the thin film. Further, the nanoparticles are adapted to resonantly enhance the spectral signature of analytes located near the surfaces of the ***nanoparticles***. Thus, via the ***nanoparticles,*** the optical device is addressable so as to detect a measurable property of a sample in contact with the ***sensor***. The ***sensors*** include chemical ***sensors*** and thermal ***sensors***. The optical devices include reflective devices and waveguide devices. Still further, the ***nanoparticles*** include solid metal particles and metal nanoshells. Yet further, the ***nanoparticles*** may be part of a ***nano***-structure that further includes nanotubes.
3	20050005688	**Dual stage instrument for scanning a specimen** A dual stage scanning instrument includes a ***sensor*** for sensing a parameter of a sample and coarse and fine stages for causing relative motion between the ***sensor*** and the sample. The coarse stage has a resolution of about 1 micrometer and the fine stage has a resolution of 1 ***nanometer*** or better. The ***sensor*** is used to sense the parameter when both stages cause relative motion between the ***sensor*** assembly and the sample. The ***sensor*** may be

		used to sense height variations of the sample surface as well as thermal variations, electrostatic, magnetic, light reflectivity or light transmission parameters at the same time when height variation is sensed. By performing along scan at a coarser resolution and short scans a high resolution using the same probe tip or two probe tips at fixed relative positions, data obtained from the long and short scans can be correlated accurately.
4	20050005675	**Formation of metal nanowires for use as variable-range hydrogen sensors** The present invention provides for variable-range hydrogen ***sensors*** and methods for making same. Such variable-range hydrogen ***sensors*** comprise a series of fabricated Pd–Ag (palladium–silver) nanowires—each wire of the series having a different Ag to Pd ratio—with ***nanobreakjunctions*** in them and wherein the nanowires have predefined dimensions and orientation. When the nanowires are exposed to H_2, their lattice swells when the H_2 concentration reaches a threshold value (unique to that particular ratio of Pd to Ag). This causes the ***nanobreakjunctions*** to close leading to a 6-8 orders of magnitude decrease in the resistance along the length of the wire and providing a sensing mechanism for a range of hydrogen concentrations.
5	20050002628	**Novel photonic waveguide structures for chip-scale photonic integrated circuits**
6	20050001579	**Ultra-fast precision motor with X, Y and Theta motion and ultra-fast optical decoding and absolute position detector**
7	20050000565	**Self-assembly methods for the fabrication of McFarland-Tang photovoltaic devices**
8	20040261500	**Method and apparatus for sensing hydrogen gas** A hydrogen ***sensor*** and/or switch fabricated from an array of nanowires or a ***nanoparticle*** thick film composed of metal or metal alloys. The ***sensor*** and/or switch demonstrate a wide operating temperature range and shortened response time due to fabrication materials and methods. The nanowires or ***nanoparticle*** thick films demonstrate an increase in conductivity in the presence of hydrogen.
9	20040255682	**Flexible thin film pressure sensor** Low pressure sensing and imperviousness to corrosion and to the effects of harsh environments are achieved in a pressure ***sensor*** that employs a flexible membrane supporting piezoresistive elements. A plurality of piezoresistive elements are aligned substantially collinearly across one surface of the flexible membrane. Innermost piezoresistive elements are disposed in such a way that they experience tension in response to an applied pressure, whereas outermost piezoresistive elements are disposed in such a way that they experience compression in response to the same applied pressure. Contact pads for each end of each piezoresistive element allow the elements to be configured in any number of desirable

		arrangements. In one exemplary embodiment, four piezoresistive elements are disposed along a main central axis of the membrane. The contacts of the elements are connected to form a Wheatstone bridge. Conventional Wheatstone bridge techniques are utilized to convert an applied pressure into an output electrical signal. The membrane includes amorphous or ***nanocrystalline*** semiconductor layers grown on a flexible substrate such as Kapton or suitable plastic materials.
10	20040239210	**Electrical assemblies using molecular-scale electrically conductive and mechanically flexible beams and methods for application of same**
11	20040232339	**Hyperspectral imaging workstation having visible/near-infrared and ultraviolet image sensors**
12	20040227694	System and method for a three-dimensional color image display utilizing laser induced fluorescence of nanoparticles and organometallic molecules in a transparent medium A system and a method of a three-dimensional color image display utilizing laser induced fluorescence (LIF) of ***nano***-particles and molecules in a transparent medium are disclosed. In one preferred embodiment, a three-dimensional display volume contains three types (for red, green and blue color) of LIF ***nano***-particles and/or molecules dispersed in a random, uniform fashion in a transparent, fluid like medium. In another preferred embodiment, a color image display system consists of at least two light sources each equipped with two-dimensional scanning hardware and a LIF display volume, a protective coating and at least two light ***sensors***. The protective wavelength filtering coating blocks intense excitation light sources from harming image viewers while passing the LIF display light. The light ***sensors*** provide calibration and timing reference signals to maintain stable performance. A host of preferred fluorescence materials are also disclosed. These materials fall into three categories: inorganic ***nano***-meter sized phosphors; semiconductor based ***nano*** particles; fluorescent polymers, dye molecules and organometallic molecules. Additionally, a preferred fast laser scanning system is disclosed. The preferred scanning system consists of dual-axes acousto-optic light deflector, signal processing and control circuits equipped with a close-loop image feedback to maintain position accuracy and pointing stability of the laser beam.
13	20040223266	**FeTa nano-oxide layer as a capping layer for enhancement of giant magnetoresistance in bottom spin valve structures**
14	20040218262	**Inspection system using small catadioptric objective**
15	20040194535	**Nanodisk sensor and sensor array** The invention provides a ***sensor*** array with different ***nanodisk sensors*** that may be fabricated by direct site-specific dip-pen nanopatterning (DPN) using precursor inks. The good flow characteristics and strong affinity of the sols to measurement electrodes enable intimate ohmic contact. The measurable, reproducible and proportionate changes in the resistance of the ***sensors*** when exposed to trace quantities of oxidative and reducing gases

		constitute the basis for ***nanodisk*** gas ***sensors***. The ***nanodisk sensors*** show rapid response and ultra-fast recovery for the detection of nitrogen dioxide and acetic acid vapor. Based on the principles of pattern recognition of the olfactory system, an electronic nose that can "smell" different gaseous species is provided with the multiple ***nanodisk sensor*** array. These ***nanodisk sensors*** have gas recognition ability, instant response and rapid recovery, compact size and integration with the established microelectronics platform and are well-suited for the on-site and real-time detection of gases.
16	20040150818	**Optical devices and methods employing nanoparticles, microcavities, and semicontinuous metal films**
17	20040142409	**Nanomotion sensing system and method**
18	20040138544	**Body fluid trap analyte sensor**
19	20040137209	**Porous sintered composite materials** The present invention is directed to porous composite materials comprised of a porous base material and a powdered ***nanoparticle*** material. The porous base material has the powdered ***nanoparticle*** material penetrating a portion of the porous base material; the powdered ***nanoparticle*** material within the porous base material may be sintered or interbonded by interfusion to form a porous sintered ***nanoparticle*** material within the pores and or on the surfaces of the porous base material. Preferably this porous composite material comprises ***nanometer*** sized pores throughout the sintered ***nanoparticle*** material. The present invention is also directed to methods of making such composite materials and using them for high surface area catalysts, ***sensors,*** in packed bed contaminant removal devices, and as contamination removal membranes for fluids.
20	20040136121	**Spin valve with thermally stable pinned layer structure having ruthenium oxide specular reflecting layer**
21	20040131504	**Remote temperature sensing of small volume and related apparatus thereof** The present invention relates to methods of and apparatus for rapidly and accurately measuring the temperature of a small volume sample. The remote temperature ***sensor*** contains an optical interferometric ***sensor,*** preferably an extrinsic Fabry-Perot interferometer (EFPI), for measuring the difference in the distance traveled by a reference reflection and a sensing reflection. Because the refraction index of a solution is proportional to temperature, the output of the optical interferometric ***sensor*** can be converted to a temperature with a standard curve. Further, the present invention also provides methods and apparatus for measuring the temperature of the sample in performing non-contact (remote) thermocycling on small, micro to ***nanoliter,*** volume samples, wherein each cycle can be completed in as little as a few seconds.
22	20040118184	**Liquid flow proximity sensor for use in immersion lithography**
23	20040118183	**High-resolution gas gauge proximity sensor**

24	20040115855	**Method of forming dual exposure glass layer structures**
25	20040113089	**Apparatus and process for measuring light intensities**
26	20040103725	**Stress sensor** A stress or magnetic field ***sensor*** comprises a generally elongate magnetically soft amorphous or ***nanocrystalline*** electrically resistive element and biasing means for applying to the element a bias magnetic field of which the component directed along the length of the ***sensor*** has an amplitude variation pattern along the element. A periodically varying pattern has the effect of reducing the sensitivity of a stress ***sensor*** to external ambient fields (Fig. 3 shows that with a sawtooth bias field the sensitive portions a of a ***sensor*** move to positions b in the presence of an ambient field, but their number remains the same). A ramped bias field enables the position of the sensitive region of the ***sensor*** to be controlled, for measuring local stress, or for mapping an external magnetic field. Control of the regions where the ***sensor*** is active may include selective conductive coating of portions of its length. Potential uses of the stress ***sensor*** include a pressure ***sensor,*** embedment in moving parts (using rf communication) such as vehicle tyres, aircraft wings or machine parts, and in structures such as bridges where stray magnetic fields are a problem.
27	20040080726	**Photonic crystal reflectors/filters and displacement sensing applications**
28	20040070006	**Formation of metal nanowires for use as variable-range hydrogen sensors** The present invention provides for variable-range hydrogen ***sensors*** and methods for making same. Such variable-range hydrogen ***sensors*** comprise a series of fabricated Pd–Ag (palladium–silver) nanowires—each wire of the series having a different Ag to Pd ratio—with ***nanobreakjunctions*** in them and wherein the nanowires have predefined dimensions and orientation. When the nanowires are exposed to H_2, their lattice swells when the H_2 concentration reaches a threshold value (unique to that particular ratio of Pd to Ag). This causes the ***nanobreakjunctions*** to close leading to a 6-8 orders of magnitude decrease in the resistance along the length of the wire and providing a sensing mechanism for a range of hydrogen concentrations.
29	20040069063	**Tunnel effect nanodetector of mechanical vibrations and method for preparation thereof**
30	20040048075	**Surface plasmon-excitable granular thin film of noble metal**
31	20040036940	**Adaptive optic with discrete actuators for continuous deformation of a deformable mirror system**
32	20040027462	**Image sensor device, apparatus and method for optical measurements** The invention relates to an apparatus and processes for optical measurement and detection with real-time closed-loop controls, which enable higher levels of performance. The invention is especially suitable for applications such as spectroscopy; microscopy; biochemical assays;

		processes and reactions on miniaturized formats (such as those involving micro-***/nano***-plates, micro-formats and micro-arrays, chemistry-on-chip, lab-on-chip, micro-channels and micro-fluidics, where dimensions are on micron scale and volumes are in the sub-***nanoliter*** range). Such "intelligent sensing" allows higher data quality and reliability, higher measurement and analysis throughput and lower cost. The invention uses fast real-time adaptive digital signal processing and controls directly at the point where data is sensed. Through real-time adaptive control of ***sensors,*** chemical/opto-mechanical/opto-electronic processes and other components during the measurement process, consistently higher quality results and higher reliability are achieved. This invention furthermore includes an improved image ***sensor*** architecture that enables very intra-array dynamic range at fast frame rates and low noise performance.
33	20040018548	**Nucleotide detector, method for manufacturing the same, and method for producing particulate film**
34	20040018160	**Synthesis, uses and compositions of crystal hydrogels**
35	20030219822	**Biosensor and method** Surface plasmon resonance (SPR) ***sensor*** biointerface with a rigid thiol linker layer and/or interaction layer ligand loading with reversible collapse and/or iron oxide ***nanoparticle sensor*** response amplification.
36	20030219753	**Biosensor and method** Surface plasmon resonance (SPR) ***sensor*** biointerface with a rigid thiol linker layer and/or interaction layer ligand loading with reversible collapse and/or iron oxide ***nanoparticle sensor*** response amplification.
37	20030215865	**Integrated nanomechanical sensor array chips** The invention provides ***sensor,*** preferably biosensor devices and method of fabrication. The devices have significant advantages over the prior art methods having compatibility with future trends in clinical diagnostics and chemical detection. The underlying principle involves the integration of ***nanometer*** diameter, micron long metal or semiconductor rods onto a substrate to form a suspended ***nanomechanical*** cantilevers. The cantilever rods are rigidly attached to the substrate on one or both ends, and resonate at a characteristic frequency depending on the diameter, length, and stiffness of the rod. The metal or semiconductor rods are integrated onto the substrate using electrofluidic or fluidic assembly techniques. A receptor coating is placed on the metal or semiconductor rods prior to or following rod alignment using self-assembly chemistries. Sensing is accomplished when the target agent binds to the receptor substance, causing a change in the mass of the cantilever rod, and a corresponding change in the resonant frequency. This change in resonant frequency can be detected using an electrical readout. The sensing circuitry is integrated with CMOS or TFT technologies to form compact multi-analyte senor arrays on single crystal silicon, glass, or polymeric substrates. Circuits can also be included on the substrate to transmit the array data via wireless methods to a remote

		workstation for analysis. Devices may be integrated on chips with other analysis devices.
38	20030209433	**Gas sensor** Disclosed herein is a gas ***sensor*** and a method of making a gas ***sensor*** comprising disposing a reference electrode on an inner surface of an electrolyte; sputtering a sensing electrode on an outer surface of the electrolyte; sputtering a zirconia layer on a side of the sensing electrode opposite the electrolyte, wherein the zirconia layer has a thickness of about 20 ***nanometers*** to about 1 micrometer, and disposing a protective layer on a side of the zirconia layer opposite the sensing electrode.
39	20030189800	**Antiparallel-pinned type spin valve sensor having ultra-thin free layers**
40	20030189235	**Photoelectric conversion element and photoelectric conversion device**
41	20030180446	**Production method of gas sensor** To provide a method for producing a sensing film for gas ***sensors*** by sintering particles comprising a metal or a metal oxide on a substrate, where the sensing film for gas ***sensors*** having excellent ***sensor*** properties such as sensitivity and responsibility can be easily and simply formed. A ***nanometer***-order particle (100), a dispersant (110) for preventing aggregation of the particles (100), and a scavenger (120) for trapping the dispersant (110) at the sintering are mixed in a solvent (130) to prepare a paste body (140), and this paste body (140) is coated on a base material and fired, thereby forming a sensing film.
42	20030175945	**Scanning Kelvin microprobe system and process for analyzing a surface** A scanning Kelvin microprobe (SKM) system capable of measuring and analyzing surface characteristics of samples is provided. Also provided is a process of measuring and analyzing surface characteristics of samples. Further, there are provided uses of the SKM system in measuring and analyzing surface characteristics of conductors, semiconductors, insulators, chemicals, biochemicals, photochemicals, chemical ***sensors,*** biosensors, biochemical microarrays, microelectronic devices, electronic imaged devices, micromachined devices, ***nano***-devices, corroded materials, stressed materials, coatings, adsorbed materials, contaminated materials, oxides, thin films, and self assembling monolayers.
43	20030174384	**Nanoparticle-based all-optical sensors** The present invention provides a ***sensor*** that includes an optical device as a support for a thin film formed by a matrix containing resonant ***nanoparticles***. The ***nanoparticles*** may be optically coupled to the optical device by virtue of the geometry of placement of the thin film. Further, the ***nanoparticles*** are adapted to resonantly enhance the spectral signature of analytes located near the surfaces of the ***nanoparticles***. Thus, via the ***nanoparticles,*** the optical device is addressable so as to detect a measurable property of a sample in contact with the ***sensor***. The ***sensors*** include chemical ***sensors*** and thermal ***sensors***. The optical devices include

		reflective devices and waveguide devices. Still further, the ***nanoparticles*** include solid metal particles and metal nanoshells. Yet further, the ***nano-particles*** may be part of a ***nano***-structure that further includes nanotubes.
44	20030159927	**Colloidal particles used in sensing arrays** Chemical ***sensors*** for detecting analytes in fluids comprising a plurality of alternating nonconductive regions (comprising a nonconductive material) and conductive regions (comprising a conductive material). In preferred embodiments, the conducting region comprises a ***nanoparticle***. Variability in chemical sensitivity from ***sensor to sensor*** is provided by qualitatively or quantitatively varying the composition of the conductive and/or nonconductive regions. An electronic nose for detecting an analyte in a fluid may be constructed by using such arrays in conjunction with an electrical measuring device electrically connected to the conductive elements of each ***sensor***.
45	20030158474	**Method and apparatus for nanomagnetic manipulation and sensing**
46	20030152629	**Multi component controlled release system for oral care, food products, nutraceutical, and beverages**
47	20030151407	**Magnetic-field sensor device having magnetic nanop articles and a method of forming the same**
48	20030148088	**Light emitting photonic crystals** The invention relates to processes for the synthesis of 2-D and 3-D periodic porous silicon structures and composites with improved properties having the advantages of porous silicon and photonic bandgap materials. Photonic crystals comprise a two dimensionally periodic or three dimensionally periodic microporous structural matrix of interconnecting, crystallographically oriented, monodispersed members having voids between adjacent members, and said members additionally having randomly nanoporous surface porosity. The silicon ***nanofoam*** material shows enhanced and spectrally controlled/tunable photoluminescence and electroluminescence and finds use as transparent electrodes, high-luminosity light emitting diodes (LEDs), wavelength division multiplexers, high-active-area catalyst supports, photonic bandgap lasers, silicon-based UV detectors, displays, gas ***sensors,*** and the like.
49	20030147956	**Biodegradable bioadhesive controlled release system of nano-particles for oral care products**
50	20030138490	**Synthesis and uses of polymer gel nanoparticle networks**
51	20030138368	**High purity nanomaterials**
52	20030134959	**Luminescent polymer particles** This invention involves a series of articles, dispersions, compositions, methods, and kits. Several aspects of the invention involve dispersed particles made from polymers having a delocalized pi-orbital backbone structure, as well as methods for making and using such particles. The delocalized pi-orbital backbone allows the polymer to have a high degree of luminosity, useful in many embodiments of the invention. The polymers

		of this invention can also have bulky substituents to prevent intermolecular pi-pi interactions that can decrease luminosity. The polymer may also have charged side chains immobilized relative to the backbone, which can allow the polymer to be made into stably suspended micro- or ***nanoparticles*** dispersed in solution, sometimes with very narrow size distributions. In some embodiments, depending on the conditions used to synthesize and prepare the particles, the particles each consist of a single polymer molecule. Side groups, including biological, biochemical, or chemical molecules, can be attached to the polymer to provide additional functions, such as altering the luminosity of the polymer, or allowing the polymer to bind to certain molecules, such as in a chemical ***sensor*** or in a biological assay. As the binding of a molecule to a side group on the polymer can affect the structure of the polymer or alter the luminosity of the particle, the particles of the invention may be used, in certain embodiments, to detect the presence of single molecules.
53	20030133232	**FeTa nano-oxide layer as a capping layer for enhancement of giant magnetoresistance in bottom spin valve structures**
54	20030126948	**High purity fine metal powders and methods to produce such powders**
55	20030124043	**High purity nanoscale metal oxide powders and methods to produce such powders**
56	20030109056	**Chemical sensors from nanoparticle/dendrimer composite materials** The invention relates to a chemical ***sensor*** comprising a ***sensor*** film formed of a ***nanoparticle*** network in which the ***nanoparticles*** are interlinked by functionalized dendrimer molecules. The dendrimers support an efficient uptake of analyte molecules by the film material and therefore enable a high sensitivity of the ***sensor***. In addition, the chemical nature of the dendrimers strongly determines the chemical selectivity of the ***sensor*** device. By cross-linking the components of the sensitive material the ***sensor*** displays a good mechanical stability.
57	20030108785	**Meso-porous carbon and hybrid electrodes and method for producing the same**
58	20030102099	**Nano-dispersed powders and methods for their manufacture**
59	20030089899	**Nanoscale wires and related devices**
60	20030089162	**Dual stage instrument for scanning a specimen**
61	20030082237	**Nanoparticle assembled hollow spheres** A design strategy for constructing hierarchically structured materials using ***nanoparticles*** and synthetic biopolymers has been developed. Block copolypeptides or homopolymer polyelectrolytes are used as structure-directing agents to arrange ***nanoparticles*** (composed of metals, metal non-oxides, metal oxides, or organics) into unusual microstructures, such as spheres, "apples" and "cups." Hollow spheres can be made wherein ***nanoparticles*** of one composition are spatially oriented completely interior or exterior to ***nanoparticles*** of a second composition. These aggregates contain ***nanoparticles*** only in the shell walls, and maintain their

		hollowness upon calcination. These shapes can also be fabricated into films. These robust materials are anticipated to have great promise in applications that require surface catalysis, magnetic/electronic/optic properties, transport capabilities, and combinations thereof, such as drug delivery, packaging, catalysis, and ***sensors***.
62	20030064532	**Nanoparticle optical storage apparatus and methods of making and using same**
63	20030053974	**Compositions and method for targeted controlled delivery of active ingredients and sensory markers onto hair, skin, and fabric**
64	20030053266	**Multilayered structures comprising magnetic nano-oxide layers for current perpendicular to plane GMR heads**
65	20030048619	**Dielectrophoretic assembling of electrically functional microwires**
66	20030047675	**Diffractive optical position detector** An apparatus and method for measuring optically the position or angle of a variety of objects or arrays of objects, including cantilevers in scanning probe microscopy, micromechanical biological and chemical ***sensors*** and the sample or a probe in surface profilometry. The invention involves the use of one or more diffractive optical elements, including diffraction gratings and holograms, combined with conventional optical elements, to form a plurality of light beams, each with a selectable shape and intensity, from a single light source, reflect the beams off mechanical objects and process the reflected beams, all to the end of measuring the position of such objects with a high degree of precision. The invention may also be used to effect mechanical changes in such objects. Devices with these improvements have numerous applications, including molecular force measurements, atomic force microscopy and manipulation technology, lithographic manufacturing, ***nanometer*** scale surface profiling and other aspects of nanotechnology.
67	20030047076	**Dynamic filtration method and apparatus for separating nano powders** A method and apparatus for separating ***nanometer-sized*** particles of a powder. The method includes (a) feeding the powder particles into a pressurized gas stream which carries the particles into a first stage filter device of a multiple-stage separator system; (b) operating the first stage filter device to remove and collect coarse particles and a filter device in at least another stage to remove and collect finer particles of the powder; the filter device having a dynamic filter which is composed of (b1) a mesh of a multiplicity of openings with the opening size at least two times larger than the average size of the particles, (b2) vibration devices or shakers to shake off the particles that may otherwise clog up the mesh openings, (b3) size ***sensors*** to measure the sizes of the particles collected by the filter devices, and (b4) a controller to regulate the operations of the shakers and ***sensors*** in order to form desired dynamic mesh holes for the purpose of filtering out the coarse particles in the first stage or the finer particles in another stage;

		and (c) operating a dust collector to exhaust the residual gas, allowing the finest particles of the powder to be separated and collected.
68	20030030067	**Upconversion luminescence materials and methods of making and using same** The present relates in general to upconversion luminescence ("UCL") materials and methods of making and using same and more particularly, but not meant to be limiting, to Mn^{2+} doped semiconductor ***nanoparticles*** for use as UCL materials. The present invention also relates in general to upconversion luminescence including two-photon absorption upconversion, and potential applications using UCL materials, including light emitting diodes, upconversion lasers, infrared detectors, chemical ***sensors,*** temperature ***sensors*** and biological labels, all of which incorporate a UCL material.
69	20030013096	**Nucleotide detector, process for producing the same and process for forming fine particle membrane**
70	20020192441	**Electronic and opto-electronic devices fabricated from nanostructured high surface to volume ratio thin films** An electronic or opto-electronic device or a chemical ***sensor*** comprising: an interpenetrating network of a nanostructured high surface area to volume ratio film material and an organic/inorganic material forming a ***nanocomposite***. The high surface area to volume film material is obtained onto an electrode substrate first, such that the ***nano***-scale basic elements comprising this film material are embedded in a void matrix while having electrical connectivity with the electrode substrate. For example, the film material may comprise an array of ***nano***-protrusions electrically connected to the electrode substrate and separated by a void matrix. The interpenetrating network is formed by introducing an appropriate organic/inorganic material into the void volume of the high surface area to volume film material. Further electrode(s) are defined onto the film or intra-void material to achieve a certain device. Charge separation, charge injection, charge storage, field effect devices, ohmic contacts, and chemical ***sensors*** are possible.
71	20020184939	**Multilaminated nano-engineered devices** Novel multilaminated ***nano***-engineered devices and methods of forming multi-layer devices that exhibit quantum-confinement effects are disclosed. Benefits of multi-layer sensing, piezoelectric, photonic, biomedical, and thermal devices based on ***nanomaterials*** are disclosed. Quantum-confined device layer thickness can be in the range of 1 nm to 10 cm, a preferred thickness being less than 10 microns, and a most preferred thickness being less than 1 micron. Devices can be built using chalcogenides, oxides, nitrides, borides, phosphides, halides, silicates, hydrides, oxynitrides, oxycarbides, and other complex compositions. ***Sensors*** for monitoring environmental variables such as chemical composition are disclosed. These low-cost ***sensors*** comprise multiple layers in a laminated stack. Very high numbers of sensing layers (e.g., 500) may be incorporated into a single

		laminated ***sensor*** device. The ***sensors*** may be produced from nanostructured materials.
72	20020180306	**Carbon nanobimorph actuator and sensor**
73	20020177522	**Solid media** Solid media useful for a variety of applications, such as separations, catalysis, drug carriers, ***sensors,*** and combinatorial chemistry, are disclosed. The solid media are prepared with PNPs having a diameter of 1 to 50 ***nanometers,*** the PNPs including as polymerized units a multi-ethylenically-unsaturated monomer. Also provided are methods for preparing the solid media.
74	20020167374	**Pattern-aligned carbon nanotube growth and tunable resonator apparatus**
75	20020155600	**Optical fiberless sensors**
76	20020148278	**Nanocrystalline films for gas-reactive applications** A gas ***sensor*** for detection of oxidizing and reducing gases, including O_2, CO_2, CO, and H_2, monitors the partial pressure of a gas to be detected by measuring the temperature rise of an oxide-thin-film-coated metallic line in response to an applied electrical current. For a fixed input power, the temperature rise of the metallic line is inversely proportional to the thermal conductivity of the oxide coating. The oxide coating contains multi-valent cation species that change their valence, and hence the oxygen stoichiometry of the coating, in response to changes in the partial pressure of the detected gas. Since the thermal conductivity of the coating is dependent on its oxygen stoichiometry, the temperature rise of the metallic line depends on the partial pressure of the detected gas. ***Nanocrystalline*** (<100 nm grain size) oxide coatings yield faster ***sensor*** response times than conventional larger-grained coatings due to faster oxygen diffusion along grain boundaries rather than through grain interiors.
77	20020146379	**Controlled delivery system for hair care products**
78	20020134177	**Double-headed mass sensor and mass sensing method** There is provided a double-headed mass ***sensor*** (25) in which between a first connecting plate (22A) joined to a first diaphragm (21A) at respective sides and a second connecting plate (22B) joined to a second diaphragm (21B) at respective sides, a first sensing plate (41A), on which a main element (44) is provided on at least one plane surface, is bridged, and a resonating portion comprising the diaphragms (21A), (21B), the connecting plates (22A), (22B), the first sensing plate (41A) and the main element (44) is joined to a ***sensor*** substrate (27). Change in the mass of each of the diaphragms (21A), (21B) is measured by measuring change in the resonant frequency of the resonating portion accompanying the change in the mass of the diaphragms (21A), (21B). The mass ***sensor*** of the present invention enables the easy and highly accurate measurement of a minute mass of a ***nanogram*** order including microorganisms such as bacteria and viruses, chemical substances, and the thickness of vapor-deposited films.

79	20020132361	**Selective chemical sensors based on interlinked nanoparticle assemblies** The invention relates to a ***nanoparticle*** film comprising a ***nanoparticle*** network formed of ***nanoparticles*** interlinked by linker molecules. The linker molecules have at least two linker units that can bind to the surface of the ***nanoparticles***. By introducing selectivity-enhancing units in the linker molecule, the selectivity of the ***nanoparticle*** film towards target analytes can be enhanced. A fine-tuning of the selectivity can be achieved by including a fine-tuning unit in the vicinity of the selectivity-enhancing unit. The ***nanoparticle*** film can be used to produce chemical ***sensors*** which are selective and stable in their performance.
80	20020122179	**Sensitive and selective chemical sensor with nanostructured surfaces** A chemical ***sensor*** is provided which includes an optical resonator including a nanostructured surface comprising a plurality of ***nanoparticles*** bound to one or more surfaces of the resonator. The ***nanoparticles*** provide optical absorption and the ***sensor*** further comprises a detector for detecting the optical absorption of the ***nanoparticles*** or their environment. In particular, a selective chemical interaction is provided which modifies the optical absorption of the ***nanoparticles*** or their environment, and an analyte is detected based on the modified optical absorption. A light pulse is generated which enters the resonator to interrogate the modified optical absorption and the exiting light pulse is detected by the detector.
81	20020120296	**Implantable device using ultra-nanocrystalline diamond**
82	20020118027	**Nanostructured ceramic platform for micromachined devices and device arrays** The present invention discloses a type of nanostructured ceramic platform for gas ***sensors and sensor*** arrays. These ***sensors*** comprise micromachined anodic aluminum oxide films, which contains extremely high density (e.g., 10^{11} cm^{-2}) nanoscale pores. Sensing materials deposited inside this self-organized network of nanopores have ultra-high surface area and ***nanometer*** grain structure, therefore enabling high sensitivity. Refractory nature of alumina ceramic enables the desired robustness, long lifetime and stability in harsh environment. This ***sensor*** platform can be used for both chemical gas and physical (humidity, temperature) ***sensors and sensor*** arrays.
83	20020088284	**Mass sensor and mass sensing method** A mass ***sensor*** (30) in which a connection plate (33) and a diaphragm (31) are joined together at their respective sides; a sensing plate (32) is joined to the connection plate (33) at their respective sides in the direction perpendicular to the direction where the diaphragm (31) is joined to the connection plate (33); a piezoelectric element (35) consisting of a piezoelectric film and an electrode is installed on at least either one of plate surfaces of the sensing plate (32); and a resonating portion consisting of the diaphragm (31), the sensing plate (32), the connection plate (33), and the piezoelectric element (35) is joined to a ***sensor*** substrate (34). Change in

		the mass of the diaphragm (31) is measured by measuring change in the resonant frequency of the resonating portion accompanying the change in the mass of the diaphragm (31). The mass ***sensor*** of the present invention enables the easy and accurate measurement of a minute mass of a ***nanogram*** order including microorganisms such as bacteria and viruses, chemical substances, and the thickness of vapor-deposited films.
84	20020055033	**Nanostructured deposition and devices** Ion-conducting solid electrolytes are constructed from nanoscale precursor material. ***Nanocrystalline*** powders are pressed into disc structures and sintered to the appropriate degree of densification. Metallic material is mixed with 0 to 65 vol % nanostructured electrolyte powders to form a cermet mix and then coated on each side of the disc and fitted with electrical leads. The electrical conductivity of a Ag/YSZ/Ag cell so assembled exhibited about an order of magnitude enhancement in oxygen ion conductivity. As an oxygen-sensing element in a standard O_2/Ag/YSZ/Ag/N_2 set up, the ***nanocrystalline*** YSZ element exhibited commercially significant oxygen ion conductivity at low temperatures. The invention can be utilized to prepare nanostructured ion conducting solid electrolytes for a wide range of applications, including ***sensors,*** oxygen pumps, fuel cells, batteries, electrosynthesis reactors and catalytic membranes.
85	20020034757	**Single-molecule selection methods and compositions therefrom** Single-molecule selection methods are provided for identifying target-binding molecules from diverse sequence and shape libraries. Complexes and imprints of selected target-binding molecules are also provided. The subject selection methods are used to identify oligonucleotide and nonnucleotide molecules with desirable properties for use in pharmaceuticals, drug discovery, drug delivery, diagnostics, medical devices, cosmetics, agriculture, environmental remediation, smart materials, packaging, microelectronics and ***nanofabrication***. Single oligonucleotide molecules with desirable binding properties are selected from diverse sequence libraries and identified by amplification and sequencing. Alternatively, selected oligonucleotide molecules are identified by sequencing without amplification. Nonnucleotide molecules with desirable properties are identified by single-molecule selection from libraries of conjugated molecules or nucleotide-encoded nonnucleotide molecules. Alternatively, target-specific nonnucleotide molecules are prepared by imprinting selected oligonucleotide molecules into nonnucleotide molecular media. Complexes and imprints of molecules identified by single-molecule selection are shown to have broad utility as drugs, prodrugs, drug delivery systems, wilfully reversible cosmetics, diagnostic reagents, ***sensors,*** transducers, actuators, adhesives, adherents and novel multimolecular devices.
86	20020015150	**Sensors employing nanoparticles and microcavities**
87	20010053337	**Dual manifold system and method for fluid transfer**

88	20010047682	**Dual stage instrument for scanning a specimen** A dual stage scanning instrument includes a ***sensor*** for sensing a parameter of a sample and coarse and fine stages for causing relative motion between the ***sensor*** and the sample. The coarse stage has a resolution of about 1 micrometer and the fine stage has a resolution of 1 ***nanometer*** or better. The ***sensor*** is used to sense the parameter when both stages cause relative motion between the ***sensor*** assembly and the sample. The ***sensor*** may be used to sense height variations of the sample surface as well as thermal variations, electrostatic, magnetic, light reflectivity or light transmission parameters at the same time when height variation is sensed. By performing along scan at a coarser resolution and short scans a high resolution using the same probe tip or two probe tips at fixed relative positions, data obtained from the long and short scans can be correlated accurately.
89	20010042845	**Wafer orientation sensor for GaAs wafers**
90	20010016177	**Microvolume liquid handling system**
91	20010015878	**Magnetic sensor and magnetic storage using same**
92	20010014477	**Microvolume liquid handling system**
93	20010001397	**Amorphous and nanocrystalline glass-covered wires and process for their production**

Appendix C. Literature Reviews

C1. Bibliography for Nanotechnology and Soil Remediation, Water Purification or Water Desalination:

Selected Reviews and News Articles from 1995 to 2004

Anonymous. The chemistry of the future: Nanotechnology. A memorandum for policy-makers. [Web Page]. 2001 May 4; Available at http://www.chemsoc.org/pdf/enc/allcheme_nano.pdf.
Abstract: This memorandum represents the essence of the conclusions of a workshop organised by AllChemE in Brussels on May 4th , 2001 at which were present forty scientists and engineers from academia, research institutes and industry.

Anonymous. Large-scale plants show promise. American Water Works Association Journal 1997;89(10):39.
Keywords: Membrane filters/ Water filtration
Abstract: New technology is making membranes more feasible for large-volume applications. Nowadays, membranes are more versatile and more affordable and provide wider choices to both groundwater and surface water systems. The options currently available include microfiltration, ultrafiltration, and nanofiltration. As these membrane processes increase in popularity, the evaluation of pretreatment techniques becomes paramount. In a world of increasingly complex regulatory requirements, the membranes may become more cost-effective than costly.

Anonymous. NSTI: the Nano Science and Technology Institute [Web Page]. 2005; Available at http://www.nsti.org/.
Abstract: This is the website of NSTI, the Nano Science and Technology Institute. The Nano Science and Technology Institute (NSTI) is chartered with the promotion and integration of nano and other advanced technologies through education, technology and business development. NSTI accomplishes this mission through its offerings of consulting services, continuing education programs, scientific and business publishing and community outreach. NSTI produces the annual Nanotech conference and trade show, the most comprehensive international nanotechnology convention in the world. NSTI also produces BioNano and Stem Cell Strategies conferences. NSTI was founded in 1997 as a result of the merger between various scientific societies, and is headquartered in Cambridge, Massachusetts with additional offices in California and Switzerland.

Anonymous. Research trends. Membrane Technology 2003;2003(9):14-6 .
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VJF-49FG841-M&_coverDate=09%2F30%2F2003&_alid=197901678&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=6093&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=42529bf3fa327a9b52a5d1cf03dd405e
Abstract: Including information on

- Pore size determination
- Crossflow filtration

- Thin-layer composite molecularly imprinted membranes
- Polymeric membrane and coated graphite samarium(III)-selective electrodes
- Blood compatibility of cellulose membranes
- Chemical modification of cellulose membranes
- Reclaiming spent rinses from nickel-plating operations
- Evaluation of polyethylene hollow-fibre membranes
- Nano-structure of Nafion membranes

Bellona C, Drewes JE, Xu P, Amy G. Factors affecting the rejection of organic solutes during NF/RO treatment--a literature review. Water Research 2004;38(12):2795-809.

Abstract: The incomplete rejection of certain pesticides, disinfection by-products, endocrine disrupting compounds, and pharmaceutically active compounds has been reported during full- and pilot-scale high-pressure membrane applications. Since the removal of these compounds in water and wastewater treatment applications is of great importance where a high product water quality is desired, an understanding of the factors affecting the permeation of solutes in high-pressure membrane systems is needed. In this paper, findings of a comprehensive literature review are reported, targeting membrane rejection mechanisms and factors affecting rejection. The following key solute parameters were identified to primarily affect solute rejection: molecular weight (MW), molecular size (length and width), acid disassociation constant (pK_a), hydrophobicity/hydrophilicity ($\log K_{ow}$), and diffusion coefficient (D_p). Key membrane properties affecting rejection that were identified include molecular weight cut-off, pore size, surface charge (measured as zeta potential), hydrophobicity/hydrophilicity (measured as contact angle), and surface morphology (measured as roughness). In addition, feed water composition, such as pH, ionic strength, hardness, and the presence of organic matter, was also identified as having an influence on solute rejection. From the knowledge gained during the literature review, a rejection diagram was proposed, which qualitatively allows prediction of solute rejection if certain solute and membrane properties are known.

Bhattacharyya D, Hestekin J, Shah D, Ritchie S. An overview of selected membrane techniques for environmental applications. J Chin Inst Chem Eng 2002;33(1):61-6.

URL: http://nr.stic.gov.tw/ejournal/ChiChemEng/2002/EJ53-2002-61.pdf

Abstract: Membrane processes provide a powerful technique for solvent and solute recovery from dilute (reverse osmosis, RO; nanofiltration, NF; ultrafiltration, UF) to concentrated (pervaporation, PV) solutions. The special features for membrane processes that make them attractive for environmental applications are their compactness, ease of fabrication, operation, and modular design. Considerable volume reduction of waste streams is also possible with membranes (for example, 30-fold for RO and up to 1000-fold for PV). Removal of heavy metals, arsenic, nitrates, and other inorganics is of immense interest for drinking water production and also for dilute aqueous systems. Although many conventional techniques (i.e., ion exchange, precipitation, inorganic adsorbents, etc.) are effective for removing some of these pollutants, they are limited in their capacity to accomplish simultaneous removal of all species (including natural organics and pesticides). This paper deals with the applications of RO/NF/PV, and novel functionalized (with polymeric ligands) microfiltration membranes. The results of high performance zeolite pervaporation membranes showed high water flux and outstanding water/organic solvent selectivity. With a new generation aromatic polyamide and other composite RO membranes, rejection of heavy metals such as Pb and As(V) are greater than 98% and nitrate rejections range between 95-97%. Novel microfiltration based metal sorbents with capacities considerably higher than conventional ion exchange have been developed.

Bridges A. Nanomaterials Don't Move Predictably in Water [Web Page]. 2004 Apr 1; Available at http://www.msnbc.msn.com/id/4649014/.
Abstract: Preliminary research, the first of its kind, suggests that the ways in which so-called nanoparticles behave in groundwater environments or water treatment plants are as varied as the diverse molecules or atoms used to assemble them. (American Chemical Society)

Cartwright PS. Water purification. ASHRAE Journal 1999;41(5):69-74.
Keywords: Water purification
Abstract: The writer explains less usual water-purification technologies that have increasing application potential. The technologies described are reverse osmosis, deionization, electrodeionization, carbon adsorption, and UV radiation and the membrane separation techniques of crossflow microfiltration, ultrafiltration, and nanofiltration. Advice on designing a high-purity water-production system is provided.

Cheetham AK, Grubstein PSH. Nanomaterials and venture capital. NanoToday [Materials Today, Supplement 1] 2003;6(12):16-9.
URL: http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6X1J-4DK5VV4-N-3&_cdi=7244&_user=10&_orig=browse&_coverDate=12%2F31%2F2003&_sk=999939987.8998&view=c&wchp=dGLbVlb-zSkzS&md5=1c22a6eef30afa9cdf2917b678b5ac1e&ie=/sdarticle.pdf
Keywords: Nanomaterials, emerging applications and commercialization
Abstract: There has been much publicity in the recent past, both in the popular press and in the scientific literature, concerning the dramatic developments in nanotechnology. The excitement surrounding the field has resulted in a high level of government funding for research worldwide. In the US alone, the government has invested over $2 billion since 1996, and in 2004 the annual level of funding from the National Nanotechnology Initiative is expected to reach $847 million. In response to the growing interest in the nanotechnology area and, notwithstanding the collapse of the technology sector following the dot.com bubble during the period 1998-2000, the venture capital (VC) community has responded enthusiastically to the promises held by nanotechnology.

Chellam S, Serra CA, Wiesner MR. Estimating costs for integrated membrane systems. American Water Works Association Journal 1998;90(11):96-104.
Keywords: Water purification, costs/ Membrane filters/ Product life cycle cost
Abstract: [This article was part of a special section on membrane systems.] A cost model was used to estimate the cost of integrated membrane systems. Costs for large systems were determined and compared with extrapolations from cost surveys of existing membrane installations. Despite increased nanofiltration fouling rates, life cycle costs for membrane facilities appear to be lower when membranes are operated at enhanced permeate fluxes and feedwater recoveries.

Daufin G, Escudier JP, Carrere H, Berot S, Lillaudeau L, Decloux M. Recent and emerging applications of membrane process in the food and dairy industry. Trans IChemE [Chemical Engineering

Research and Design] 2001;79(C2):89-102.
URL: http://www.extenza-eps.com/extenza/loadHTML?objectIDValue=42557&type=abstract
Keywords: Food industry/ Milk/ Dairy/ Wine/ Beer/ Vegetable protein/ Beverage/ Waste water/ Membrane process
Abstract: Membrane processes have been major tools in food processing for more than 25 years. The food industry represents a significant part of the turnover of the membrane manufacturing industry world-wide. The main applications of membrane operations are in the dairy industry (whey protein concentration, milk protein standardization, etc.), followed by beverages (wine, beer, fruit juices, etc.) and egg products. Among the very numerous applications on an industrial scale, a few of the main separations which represent the latest advances in food processing, are reported. Clarification of fruit, vegetable and sugar juices by microfiltration or ultrafiltration allows the flow sheets to be simplified or the processes made cleaner and the final product quality improved. Enzymatic hydrolysis combined with selective ultrafiltration can produce beverages from vegetable proteins. In the beer industry, recovery of maturation and fermentation tank bottoms is already applied at industrial scale. During the last decade significant progress has been made with microfiltration membranes in rough beer clarification which is the most important challenge of this technology. In the wine industry the cascade cross-flow microfiltration (0.2 μm pore diameter)—electrodialysis allows limpidity, microbiological and tartaric stability to be ensured. In the milk and dairy industry, bacteria removal and milk globular fat fractionation using cross-flow microfiltration for the production of drinking milk and cheese milk are reported. Cross-flow microfiltration (0.1 μm) makes it possible to achieve the separation of skim milk micellar casein and soluble proteins. Both streams are given high added value in cheese making (retentate) through fractionation and isolation of soluble proteins (ß-lactoglobulin;α-lactalbumin) (permeate). At last, a large field of applications is emerging for the treatment of individual process streams at source for water and technical fluids re-use, and end-of-pipe treatment of wastewaters, while reducing sludge production and improving the final purified water quality.

Fakir S. The sociological and environmental implications of nanotechnology: The promise of a new ecological utopia [Web Page]. 2002 Jan; Available at http://www.iucn.org/wssd/files/sa/sa_wssd_pol_tt_16.pdf.
Abstract: The speculative promises and possibilities of nanotechnology, the science or technology of 'manipulating and controlling things on a small scale' are changing the practices of ecology. Consequently, we're seeing the birth of the new science of nanoecology. Indeed, as nanotechnology increases the potential spin spin-offs for nanoecology it will have social implications and induce dramatic changes. But, argues Saliem Fakir, we should adopt a measured sense of prophecy and foresight. More important, we should guard from the overzealous promises of an accelerated frontier of extreme sciences and a new ecological utopia.

Gillett SL. Nanotechnology, resources, and pollution control. Nanotechnology 1996;7(3):177-82.
Abstract: The separation of different kinds of atoms or molecules from each other is a fundamental technological problem. Current techniques of resource extraction, which use the ancient paradigm of the differential partitioning of elements into coexisting phases, are simple but extremely wasteful and require feedstocks ('ores') that are already anomalously enriched. This is impractical for pollution control and desalination, which require extraction of low

concentrations; instead, atomistic separation, typically by differential motion through semipermeable membranes, is used. The present application of such membranes is seriously limited, however, mostly because of limitations in their fabrication by conventional bulk techniques. The capabilities of biological systems, such as vertebrate kidneys, are vastly better, largely because they are intrinsically structured at a molecular scale. Nanofabrication of semipermeable membranes promises capabilities on the order of those of biological systems, and this in turn could provide much financial incentive for the development of molecular assemblers, as well established markets exist already. Continued incentives would exist, moreover, as markets expanded with decreasing costs, leading to such further applications as remediation of polluted sites, cheap desalination, and resource extraction from very low-grade sources.

Gillham RW. Discussion of nano-scale iron for dehalogenation. Ground Water Monitoring and Remediation 2003;23(1):6,8.
Keywords: Groundwater remediation technologies/ Iron catalysts/ Dechlorination
Abstract: In a discussion of the 2001 article by Nyer and Vance on nano-scale iron for dehalogenation, the writer acknowledges its usefulness in bringing a new development to the attention of a broad audience, but regrets the failure to point out the potential difficulties and limitations of the technology. A different perspective on some of the issues raised is provided.

Goswami DY, Vijayaraghavan S, Lu S, Tamm G. New and emerging developments in solar energy. Solar Energy 2004;76(1-3):33-43.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V50-48F5CXR-1&_coverDate=03%2F31%2F2004&_alid=197827850&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5772&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=fa58c68eb12b983cdacba25c31dfe5a7
Abstract: Solar energy can potentially play a very important role in providing most of the heating, cooling and electricity needs of the world. With the emergence of solar photocatalytic detoxification technology, solar energy also has the potential to solve our environmental problems. However, we do not see widespread commercial use of solar energy. Some of the emerging developments in solar may change that situation. This paper describes some of the new and emerging developments, with special emphasis on (1) nanoscale antennas for direct conversion of sunlight to electricity with potential conversion efficiencies approaching 8090%; (2) new thermodynamic cycles for solar thermal power, that have the potential to reduce capital costs by 50%; and (3) solar photocatalytic oxidation for cleanup of industrial wastewater, drinking water, soil and air. The paper describes the fundamentals of each of these developments, their potential, present status and future opportunities for research.
(1) Nanoscale antenna solar energy conversion: The current photovoltaic technologies rely on the quantum nature of light and semiconductors which are fundamentally limited by the bandgap energies. A revolutionary new approach suggested by Professor Robert Bailey in 1972 revolves around the wave nature of light. Professor Bailey suggested that broadband rectifying antennas could be used for solar to d.c. conversion. These rectennas would not have the fundamental limitation of semiconductor bandgap limiting their conversion efficiencies. Rectennas for solar conversion would have dimensions of the order of the wavelengths of solar radiation which falls mostly in the submicron range. The challenges in actually achieving the objectives are many. This paper describes the challenges and approaches to their solution.

(2) New thermodynamic cycles for solar thermal power: It is recognized that the capital costs of solar thermal power will have to be reduced by about 50% in the near future in order to make it competitive with fossil fuels (especially natural gas) based power systems. Potential exists for meeting this goal by reducing the costs and improving the thermodynamic performance of power cycles by hybridization and combined cycle approaches and by employing new and innovative ideas in thermal power cycles. This paper describes the new thermodynamic approaches with an emphasis on an innovative new thermodynamic cycle using ammonia and water mixtures as the working fluids.
(3) Solar photocatalytic detoxification and disinfection of water and air: Although the potential of solar radiation for disinfection and environmental mitigation has been known for years, only recently has this technology been scientifically recognized and researched. Solar photocatalytic oxidation has been demonstrated to effectively treat groundwater, drinking water, and industrial wastewater. In some applications such as decoloration and reduction of COD it may be the only effective method of treatment. Treatment of indoor air by the photocatalytic method has been demonstrated as the most effective technology for that application. This paper describes the recent developments and identify challenges and future research opportunities. Copyright (c) 2003 Elsevier Ltd.

Harper T, Vas Roman C, Holister P. Fueling the chemical industry's future. Chemical Engineering Progress 2003;99(11):34S-8S.
URL: http://www.jobwerx.com/news/Archives/chemical-industry-future.html [text only]
Keywords: Nanotechnolgy, commercial applications/ Nanotechnology, companies

Hey N. Nano revolution. IEE Review 2003;49(4):46-8.
Keywords: Nanotechnology/ Semiconductor devices, miniaturization
Abstract: This article is part of a special report on nanotechnology. An overview of nanotechnology research developments at Sandia National Laboratories is presented. Sandia has developed its own technique for producing nano-sized clusters with the aim of developing inexpensive metal and semiconductor clusters as alternatives to precious metal catalysts for coal liquefaction, environmental remediation, and solar photocatalysis. They have also researched molecular movements that could evolve into useful tools for nanotechnology construction.

Hillis P, Editor. Membrane Technology in Water and Wastewater Treatment. The Royal Society of Chemistry, 2000.
URL: http://www.springeronline.com/sgw/cda/frontpage/0,11855,4-10006-22-30254163-0,00.html
Abstract: Presenting a useful reference to the current state of membrane technology and its likely future growth, this book covers all aspects of the technology and its applications in the water industry. Drawing on the experience of international experts, the book encompasses many practical applications of specific membranes, including MF, UF, NF, RO and EDR, in the treatment of ground and surface water, backwashwater, seawater, and industrial and domestic wastewater. it also discusses novel applications, process enhancements and the latest systems. This book is an excellent guide to membrane technology and will be of great interest to water companies, industrialists, legislative bodies and anyone with an interest in the technology or its applications.

Holister P. The Tiny Revolution [Web Page]. 2002 Jul; Available at http://www.nanotech-now.com/CMP-reports/NOR_White_Paper-July2002.pdf.
Abstract: This white paper is a preview of what is covered in the Nanotechnology Opportunity Report™. The Nanotechnology Opportunity Report™ provides a thorough analysis of the overall nanotechnology market and of the key technologies coming to market now and in the near future. It will also includes an extensive guide to the 455 public and private companies, 95 investors, and 271 academic institutions, and government entities that are involved in the near-term applications of the technology worldwide. Analysis is provided on both markets and technologies.

Kamat PV, Meisel D. Nanoparticles in advanced oxidation processes. Current Opinion in Colloid & Interface Science 2002;7(5-6):282-7.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VRY-46RDG4V-2&_coverDate=11%2F30%2F2002&_alid=198261023&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=6247&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b558bab3e4e5f5958c17db76c092fb86
Keywords: Photocatalysis/ Advanced oxidation/ TiO_2/ Nanoparticles/ Semiconductors/ Metals
Abstract: Photocatalysis using semiconductor nanoparticles as an advanced oxidation technique (AOT) has been a focus of research by a number of groups during the last two decades. The photocatalytic approach has been adopted successfully to develop self-cleaning glasses and air purification systems. Enhancing the photoconversion efficiency, maximizing the rate of degradation, and extending the photoresponse of the semiconductor catalyst into the visible range still pose a major challenge. Recent developments that address these issues and new approaches that expand the scope of semiconductor and metal nanoparticles in AOTs and related applications are presented in this overview.

Kamat PV, Meisel D. Nanoscience opportunities in environmental remediation. Comptes Rendus Chimie 2003;6(8-10):999-1007.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6X18-4B0BX5J-10&_coverDate=08%2F31%2F2003&_alid=197903285&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=7236&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=f0ed78f85f40fb20d9e3820c87cd9aa9
Abstract: Semiconductor nanostructures play an important role in developing smart materials that can simultaneously sense and destroy harmful chemical contaminants from our environment. This review article highlights some recent advances of nanoscience in the area of environmental remediation. The potential for improving the effectiveness of photocatalytic processes by means of semiconductor–metal nanocomposites and merits of combining two advanced oxidation processes are discussed. To cite this article: P.V. Kamat, D. Meisel, C. R. Chimie 6 (2003).

Liqiang J, Xiaojun S, Jing S, Weimin C, Zili X, Yaoguo D, et al. Review of surface photovoltage spectra of nano-sized semiconductor and its applications in heterogeneous photocatalysis. Solar Energy Materials and Solar Cells 2003;79(2):133-51.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V51-47G414B-2&_coverDate=09%2F01%2F2003&_alid=197931484&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5773&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid

=10&md5=a4b4a5a3f83b0348729df0a377bf4bcc
Keywords: Surface photovoltage spectra/ Semiconductor/ Nanoparticle/ Surface properties/ Photocatalysis
Abstract: Heterogeneous photocatalysis is a promising technique valuable for environmental purification. Nano-sized semiconductors such as ZnO and TiO_2, which is one of the most basic functional materials, have emerged as effective photocatalyst materials. The surface photovoltage spectra (SPS) can be an effective method for quickly evaluating the photocatalytic activity of semiconductor materials since it can provide a rapid, non-destructive monitor of the semiconductor surface properties such as surface band bending, surface and bulk carrier recombination and surface states, mainly showing the carrier separation and transfer behavior with the aid of light, especially the electric-field-induced surface photovoltage spectra (EFISPS), in which SPS is combined with the electric-field-modified technique. In this review, the basic principles, measurement and applications of the SPS and EFISPS are mainly discussed together with some fundamental aspects like the electric properties of semiconductor surface and the principle of electric field effect. In particular, the applications of SPS to nano-sized semiconductors such as ZnO and TiO_2 in heterogeneous photocatalysis are emphasized, which involve mainly evaluating the photocatalytic activity by analyzing semiconductor surface properties such as the separation efficiency of photoinduced carriers under illumination by the SPS measurement, highlighting our own contributions. The results show that the weaker the surface photovoltage signal is, the higher the photocatalytic activity is in the case of nano-sized semiconductor photocatalysts.

Madaeni SS. The application of membrane technology for water disinfection. Water Research 1999;33(2):301-8.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-3VGK7KC-19&_coverDate=02%2F28%2F1999&_alid=196233389&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d9952298ae91cace53893ae2d79f645a
Keywords: Membrane/ Water/ Disinfection/ Viruses/ Bacteria/ Fouling
Abstract: This general review paper with 70 references explains the various aspects of membrane technology for water disinfection. Membrane capabilities for removing bacteria, viruses and other microorganisms are discussed and advantages are shown. Fouling, which is the main problem in membrane-based water treatment and its control are explained. Finally the advantages and disadvantages of using membranes for water treatment are summarized.

Masciangioli T, Zhang WX. Environmental technologies at the nanoscale. Environmental Science and Technology 2003;37(5):102A-8A.
URL: http://www.nano.gov/html/res/GC_ENV_PaperZhang_03-0304.pdf
Keywords: Nanotechnology/ Environmental engineering
Abstract: Nanotechnology offers great promise for enhancing environmental quality and sustainability. Nanotechnology, the revolutionary manipulation of matter at the atomic or molecular scale, results in materials and systems that often exhibit novel and significantly changed physical, chemical, and biological properties due to their size and structure. The early impact of nanotechnology research has been mainly in remediation and end-of-pipe treatment technologies. Nanotechnology applications could also play a key role in pollution prevention technologies by reducing energy consumption, improving manufacturing processes, detecting

pollutants at the molecular level, and helping create benign substances that replace currently used toxic materials. Despite the potential benefits of nanotechnology, its proliferation could cause new environmental problems, such as new classes of toxins or related environmental hazards.

Matsuura JH. Anticipating the public backlash: Public relations lessons for nanotechnology from the biotechnology experience. Nanotech 2004: Technical Proceedings of the 2004 NSTI Nanotechnology Conference and Trade Show. Cambridge, Massachusetts, USA: NSTI: Nano Science and Technology Institute, 2004: 491-3.
URL: http://www.nsti.org/procs/Nanotech2004v3/11/T69.01
Keywords: Nanotechnology/ Public opinion/ Politics/ Public policy/ Public relations
Abstract: Public concern about the safety of nanotechnology is growing. Whether rationally based, or not, that concern can impede research and commercialization in the nanotechnology industry. This risk parallels problems already encountered by the biotechnology industry, particularly with regard to genetically modified foods. The nanotechnology industry should learn from the experience of biotechnology, and implement more effective public relations strategies to respond to public concern that can threaten nanotechnology development. The biotechnology industry made two key mistakes when dealing with early public concern about its technology. It first tried to ignore the concern, and later attempted to address it through rational arguments. The nanotechnology industry currently appears to be following a similar path. Instead, nanotechnology proponents should launch an aggressive public relations campaign in support of the technology immediately. That campaign should be based on both rational arguments and best sales and marketing practices that appeal to the emotions of the public. Immediate action to promote nanotechnology to the public is necessary to avoid the type of public backlash that could impede nanotechnology development. Such a backlash could have significant adverse economic consequences.

Mnyusiwalla A, Daar AS. 'Mind the gap': Science and ethics in nanotechnology. Nanotechnology 2003;14:R9-R13.
URL: http://www.utoronto.ca/jcb/genomics/documents/nanotechnology.pdf
Abstract: Nanotechnology (NT) is a rapidly progressing field. Advances will have a tremendous impact on fields such as materials, electronics, and medicine. A thorough review of the current literature, governmental funding, and policy documents was undertaken. Despite the potential impact of NT, and the abundance of funds, our research revealed that there is a paucity of serious, published research into the ethical, legal, and social implications of NT. As the science leaps ahead, the ethics lags behind. There is danger of derailing NT if the study of ethical, legal, and social implications does not catch up with the speed of scientific development.

Nyer EK, Vance DB. Nano-scale iron for dehalogenation. Ground Water Monitoring and Remediation 2001;21(2):41-6.
Keywords: Dechlorination/ Iron catalysts/ Groundwater remediation technologies
Abstract: Nano-scale iron is the latest tool being used to remove chlorinated hydrocarbons. Biological destruction methods and reactive iron walls have proved effective in the past. The injection of nano-scale iron particles is easier and more economical to use. The reaction chemistry and the methods of delivery and effectiveness in different soil types are described.

Pitkethly MJ. Nanoparticles as building blocks? NanoToday [Materials Today, Supplement 1] 2003 Dec;36-42.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6X1J-4B6SBTD-S&_coverDate=12%2F31%2F2003&_alid=197845059&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=7244&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ae607e0409991ad0b0ced0b12942ae9b#bbib9
or http://www.materialstoday.com/nanotoday/pitkethly.pdf

Keywords: Companies/ Commercial/ Review

Abstract: Nanomaterials and, in particular, nanoparticles are at the forefront of the nanotechnology wave. Over recent years there has been a rapid increase in the range of available nanomaterials and the number of companies that supply them. A variety of production techniques is used, each with benefits and drawbacks, but these are being improved all the time. The current and potential applications for nanoparticles are growing and cover an extremely broad range of markets. Analysts have estimated that the size of the market will be $900 million in 2005 and $11 billion in 2010. This is causing a great deal of interest among companies, but there are still a number of hurdles to be overcome before the potential of nanoparticles is fully realized.

Pitkethly MJ. Nanoparticles— the driving force. NanoToday [Materials Today Supplement 1] 2004 Dec;20-9.

URL: http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6X1J-4F07P23-W-1&_cdi=7244&_user=10&_orig=search&_coverDate=12%2F01%2F2004&_qd=1&_sk=999929987.8998&view=c&wchp=dGLbVzb-zSkWb&md5=d59c597febe3cee40f214997c53a6e84&ie=/sdarticle.pdf

Keywords: Companies/ Commercial/ Review

Abstract: The growth in activity surrounding nanomaterials continues unabated as more R&D funds are poured into nanotechnology and companies look to exploit the expanding range of novel properties that are being discovered. Advances in existing production techniques are improving the quality and yields, providing a clear prospect of commercially viable volume production. There is still a wide range of processes being used, and it is clear those that will be commercially successful will be those for which the materials have been developed at the same time as the application. Recent reports from a number of orking groups have highlighted the need forincreased examination of the health, environmental,and ethical aspects of nanotechnology, and this is an area that the industry will need to understand more fully and take appropriate action on if the benefits of nanomaterials are to be realized.

Reardon RD. Clearing the water about wastewater treatment with membranes [Web Page]. 2004; Available at
http://www.cdm.com/Ideas@Work/Viewpoint/Treating+Wastewater+with+Membranes.htm?bc=archive

Keywords: Nanofiltration/ Ultrafiltration/Microfiltration/Reverse osmosis/Wastewater treatment

Abstract: The use of advanced water treatment technologies to reclaim wastewater has evolved with each new generation of facilities. Membrane technology—typically thought of in terms of water treatment—has begun to emerge as the most significant advancement in wastewater treatment in the past 20 years, and its presence is expected to become wide spread

in the future. . . . This technology includes high-pressure membranes: nanofiltration or reverse osmosis pressure systems for treatment and production of high-quality product water suitable for indirect potable reuse and high-purity industrial process water.

Roco MC. A frontier for engineering. Mechanical Engineering Magazine 2001 Jan.
URL: http://www.memagazine.org/backissues/jan01/features/frontier/frontier.html
Abstract: This article, by Dr. Mihail Roco, an ASME Fellow and senior advisor for nanotechnology at the National Science Foundation's Directorate for Engineering, kicks off an initiative by Mechanical Engineering magazine to delve into the topic of nanotechnology. This is a technology that promises to change the way we live, the way we combat disease, the way we manufacture products, and even the way we explore the universe. Simply put, nanoscale manufacturing allows us to work with the building blocks of matter, at the atomic and molecular levels. This enables the creation of systems that are so small that we could only dream about their application years ago.

Rotman D. Nanosys's wise move [Web Page]. 2004 Aug 5; Available at http://www.technologyreview.com/blog/blog.asp?byAuthor=16
Abstract: Nanotech's first big IPO is not happening. Yesterday, Nanosys announced it was withdrawing its initial public offering because of "adverse market conditions." The plethora of analysts and pundits suddenly expert on the nanotech market (what market, you might wisely ask) are having a heyday on the profound question of the day: what does it all mean for the future of nanotechnology? The answer is nothing has changed: nanotech is still a few years away from having any significant commercial impact.

The Royal Society & The Royal Academy of Engineering. Nanoscience and nanotechnologies: Opportunities and uncertainties. London, UK: The Royal Society & The Royal Academy of Engineering, 2004 Jul.
URL: http://www.nanotec.org.uk/finalReport.htm
Abstract: Nanoscience and nanotechnologies are widely seen as having huge potential to bring benefits to many areas of research and application, and are attracting rapidly increasing investments from Governments and from businesses in many parts of the world. At the same time, it is recognised that their application may raise new challenges in the safety, regulatory or ethical domains that will require societal debate. In June 2003 the UK Government therefore commissioned the Royal Society and the Royal Academy of Engineering to carry out this independent study into current and future developments in nanoscience and nanotechnologies and their impacts. The remit of the study was to:
- define what is meant by nanoscience and nanotechnologies;
- summarise the current state of scientific knowledge about nanotechnologies;
- identify the specific applications of the new technologies, in particular where nanotechnologies are already in use;
- carry out a forward look to see how the technologies might be used in future, where possible estimating the likely timescales in which the most far-reaching applications of the technologies might become reality;
- identify what health and safety, environmental, ethical and societal implications or uncertainties may arise from the use of the technologies, both current and future; and
- identify areas where additional regulation needs to be considered.

Van der Bruggen B, Vandecasteele C. Removal of pollutants from surface water and groundwater by nanofiltration: Overview of possible applications in the drinking water industry. Environmental Pollution 2003;122(3):435-45.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VB5-47HBWD0-J&_coverDate=04%2F30%2F2003&_alid=242643416&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5917&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=64cac15e77f7ea9f31bddf156dc8e715
Keywords: Nanofiltration/ Softening/ Organics removal/ Pesticides/ Micropollutants/ Nitrate/ Arsenic/ Desalination/ NOM/ Disinfection
Abstract: During the last decade, nanofiltration (NF) made a breakthrough in drinking water production for the removal of pollutants. The combination of new standards for drinking water quality and the steady improvement of the nanofiltration process have led to new insights, possible applications and new projects on the lab scale, pilot scale and industrial scale. This paper offers an overview of the applications in the drinking water industry that have already been realised or that are suggested on the basis of lab-scale research. Applications can be found in the treatment of surface water as well as groundwater. The possibility of using NF for the removal of hardness, natural organic material (NOM), micropollutants such as pesticides and VOCs, viruses and bacteria, salinity, nitrates, and arsenic will be discussed. Some of these applications have proven to be reliable and can be considered as known techniques; other applications are still studied on laboratory scale. Modelling is difficult due to effects of fouling and interaction between different components. The current insight in the separation mechanisms will be briefly discussed.

Van der Bruggen B, Vandecasteele C, Van Gestel T , Doyen W, Leysen R. A review of pressure-driven membrane processes in wastewater treatment and drinking water production. Environmental Progress 2003;22(1):46-56.
Abstract: In pressure-driven membrane processes (reverse osmosis, nanofiltration, ultrafiltration, and microfiltration) a pressure exerted on the solution at one side of the membrane serves as a driving force to separate it into a permeate and a retentate. The permeate is usually pure water, whereas the retentate is a concentrated solution that must be disposed of or treated by other methods. Membranes may be polymeric, organo-mineral, ceramic, or metallic, and filtration techniques differ in pore size, from dense (no pores) to porous membranes. Depending on the type of technique, salts, small organic molecules, macromolecules, or particles can be retained, and the applied pressure will differ. This paper reviews the principles behind the different techniques, the types of membranes used, rejection mechanisms, and process modeling. Applications of pressure-driven membrane processes are also considered, including reverse osmosis and nanofiltration for the treatment of wastewater from landfills and composting plants, nanofiltration in the textile industry, and ultrafiltration and microfiltration in drinking water production and wastewater treatment. Lastly, the paper discusses recent developments, including techniques to prevent membrane fouling by modifications affecting surface roughness or hydrophilicity/hydrophobicity, or by cleaning the membranes, and methods for treating or disposing of the retentate.

Ying JY. Nanostructural tailoring: Opportunities for molecular engineering in catalysis. AIChE Journal 2000;46(10):1902-6.
URL: http://www3.interscience.wiley.com/cgi-bin/abstract/108066685/ABSTRACT

Keywords: Catalysis research/ Nanostructured materials/ Supramolecular chemistry/ Molecular templates

Abstract: Some unique facets of nanostructure processing and the usefulness of this approach for nanostructure processing are discussed. Catalysis is considered since it is of such importance in the core chemical engineering businesses, such as chemicals and fuels production, environmental protection and remediation, and processing of consumer products and advanced materials.

C2. Bibliography of Nanotechnology and Soil Remediation, Water Purification or Water Desalination: Selected Research Articles and Reports from 1995 to 2004

Aardahl CL, Grate JW, Hartman JS, Zheng F, Alexander ML, and Shin Y. Preconcentration of organic signatures based on carbon nanotube composites [Web Page]. 2003; Available at http://www.pnl.gov/nano/projects/organicsignatures.pdf.
Abstract: This work is focused on the fundamental understanding of the interactions of carbon nanotubes with vapor species and the development of novel preconcentration platforms for trace chemical detection based on that understanding.

Addleman RS, Fryxell GE, Zemanian TS, and Egorov O. Highly selective monolayer sorbents for advanced analytical applications [Web Page]. 2003; Available at http://www.pnl.gov/nano/projects/monolayersorbents.pdf.
Abstract: This research focuses on the synthesis and understanding of novel nanostructures and monolayers. The work will provide highly effective materials for preconcentration, separation, sensing, and spectroscopy, enabling the development of a wide range of novel measurement technologies for the detection of trace levels of chemical and nuclear materials.

Agenson KO, Oh JI, Urase T. Retention of a wide variety of organic pollutants by different nanofiltration/reverse osmosis membranes: controlling parameters of process. Journal of Membrane Science 2003;225(1-2):91-103.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-49SWCKM-1&_user=10&_handle=B-WA-A-A-WW-MsSAYZA-UUW-AUEVCDVEEC-AUEWACCDEC-CZUBABBYB-WW-U&_fmt=summary&_coverDate=11%2F01%2F2003&_rdoc=8&_orig=browse&_srch=%23toc%235257%232003%23997749998%23469084!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=2017fe9a9313a81f6694b8caae0a6703
Keywords: Nanofiltration/ Organic pollutants/ Endocrine disrupting chemicals/ Sieving/ Physicochemical interactions
Abstract: Retention of a wide variety of organic pollutants including endocrine disrupting chemicals, plastic additives and low molecular weight priority pollutants from aqueous solutions by the use of many recent type nanofiltration (NF)/reverse osmosis (RO) membranes was investigated. Retention was dependent on membrane type and solute size though other factors such as solute–membrane interaction influenced the result. At low pressure of 0.3 MPa, the high desalting membranes effectively retained virtually all of the semi-volatile organic compounds (SVOCs) at greater than 90% but not the volatile organic compounds (VOCs). The low desalting membrane UTC60, rejected most of the VOCs at lower than 20%. The molecular weight of solutes was useful but the molecular width was a more appropriate parameter for describing the sieving retention by membranes. A multi-linear regression analysis gave the best fitting when the retention was correlated with molecular width, molecular length and logarithm of octonol–water partition coefficient of the target solutes. The prediction indicated that a higher retention will be obtained for a more hydrophobic molecule with a larger width and length.

Ahmad A, Mukherjee P, Senapati S, Mandal D, Khan MI, Kumar R, et al. Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium oxysporum*. Colloids and Surfaces B: Biointerfaces 2003;28(4):313-8.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFS-47PGCDW-2&_coverDate=05%2F01%2F2003&_alid=197933536&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5234&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=90fee7e8ce46603de93c1697cba50845

Keywords: Nanoparticles/ Biosynthesis/ Fungi/ Enzymes/ Hydrosols

Abstract: The development of reliable, eco-friendly processes for the synthesis of nanomaterials is an important aspect of nanotechnology today. One approach that shows immense potential is based on the biosynthesis of nanoparticles using biological micro-organisms such as bacteria. In this laboratory, we have concentrated on the use of fungi in the intracellular production of metal nanoparticles. As part of our investigation, we have observed that aqueous silver ions when exposed to the fungus *Fusarium oxysporum* are reduced in solution, thereby leading to the formation of an extremely stable silver hydrosol. The silver nanoparticles are in the range of 5–15 nm in dimensions and are stabilized in solution by proteins secreted by the fungus. It is believed that the reduction of the metal ions occurs by an enzymatic process, thus creating the possibility of developing a rational, fungal-based method for the synthesis of nanomaterials over a range of chemical compositions, which is currently not possible by other microbe-based methods.

Akoum O, Jaffrin MY, Ding LH, Rappart M. Treatment of dairy process waters using a vibrating filtration system and NF and RO membranes. Journal of Membrane Science 2004;235(1-2):111-22.

Keywords: Dynamic filtration/ VSEP/ Dairy effluent/ Nanofiltration/ Reverse osmosis

Abstract: The permeate flux and chemical oxygen demand (COD) reduction were investigated in dairy process waters using a vibratory shear-enhanced filtration system (VSEP) and various nanofiltration (NF) and reverse osmosis (RO) membranes. Dairy process waters were simulated by UHT skim milk diluted 1:3 to obtain an initial COD of 36 000 mg O_2 L^{-1}. In NF the highest permeate flux (270 L h^{-1} m^{-2} at 4 MPa, 45 °C and initial concentration) was obtained with a Filmtec membrane which yielded also the highest permeate COD (94 mg O_2 L^{-1}). The best compromise was obtained with a Desal 5 DK membrane which yielded a COD of 36 mg O_2 L^{-1} and a flux of 240 L h^{-1} m^{-2} under same conditions. In concentration tests, the permeate flux decreased with increasing volume reduction ratio (VRR) to reach 25 L h^{-1} m^{-2} for the 5 DK membrane at VRR = 7 while permeate COD soared to 1050 mg O_2 L^{-1}. A comparison with published data collected using a spiral module and same test fluid at 25 °C and 1.9 MPa showed a definite advantage for the VSEP equipped with the same 5 DL membrane and operated at same pressure and temperature. The VSEP yielded a permeate COD of 24 mg O_2 L^{-1} versus 128 mg O_2 L^{-1} for the spiral module together with a higher flux 71 L h^{-1} m^{-2} versus 24 L h^{-1} m^{-2}. The better performance of the VSEP can be attributed to its higher membrane shear rate which reduces lactose concentration at membrane and its transmission. As expected, permeate COD was further reduced to less than 22 mg O_2 L^{-1} at a VRR of 5.6 by using an RO membrane.

Alborzfar M, Jonsson G, Gron C. Removal of natural organic matter from two types of humic ground waters by nanofiltration. Water Research 1998;32(10):2983-94.

Keywords: Water filtration/ Groundwater pollution, Denmark/ Organic matter
Abstract: The efficiency of nanofiltration (NF) for producing drinking water from two types of humic groundwaters was examined on a pilot scale in Denmark. The effects of changes in NF product parameters and of water types on product quality and membrane productivity were also studied.

Allgeier SC, Summers RS. Evaluating NF for DBP control with the RBSMT. American Water Works Association Journal 1995 Mar;87:87-99.
Keywords: Disinfection and disinfectants, by-products/ Waterworks, experimental plants/ Membrane separation
Abstract: Part of a special section on membrane technology. Four conventionally treated surface waters and an untreated groundwater were investigated using a rapid bench-scale membrane test (RBSMT). The RBSMT was designed to measure critical aspects of full-scale systems, especially water flux and solute rejection, while maintaining the benefits of a bench-scale system. The RBSMT consisted of a tangential-flow flat-sheet cell with recycle, which represented a differential element of a full-scale spiral-wound nanofiltration element treating the average feed for a full-scale system. The operational parameters incorporated in the RBSMT included recovery, pressure, crossflow velocity, and hydraulic conditions. After nanofiltration, all of the waters tested were found to meet the Stage 1 requirements of the Disinfectants/Disinfection By-product rule. The four surface waters were found to satisfy Stage 2 requirements.

Alspach B, Watson I. Sea change. Civil Engineering (American Society of Civil Engineers) 2004;74(2):70-5.
Keywords: Water supply, United States/ Saline water conversion
Abstract: The writer discusses technological developments in seawater desalination. Seawater desalination has become a well-established water treatment practice in some areas of the world, but remains rare in the U.S due to the high cost. Concerns have also centered on the damaging brine discharge from desalination plants. However, the practice of collocating seawater reverse osmosis (SWRO) facilities with existing water-cooled coastal power plants directly addresses some of the most pressing concerns over desalination. In the future, cost reductions should make it possible for more utilities with water-cooled coastal power plants to regard these installations as sites for SWRO facilities. With more than 50 percent of the U.S. population residing in coastal areas, the finite supply of freshwater sources in these areas will certainly prove insufficient and seawater desalination will eventually become a realistic alternative.

Anonymous. Chemistry yields DNA fossils [Web Page]. 2004 Aug 4; Available at http://www.technologyreview.com/articles/04/08/rnb_080404.asp?trk=nl.
Abstract: One way to make things at the molecular scale is to use DNA, which can be coaxed to self-assemble into various structures. The trick is getting other useful materials like inorganics into the mix. Researchers from Kyushu University in Japan have used bacterial DNA as a matrix for making structures from silicates, which are materials like glass and concrete that contain silicon. The technique could be used to make nanoscale containers, wires, patterns, and chemical catalysts.

Anonymous. Customizable self generating nanotubes offer designer properties. Chemical Engineering Progress 2002;98(12):18-9.

Keywords: Nanotubes, synthesis/ Carbon nanotubes

Abstract: An overview of four areas of current research and development in the field of carbon nanotubes and porous sorbents is presented. First, a novel way to create multiple species of nanotubes with unprecedented physical and chemical properties is presented. Second, it is reported that diffusion rates of light gases inside single-walled carbon nanotubes are several orders of magnitude higher than in microporous zeolites or polymers with similar pore sizes. Third, a new technique that removes mercury from flue gas by adsorption/absorption onto a thermally activated sorbent produced in situ is reported. Fourth, a dramatic increase in the efficiency of microfluidic devices for extracting compounds from air, soil, and water samples by combining two existing technologies—microfluidic chips and monolithic porous polymers—is reported.

Anonymous. Desalination facility tests three membrane technologies. Civil Engineering (American Society of Civil Engineers) 1999;69(3):16.

Keywords: Saline water conversion

Abstract: A new water-treatment facility in Oxnard, California, promises to vastly improve drinking water while providing engineers with data on desalination technologies. The $14 million reclamation facility uses nanofiltration, reverse osmosis, and electrodialysis reversal to remove high mineral concentrations from groundwater. The plant, which began operating in December 1998, will double as a research facility to compare the performances of the technologies.

Anonymous. Nanoporous Polymers for Water Purification [Web Page]. 2004; Available at http://www-emtd.lanl.gov/TD/Remediation/NanoPorousPolymer.html.

Abstract: The removal of organic materials from water is an important industrial and municipal problem. We have developed a completely new class of nanoporous polymeric materials that can be used to reduce the concentration of common organic contaminants in water to parts-per-trillion levels. The binding between organic contaminants and the nanoporous polymer is 100,000 times greater than the binding between organic contaminants and activated carbon. These materials are based on molecular building blocks known as cyclodextrins. Cyclodextrins have a well-defined cylindrical cavity. The Los Alamos technique of polymerizing cyclodextrins converts the cylindrical cavity into a nanometer-sized cage that traps organic molecules. A simple alcohol rinsing releases the collected contaminates from the polymer, enabling workers to use the material again and again. These polymers can be fabricated into granular particles, powders, and optical quality films, making them compatible with most water treatment technologies. Furthermore, unlike conventional technologies such as activated carbon and zeolites, these materials work effectively in both water and air.

Applications:

- Purification of municipal water supply
- Recycling and reuse of industrial waste water in a continuous on-line process
- Clean up of oil or organic chemical spills
- In situ remediation of hazardous organics in underground water
- Clean up of organic explosives

Anonymous. Nanoscale iron to clean up?: Metals and alloys. Materials Today 2003;6(12):10.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6X1J-4B6SBTD-B&_coverDate=12%2F31%2F2003&_alid=197908977&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=7244&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=819293067c52dd622f31fd59c8c40096

Abstract: Nanoscale Fe particles represent a new generation of environmental remediation technologies that could quickly and cost-effectively clean up contaminated soil and groundwater.

Anonymous. Nanotubes make fluid filter [Web Page]. 2004 Aug 24; Available at http://www.technologyreview.com/articles/04/08/rnb_082404.asp?trk=nl.

Abstract: Researchers from Rensselaer Polytechnic Institute have devised a simple and inexpensive way to manufacture very fine filters from carbon nanotubes. Carbon nanotubes are rolled-up sheets of carbon atoms that can be narrower than 1 nanometer, which is about the span of 10 hydrogen atoms. The researchers showed that the filters could be used to separate heavy hydrocarbons from petroleum and bacteria and viruses from water. Filtering heavy hydrocarbons is a crucial step in distilling crude oil. The filters are capable of filtering viruses as small as 25 nanometers, including the especially tiny polio virus, according to the researchers. The researchers fabricated well-organized filtration tubes as long as five centimeters that consist solely of nanotubes. They made the filter by using argon gas to force a benzene-ferrocene solution through a spray nozzle into a quartz tube, then heating the solution to 900 degrees Celsius. The formation of large carbon nanotube structures is dependent on the size of the spray nozzle and the flow rate of the solution, according to the researchers. The process is inexpensive, relatively easy, and allows for specific-size pores, making for specific types of filters, according to the researchers. Because carbon nanotubes are very strong and heat-resistant, the filters can be cleaned using heat and ultrasound and reused. The researchers' method could be used to make practical filters within five years, according to the researchers. The work appeared in the August 1, 2004 issue of Nature Materials.

Anonymous. Town beats shortage with treated pond water. American City and County 2002;117(1):27.

Keywords: Water purification/ Ponds/ Water supply, Maine

Abstract: A dual water-treatment system in Stonington, Maine, was developed to expand the community water supply. A new system went online in August 2001 that is designed to alleviate summer shortages. The new facility treats water from the 21-acre Burntland pond. The facility, designed, installed, and operated by Ionics of Watertown, Massachusetts, uses ozonation, ultrafiltration, and nanofiltration to treat the high-organic-content acid pond water.

Arabatzis IM, Antonaraki S, Stergiopoulos T, Hiskia A, Papaconstantinou E, Bernard MC, et al. Preparation, characterization and photocatalytic activity of nanocrystalline thin film TiO_2 catalysts towards 3,5-dichlorophenol degradation . Journal of Photochemistry and Photobiology A: Chemistry 2002;149(1-3):237-45.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGY-44V1X5T-1&_user=10&_handle=B-WA-A-W-BA-MsSAYVA-UUW-AAUEEWWBEE-AAUDCUBAEE-YEVUDWVZW-BA-U&_fmt=summary&_coverDate=06%2F28%2F2002&_rdoc=28&_orig=browse&_srch=%23toc%235267%232002%23998509998%23321327!&_cdi=5267&view=c&_acct=C000050221

&_version=1&_urlVersion=0&_userid=10&md5=d44cece6ff254c091b6377e53c00e4bc

Keywords: Surface properties/ TiO_2 films/ Dip coating/ Doctor blade/ 3,5-Dichlorophenol/ Photocatalysis

Abstract: Both opaque and transparent TiO_2 nanocrystalline thin films were developed on glass substrates by applying dip coating and doctor-blade deposition techniques, using titanium(IV) butoxide and Degussa P25 TiO_2 powder as precursor and starting material, respectively. Atomic force microscopy (AFM) and scanning electron microscopy (SEM) evaluated the surface characteristics of the films. Results on their structure and crystallinity were obtained by means of X-ray diffraction and Raman spectroscopy. The catalytic activity of the films towards photodegradation of 3,5-dichlorophenol (3,5-DCP) pollutant was examined and their efficiency was compared to that of the TiO_2 powder (slurry) suspensions. Pseudo-first-order photodegradation kinetics were observed and the reaction constants were determined. It has been shown that the film photocatalysts can efficiently decompose the pollutant, although relatively higher decomposition rates were observed with the commercial starting powder. Differences in the film efficiencies can be attributed to differences in their grain size, surface roughness and fractal parameters. No altering on the doctor-blade films surface characteristics was observed for several hours of cyclic operation during which their photocatalytic efficiency remained remarkably stable.

Balannec B, Gésan-Guiziou G, Chaufer B, Rabiller-Baudry M, Daufin G. Treatment of dairy process waters by membrane operations for water reuse and milk constituents concentration. Desalination 2002;147(1-3):89-94.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-46WM7WP-86&_coverDate=09%2F10%2F2002&_alid=193753364&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=aff2e94633ea0e52f7b6adb6966d08cf

Keywords: Effluent/ Milk/ Process water / Nanofiltration/ Reverse osmosis/ Water reuse

Abstract: In the dairy industry non-accidental losses of milk or dairy products to sewer amount to 1–3% of the total milk processed. These significantly contribute to the 0.5–6.0 g COD/L of end-of-pipe wastewater. The major part of this polluting charge originates from starting, interrupting, and stopping dairy plant procedures, where milk products are diluted with water and discharged to a purification station or collected to be spread on land. The very few works, that have been dedicated to the treatment of the so-called process waters (flushing waters, first rinse waters or "white waters"), show that nanofiltration (NF) or reverse osmosis (RO) is adequate for the concentration of milk components. The present work reports NF and RO performances (permeate flux, milk components rejection) of an effluent model solution (diluted skimmed milk). Performances of eight NF and RO membranes were compared by dead-end filtration. Crossflow experiments with NF and RO spiral-wound membranes confirm the results obtained by dead-end filtration. The results showed that one single membrane operation allowed the milk constituents to be concentrated in the retentate but reusable water of composition complying with the standard of purified water from process water was not reached. A finishing step (RO membrane, other) is needed for the production of reusable water.

Barsema JN, Balster J, Jordan V, van der Vegt NFA, Wessling M. Functionalized carbon molecular sieve membranes containing Ag nanoclusters. Journal of Membrane Science 2003;219(1-

2):47-57.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-48XJNK8-1&_user=10&_handle=B-WA-A-A-AZ-MsSAYVA-UUW-AUEVCZVEWZ-AUEWAVCDWZ-CZUWCEEUA-AZ-U&_fmt=summary&_coverDate=07%2F15%2F2003&_rdoc=4&_orig=browse&_srch=%23toc%235257%232003%23997809998%23441051!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5e98457dfdad865ddab63eab456fb436
Keywords: Carbon molecular sieve/ Ag/ Nanocluster/ Gas separation/ Functionalized membrane
Abstract: In carbon molecular sieve (CMS) membranes, the separation of O_2 and N_2 is primarily based on the difference in size between the gas molecules. To enhance the separation properties of these CMS membranes it is necessary to functionalize the carbon matrix with materials that show a high affinity to one of the permeating gas species. Adding Ag nanoclusters increases the selectivity of O_2 over N_2 by a factor 1.6 compared to a non-functionalized CMS membrane prepared by the same pyrolysis procedure. We have analyzed the structure of Ag nanocluster ($d_{\mathrm{cluster}} \sim 50$ nm) containing membranes produced from different Ag sources, $AgNO_3$ and AgAc, and with different Ag content (0, 6, 25, and 40 wt.%). By measuring the pure gas permeabilities of He, CO_2, O_2, and N_2 we have determined the effect of Ag nanoclusters in the carbon matrix, concluding that in the case of pure gases, the Ag nanoclusters act primarily as a spacer at pyrolysis end temperatures up to 600 C, increasing the O_2 permeability by a factor of 2.4. However, they enhance the separation of O_2 over N_2 at higher pyrolysis end temperatures (700 and 800 C). It was shown that the build up of an Ag layer on the surface of the membrane reduces the permeability, but does not affect the selectivity.

Berg P, Hagmeyer G, Gimbel R. Removal of pesticides and other micropollutants by nanofiltration. Desalination 1997;113(2-3):205-8.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-3SFNV8K-G&_coverDate=11%2F30%2F1997&_alid=196212464&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=31408f871acd31e85ddb5bae0fb470bd
Keywords: Nanofiltration/ Pesticides/ Trace organics/ Drinking water
Abstract: Mainly in the US nanofiltration (NF) is used for water softening and removal of natural organic matter regarding disinfection by-products. Because it is possible to substitute several conventional treatment steps, NF can also be economically competitive. A relatively high content of organic substances as well as pesticides are present in Elbe River water. Furthermore, the bank filtrate is mixed with hard groundwater which contains a high amount of sulphate. NF was tested to treat the bank filtrate, mainly to investigate the rejection of trace organics like pesticides using NF. It was found that the rejection of uncharged trace organics is mainly influenced by steric hindrances while the high rejection of polar trace organics can be explained by electrostatic interactions with the charged membrane surface. Because the dissociation of polar organics and the surface charge of the membrane depend on pH value, the rejection increases with increased pH. At neutral pH values which are normal in the drinking water treatment, a nearly complete rejection of polar organics was observed.

Braeken L, Van der Bruggen B, Vandecasteele C. Regeneration of brewery waste water using nanofiltration . Water Research 2004;38(13):3075-82.
URL: http://dx.doi.org/10.1016/j.watres.2004.03.028
Keywords: Nanofiltration/ Waste water/ Reuse;/ Retention/ Flux decline
Abstract: The brewing industry is a large consumer of groundwater for brewing, rinsing and cooling purposes. As regulations become more and more stringent and the cost of water increases, water recycling gains interest. This paper investigates the possibilities of nanofiltration for the treatment of brewery waste water streams in view of recycling. Four different water streams (waste water after biological treatment, bottle rinsing water, rinsing water of the brewing room and rinsing water of the bright beer reservoir) were filtered with four different nanofiltration membranes (UTC-20, UTC-60, Desal-HL-51 and Desal-5-DK). The results for the biologically treated waste water were the most promising. For the other streams, rejection of organics was insufficient to obtain the required quality, mainly due to the high concentrations of organics such as ethanol in the feed water. Over the periods considered (3 h) only moderate flux decline (10–40%) was observed for most membranes and feed solutions. For Desal-5-DK at high pH, an increase of the flux was observed.

Brennan MB. Waterworks. Chemical and Engineering News 2001;79(15):32-8.
Keywords: Water purification, reverse osmosis process/ Waterworks, design/ Saline water conversion
Abstract: Research in the area of advanced water-treatment technologies is accelerating, and the use of these technologies in the purification process is growing. Advanced water-treatment technologies that can purify saltwater, brackish water, surface water, or wastewater are being used to preserve aquifers while meeting municipal water demands. The research that is being undertaken into the use of such membrane-based filtration systems as reverse osmosis, and micro-, ultra-, and nanofiltration and a new process that involves disinfecting water with ultraviolet light is discussed.

Campas M, O'Sullivan C. Layer-by-layer biomolecular assemblies for enzyme sensors, immunosensing and nano-architectures. Analytical Letters 2003;36(12):2551-69.
URL: http://www.dekker.com/servlet/product/DOI/101081AL120024632
Keywords: Layer-by-layer/ Biosensor/ Biocatalysis/ Immunosensing/ Nanoparticle/ Nanoarchitecture
Abstract: Layer-by-Layer (LbL) assemblies are multi-modular constructions created on solid substrate mainly via electrostatic interactions between polyanions and polycations. The LbL approach can be used for the inter-layer immobilization of biomolecules with enhanced properties for biocatalytic and immunosensing applications, and to create nanoarchitectures for drug encapsulation and release systems. This LbL approach is generic and provides a strategy to rationally design the properties of immobilized films. The following review reports on the LbL state-of-the-art, characterization techniques, applications in biosensing and nanoarchitectures.

Capelle N, Moulin P, Charbit F, Gallo R. Purification of heterocyclic drug derivatives from concentrated saline solution by nanofiltration. Journal of Membrane Science 2002;196(1):125-41.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-449TSHB-

D&_coverDate=02%2F15%2F2002&_alid=195996912&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d94b06fde373faedb70f5f064d05786b
Keywords: Nanofiltration/ Pharmaceutical application/ Saline solution/ High concentration/ Organic-inorganic separation
Abstract: We purified by nanofiltration a highly concentrated (11–17% w/v) mixture of organic/inorganic salts, generated from pharmaceutical industries to separate mineral salts (sodium acetate and sodium chloride) from heteroaromatic quaternary ammonium chloride salts soluble in water. The process, using a spiral-wound nanofiltration module, consists of a diafiltration step until the minerals salts were almost completely eliminated followed by a concentration step. To optimise the process, three variables were studied: transmembrane pressure (TMP), velocity, pH. The retention of organic salts was higher than 99.5%. The higher the molecular weight, the higher the retention factor. The flux and rejection show that it is not necessary to increase transmembrane pressure to obtain the faster salt elimination. The best result is obtained with the highest velocity which reduces membrane fouling. Changing pH from 3 to 4.5 had little effect on permeate flow; however, the purification of a solution at pH 5.4 is difficult because of a very low permeate flow. Less than 2% of the ammonium salts entrapped in the membrane were lost. Under optimal experimental conditions, more than 99% of mineral salts can be eliminated.

Carbonaro A, Walczak R, Mario Calderale P, Ferraric M. Nano-pore silicon membrane characterization by diffusion and electrical resistance. Journal of Membrane Science 2004;242:[In press].
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CYWNBG-3&_user=10&_handle=B-WA-A-B-BB-MsSAYWA-UUW-AUEVZWEUUE-AUEWWUEYUE-CZUZECZCU-BB-U&_fmt=summary&_coverDate=07%2F29%2F2004&_rdoc=7&_orig=browse&_srch=%23toc%235257%239999%23999999999%2399999!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=092db0a97e0c5bb1cc58f0da7e879f29
Keywords: Silicon membrane/ Quality control (QC)/ Glucose diffusion/ Electrical conductance/ Membrane pore area
Abstract: An inexpensive, non destructive and rapid quality control (QC) procedure for nano-pore silicon membranes is presented. Membranes with different pore sizes were characterized in terms of glucose diffusion and by electrical resistance measurements. Electrical resistance results versus membrane pore size allowed to trace a reference curve to be used to verify the machining process. Diffusion was plotted versus conductance data. An experimental linear relationship was determined, which allows to predict the membrane diffusion properties without running destructive diffusion tests.

Cartier S, Theoleyre MA, Decloux M. Treatment of sugar decolorizing resin regeneration waste using nanofiltration. Desalination 1997;113(1):7-17.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-3SDKT9Y-B&_coverDate=11%2F30%2F1997&_alid=196216009&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ec215847592c677bc90057fc5eef0875
Keywords: Nanofiltration; Ion exchange resins; Regeneration effluent
Abstract: In the sugar industry, ion-exchange resins have a problem with regeneration waste

disposal since the regeneration effluent contains a high concentration of sodium chloride and colored organics. In the present work the recovery and recycling of waste brine previously used for decolorizing sugar liquor has been investigated using cost-effective organic spiral-wound nanofiltration membranes. A 74% reduction in salt consumption and an 89% reduction in water consumption were achieved in the batch configuration at VCF 9.

Chambers Vick R. Lab offers partnerships for wastewater treatment. Pollution Engineering 1998;30(8):23-4.
Keywords: Los Alamos National Laboratory/ Public-private sector cooperation/ Water purification
Abstract: Los Alamos National Laboratory, New Mexico, is offering partnerships with industry for wastewater treatment. The lab is involved in two research topics that will attract industry: the treatment of nitrate waste by using transition metals and catalysts to reduce nitrates to nitrites and then to nitrogen gas via a novel non-thermal and non-biological method and the use of nanoporous polymers for municipal water purification.

Chellam S, Krasner SW. Disinfection byproduct relationships and speciation in chlorinated nanofiltered waters. Environmental Science and Technology 2001;35(19):3988-99.
Keywords: Water filtration/ Water purification, chlorination/ Disinfection and disinfectants, by-products
Abstract: The formation and speciation of disinfection byproducts (DBPs) resulting from chlorination of nanofilter permeates obtained from various source water locations and membrane types are examined. Specific ultraviolet absorbance and bromide utilization are shown to decrease following nanofiltration. Both dissolved organic carbon (DOC) concentration and ultraviolet absorbance at 254 nm were found to correlate strongly with trihalomethane (THM), haloacetic acid (HAA), and total organic halide (TOX) concentrations in chlorinated nanofilter permeates, suggesting that they can be employed as surrogates for DBPs in nanofiltered waters. Because smooth curves were obtained for individual THM and HAA species as well as bromine and chlorine incorporation into THMs and HAAs as a function of Br-/DOC molar ratio, it is likely that mole fractions of these DBPs are more strongly influenced by chlorination conditions, Br^-, and DOC concentrations than NOM source and membrane type. Mole fractions of mono-, di-, and trihalogenated HAAs were found to be independent of Br^-/DOC. Even at a very low Br^-/DOC of 2.9 mM/mM, the mixed bromochloro- and tribromoacetic acids constituted 20% of total HAAs on a molar basis. This increased to ~50% as Br^-/DOC increased to ~25 mM/mM or more, proving that a large fraction of HAAs may not be covered under existing federal regulations. Total THM and HAA9 concentrations decreased in permeate waters with increasing Br^-/DOC suggesting that nanofilter permeates are limited with respect to DBP precursors. Reprinted by permission of the publisher.

Chen SS, Taylor JS, Mulford LA, Norris CD. Influences of molecular weight, molecular size, flux, and recovery for aromatic pesticide removal by nanofiltration membranes. Desalination 2004;160(2):103-11.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-4BVBRPT-1&_coverDate=01%2F15%2F2004&_alid=196200562&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid

=10&md5=a26bd6f64bfaa4b8765aee50af34e49d
Keywords: Aromatic pesticide/ Nanofiltration/ Molecular weight/ Flux/ Recovery/ Diffusion control
Abstract: Eleven aromatic pesticides were used for a removal study using a 4040 spiral-wound polyamide nanofiltration (NF) membrane. The influences of molecular weight, molecular size (length and width), flux, and recovery were studied. The molecular weights of these pesticides are from 198 Da to 286 Da. Molecular sizes were determined by theoretical calculation for their length and width by "Hyperchem" based on their structures and orientation. Furthermore, the study held constant for two operated recoveries and fluxes to determine their effects. The results showed that the NF membrane can remove pesticides from 46% to 100% based on their molecular weights, lengths, fluxes and recoveries. The rejections were increased as the molecular weight increased, and a sharp increase to complete rejection (100%) was observed around MW 200 Da. Therefore, a molecular weight cut-off (MWC) of 200 Da can be determined for this membrane from this result. In addition, the results showed the molecular length was more significant than molecular width for these pesticides. The rejections were not only dependent on molecular weight and length, but also on operational flux and recovery. For a particular pesticide in the two operational fluxes and recoveries, the highest percent rejections occurred on high flux and low recovery, and lowest percent rejection occurred on low flux and high recovery, which would indicate the basic diffusion control theory.

Choe S, Chang YY, Hwang KY, Khim J. Kinetics of reductive denitrification by nanoscale zero-valent iron. Chemosphere 2000;41(8):1307-11.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V74-40D60YB-10&_coverDate=10%2F31%2F2000&_alid=199676463&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5832&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=8eda8c1cbe40bd8baaebfb78b20c4c8d
Keywords: Denitrification/ Nanoscale Fe^0/ Pseudo first-order/ Iron content/ Mixing intensity
Abstract: Zero-valent iron powder (Fe^0) has been determined to be potentially useful for the removal of nitrate in the water environment. This research is aimed at subjecting the kinetics of denitrification by nanoscale Fe^0 to an analysis of factors affecting the chemical denitrification of nitrate. Nanoscale iron particles with a diameter in the range of 1–100 nm, which are characterized by the large BET specific surface area to mass ratio (31.4 m^2/g), removed mostly 50, 100, 200, and 400 mg/L of nitrate within a period of 30 min with little intermediates. Compared with microscale (75–150 µm) Fe^0, endproduct is not ammonia but N_2 gas. Kinetics analysis from batch studies revealed that the denitrification reaction with nanoscale Fe^0 appeared to be a pseudo first-order with respect to substrate and the observed reaction rate constant (k_{obs}) varied with iron content at a relatively low degree of application. The effects of mixing intensity (rpm) on the denitrification rate suggest that the denitrification appears to be coupled with oxidative dissolution of iron through a largely mass-transport-limited surface reaction (< 40 rpm).

Choe S, Lee SH, Chang YY, Hwang KY, Khim J. Rapid reductive destruction of hazardous organic compounds by nanoscale Fe^0. Chemosphere 2000;42(4):367-72.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V74-41JM945-5&_coverDate=02%2F28%2F2001&_alid=199323841&_rdoc=1&_fmt=&_orig=search&_qd

=1&_cdi=5832&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=2528f2d1b30480dd1eee033ddd18c855

Keywords: Fe^0-mediated reductive destruction/ Chlorinated organic compounds/ Nitroaromatic compounds/ Reductive degradation/ Nanoscale Fe^0

Abstract: Fe^0-mediated reductive destruction of hazardous organic compounds such as chlorinated organic compounds (COCs) and nitroaromatic compounds (NACs) in the aqueous phase is one of the latest innovative technologies. In this paper, rapid reductive degradation of COCs and NACs by synthesized nanoscale Fe^0 in anaerobic batch systems was presented. The nanoscale Fe^0, characterized by high specific surface area and high reactivity, rapidly transformed trichloroethylene (TCE), chloroform (CF), nitrobenzene (NB), nitrotoluene (NT), dinitrobenzene (DNB) and dinitrotoluene (DNT) under ambient conditions, which results in complete disappearance of the parent compounds from the aqueous phase within a few minutes. GC analysis reported that the main products of the dechlorination of TCE and CF were ethane and methane as well as that most of the nitro groups in NACs were reductively transformed to amine groups. These results suggest that the rapid reductive destruction by nanoscale Fe^0 is potentially a viable in situ or aboveground treatment of groundwater contaminated with hazardous organic compounds including COCs and NACs.

Cortalezzi MM, Rose J, Wells GF, Bottero JY, Barron AR, Wiesner MR. Ceramic membranes derived from ferroxane nanoparticles: A new route for the fabrication of iron oxide ultrafiltration membranes. Journal of Membrane Science 2003;227(1-2):207-17.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4B0SVRG-3&_user=10&_handle=B-WA-A-A-WB-MsSAYVW-UUA-AUEVCDVDDE-AUEWACCCDE-CZUBAWUUE-WB-U&_fmt=summary&_coverDate=12%2F15%2F2003&_rdoc=16&_orig=browse&_srch=%23toc%235257%232003%23997729998%23472046!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=11ab7464551443f9d8547e54ee53af7b

Keywords: Inorganic membranes/ Ceramic membranes/ Ultrafiltration/ Membrane preparation/ Structure

Abstract: Ferroxane nanoparticles, obtained from reaction of lepidocrocite (FeOOH) and acetic acid at room temperature, were applied to the fabrication of ceramic membranes. The size of the nanoparticles and the kinetics of the reaction were investigated. Ferroxane-derived membranes were prepared and characterized by nitrogen adsorption/desorption isotherms, scanning electron microscopy (SEM), and atomic force microscopy (AFM). Permeability and molecular weight cut off measurements were conducted on asymmetric ferroxane-derived membranes. The average pore size was determined to be 24.11 nm and the BET surface area was 75.6 m^2/g. Permeability was measured for membranes with one, two, and three coatings, to determine the effect of thickness of the ferroxane layer on the membrane hydraulic resistance. The MWCO of the ferroxane-derived membranes was 150,000 Da, which falls in the ultra-filtration range.

Cyna B, Chagneau G, Bablon G, Tanghe N. Two years of nanofiltration at the Méry-sur-Oise plant, France. Desalination 2002;147(1-3):69-75.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-46WM7WP-83&_user=10&_handle=B-WA-A-A-DZ-MsSAYWW-UUW-AUEZUUYAAD-AUEBCYYEAD-CYZUCVDEE-DZ-

U&_fmt=summary&_coverDate=09%2F10%2F2002&_rdoc=12&_orig=browse&_srch=%23toc%235238%232002%23998529998%23345095!&_cdi=5238&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=dafc0d10ef5c8f2d8653cc00526cfb15

Keywords: Méry-sur-Oise/ Nanofiltration/ Membranes/ Clogging/ Organic matter/ Monitoring

Abstract: For more than two years, the extension of the Méry-sur-Oise plant has been producing water from the river Oise, using nanofiltration technology for a production capacity of 140,000 m^3/d, a world premiere on surface water. After presenting the reasons for the nanofiltration choice and the treatment processes, we'll analyze the performances of the plant at its different stages: pretreatment upstream, nanofiltration itself and water quality in the distribution system. Performances are very satisfactory, especially for the two main objectives: elimination of organic matters and of pesticides. The consumers are also satisfied with the reduction of the chlorine taste (chlorine rate has been diminished by factor 2) and of calcium concentration. During these two years of operation, several tunings have been conducted to optimize the process, such as active pretreatment parameters and membrane cleaning process. The whole plant is automated and the process control is performing very efficiently. An automatic piloting system has been developed and has been operative since the beginning of 2002. So far, operation additional costs, compared to a traditional plant with refining using ozone and carbon, are lower than foreseen. Nanofiltration in Méry-sur-Oise turns out to have been the right choice and is a complete success.

DeFriend KA, Wiesner MR, Barron AR. Alumina and aluminate ultrafiltration membranes derived from alumina nanoparticles. Journal of Membrane Science 2003;224(1-2):11-28.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-49HXFVT-1&_user=10&_handle=B-WA-A-A-WW-MsSAYWA-UUW-AUEVCDCUVE-AUEWACCYVE-CZUBABDCW-WW-U&_fmt=summary&_coverDate=10%2F15%2F2003&_rdoc=3&_orig=browse&_srch=%23toc%235257%232003%23997759998%23464412!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=4f8afcb903bd2d1aa2efa09797756bea

Keywords: Ceramic membranes/ Nanoparticle/ Ultrafiltration/ Synthetic dyes/ Chemical functionalization

Abstract: The fabrication of alumina ultrafiltration membranes using acetic acid surface stabilized alumina nanoparticles (A-alumoxanes) has been investigated. The pore size, pore size distribution, and molecular weight cut-off (MWCO) parameters of the resulting membranes are highly dependant on the uniformity of the nanoparticle precursor, which is a function of the reaction time and reaction pH during their synthesis. By the control over the alumina nanoparticles, a significant improvement of the membrane performance is observed over our prior results. The new alumoxane-derived membranes have a molecular weight cut-off in the range of <1000 g mol^{-1}, and show good selectivity to a range of synthetic dyes. Further control over selectivity and flux of these ceramic membranes may be obtained by the use of doped alumina nanoparticles (Fe, Mn, and La) that result in the formation of the appropriate aluminate membranes. Of these, $LaAlO_3$ shows the most promising results, with an increase in selectivity and increased flux as compared to the alumina analogue. Retention coefficients and flux values may also be altered by the chemical functionalization of the interior surface of the membranes by reacting the alumina surface with carboxylic acids.

DeMarco MJ, SenGupta AK, Greenleaf JE. Arsenic removal using a polymeric/inorganic hybrid sorbent. Water Research 2003;37(1):164-76.

Keywords: Water purification, arsenic removal/ Water purification, ion-exchange process/ Groundwater pollution/ Hydrated Fe oxide (HFO) nanoparticles

Abstract: A fixed-bed sorption process can be very effective in removing trace concentrations of arsenic from contaminated groundwater provided: the sorbent is very selective toward both As(III) and As(V) species; the influent and treated water do not warrant any additional pre- or post- treatment; pH and composition of the raw water with respect to other electrolytes remain unchanged besides arsenic removal; and the sorbent is durable with excellent attrition resistance properties. In addition, the sorbent should be amenable to efficient regeneration for multiple reuse. This study reports the results of an extensive investigation pertaining to arsenic removal properties of a polymeric/inorganic hybrid sorbent. Each hybrid sorbent particle is essentially a spherical macroporous cation exchanger bead within which agglomerates of nanoscale hydrated Fe oxide (HFO) particles have been uniformly and irreversibly dispersed using a simple chemical-thermal treatment. The new sorbent, referred to as hybrid ion exchanger or HIX, combines excellent mechanical and hydraulic properties of spherical polymeric beads with selective As(III) and As(V) sorption properties of HFO nanoparticles at circum-neutral pH. Comparison of the results of fixed-bed column runs between the new sorbent and the polymeric anion exchanger confirmed that both As(V) and As(III) were removed very selectively with HIX. Equally important, no pH adjustment, pre- or post-treatment was warranted. Besides the absence of arsenic, the treated water composition was identical to that of influent water. HIX was amenable to efficient in situ regeneration with caustic soda and could subsequently be brought into service following a short rinse with carbon dioxide sparged water. During fixed-bed column runs, intraparticle diffusion was identified as the primary rate-limiting step for both As(III) and As(V) sorption. Repeated use of the same HIX particles during various laboratory investigations provided strong evidence that the new sorbent possesses excellent attrition r esistance properties and retains its arsenic removal capacity over cycles. Copyright (c) 2002 Elsevier Science Ltd.

Devitt EC, Wiesner MR. Dialysis investigations of atrazine-organic matter interactions and the role of a divalent metal. Environmental Science and Technology 1998;32(1):232-7.

Keywords: Water filtration/ Organic matter Groundwater pollution, pesticides

Abstract: Contamination of surface and groundwaters by atrazine is a problem for water utilities in the United States and Europe. Though not removed by traditional liquid-solid separation, it is removed by nanofiltration. Retention of atrazine by a series of dialysis membranes was investigated over a range of solution chemistries with the goal of better understanding how the solution matrix may influence atrazine retention by membranes. Atrazine was significantly retained by membranes with molecular mass cut-offs less than 500 Da in the presence of natural organic matter (NOM), presumably by association with NOM. Atrazine retention was independent of the initial concentration. Solution chemistry was important in determining the extent of atrazine retention. Where NOM aggregation and hence NOM retention increased, atrazine retention decreased, and vice versa. Atrazine retention tended to decrease at higher ionic strengths. This effect was significantly stronger with divalent calcium than with monovalent sodium. Partitioning coefficients calculated here are much higher than values reported from experiments of atrazine retention by soil organic matter. It is speculated that the most likely mechanism of atrazine retention by NOM is through association of atrazine with interior adsorption sites on the NOM molecule by transitory hydrogen bonding and subsequent physical entrapment. Copyright 1998, American Chemical Society.

Diawara CK, Lô SM, Rumeau M, Pontie M, Sarr O. A phenomenological mass transfer approach in nanofiltration of halide ions for a selective defluorination of brackish drinking water. Journal of Membrane Science 2003;219(1-2):103-12.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-48YVX16-1&_user=10&_handle=B-WA-A-A-AZ-MsSAYVA-UUW-AUEVCZVEWZ-AUEWAVCDWZ-CZUWCEEUA-AZ-U&_fmt=summary&_coverDate=07%2F15%2F2003&_rdoc=8&_orig=browse&_srch=%23toc%235257%232003%23997809998%23441051!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=a4c5c51dd154accb7059f2dfdd6bc5d1
Keywords: Nanofiltration/ Mass transfer/ Defluorination/ Non-equilibrium thermodynamics/ Brackish drinking water
Abstract: Our article deals with the possibility to treat highly fluorinated brackish drinking water using nanofiltration (NF). Our approach is based on the phenomenological model of Spiegler, Kedem and Katchalsky (SKK) under dilute solution condition and neglects the charges carried by the membrane used (denoted NF45 from Dow, USA). We have calculated the phenomenological parameters (the membrane reflection coefficient) and can be linked linearly to the hydration energy of the halide ions. Furthermore, values are highly dependent on the anion present in the salty solutions. If NF is generally used for elimination of divalent ions, the present work describes its potential to selectively separate the following single halide salts: NaF, NaCl, NaI, LiF and LiCl. We have observed for the first time that a selective defluorination can occur using a NF membrane. Furthermore, we have developed a very simple method, following the permeate salt concentration versus the reverse of the permeate flux, to quantify separately both parts of the mass transfer occurring in NF: convection and/or solution–diffusion.

Drabi A, Viraraghavan T, Jin YC. Sulfate removal from water. Water Quality Research Journal of Canada 2003;38(1):169-82.
Keywords: Water supply, sulfur content/ Bentonite/ Nanofiltration
Abstract: Sulfate occurs naturally in groundwater. Concerns regarding the health effects from sulfate in drinking water have been raised because of reports that diarrhea may be associated with water that contains high levels of sulfate. In the livestock production industry, there is a concern that high levels of sulfate in water can adversely affect productivity. Different methods can be used to remove sulfate from water. Proven technologies are ion exchange, nanofiltration, reverse osmosis, and electrodialysis. A few earlier studies have shown that the use of bentonite/kaolinite for sulfate removal has produced encouraging results. Experimental work was undertaken to examine in detail the feasibility of such processes. Laboratory studies using bentonite showed poor or no removal in the case of high sulfate water. Ion exchange and nanofiltration were found to be very effective in removing sulfate. Ion exchange is likely to be more reliable than nanofiltration because of the sensitivity of the nanofiltration process to total dissolved solids and biofouling.

Drioli E, Curcio E, Criscuoli A, Di Profio G. Integrated system for recovery of $CaCO_3$, NaCl and $MgSO_4 \cdot 7H_2O$ from nanofiltration retentate. Journal of Membrane Science 2004;239(1):27-38.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4C6TJ1W-2&_user=10&_handle=B-WA-A-W-AD-MsSAYZA-UUW-AUEVZWYZZE-AUEWWUEVZE-CZUZEWBYU-AD-U&_fmt=summary&_coverDate=08%2F01%2F2004&_rdoc=5&_orig=browse&_srch=%23toc%235257%232004%23997609998%23506761!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d7071f1e2257b50287395acfe0193bd3
Keywords: Integrated membrane systems/ Seawater desalination/ Membrane contactors/ Calcium carbonate precipitation/ Membrane crystallization
Abstract: An integrated membrane system has been developed in order to recover dissolved salts that are present, at low concentration, in typical feed streams to desalination plants. The experimental work aimed to obtain $CaCO_3$, NaCl and $MgSO_4 \cdot 7H_2O$ as solid products from nanofiltration retentate. Since gypsum scale causes reduction of SO_4^{2-} content in the solution and drastically limits the recovery of epsomite, Ca^{2+} ions have been almost quantitatively precipitated by reaction with $NaHCO_3/Na_2CO_3$. Sodium (bi)carbonate solutions have been produced by reactive absorption of CO_2 into sodium hydroxide solutions carried out by membrane contactors technology. The flow sheet has been completed with a membrane crystallization stage that allows the generation of supersaturation for salts crystallization.

Du R, Zhao J. Properties of poly (*N*,*N*-dimethylaminoethyl methacrylate)/polysulfone positively charged composite nanofiltration membrane. Journal of Membrane Science 2004;239(2):183-8.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CHS0FW-2&_user=10&_handle=B-WA-A-W-AE-MsSAYWW-UUW-AUEVCDZAAV-AUEWACZEAV-CZUBWUZEV-AE-U&_fmt=summary&_coverDate=08%2F15%2F2004&_rdoc=4&_orig=browse&_srch=%23toc%235257%232004%23997609997%23506872!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=8ea470363e4e78f4b6a7792412eda48d
Keywords: Poly (*N*,*N*-dimethylaminoethyl methacrylate)/ Polysulfone/ Nanofiltration membrane/ Composite membrane/ Positively charged membrane
Abstract: Poly (*N*,*N*-dimethylaminoethyl methacrylate)/polysulfone (PDMAEMA/PSF) positively charged nanofiltration (NF) membrane was developed by the interfacial crosslinking polymerization using PSF flat-sheet microfiltration (MF) membrane as support layer, PDMAEMA aqueous solution as coating solution, *p*-xylylene dichloride/*n*-heptane as crosslinking agent. This membrane has a rejection to inorganic salts in aqueous solution. The rejection of $MgSO_4$ (1 g/L aqueous solution) is almost 90% and the rejection of NaCl (1 g/L aqueous solution) is almost 78% at 0.8 MPa and 30 °C. The rejection of the following inorganic salts to this membrane is decreasing in the order of $MgCl_2$, $MgSO_4$, NaCl and Na_2SO_4. The membrane exhibits higher permeate flux and rejection of inorganic salts in a neutral solution than in an acid or alkali solution. The membrane has a certain resistance to oxidative media or free chlorine. The results of the study also show that this membrane should be preserved in antiseptic solution.

Duchesne TA, Brown JQ, Guice KB, Lvov YM, McShane MJ. Encapsulation and stability properties of nanoengineered polyelectrolyte capsules for use as fluorescent sensors. Sensors and Materials 2002;14(6):293-308.
URL: http://www.myu-inc.jp/myukk/S&M/archives/pdf/S&M0491.pdf

Keywords: Fluorescent sensors,/ Layer-by-layer electrostatic self assembly/ Nanoparticles/ Polyelectrolytes

Abstract: This is the first report about a novel fluorescence sensor technology based on hollow micro- and nanoscale polyelectrolyte capsules. The nanostructured shells were constructed using the electrostatic layer-by-layer assembly process to deposit multilayer polyion films onto microtemplates (melamine formaldehyde microspheres). The latex cores were subsequently dissolved and removed, leaving hollow shells. The capsules were then loaded with a model fluorescent assay consisting of a sodium-sensitive dye and a reference fluorophore. Fluorescence spectroscopy was used to analyze properties of the capsules with respect to their potential application as biosensors. The results show that multiple dye molecules can be introduced into the interior of the capsules with excellent control over relative levels, and the capsules retain > 99% of fluorescence during 30 days of storage in a buffer. The findings also demonstrate that the capsules are mechanically robust, and only extremes in solvent pH cause significant leaching of fluorophores from the interior of the shells. Finally, results from sodium sensitivity experiments suggest that capsules have excellent potential for use as sensors, with a highly linear response over a broad range (0–100 mM).

Eckelt J, Loske S, Gonçalves MC, Wolf BA. Formation of micro- and nano-spheric particles (filter dust) during the preparation of cellulose acetate membranes. Journal of Membrane Science 2003;212(1-2):69-74.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-479THYD-6&_user=10&_handle=B-WA-A-A-BU-MsSAYZA-UUW-AUEVZVVVYD-AUEWWWCWYD-CZUEUEZUD-BU-U&_fmt=summary&_coverDate=02%2F15%2F2003&_rdoc=6&_orig=browse&_srch=%23toc%235257%232003%23997879998%23377582!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=fe2a8b487b219339fb0d1e9031d80e97

Keywords: Filter dust/ Cellulose acetate/ 2-Propanole/ Microspheres

Abstract: Membranes were prepared from six samples of cellulose acetate (CA) differing in their average molecular weight (75–260 kg/mole) and molecular weight distribution using methyl acetate as solvent and 2-propanole as precipitant. The routes through the phase diagram and the evaporation times were varied in these experiments. Electron microscopy demonstrates that the amount of filter dust (CA particles deposited on the membrane surface) decreases as the fraction of low molecular weight material in the starting polymer becomes less. For low average molar mass of CA and moderate polymer concentrations in the casting solution, the dust consists of individual spheres of relatively uniform size (1–2 μm) which cover the surface in a number of layers. With rising molar mass of the polymer the dust particles consist increasingly of strings of cohering and deformed beads of comparable size. Under these condition, some considerably smaller particles (less than or equal to 0.1 μm) are also formed. Possible mechanisms of filter dust formation are discussed and measures for its prevention are proposed.

Elliott DW, Zhang WX. Field assessment of nanoscale bimetallic particles for groundwater treatment. Environmental Science and Technology 2001;35(24):4922-6.

Keywords: Trichloroethylene reduction/ Nanoparticles/ Zero-valent metals technology

Abstract: A field demonstration was performed in which nanoscale bimetallic (Fe/Pd) particles were gravity-fed into groundwater contaminated bytrichloroethene and other chlorinated aliphatic hydrocarbons at a manufacturing site. With diameters on the order of 100-200 nm, the nanoparticles are uniquely suited to rapidly degrade redox-amenable contaminants and for optimal subsurface delivery and dispersion. Approximately 1.7 kg of the nanoparticles was fed into the test area over a two-day period, resulting in minimal clogging of the injection well. The test area was located within a well-characterized region of the contaminant plume and included an injection well and three piezometer couplets spaced 1.5 m apart. Despite the low nanoparticle dosage, trichloroethene reduction efficiencies of up to 96% were observed over a four-week monitoring period with the highest values observed at the injection well and adjacent piezometers. Data from the field assessment were consistent with the results of pre-injection laboratory studies, which showed rapid dechlorination of target chlorinated compounds accompanied by a sharp decrease of standard oxidation potential and an increase in pH.

Ernst M, Sachse A, Steinberg CEW, Jekel M. Characterization of the DOC in nanofiltration permeates of a tertiary effluent. Water Research 2000;34(11):2879-86.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-40917BX-4&_coverDate=08%2F01%2F2000&_alid=206154698&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=e8fe5d984218e5b392927a4076fe9310
Keywords: Nanofiltration/ Tertiary effluent/ Dissolved organic carbon/ Adsorption/ Powdered activated carbon/ Size exclusion chromatography
Abstract: In order to develop a feasible technology for a safe ground water recharge with treated waste water, quality and characteristics of four different nanofiltration (NF) permeates were investigated for separation of organic constituents in the treated tertiary effluent. To avoid high fouling and scaling potentials during the membrane process, we also used NF membranes with larger pore size, and with a molecular weight cut-off (MWCO) in the range of several thousands $g \cdot mol^{-1}$. Adsorption behavior on powdered activated carbon (PAC) of the dissolved organic carbon (DOC) permeating through these membranes was significantly better than that of the feed waters (tertiary effluent and microfiltered tertiary effluent). A numerical analysis of the adsorption isotherm data according to the Ideal Adsorbed Solution Theory (IAST) confirmed these results. Size exclusion chromatography (SEC) prooved that the reduction rate for adsorptive removal of DOC from NF permeates increases with decreasing molecular weight. In the feed water DOC adsorption on PAC is negatively influenced by humic substances (HS). As well as the adsorptive removal of DOC by PAC, soil aquifer treatment (SAT) showed similar DOC removal rates in the low molecular range and therefore offers a promising option by combining "large pore" NF-membrane filtration with conventional SAT for more effective DOC removal with the aim of an artificial ground water recharge.

Favre Reguillon A, Lebuzit G, Foos J. Selective concentration of uranium from seawater by nanofiltration. Industrial and Engineering Chemistry Research 2003;42(23):5900-4.
Keywords: Nanofiltration/ Water purification, radioactive substances removal/ Uranium, reclamation
Abstract: A new procedure for the concentration of uranium, dissolved in seawater with extremely low concentration, was studied. Plate module membrane filtration equipment was

operated to evaluate the performance and selectivity of four different nanofiltration flat sheet membranes. Experiments were first carried out using different model waters. The membranes were discriminating by the rejection of uranium, calcium, and sodium. Then, a uranium concentration test using a nanofiltration membrane showing the highest selectivity for uranium toward alkaline and alkaline-earth ions has been performed on natural seawater. A nanofiltration membrane shows a high selectivity for U(VI), illustrating the advantageous use of nanofiltration for the concentration of uranium from seawater.

Ferjani E, Roudesli S, Deratani A. Desalination of brackish water from Tunisian Sahel using composite polymethylhydrosiloxane-cellulose acetate membranes. Desalination 2004;162:103-9.
URL: http://www.desline.com/articoli/5339.pdf
Keywords: Nanofiltration/ Composite membranes/ Cellulose acetate/ Desalination/ Brackish water
Abstract: Composite cellulose acetate (CA) based membranes having a hydrophobic top layer made of polymethylhydrosiloxane (PMHS) were prepared with the aim of desalination of brackish waters from the Sahel region of Tunisia having a total dissolved salt content (TDS) of about 4100 $\mathrm{g.m^{-3}}$. The porous substructure made of CA was obtained by a phase separation process from acetone/formamide (2/1 wt/wt) casting solutions. Two polymer concentrations (20 and 22 wt. %) were used with a heat post-treatment temperature going from 60 to 90°C in order to produce membranes with pore sizes responding to nanofiltration needs. Overcoating the CA substructure with a PMHS thin layer gave rise to the composite membranes. Scanning electron microscopy analysis showed the asymmetric and composite feature of the CA–PMHS membrane morphology. Contact angle measurements clearly pointed out a marked hydrophobic character of the composite membranes due to the PMHS surface modification. When compared to the corresponding unmodified CA membranes, the salt rejection determined by conductivity in the range of 78–93% was strongly enhanced whereas the pure water permeability of the composite membranes was reduced by a factor of 15–50% depending on the starting pore size. It results in the same salt retention — an improvement factor of 50–100% for the permeation rate when using the composite membranes. The ion rejection in decreasing order was $SO_4^{2-} > Cl^- > NO_3^-$ and Mg^{2+} less than or equal to $Ca^{2+} > Na^+$ for anions and cations, respectively.

Fokema MD, Zarur AJ, Ying JY. Lean-burn natural gas engine exhaust remediation using nanostructured catalysts and coatings . Final Proceedings of the NATO Advanced Research Workshop on Nanostructured Films and Coatings. Santorini, Greece. 1999: 355-65.
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Freger V, Arnot TC, Howell JA. Separation of concentrated organic/inorganic salt mixtures by nanofiltration. Journal of Membrane Science 2000;178(1-2):185-93.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4118DH5-N&_coverDate=09%2F15%2F2000&_alid=196001780&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=41a96f785065b0697051e1a683a62904

Keywords: Nanofiltration/ Organic-inorganic separation/ Rejection/ Osmotic pressure/ Sorption

Abstract: This paper considers nanofiltration (NF) of concentrated organic/inorganic mixtures using the FILMTEC™ NF-200B membrane. Mixtures of salt (up to 17% (w/v)) and lactic acid (2% (w/v)) were used as model solutions. The work centres on the effects of salt concentration, pH and temperature on the flux and rejection of lactate. For all solutions under study, the rejection of salt was low, while the rejection of lactate was maximal at neutral pH, and decreased with salt concentration and temperature. The flux was found to decrease with salt concentration and increase with temperature, the activation energy being higher for low fluxes. The flux for pure water and 2% (w/v) lactic acid was at a maximum at neutral pH, but for salt-containing solutions, it increased with pH in the whole range analysed (pH 3–10). The observed flux and rejection patterns suggest that the effects of skin shrinkage in concentrated salt solutions, and sorption of lactate by the membrane, affect behaviour in addition to the conventional effects of charge, solute size and osmotic difference between the retentate and permeate streams.

Garcia-Aleman J, Dickson J, Mika A. Experimental analysis, modeling, and theoretical design of McMaster pore-filled nanofiltration membranes. Journal of Membrane Science 2004;240(1-2):237-55.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CS4J2G-3&_user=10&_handle=B-WA-A-W-BU-MsSAYZA-UUW-AUEVCVWWDY-AUEWAWBUDY-CZUACDAZZ-BU-U&_fmt=summary&_coverDate=09%2F01%2F2004&_rdoc=24&_orig=browse&_srch=%23toc%235257%232004%23997599998%23510566!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b6cc3ba19ca26f734b75544e1a4b3d96

Keywords: Nanofiltration/ Mixed electrolytes/ Pore-filled/ Donnan exclusion/ Gel network/ Modeling

Abstract: A side-by-side comparison of the performance of McMaster pore-filled (MacPF) and commercial nanofiltration (NF) membranes is presented here. The single-salt and multi-component performance of these membranes is studied using experimental data and using a mathematical model. The pseudo two-dimensional model is based on the extended Nernst-Planck equation, a modified Poisson-Boltzmann equation, and hydrodynamic calculations. The model includes four structural properties of the membrane: pore radius, pure water permeability, surface charge density and the ratio of effective membrane thickness to water content. The analysis demonstrates that the rejection and transport mechanisms are the same in the commercial and MacPF membranes with different contributions from each type of mechanism (convection, diffusion and electromigration). Solute rejection in NF membranes is determined primarily by a combination of steric and electrostatic effects. The selectivity of MacPF membranes is primarily determined by electrostatic effects with a significantly smaller contribution of steric effects compared to commercial membranes. Hence, these membranes have the ability to reject ions while remaining highly permeable to low molecular weight organics. Additionally, a new theoretical membrane design approach is presented. This design procedure potentially offers the optimization of NF membrane performance by tailoring the membrane structure and operating variables to the specific process, simultaneously. The procedure is validated at the laboratory scale.

Garcia-Aleman J, Dickson JM. Mathematical modeling of nanofiltration membranes with mixed electrolyte solutions. Journal of Membrane Science 2004 ;235(1-2):1-13.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4C47GT3-1&_user=10&_handle=B-WA-A-A-WU-MsSAYZW-UUA-AUEVCVYYBD-AUEWAWEZBD-CZUAYDAWV-WU-U&_fmt=summary&_coverDate=06%2F01%2F2004&_rdoc=1&_orig=browse&_srch=%23toc%235257%232004%23997649998%23497753!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=7c9afa3d76a3d0f45dd0fa96eb2cba6e

Keywords: Nanofiltration/ Mixed electrolytes/ Nernst-Planck/ Gouy-Chapman/ Donnan exclusion

Abstract: A one-dimensional mathematical model is developed and used to describe and predict the performance of commercial nanofiltration (NF) membranes (DDS HC-50, Hydranautics HN-4040-TFV-7450, FilmTec NF-45) for mixed electrolyte solutions. The model is based on three fundamental ideas: the extended Nernst-Planck equation, Donnan equilibrium model, and Gouy-Chapman theory. The membrane is characterized using only three fitting parameters (L_p, r_p, ϕ). Two solutions (flat and cylindrical surface) of the Gouy-Chapman equation (GCE) are used and compared. The pure water permeability (L_p) is obtained experimentally (independently). The pore radius (r_p) and surface electrical potential (ϕ) are fitted simultaneously to experimental data from mixed electrolyte solutions, and the ratio of membrane thickness/water content (λ/E) is calculated from Darcy's law. The parameters are independent of operating conditions (solute, pressure, and concentration). Model calculations are in agreement with the experimental data, especially when a cylindrical surface (GCE) is assumed. At very low concentrations the flat surface assumption is unsatisfactory. This mechanistic model has good predicting capabilities. The fitted parameters are compared to independently measured parameters from the literature.

Garcia-Aleman J, Dickson JM. Permeation of mixed-salt solutions with commercial and pore-filled nanofiltration membranes: Membrane charge inversion phenomena. Journal of Membrane Science 2004;239(2):163-72.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CJVF4H-2&_user=10&_handle=B-WA-A-W-AE-MsSAYWW-UUW-AUEVCDZAAV-AUEWACZEAV-CZUBWUZEV-AE-U&_fmt=summary&_coverDate=08%2F15%2F2004&_rdoc=2&_orig=browse&_srch=%23toc%235257%232004%23997609997%23506872!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=37baf053d44df69605857814cc9e5267

Keywords: Nanofiltration/ Mixed electrolytes/ Charge inversion/ Pore-filled/ Counter-ion adsorption

Abstract: This paper presents experimental observations on the permeation of mixed-salt solutions through commercial and McMaster pore-filled nanofiltration membranes. Two types of mixed-salt solutions are analyzed (common co-ions and common counter-ions). The permeation of solutions with common counter-ions can be explained from theory and has been predicted accurately in previous work. However, the performance of these membranes when common co-ions are present does not directly follow the behavior expected from normal electrostatic and steric exclusion mechanisms. The membranes behave as if the charge has been inverted. Multivalent counter-ion adsorption is believed to play an important role in the inversion of the effective charge of the membrane, and the subsequent anomalous permeation

of counter-ions.

Gaubert E, Barnier H, Maurel A, Foos J, Guy A, Bardot C, et al. Selective strontium removal from a sodium nitrate aqueous medium by nanofiltration-complexation. Separation Science and Technology 1997;32(1-4):585-97.

Glazier R, Venkatakrishnan R, Gheorghiu F, Walata L, Nash R, Zhang WX. Nanotechnology takes root. Civil Engineering (American Society of Civil Engineers) 2003;73(5):64-9.
Abstract: Research at Lehigh University has established bimetallic nanoscale particles as effective reductants and catalysts for rapidly treating common environmental contaminants such as chlorinated organic solvents and hexavalent chromium. The Lehigh University research involved a field demonstration of bimetallic nanoscale particle treatment of contaminated groundwater at an industrial site in Trenton, New Jersey. The findings of the field-scale pilot test to assess treatability are in good accord with those of published laboratory and field tests.

Gorenflo A., Velázquez-Padrón D, Frimmel FH. Nanofiltration of a German groundwater of high hardness and NOM content: Performance and costs. Desalination 2003;151(3):253-65.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-47T7460-N&_coverDate=01%2F20%2F2003&_alid=195968169&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=7babdc654c5da15e39d57705bbbbce3e
Abstract: Nanofiltration of conventionally pretreated groundwater with elevated hardness and content of NOM (Ca^{2+}: 115 mg/L; Mg^{2+}: 12 mg/L; *DOC* = 2.9 mg/L) was carried out in a German water treatment plant of the public works of Mainz. For the investigated water the employed membrane (NF200B, Filmtec/DOW) showed almost complete rejection (>95%) of NOM, determined by measuring DOC, UVA (254 nm) and AOX- and THM-formation potential. Due to the high concentration of SO$_4^{2-}$ and presumably due to complexation of Ca^{2+} with humic substances the rejection of Ca^{2+} and Mg^{2+} was unexpectedly high (>74% and >86%, respectively) compared to a pure CaCl$_2$ solution (R(CaCl$_2$) <45%). Within an operation period of four weeks, no significant fouling occurred (flux decline <2%). This was mainly due to the pre-treatment of the raw water (deferrization, demanganization, rapid sand filtration). The operating costs for a nanofiltration plant were calculated to about € 0.23/m^3 at a permeate output of 20,000 m^3/d which means an increase of the price for drinking water of approximately 9%. By blending the permeate and the conventionally treated water at a ratio to yield a DOC concentration in the blend of 1 mg/L, the additional costs for nanofiltration would come to € 0.11/m^3.

Gu F, Wang SF, Lü MK, Zou WG, Zhou GJ, Xu D, et al. Combustion synthesis and luminescence properties of Dy^{3+}-doped MgO nanocrystals. Journal of Crystal Growth 2004;260(3-4):507-10.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TJ6-49KSTTD-8&_coverDate=01%2F09%2F2004&_alid=197929203&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5302&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=6a7568631a167e817665fcac9c56369f
Keywords: Doping/ Oxides/ Nanomaterials
Abstract: MgO nanocrystals doped with Dy^{3+} have been synthesized by a combustion method.

The synthesized sample is characterized by X-ray diffraction, transmission electron micrograph, Fourier transform infrared, and photoluminescence spectroscopy. The as-prepared MgO nanocrystals appear to be single cubic crystalline phase and the diameter is in the range of 20–25 nm. The hypersensitive transition ($^4F_{9/2} \rightarrow {}^6H_{13/2}$ of Dy^{3+}) emission is prominent in the emission spectra resulting from the low-symmetry local site at which Dy^{3+} ions locate. In addition, the dependence of the luminescence intensity on Dy^{3+} concentration is also discussed.

Hagmeyer G, Gimbel R. Modelling the salt rejection of nanofiltration membranes for ternary ion mixtures and for single salts at different pH values. Desalination 1998;117(1-3):247-56.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-3W2SBV1-W&_coverDate=09%2F20%2F1998&_alid=196218647&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=6e747afc0d132e00f23a7c294117c7da
Keywords: Nanofiltration / Salt rejection/ Zeta potential/ Dielectric exclusion/ Charged membrane/ Extended Nernst-Planck equation
Abstract: Zeta potential measurements were performed to gain more insight in the rejection mechanisms of nanofiltration membranes. The zeta potential as well as the calculated surface charge increased at pH 7 with increasing salt concentration in the bulk. The isoelectric point of both membranes investigated (PVD1, Desal 5DK) is at a pH of about 4. The membranes are positively charged below this pH value and are negative at higher pH values. Rejection measurements were performed for both membranes. The rejection of single salt solutions at different concentrations, the rejection of ternary ion mixtures as well as the rejection at different pH values were determined experimentally. For the modelling of the rejection by nanofiltration membranes, the zeta potential measurements were used to calculate the surface charge of the membrane. An empirical approach was proposed to incorporate the change of the dielectric constant between bulk and pore solution to calculate the ion distribution between bulk and pore solution. The decrease of the NaCl rejection as well as the increase of the $CaCl_2$ rejection was well described by the model. The rejection of ternary ion mixtures of $NaCl/Na_2SO_4$ and $NaCl/CaCl_2$ were determined experimentally and were predicted by the model except for the $NaCl/CaCl_2$ mixture in the case of the Desal 5DK membrane, where the negative rejections of Na^+ were not predicted. The rejections at different pH values exhibit a minimum, which coincides in the case of the PVD1 with the isoelectric point of the membrane surface. The pH of the rejection minimum for the Desal 5DK is one pH unit higher than the isoelectric point.

Hairston D. Getting a return on process water treatment. Chemical Engineering 2003;110(7):25-9.
Keywords: Water supply for the chemical industry/ Water reuse/ Water filtration
Abstract: Methods for getting a return on process water treatment are described. Treatment technologies already developed for operations with stringent water requirements are making the production of process water more cost effective. Zero liquid discharge; membrane filtration; new antiscalants, biocides, and flocculants; and seawater desalination are discussed.

Hartman J. Nanoparticles help cut groundwater cleanup costs. Civil Engineering (American Society of Civil Engineers) 2002;72(5):33.
Keywords: Groundwater remediation technologies/ Nanoparticles/ Iron alloys, oxidation
Abstract: Nanoparticles of iron injected directly into underground aquifers are being used in a

new groundwater cleanup technique. It is hoped that this method will offer significant savings over traditional pump-and-treat processes. The system has proven successful in treating water contaminated with trichloromethylene (TCE), which is commonly found in dry-cleaning solvents. Developed by researchers at Lehigh University, the aim is to make the technology easy to operate and less expensive than conventional approaches. A standard lab process converts iron salts into nanoparticles. The iron and TCE are involved in oxidation-reduction reactions that remove chlorine and convert the solvents to benign hydrocarbons and chlorides.

He CH, Gong J. The preparation of PVA–Pt/TiO_2 composite nanofiber aggregate and the photocatalytic degradation of solid-phase polyvinyl alcohol . Polymer Degradation and Stability 2003;81(1):117-24.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TXS-48H888W-1&_coverDate=12%2F31%2F2003&_alid=198260683&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5598&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5be8f0a328b5fa03d49b8d1b42247de2

Keywords: Polyvinyl alcohol/ Nanosize fiber/ Photocatalytic degradation/ Pt/ TiO_2 photocatalyst

Abstract: Polyvinyl alcohol(PVA)–Pt/TiO_2 composite nanofiber aggregate was prepared by electrospinning method and the photocatalytic degradation of solid-phase PVA was investigated. The experimental results showed that the 150–350 nm PVA–Pt/TiO_2 composite fiber could be obtained from the PVA–Pt/TiO_2 sol-like system by the electrospinning method and the photocatalytic technique was effective for the degradation of solid-phase PVA in this fiber. The weight loss of PVA depended on the wavelength of UV light and the irradiation time; it reached 78.5 and 40.2%, respectively under average 250 and 360 nm UV light irradiation for 16 h. The degradation rate of PVA in composite fiber was higher than that in composite film under identical conditions. The samples were characterized by scanning electron microscopy (SEM), X-ray energy dispersive spectrometer (EDS), X-ray diffraction (XRD), Ultraviolet-visible diffuse reflectance spectroscopy (UV-vis) and Fourier transform infrared (FTIR) techniques. The possible mechanism of PVA degradation was also discussed in this paper.

Ismail AF, Hassan AR. The deduction of fine structural details of asymmetric nanofiltration membranes using theoretical models. Journal of Membrane Science 2004;231(1-2):25-36.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4BHJXV7-1&_user=10&_handle=B-WA-A-A-WZ-MsSAYZW-UUW-AUEVCBDYCC-AUEWAAYZCC-CZUABZZEW-WZ-U&_fmt=summary&_coverDate=03%2F01%2F2004&_rdoc=3&_orig=browse&_srch=%23toc%235257%232004%23997689998%23480747!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=cec86bc5a550de261ea30000caccdf56

Keywords: Nanofiltration/ Modeling/ Nernst-Plank equation/ Steric-hindrance pore

Abstract: Asymmetric cellulose acetate nanofiltration (NF) membranes were prepared at different shear rate between 152.0 and 506.67 s^{-1} to investigate the effect of casting shear rate on the fine structural details of the membrane and membrane performance by using sodium chloride solution. The experimental data is modeled based on the pore flow, solution–diffusion mechanisms and the extended Nernst-Plank equation. The Spiegler-Kedem membrane transport model was used to evaluate the membrane parameters such as reflection coefficient, and solute permeability, P_s. The fine structural details of the nanofiltration membrane were evaluated in terms of effective pore radius r_p, effective charge density X_d, ratio of effective membrane thickness to membrane porosity. The measurement was conducted using steric-hindrance pore (SHP) model. The effective charge density X_d, was determined using Teorell-Meyer-Sievers (TMS) model. The modeling results show that, the obtained values were in the range of the commercial available NF membranes.

Israel LB, Kariuki NN, Han L, Maye MM, Luo J, Zhong CJ. Electroactivity of Cu^{2+} at a thin film assembly of gold nanoparticles linked by 11-mercaptoundecanoic acid. Journal of Electroanalytical Chemistry 2001;517(1-2):69-76.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGB-44GKXW2-1&_coverDate=12%2F28%2F2001&_alid=199318434&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5250&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=15441c5d2592f72b638e2d571e0588a5
Keywords: Nanostructured thin film assembly/ Gold nanoparticles/ Carboxylic acid/ Electrochemistry/ Copper ion/ Heavy metal
Abstract: Core-shell nanoparticles are emerging advanced materials for developing novel electroanalytical platforms. This paper describes the results of an investigation of the electroactivity of Cu^{2+} ions on electrodes coated with thin films assembled from thiolate-encapsulated gold nanoparticles of 2 nm core size ($Au_{2\text{-nm}}$) and a carboxylic functionalized alkyl thiol linker, i.e. 11-mercaptoundecanoic acid (MUA). The high surface-to-volume ratio and the 3D ligand network properties are potentially useful as sensitive and selective nanomaterials for the monitoring and removal of environmental heavy metals. The nanostructured MUA–$Au_{2\text{-nm}}$ film is sensitive to Cu^{2+} below 1 ppm. The selectivity of the electroactivity is also probed using mixed-metal systems such as Cu^{2+} and Fe^{3+} and Cu^{2+} and Zn^{2+}. Issues related to the electrochemical activity of these metal ions are also discussed.

Jiang D, Zhao H, Jia Z, Cao J, John R. Photoelectrochemical behaviour of methanol oxidation at nanoporous TiO_2 film electrodes. Journal of Photochemistry and Photobiology A: Chemistry 2001;144(2-3):197-204.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGY-4477Y0J-K&_coverDate=11%2F07%2F2001&_alid=199320791&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5267&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=7d6a7835abe7a443599910303e747ccc
Keywords: Nanoporous TiO_2 film/ Methanol oxidation/ Photoelectrochemistry
Abstract: A study of photoelectrochemical oxidation of methanol at nanoporous TiO_2 film electrodes was carried out. The effect of variables such as applied potential, light intensity, methanol concentration and pH on the photoelectrochemical behaviour was investigated. It was found that the photoresponse was greatly influenced by these factors and a unique photocurrent/potential characteristic of the electrode in solution was observed which was similar to that of the single crystal semiconductor electrode. It was also found that the rate-limiting step for the overall photooxidation process varied depending on potential, light intensity and methanol surface coverage. In low potential region at a given light intensity and methanol concentration the migration of electron across the TiO_2 film is the rate-limiting step. While in the relatively high potential region the interfacial charge transfer was found to be the rate-limiting step. A deviation of onset potential dependence on pH from the Nernstian

relationship was also observed, and based on the energy band theory and the existence of deep electron traps an explanation was given. An unusual abrupt increase of photocurrent in strong basic methanol solution was observed, which was attributed to the existence of acidic hydroxyl group on TiO_2 and its stronger adsorption to methanol molecule after its reaction with OH^-, and the higher reactivity of the methanol thus adsorbed.

Jin W, Toutianoush A, Tieke B. Use of polyelectrolyte layer-by-layer assemblies as nanofiltration and reverse osmosis membranes. Langmuir 2003;19(7):2550-3.
URL: http://pubs.acs.org/cgi-bin/abstract.cgi/langd5/2003/19/i07/abs/la020926f.html
Abstract: Measurements of ion transport and water flux across ultrathin multilayered membranes of polyelectrolytes were carried out under nanofiltration and reverse osmosis conditions. The polyelectrolyte membranes were prepared upon alternating electrostatic layer-by-layer adsorption of polyvinylamine (PVA) and polyvinyl sulfate (PVS) on porous supports. The pressure-driven transport of aqueous electrolyte solutions containing NaCl, Na_2SO_4, $MgCl_2$, and $MgSO_4$ in 1 and 10 mM concentration was investigated. For $MgCl_2$ and $MgSO_4$, a complete rejection was observed independently from the concentration of the feed solution and the pressure applied. For NaCl and Na_2SO_4, the rejections were 84 and 96% at 5 bar, and 93.5 and 98.5% at 40 bar, respectively. The hydraulic permeability of the composite membrane was 113.7 mL/(m^2 h bar). It was only little affected by the presence of salt. At low and moderate pressure the membranes are suitable for water softening applications, while at pressures of 40 bar or higher they can be used for water desalination. Effects of the stirring of the feed solution on the membrane characteristics are also discussed.

Karamanis DT, Aslanoglou XA, Assimakopoulos PA, Gangas NH. PIGE and XRF analysis of a nano-composite pillared layered clay material for nuclear waste applications. Nuclear Instruments and Methods in Physics Research Section B:Beam Interactions With Materials and Atoms 2001;181(1-4):616-21.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TJN-43XFNW8-3X&_coverDate=07%2F31%2F2001&_alid=199322427&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5315&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=09e74298f0c5c3cc4f8eea63ff51bba7
Keywords: PIGE/ XRF/ Pillared layered materials;/ Radioactive wastes
Abstract: A special tailored aluminium pillared montmorillonite was prepared for radiostrontium removal in complex ionic environment. In a first series of experiments, the methods of PIGE and XRF were used to characterise the material as a cation exchanger. Furthermore, the charge carried by the pillars, a critical quantity of the pillaring process, was estimated. A qualitative model for the organisation and structural evolution of the clay lamellas from the nm to the mm scale was developed. The possible use of a microbeam for quantitative studies of pillared clays will be discussed.

Kelly SD, Kemner KM, Fryxell GE. X-ray-absorption fine-structure spectroscopy study of the interactions between contaminant tetrahedral anions and self-assembled monolayers on mesoporous supports. The Journal of Physical Chemistry B 2001;105(27):6337-46.
Keywords: Groundwater remediation technologies/ Heavy metals, reclamation/ Adsorbents, testing
Abstract: Self-assembled monolayers on mesoporous supports (SAMMSs) have been found to

be superior sorbent materials for sequestering environmentally problematic species. Coupling the rich coordination chemistry of transition metal complexes with the SAMMS concept has afforded anion-specific sorbent materials with unprecedented anion binding capabilities. X-ray absorption fine structure (XAFS) spectroscopy is used to investigate the chemical interaction between an interfacially bound copper ethylenediamine complex (Cu-(EDA)) and arsenate and chromate anions within these nanoporous hybrid materials. The Cu *K*-edge XAFS data indicate a structural change of $Cu(EDA)_3$ caused by the anion bonding, consistent with a lock-and-key mechanism. The As and Cr *K*-edge features of the normalized absorption data signify As(V) and Cr(VI) in the SAMMS samples. The Cr *K*-edge data show a distorted CrO_4 tetrahedron with two short and two long oxygen distances, whereas the AsO_4 tetrahedron is symmetric. The average local structure about Cu, As, and Cr consistently indicate direct Cu–O bond formation, a monodentate linkage between the anion and the Cu(II) cation, and a trigonal bipyramidal geometry of the Cu center in the adduct.

Kharaka YK, Ambats G, Thordsen JJ. Deep well injection of brine from Paradox Valley, Colorado: Potential major precipitation problems remediated by nanofiltration. Water Resources Research 1997;33(5):1013-20.
URL: http://www.agu.org/pubs/abs/wr/97WR00573/97WR00573.html
Keywords: Rivers, Colorado/ Disposal wells/ Water supply, salt water intrusion/ Nanofiltration
Abstract: Groundwater brine that is seeping into the Dolores River in Paradox Valley, Colorado, is to be piped and injected mainly into the Mississippian Leadville Limestone. This disposal is to be performed to abate this natural contamination, which is increasing the dissolved solids load of the Colorado River by approximately 2×10^8 kg per annum. To prevent precipitation of such a high mass of anhydrite that the Leadville Limestone aquifer would be plugged, laboratory flow experiments with nanofiltration membranes demonstrate that approximately 98 percent of SO_4 can be removed from the brine prior to injection, thereby preventing the anhydrite precipitation. These results have stimulated plans for field testing this treatment method.
Published abstract: Groundwater brine seepage into the Dolores River in Paradox Valley, Colorado, increases the dissolved solids load of the Colorado River annually by about 200 million kg. To abate this natural contamination, the Bureau of Reclamation plans to pump 3,540 m^3/d of brine from 12 shallow wells located along the Dolores River. The brine, with a salinity of 250,000 mg/L, will be piped to the deepest (4.9 km) disposal well in the world, and injected mainly into the Mississippian Leadville Limestone. Geochemical modeling indicates, and water-rock experiments confirm, that a huge mass of anhydrite (about 10,000 kg/d) likely will precipitate from the injected brine at downhole conditions of 120 C and 500 bar. Anhydrite precipitation could increase by up to three times if the injected brine is allowed to mix with the highly incompatible formation water of the Leadville Limestone and if the Mg in this brine dolomitizes the calcite of the aquifer. Laboratory experiments demonstrate that nanofiltration membranes, which are selective to divalent anions, provide a new technology that remediates the precipitation problem by removing about 98% of dissolved SO_4 from the hypersaline brine. The fluid pressure used (50 bar) is much lower than would be required for traditional reverse osmosis membranes, because nanofiltration membranes have a low rejection efficiency (5–10%) for monovalent anions. Our experiments and calculations indicate that the proportion of brine treatable increases from about 60% to more than 80% with the addition of

trace concentrations of a commercially available organic precipitation inhibitor, and to more than 85% by blending the raw brine with the effluent stream. Pilot field testing of this methodology is currently underway.

Kilduff JE, Mattaraj S, Belfort G. Flux decline during nanofiltration of naturally-occurring dissolved organic matter: Effects of osmotic pressure, membrane permeability, and cake formation. Journal of Membrane Science 2004;239(1):39-53.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CB09YP-1&_user=10&_handle=B-WA-A-W-AD-MsSAYZA-UUW-AUEVZWYZZE-AUEWWUEVZE-CZUZEWBYU-AD-U&_fmt=summary&_coverDate=08%2F01%2F2004&_rdoc=6&_orig=browse&_srch=%23toc%235257%232004%23997609998%23506761!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=863d14fbe453c3e95062a6167a7a8ada
Keywords: Nanofiltration/ Fouling/ Natural organic matter/ Water treatment
Abstract: Nanofiltration of naturally-occurring dissolved organic matter (NOM) by an aromatic polyamide membrane was measured in a crossflow bench-scale test cell and modeled using a semi-empirical osmotic pressure/cake formation model. Our objective was to examine flux decline due to NOM fouling while explicitly accounting for flux decline due to osmotic effects and changes in membrane permeability. This approach allowed quantification of the effect of ionic composition on specific NOM cake resistance, and yielded insight into flux decline due to enhanced NaCl rejection by the NOM deposit. In the absence of NOM, increasing NaCl concentration reduced salt rejection and decreased membrane permeability. Flux decline was modeled by accounting for changes in osmotic pressure with time, and by employing an effective permeability. The addition of calcium significantly reduced rejection of sodium and feed conductivity, and thus mitigated flux decline. Increasing pH from 4 (near membrane pI) to 10 increased the effective permeability but also increased NaCl rejection, which resulted in greater flux decline. The presence of NOM caused greater flux decline resulting from a combination of NOM cake resistance and increased rejection of NaCl by negatively charged NOM functional groups. Increasing NaCl concentration had little effect on the mass of NOM deposited, but significantly increased the specific resistance of the NOM cake. The effect of ionic strength on specific resistance correlated with a reduction in NOM size, estimated by separate UF permeation experiments and size exclusion chromatography analysis of UF permeate. Therefore, increased specific cake resistance is consistent with a more compact, less porous cake. Flux decline by NOM solutions showed a maximum at pH 7, where salt rejection was also a maximum. Binding of calcium reduced the ability of NOM to enhance NaCl rejection, and likely increased NOM cake resistance. Flux decline caused by NOM fouling in the presence of calcium was only significantly different than that caused by NOM in a solution of NaCl at the same ionic strength when the calcium concentration corresponded to saturation of NOM binding sites.

Kim JY, Shim SB, Shim JK. Effect of amphiphilic polyurethane nanoparticles on sorption–desorption of phenanthrene in aquifer material. J Hazard Mater 2003;98(1-3):145-60.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGF-47YR682-1&_coverDate=03%2F17%2F2003&_alid=197880955&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5253&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=1cde7d00349b338b39666ab70846406b

Keywords: Amphiphilic polymer/ Nanoparticles/ Desorption/ Sorption/ Phenanthrene
Abstract: Micelle-like amphiphilic nano-sized polyurethane (APU) nanoparticles were synthesized via chemical cross-linking reaction of nano-aggregates of urethane acrylate nonionomer (UAN) chain and were tested for extraction efficiency of sorbed phenanthrene from aquifer material. Even though the solubilizing performance and interfacial activity of APU nanoparticles were inferior to that of Triton X-100, in the low concentration region, APU nanoparticles could effectively reduce phenanthrene sorption on the aquifer material and extracted sorbed phenanthrene from the aquifer material, whereas Triton X-100 could not extract sorbed phenanthrene and rather increased phenanthrene sorption onto the aquifer materials. At higher concentrations, APU nanoparticles and Triton X-100 had almost the same soil washing effectiveness. This interesting result is mainly due to a lower degree of sorption of APU nanoparticles onto the aquifer material. The sorption of APU nanoparticles onto aquifer sand is largely hindered by their chemically cross-linked nature, resulting in better soil-washing performance of APU nanoparticles than Triton X-100.

Kim J-Y, Cohen C, Shuler ML. Use of amphiphilic polymer particles for in situ extraction of sorbed phenanthrene from a contaminated aquifer material. Environmental Science and Technology 2000;34(19):4133-9.
URL: http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/2000/34/i19/abs/es001021w.html
Keywords: Urethans/ Phenanthrene/ Adsorption, kinetics
Abstract: Amphiphilic polyurethane (APU) nano-network polymer particles were tested for their efficiency to remove a model hydrophobic pollutant (phenanthrene) from a contaminated sandy aquifer material. Results from batch experiments indicated that the APU particles were weakly adsorbed onto the aquifer sand (K_d^P = 0.0063 mL/g). In column experiments, 97 to 98IX of applied APU particles were recovered after passage of 2 to 3 pore-volumes of rinse water. The chemically cross-linked nature of the APU particles and ionic functional groups on particle surfaces decrease their affinity to adsorb onto the soil. APU nano-network suspensions extracted up to 98IX of the phenanthrene sorbed on the aquifer material with extremely low loss of particles. Passage of fewer pore-volumes of an APU emulsion was needed to achieve a given level of remediation relative to results reported for surfactant solutions. Although the concentration of APU particles in the washing solution was greater than the reported concentrations used for surfactant solutions, the enhanced phenanthrene extraction and the recovery of the APU particles suggest further research is warranted. Reprinted by permission of the publisher.

Kimura K, Amy G, Drewes JE, Heberer T, Kim TU, Watanabe Y. Rejection of organic micropollutants (disinfection by-products, endocrine disrupting compounds, and pharmaceutically active compounds) by NF/RO membranes. Journal of Membrane Science 2003;227(1-2):113-21.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-49Y418H-1&_coverDate=12%2F15%2F2003&_alid=195975456&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=12252cf2eb83f3864f88e72cb5f14985
Keywords: Nanofiltration/ Organic micropollutant/ Physico-chemical properties/ Rejection efficiency/ Reverse osmosis
Abstract: The growing demand on water resources has increased interest in wastewater reclamation for potable reuse, in which rejection of organic micropollutants such as

disinfection by-products (DBPs), endocrine disrupting compounds (EDCs), and pharmaceutically active compounds (PhACs) is of great concern. The objective of this study was to investigate the rejection of DBPs, EDCs, and PhACs by nanofiltration (NF) and reverse osmosis (RO) membranes as a function of their physico-chemical properties and initial feed water concentration. Experimental results indicated that negatively charged compounds could be rejected very effectively (i.e., > 90%) regardless of other physico-chemical properties of the tested compounds due to electrostatic exclusion. No time dependency was observed for rejection of charged compounds. In contrast, rejection of non-charged compounds was generally lower (< 90% except for one case) and influenced mainly by the molecular size of the compounds. A clear time dependency was observed for rejection of non-charged compounds, attributable to compound adsorption on the membrane. It was demonstrated that feed water concentration influenced rejection efficiency of the membrane. Experiments conducted at a low ng/L concentration range resulted in lower rejection efficiency as compared to experiments conducted at a g/L range, suggesting the need to conduct experiments at the relevant concentration of interest.

Kiso Y, Kon T, Kitao T, Nishimura K. Rejection properties of alkyl phthalates with nanofiltration membranes. Journal of Membrane Science 2001;182(1-2):205-14.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-42810KY-N&_coverDate=02%2F15%2F2001&_alid=196217510&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=58852ac11f1b5dbb4257ff20b5645218
Keywords: Reverse osmosis/ Nanofiltration/ Organic separation/ Alkyl phthalates/ Water treatment
Abstract: We have examined the rejection properties of nanofiltration (NF) membranes for alkyl phthalates and other solutes such as mono-substituted benzenes, alcohols, and saccharides. In this study, four kinds of NF membranes were used, each with nominal desalting degree (NaCl rejection) of 91, 60, 51, and 15%, respectively. The membrane separation experiments were carried out with a bench scale batch type cell at room temperature. The rejection of alcohols and saccharides was mainly controlled by steric hindrance. We have found that molecular width is a useful descriptor to represent this effect. On the other hand, the rejection of aromatic compounds, alkyl phthalates and mono-substituted benzenes, was strongly affected by their hydrophobic properties (log *P*). Higher hydrophobic alkyl phthalates (log *P* > 4.7) were rejected at more than 99% even by the lowest desalting membrane. The highest desalting membrane rejected almost all alkyl phthalates at more than 96%. However, *p*-dimethyl phthalate and *p*-diethyl phthalate showed significantly lower rejection, from which it can be concluded that their molecular widths are close to those of mono-substituted benzenes, i.e. smaller than those of the other alkyl phthalates.

Kiso Y, Mizuno A, Atul Adawiah binti Othman R, Jung YJ, Kumano A, Ariji A. Rejection properties of pesticides with a hollow fiber NF membrane (HNF-1). Desalination 2002;143(2):147-57.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-4686NGP-K&_coverDate=05%2F20%2F2002&_alid=196210324&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=3ce971dd578a6c2bb9f383da0d9c0d7d
Keywords: NF membrane/ Hollow fiber membrane/ Pesticide/ Sorption/ Steric hindrance/ log

P

Abstract: NF membranes are potentially useful to remove residual hazardous organic pollutants such as pesticides and alkyl phthalates in drinking water treatment processes. In this study, the rejection properties of a hollow fiber NF membrane (HNF-1) for 8 kinds of pesticides were investigated using a bench scale cell: the membrane consisted of polyamide skin layer and polysulfone support membrane with a nominal desalting degree fo 35% at 0.3 MPa. In addition, hydrophilic organic compounds (molecular weight: 74.1–504.5), i.e. alcohols and saccharides, were also used as reference solutes. The hydrophilic compounds were rejected at rates of 9.0–97.8%, revealing that the molecular sieving effect was significant since the logarithm of solute permeability, log *B*, correlated linearly with the molecular width parameter, MWd, of the solute. Phenylic pesticides, such as alachlor, metolachlor, methoxychlor, and thiobencarb, were rejected at 88.7–99.3%. However, non-phenylic pesticides, such as aldicarb, simazine, atrazine, and pirimicarb, were rejected at lower degrees: 42.2–89.9%. The batch type sorption experiments indicated that all of the pesticides were adsorbed on the membrane, and the adsorption properties were controlled mainly by the hydrophobic property of the pesticides. Sorption properties based on solute recovery rates in the separation experiments, however, were different from those in the batch type experiments.

Kiso YSY, Kitao T, Nishimura K. Effects of hydrophobicity and molecular size on rejection of aromatic pesticides with nanofiltration membranes. Journal of Membrane Science 2001;192(1-2):1-10.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-43S6245-1&_coverDate=10%2F15%2F2001&_alid=195998287&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=a379b0d30356246431ab3dba9be0f99a

Keywords: Reverse osmosis/ Nanofiltration/ Organic separation / Water treatment/ Pesticide

Abstract: Membrane filtration is a promising technology to remove hazardous organic micro-pollutants, such as pesticides, dyes, and many other synthesized products. In our previous work we demonstrated that nanofiltration (NF) membranes can reject effectively non-phenylic pesticides and alkyl phthalates and that hydrophobilicty of these compounds is an important factor for membrane separation. In this work, we examine and report on the rejection properties of 11 kinds of aromatic pesticides by NF membranes (nominal NaCl rejection is 92, 60, 51 and 15%). The highest desalting membrane rejected all pesticides at > 92.4%, except tricyclazole. Although the other membranes showed lower rejections, some pesticides, such as isoxathion, chloroneb, and esprocarb, were rejected at very high rates (> 95%) by all membranes. All the pesticides are adsorbed on the membranes and the experiment indicates that adsorption properties were controlled by both hydrophobicity (*n*-octanol/water partition coefficient: log *P*) and molecular shape of the solute. The solute permeability of a pesticide for each membrane can be expressed as a linear combination of the following two factors: adsorption property on the membranes, and molecular width (MWd) of the solutes. We conclude that steric hindrance is an important factor for solute permeation even in the case of hydrophobic pesticides.

Kitis M, Lozier JC, Kim JH. Microbial removal and integrity monitoring of RO and NF membranes. American Water Works Association Journal 2003;95(12):105-19.

Keywords: Water microbiology/ Water filtration/ Nanofiltration/ Water purification, reverse-

osmosis process
Abstract: The authors assessed the integrity of reverse osmosis (RO) and nanofiltration (NF) membrane systems with respect to microbial passage through the membranes. This was done using bacteriophage MS2 viruses as a microbial source and Rhodamine WT (RWT) dye and fluorescent-dyed polystyrene microspheres as nonmicrobial surrogates. Microspheres were found to be the most accurate predictor of MS2 removal; however, RWT also demonstrated good correlation and this was particularly the case for RO. NF and RO elements that were compromised via a membrane pinhole demonstrated reduced removals for all surrogates, whereas a subsequent operation of these elements increased the surrogate removal levels. Based on the findings, it was concluded that conductivity rejection could not be used as an accurate indicator of viral rejection in high-pressure membranes, but that RWT could be a practical alternative for detecting imperfections in both RO and NF membranes relative to virus removal.

Kostal J, Mulchandani A, Gropp KE. A temperature responsive biopolymer for mercury remediation. Environmental Science and Technology 2003;37(19):4457-62.
Keywords: Adsorption, temperature effect/ Polypeptides/ Industrial waste, mercury content
Abstract: Tunable biopolymers based on elastin-like polypeptides (ELP) were engineered for the selective removal of mercury. ELP undergoes a reversible thermal precipitation within a wide range of temperatures and was exploited to enable easy recovery of the sequestered mercury. A bacterial metalloregulatory protein, MerR, which binds mercury with an unusually high affinity and selectivity, was fused to the ELP to provide the highly selective nature of the biopolymers. Selective binding of mercury was demonstrated at an expected ratio of 0.5 mercury/biopolymer, and minimal binding of competing heavy metals (cadmium, nickel, and zinc), even at 100-fold excess, was observed. The sequestered mercury was extracted easily, enabling continuous reuse of the biopolymers. In repeating cycles, mercury concentration was reduced to ppb levels, satisfying even drinking water limits. Utility of the biopolymers with mercury-contaminated Lake Elsinore water was demonstrated with no decrease in efficiency. The nanoscale biopolymers reported here using metalloregulatory proteins represent a "green" technology for environmentally benign mercury removal. As nature offers a wide selection of specific metalloregulatory proteins, this technology offers promising solutions to remediation of other important pollutants such as arsenic or chromium.

Koyuncu I, Turan M, Topacik D, Ates A. Application of low pressure nanofiltration membranes for the recovery and reuse of dairy industry effluent. Water Science and Technology 2000;41(1):213-21.
URL: http://www.iwaponline.com/wst/04101/wst041010213.htm
Abstract: This paper outlines the requirements for water reuse of dairy industry treatment plant effluents. Two alternative membrane processes are described. Nanofiltration (NF) membranes were applied to the existing treatment plant effluents in the first part of the study. NF membranes were used in different operating conditions. Successive batch runs had shown that serious membrane fouling appeared not to be a problem with treatment plant effluents. Excellent rejections have been achieved. It will be possible to recover approximately 90% of the treatment plant effluent for reuse. Heavy metal removal was also very high. In the second part of the study, two pass reverse osmosis (RO) membranes were applied to the raw wastewater of the dairy industry. RO experiments demonstrated that two-pass RO produce

permeate of very good quality. Almost complete COD removals were achieved and flux values decreased slightly during the each RO run.

Košutic K, Kunst B. Removal of organics from aqueous solutions by commercial RO and NF membranes of characterized porosities. Desalination 2002 ;142(1):47-56.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-45NT8C4-R&_coverDate=01%2F20%2F2002&_alid=195989864&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=be7adb06f2591a96efe452cb5d07fdb0
Keywords: Reverse osmosis/ Nanofiltration/ Membrane porosity/ Organic pollutants/ Pesticides/ Sieving / Physicochemical interactions
Abstract: Removal of organic pollutants of petrochemical and agrochemical origin by some commercial reverse osmosis (RO) and nanofiltration (NF) membranes of characterized porosity was investigated. The rejection of organics was shown to depend on both the membrane properties like pore size, membrane material, membrane charge and solute characteristics such as molecule size, charge and polarity. The rejection of the small nonionized organic molecules by the tight pore membranes is influenced by both the sieving parameters (solute and pore size) and by the physicochemical interactions. The rejection of the same pollutants by the wider pore membranes is dominantly influenced by the physicochemical interactions. The rejection of pesticides is prevalently governed by the sieving mechanism based on the size of the solute molecule and the membrane pore size. However, the physicochemical effects cannot be totally neglected, and they can contribute to the rejection of some pesticides by certain membranes.

Kurama HPJ, Haseneder R. The application of membrane filtration for the removal of ammonium ions from potable water. Water Research 2002;36(11):2905-9.
Keywords: Membrane filters/ Nanofiltration/ Water purification, reverse osmosis process
Abstract: It is well recognized that soluble ammonia and nitrite in drinking water has chronic effects on humans. Ammonia has potential environmental health hazards, particularly to young children. European Union Standards limit the concentration of ammonia to 0.5 mg/L in drinking water. In Eskisehir (Turkey) drinking and tap water are supplied from a water treatment plant, consisting mainly of screening, sedimentation, filtration and sterilization units and having a capacity of 80,000 m^3/d. Depend on the industrial and climatic effects the observed high ammonium concentration in treated water causes undesirable effects of water quality. Therefore, people in Eskisehir do not want to use tap water for drinking. The aim of the study was to evaluate the performance of membrane processes, i.e. Nanofiltration and reverse osmosis to the removal of ammonium and Ca ions from plant effluent and recommend one of them for a subsequent pilot plant application. Copyright (c) 2002 Elsevier Scien! ce Ltd.

Kwak SY, Kim SH, Kim SS. Hybrid organic/inorganic reverse osmosis (RO) membrane for bactericidal anti-fouling. 1. Preparation and characterization of TiO_2 nanoparticle self-assembled aromatic polyamide thin-film-composite (TFC) membrane. Environmental Science and Technology 2001;35(11):2388-94.
Keywords: Membrane filters, fouling/ Water purification, reverse-osmosis process/ Polyamides
Abstract: Hybrid organic/inorganic reverse osmosis (RO) membranes composed of aromatic

polyamide thin films underneath titanium dioxide (TiO_2) nanosized particles have been fabricated by a self-assembly process, aiming at breakthrough of biofouling problems. First, positively charged particles of the colloidal TiO_2 were synthesized by a sol-gel process, and the diameter of the resulting particles in acidic aqueous solution was estimated to be ~2 nm by analyzing the UV-visible absorption characteristics with a quantum mechanical model developed by Brus. Transmission electron microscopy (TEM) further confirmed the formation of the quantum-sized TiO_2 particles (~10 nm or less). The TiO_2 particles appeared to exist in the crystallographic form of anatase as observed with the X-ray diffraction (XRD) pattern in comparison with those of commercial 100% rutile and commercial 70:30% anatase-to-rutile mixture. The hybrid thin-film-composite (TFC) aromatic polyamide membranes were prepared by self-assembly of the TiO_2 nanoparticles on the polymer chains with COOH groups along the surface. They showed improved RO performance in which the water flux even increased, though slightly. Field-emission scanning electron microscopy (FESEM) exhibited the TiO_2 nanoparticles well adsorbed onto the surface. X-ray photoelectron spectroscopy (XPS) demonstrated quantitatively that a considerable amount of the adsorbed particles were tightly self-assembled at the expense of the initial loss of those that were loosely bound, and became stabilized even after exposure to the various washing and harsh RO operating conditions. The antibacterial fouling potential of the TiO_2 hybrid membrane was examined and verified by measuring the viable number and determining the survival ratios of the *Escherichia coli* (*E. coli*) as a model bacterium, both with and without UV light illumination. The photocatalytic bactericidal efficiency was remarkably higher for the TiO_2 hybrid membrane under UV illumination, compared to that of the same membrane in darkness, as well as those for the neat membranes under either light condition.

Lahlou M. Membrane filtration as an alternative: Part 2. Water Engineering and Management 2000;147(8):30-2.
Keywords: Membrane filters/ Water filtration/ Water purification, reverse-osmosis process
Abstract: The writer discusses the use of nanofiltration membranes and reverse osmosis systems in water treatment. Nanofiltration membranes have a pore size of about 0.001 microns and a molecular weight cut-off of 1,000–100,000 daltons. They require pressures of 600–1,000 kPa and remove virtually all cysts, bacteria, viruses, and humic materials. They also remove alkalinity and hardness. Reverse osmosis systems are compact and easy to operate and are suitable for small systems. In addition, they provide an absolute barrier, but have high operating costs.

Lapointe JF, Gauthier SF, Pouliot Y, Bouchard C. Effect of hydrodynamic conditions on fractionation of β-lactoglobulin tryptic peptides using nanofiltration membranes. Journal of Membrane Science 2003;212(1-2):55-67.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4742718-3&_user=10&_handle=B-WA-A-A-BU-MsSAYZA-UUW-AUEVZVVVYD-AUEWWWCWYD-CZUEUEZUD-BU-U&_fmt=summary&_coverDate=02%2F15%2F2003&_rdoc=5&_orig=browse&_srch=%23toc%235257%232003%23997879998%23377582!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ddfe32f6a2b308f905f84180ad793f1b
Keywords: Nanofiltration/ Peptide fractionation/ β-Lactoglobulin/ Membrane selectivity/ Concentration polarization

Abstract: Fractionation of a β-lactoglobulin (β-LG) peptide mixture by nanofiltration (NF) membranes was investigated. Peptide mixture was prepared by tryptic hydrolysis of commercial β-LG followed by ultrafiltration (UF) for enzyme removal. The peptide mixture (permeate) was further fractionated using an Osmonics-SG13 cellulose acetate NF membrane with a molecular weight cut-off (MWCO) of 2500 g mol^{-1}. The effect of hydrodynamic parameters on a "resistance-in-series" model and transmission of tracer peptides was studied at 0.5 wt.% hydrolysate concentration by varying the operating pressure (0.200 and 0.500 MPa), recirculation rate (0.17 and 0.29 m s^{-1}), and recirculation time (30 and 120 min). A detailed comparison on individual peptide transmission revealed that increasing recirculation time to 120 min, at lower recirculation rates, greatly affected peptides β-LG 102–105 and β-LG 142–148 at both operating pressures. Our results are indicative of important changes in NF selectivity as affected by hydrodynamic conditions and recirculation time via possible peptide–peptide interactions occurring in the so-called weakly attached layer.

Lastra A, Gómez DRJ, Francisco JL, Luque S, Álvarez JR. Removal of metal complexes by nanofiltration in a TCF pulp mill: technical and economic feasibility. Journal of Membrane Science 2004;242.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CVX4HN-1&_user=10&_handle=B-WA-A-B-BB-MsSAYWA-UUW-AUEVZWEUUE-AUEWWUEYUE-CZUZECZCU-BB-U&_fmt=summary&_coverDate=07%2F20%2F2004&_rdoc=18&_orig=browse&_srch=%23toc%235257%239999%23999999999%2399999!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=27d640c7fbd2e1c37c256fa5d9d50695
Keywords: Nanofiltration/ Metal complexes/ Water treatment/ Economics
Abstract: The goal of this work is to remove complexed metals by nanofiltration (NF) from a chelate (Q) stage effluent in a totally chlorine-free (TCF) bleaching plant, to permit recycle of the permeate as make-up water to the same bleaching stage. There are two main industrial benefits: (i) decreased consumption of fresh water in the pulp mill and (ii) an important reduction in the amount of effluent discharged. Two composite aromatic polyamide membranes from different manufacturers and a ceramic membrane (titanium oxide supported on zirconium oxide) were tested on a pilot scale at the pulp mill to assess the viability of the nanofiltration process for the industrial application. The effluent was fed directly to the membrane installation at a temperature of 80 C. The polymeric membranes exhibited better performance than the ceramic membrane in terms of rejection and fouling, but the permeation rates were comparable. Essentially complete rejection (99–100%) of iron and manganese was achieved for volume reduction factors up to 7. The recovery in the permeate stream is equivalent to 86% of the original wastewater. For a TCF plant with a capacity of 300,000 t air-dried pulp (AD)/year, the effluent that must be treated is ca. 300 m^3/h. In order to achieve 90% recovery and produce a permeate stream free of metals, a nanofiltration plant with a membrane area of about 2400 m^2 would be required. This plant implies a capital investment of 5.3 million € and a total cost (including capital and operating costs) of 6 €/t of pulp.

Ledoux MJ, Vieira R, Pham-Huu C, Keller N. New catalytic phenomena on nanostructured (fibers and tubes) catalysts. Journal of Catalysis 2003;216(1-2):333-42.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6WHJ-47VYKV7-2&_coverDate=06%2F30%2F2003&_alid=197932248&_rdoc=1&_fmt=&_orig=search&_qd

=1&_cdi=6852&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d31c277a292c9a58946a0f08dc18a900

Keywords: Nanotubes/ Nanofibers/ Composite/ Catalyst/ Confinement effect

Abstract: The recent development of new catalytic syntheses of carbon or carbide nanostructures has enabled the production of large amounts of these materials. Consequently, it is now possible to use them as supports for active phases in novel catalytic reactions and processes. New phenomena at the surface or inside these structures open up the way to unexpected applications. We shall first present the latest methods of preparation of these nanomaterials and their characterization and then provide some examples of applications in the fields of catalysis for synthesis of chemicals and catalysis applied to environmental remediation.

Lee D, Choi M. Coalescence enhanced synthesis of nanoparticles to control size, morphology and crystalline phase at high concentrations. Journal of Aerosol Science 2002;33(1):1-16.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V6B-4471G05-1&_coverDate=01%2F31%2F2002&_alid=199319597&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5810&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ffbb8c7134b06131bbbe03517fb76445

Keywords: Nanoparticles/ Laser irradiation/ Coalescence/ Size control

Abstract: Size, morphology, and crystalline phase of nanoparticles determine the properties of nanostructured materials. Therefore, the mastery of controlling properties ultimately requires the control of size, morphology, and phase of nanoparticles. From various aerosol methods, highly pure nanoparticles can be produced; however, agglomeration has been considered as almost unavoidable when nanoparticles are generated at high concentrations that are necessary for a practical application. Efforts to control agglomeration have had only limited success. Here we report that the enhancement of coalescence of nanoparticles using laser beam irradiation on aggregates formed in flames can be a solution for this problem and successfully controls the size, morphology, and crystalline phase of high concentration nanoparticles of silica and titania. We demonstrate this principle by not only synthesizing smaller and unagglomerated nanoparticles, but also generating them in high concentrations. In addition, we show that the present method is capable of even controlling the crystalline phase of titania nanoparticles. Surprisingly, stable rutile titania particles have been transformed into metastable anatase and the weight percent of each phase could be controlled.

Lee S, Amy G, Cho J. Applicability of Sherwood correlations for natural organic matter (NOM) transport in nanofiltration (NF) membranes. Journal of Membrane Science 2004;240(1-2):49-65.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CMYN2N-2&_user=10&_handle=B-WA-A-W-BU-MsSAYZA-UUW-AUEVCVWWDY-AUEWAWBUDY-CZUACDAZZ-BU-U&_fmt=summary&_coverDate=09%2F01%2F2004&_rdoc=6&_orig=browse&_srch=%23toc%235257%232004%23997599998%23510566!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=0c7c20148d512cd1208982eb835db2af

Keywords: Sherwood correlation/ NOM–NF system/ Mass transfer coefficient/ Combined film-thermodynamic model/ Pore Peclet number/ Diffusion coefficient

Abstract: A Sherwood correlation (mass transfer correlation) pertinent to natural organic matter nanofiltration (NOM–NF) systems was established through the determination of the mass transfer coefficient (k) based on a combined film/thermodynamic approach, under laminar flow conditions. In this study, the NOM transport characteristics inside a NF membrane were quantitatively demonstrated through the pore Peclet number (Pe) calculated from experimental data. Transport experiments were performed, using a plate-and-frame crossflow test unit, at various feed flow rates, with a thin-channel type test cell that could be adjusted to different channel heights. The transport experimental results, with Suwannee River NOM (SRNOM), show that the transport of the SRNOM through the NF membrane (denoted as ESNA, MWCO of 200–250) was dominated by diffusion, which was further confirmed by the determined pore Pe ($Pe < 1.0$). The Sherwood correlation established for the SRNOM and NF membrane under ambient conditions (neither pH nor ionic strength adjustment) exhibited the standard form: $Sh = 0.853Re^{0.550}Sc^{0.363}$. The k values calculated by the correlations (k_{Sh}) were in good agreement with those determined from the experiments (k_{exp}). However, significant discrepancy between the k_{Sh} and k_{exp} was observed with alterations in the feed water chemistry. The k_{Sh} value increased with either decreasing pH or increasing ionic strength, as the experimentally determined diffusion coefficient of the SRNOM increased under these condition, whereas, the k_{exp} exhibited opposite trends, due to the decreased water permeation (or suction) rate, increased NOM transmission and decreased electrostatic repulsion. The k values for other source water NOM (but with the same membrane) were also estimated by the Sherwood correlation coupled with diffusion cell tests. The discrepancy between the k_{Sh} and k_{exp} values was less than 20%, and the discrepancy decreased with increased feed flow rate.

Lhassani A, Rumeau M, Benjelloun D, Pontie M. Selective demineralization of water by nanofiltration application to the defluorination of brackish water. Water Research 2001;35(13):3260-4.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11487124
Abstract: Nanofiltration is generally used to separate monovalent ions from divalent ions, but it is also possible to separate ions of the same valency by careful application of the transfer mechanisms involved. Analysis of the retention of halide salts reveals that small ions like fluoride are the best retained, and that this is even more marked under reduced pressure when selectivity is greatest. The selectivity desalination of fluorinated brackish water is hence feasible and drinking water can be produced directly at much lower cost than using reverse osmosis by optimizing the pressure for the type of water treated.

Li D, Ma M. Nanosponges: From inclusion chemistry to water purifying technology. Chemtech 1999;29(5):31-7.
Keywords: Organic water pollutants/ Water purification/ Cyclodextrins
Abstract: Nanosponges that can be used in water purifying technology are reported. These nanosponges employ cyclodextrin as a fundamental building block, giving them an interconnected cagelike structure that can spontaneously absorb organic contaminants from water. Indeed, they are capable of removing organic contaminants at concentrations as low as 1–50 ppb, in which activated carbon essentially has no capability. This means that nanosponges are suitable for removing the high-priority, highly toxic contaminants that are the focus of current water treatment and environmental research. One potential application for these sponges is in the treatment of ultrapure water, which is required in semiconductor chip fabrication and manufacturing.

Li F, Vipulanandan C, Mohanty KK. Microemulsion and solution approaches to nanoparticle iron production for degradation of trichloroethylene. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2003;223(1-3):103-12.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFR-493276P-4&_coverDate=08%2F21%2F2003&_alid=197840831&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5233&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=a38c1ee95632ade0f16008c0aa003b47
Keywords: Microemulsion/ Iron/ Nanoparticle/ Degradation/ TCE
Abstract: In this study, nanoscale iron particles were synthesized using the microemulsion method and the properties were compared with the particles produced by the solution method. The nanoparticles were characterized by using the transmission electron microscope (TEM) and powder X-ray diffraction (XRD). The water-in-oil (w/o) microemulsion system was made up of n-octane, cetyltrimethyl-ammonium bromide (CTAB), butanol and water, and was characterized by measuring the conductivity of the solution and interfacial tension between the surfactant solution and the n-octane. The conductivity of the microemulsion system increased from about 10 μs cm^{-1} to over thousands of μs cm^{-1} with the addition of water. Interfacial tension between the n-octane and the CTAB aqueous solution was reduced to less than 6 dyn cm^{-1} with the addition of butanol, a co-surfactant used in this study. The average diameter of synthesized iron nanoparticles using the microemulsion method was less than 10 nm, which was much smaller than the particles produced by the solution method. The performance of the nanoiron produced in the laboratory was studied by dechlorinating trichloroethylene (TCE), a dense non-aqueous phase liquid (DNAPL) and listed as a priority pollutant by the US EPA. The degradation rate of TCE by the nano iron particles produced in the laboratory was quantified and compared with a commercially available nano iron product.

Li J, Chen C, Zhao J, Zhu H, Orthman J. Photodegradation of dye pollutants on TiO_2 nanoparticles dispersed in silicate under UV-VIS irradiation. Applied Catalysis B: Environmental 2002;37(4):331-8.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TF6-452FF4K-2&_coverDate=07%2F08%2F2002&_alid=198270166&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5218&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=89b1744786b339ded784214e7dd0c95a
Keywords: Titania/ Silicate/ SRB/ UV-VIS irradiation
Abstract: A novel catalyst, TiO_2 nanoparticles dispersed in silicate, were used to photodegrade sulforhodamine B (SRB) under UV-VIS irradiation. With good photocatalytic activity and the ability to be readily separated from the reaction system, this novel catalyst exhibits the potential to be effective in the treatment of dye pollutants in aqueous systems.

Li SL, Li C, Liu YS, Wang XL, Cao ZA. Separation of L-glutamine from fermentation broth by nanofiltration. Journal of Membrane Science 2003;222(1-2):191-201.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-49BY25C-1&_user=10&_handle=B-WA-A-A-BU-MsSAYVW-UUA-AUEVCDCWBU-AUEWACZUBU-CZUBAVYEY-BU-U&_fmt=summary&_coverDate=09%2F01%2F2003&_rdoc=17&_orig=browse&_srch=%23toc%235257%232003%23997779998%23451531!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=44c8d1c791aa11039aed77b50f5e9424

Keywords: L-Glutamine/ Physicochemical environment/ Fermentation broth
Abstract: Separation of L-glutamine (L-Gln) from Gln fermentation broth by nanofiltration (NF) was investigated with NTR7450 NF membrane. The effects of various experimental parameters such as transmembrane pressure, pH and concentration of broth on the rejection of L-Gln and L-glutamate (L-Glu) showed that NTR7450 was able to effectively separate L-Gln and L-Glu when the appropriate conditions were chosen. Moreover, the rejection of L-Gln and L-Glu in a single amino acid solution was also studied with the variation of pH, concentration, and physicochemical parameters. It was demonstrated that deviations in the rejection of fermentation broth from a single L-Gln or L-Glu solution were mainly caused by the complex ionic composition of the real fermentation broth.

Lien HL, Zhang WX. Nanoscale iron particles for complete reduction of chlorinated ethenes. Colloids and Surfaces A: Physicochemical and Engineering Aspects 2001;191(1-2):97-105.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFR-43N6VPY-9&_coverDate=10%2F31%2F2001&_alid=197891109&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5233&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=30418fe229e68eb3bba0b04d7438faf0
Keywords: Ground water/ Iron/ Nanoparticle/ Palladium/ Remediation/ PCE/ TCE/ DCE/ VC
Abstract: This paper examines the potential for using laboratory synthesized nanoscale Pd/Fe bimetallic particles to reduce chlorinated ethenes. Rapid and complete dechlorination was achieved for six chlorinated ethenes: tetrachloroethene (PCE, C_2Cl_4), trichloroethene (TCE, C_2HCl_3), 1,1-dichloroethene (1,1-DCE, $C_2H_2Cl_2$), *cis*- and *trans*-1,2-dichloroethene (c-DCE, t-DCE, $C_2H_2Cl_2$), and vinyl chloride (VC, C_2H_3Cl). The chlorinated ethenes (20 mg L^{-1}) were completely reduced within 90 min at a metal loading of 5 g L^{-1}. Ethane was the primary product from these reactions, amount to 60–90% of the total carbon. Ethene (3–20%) was produced during the transformation of TCE, DCEs and VC. No chlorinated intermediates or final products were detected above the method detection limit (<5 µg L^{-1}). The remarkable performance of the nanoscale particles can be attributed to: (1) High specific surface area of the nanoscale metal particles, approximately 35 m^2 g^{-1}, tens to hundreds of times higher than commercial grade micro- or milli-scale iron particles; (2) Increased reactivity per unit metal surface area, largely due to the presence of the noble metal (Pd) on the surface. Values of the surface-area-normalized rate coefficients (k_{SA}) were two orders of magnitude higher than those reported in the literature for larger iron particles. Due to their small particle size and high reactivity, the nanoscale bimetallic particles may be useful in a wide array of environmental applications including subsurface injection for groundwater treatment.

Lien HL, Zhang WX. Transformation of chlorinated methanes by nanoscale iron particles. Journal of Environmental Engineering 1999;125(11):1042-7.
Keywords: Zero valent iron technology/ Chloromethane
Abstract: An investigation of the use of laboratory synthesized nanoscale iron particles for the transformation of chlorinated methanes is presented. It was found that palladized particles facilitated the rapid transformation of tetrachloromethane and trichloromethane. The major end products of the transformations were methane and dichloromethane, respectively. For nanoscale iron particles and commercial grade iron particles the transformation rates were much slower.

Liikanen R, Miettinen I, Laukkanen R. Selection of NF membrane to improve quality of chemically treated surface water. Water Research 2003;37(4):864-72.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-47N7D7D-D&_coverDate=02%2F28%2F2003&_alid=195993648&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=cbb5f24885c1aae2c46e6c8c3040f555

Keywords: Commercial nanomembranes/ Nanofiltration/ Membranes/ Organics removal/ Drinking water

Abstract: The requirement for higher quality drinking water necessitates the application of more efficient water treatment techniques. Nanofiltration is one promising option for enhanced water treatment, for example, in enhanced organic matter removal. The characteristics of different nanofiltration membranes vary remarkably, and the selection of a membrane has to be made according to the requirements of an application. In this study six nanofiltration membranes (NF70, NF255, NTR-7450, NTR-7410, Desal-5 and TFC-S) were evaluated in improving the quality of chemically pre-treated surface water in a pilot-scale process. The results indicate that the membrane with high organics removal and slightly reduced ion removal characteristics (NF255) performed best in terms of product water quality as well as membrane productivity and fouling. The most permeable membrane (NTR-7410) suffered intensive fouling and insufficient product water quality. An interesting finding was that the permeates of all the tested membranes possessed a significant potential for microbial growth, despite the low nutrient contents.

Lin Y, Fryxell GE, Wu H. Selective sorption of cesium using self-assembled monolayers on mesoporous supports. Environmental Science and Technology 2001;35(19):3962-6.

Keywords: Cesium/ Groundwater pollution, radioactive pollution/ Water purification, ion-exchange process

Abstract: The synthesis of a novel nanocomposite sorbent material, copper ferrocyanide immobilized within a mesoporous ceramic matrix, and its use as a novel cesium sorbent material is reported in this paper. Complete removal of cesium was achieved in the presence of competing metal ions for solutions containing 2 ppm cesium under a variety conditions. Loading capacity of more than 1.35 mmol Cs per g of sorbent material has been achieved. The exceptionally fast binding kinetics and high loading capacity, resulting from the rigidly open pore structure and extremely high surface area of the sorbent materials, make them potentially very useful for the removal of cesium from nuclear wastes and contaminated groundwater.

Liu J-Q, Xu Z-L, Zhou K-G. Study on new method of the preparation of pure ammonium metatungstate (AMT) using a coupling process of neutralization–nanofiltration–crystallization. Journal of Membrane Science 2004;240(1-2):1-9.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CMW14B-1&_user=10&_handle=B-WA-A-W-BU-MsSAYZA-UUW-AUEVCVWWDY-AUEWAWBUDY-CZUACDAZZ-BU-U&_fmt=summary&_coverDate=09%2F01%2F2004&_rdoc=1&_orig=browse&_srch=%23toc%235257%232004%23997599998%23510566!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5fb76171b7b1557011794aeeec7e6c86

Keywords: Nanofiltration membrane/ Neutralization/ Crystallization/ Ammonium paratungstate/ Ammonium metatungstate

Abstract: Using a coupling process of neutralization–nanofiltration–crystallization, pure ammonium metatungstate (AMT) was prepared. The effects of chemical neutralization of ammonium paratungstate (APT) by nitric acid, operating pressure, AMT concentration, the volume of washing water on the coupling process were systematically discussed. It was found that the better conditions of AMT preparation were as follows: the neutralization temperature was 80–95 C, pH value was 2.0–3.5; the operating pressure of HDS-12-2 nanofiltration was 1.5–2.0 MPa, the density of AMT crystallization solution was 2.39 kg/L, and then cooling. APT conversion efficiency (δ) to AMT was more than 97.62%. The removal ratio of nitrate ion (NO_3^-) was more than 99% while AMT rejection (R_{AMT}) was 99.9%. Besides, small-grained, evenly proportioned, white-colored and highly purified AMT crystal was be obtained and analyzed. This method has several advantages such as simple technological process, short production cycle, lower environmental pollution and high quality.

McCormick ML, Adriaens P. Carbon tetrachloride transformation on the surface of nanoscale biogenic magnetite particles. Environ. Sci. Technol. 2004;38(4):1045-53.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14998017
Abstract: Iron-reducing conditions in subsurface environments promote dechlorination reactions via both biotic and abiotic pathways, the latter often mediated via biologically activated minerals formed by dissimilatory iron-reducing bacteria (DIRB). Here we report the major products and pathways associated with the abiotic transformation of carbon tetrachloride (CT) by nanoscale biogenic magnetite/maghemite particles produced by the DIRB *Geobacter metallireducens*. Product formation and free radical/carbene trapping studies indicate that CT transformation occurs via three parallel pathways. The first pathway (hydrogenolysis) results in the formation of chloroform (45-50%) via a trichloromethyl free radical ($*CCl_3$) and possibly a trichloromethyl carbanion ($**CCl_3^-$). The second and third pathways involve a dichlorocarbene intermediate ($**CCl_2$), which either hydrolyzes to form CO (approximately 38%) (carbene hydrolysis), or undergoes further reduction to yield methane (8-10%) (carbene reduction). The mechanism of methane formation from $**CCl_2$ is not known, but is speculated to involve a sequence of surface coordinated carbenoid and free radical complexes. The large fraction of relatively benign products formed by the carbene-mediated pathways suggests that magnetite/maghemite particles may have a beneficial application in the remediation of CT contaminated environments.

McShane MJ, Brown JQ, Guice KB, Lvov YM. Polyelectrolyte microshells as carriers for fluorescent sensors: Loading and sensing properties of a ruthenium-based oxygen indicator. Journal of Nanoscience and Nanotechnology 2002;2(3-4):411-6.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12908271&dopt=Abstract
Abstract: A strategy for the design and fabrication of microcapsule-based fluorescent biosensors containing indicators and internal references is described. The rationale for this work is the physical immobilization and chemical separation of assay chemistry for use in biological environments. Using the general approach of depositing oppositely charged species on colloidal micro/nanotemplates, a sensor system employing polyelectrolyte microshells for uptake of functional molecules is proposed, and experiments to demonstrate the feasibility of nanoengineering the sensor properties are described in the context of an oxygen sensor.

Methods for immobilization and entrapment of fluorescent indicator and reference dyes are shown, along with the pH dependence of this process. Embedded dyes are shown to be stable and retain their function, as demonstrated with oxygen-sensitivity experiments of loaded microcapsules. Although oxygen sensitivity is presented as an example of a specific application, the overall strategy is likely more generally useful. The work suggests that polyelectrolyte microshells may be used as a platform to develop novel sensors by entrapment of functional materials.

Miller LW, Tejedor Tejedor MI, Anderson MA. Titanium dioxide-coated silica waveguides for the photocatalytic oxidation of formic acid in water. Environmental Science and Technology 1999;33(12):2070-5.

Keywords: Formic acid, oxidation/ Industrial waste disposal, ultraviolet radiation treatment/ Silica films, testing

Abstract: Photooxidation of organic compounds on the surface of titanium dioxide (TiO_2) is a potential method of removing organic pollutants from water. By coating TiO_2 on transparent substrates and illuminating the catalyst with internally reflected light, it may be possible to increase the amount of illuminated photocatalyst in a given reactor volume. Planar, silica internal reflection elements (IREs) were coated with thin, porous, nanoparticulate films of TiO_2. UV-visible internal reflection spectroscopy was performed in order to determine that visible and near-UV light propagated through the modified IREs in an attenuated total reflection (ATR) mode. The TiO_2-coated IREs were employed in a photocatalytic reactor, and their ability to oxidize formic acid was assessed. Apparent quantum yields and quantum efficiencies of formic acid oxidation as a function of catalyst film thickness and incident angles of internally propagating UV light (310-380 nm) were determined. Quantum efficiency was enhanced when UV light propagated through the TiO_2-coated waveguide in an ATR mode. Photocatalytic reactors based on waveguide-supported TiO_2 films operating in an ATR mode may utilize light more effectively than reactors based on direct irradiance of TiO_2 and could facilitate the scale-up of photocatalytic oxidation processes for commercial remediation applications. Copyright 1999, American Chemical Society.

Minhalma M, Norberta de Pinho M. Integration of nanofiltration/steam stripping for the treatment of coke plant ammoniacal wastewaters. Journal of Membrane Science 2004;242.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CTN5PX-2&_user=10&_handle=B-WA-A-B-BB-MsSAYWA-UUW-AUEVZWEUUE-AUEWWUEYUE-CZUZECZCU-BB-U&_fmt=summary&_coverDate=07%2F15%2F2004&_rdoc=24&_orig=browse&_srch=%23toc%235257%239999%23999999999%2399999!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=6e03aac2e8d729544742c67fc7c773f4

Keywords: Ammoniacal wastewater treatment/ Nanofiltration

Abstract: Nanofiltration of ammoniacal wastewaters containing phenols and cyanide ions is investigated in order to obtain concentrate streams enriched in ammonium and phenol and permeate streams enriched in cyanide ions. This is achieved through the variation of the feed pH, when nanofiltration is run in concentration mode. The concentrate streams are further fractionated by steam stripping. The nanofiltration/steam stripping integrated process allows the confinement of ammonium, phenol and cyanides into three separate streams that can be further subjected to specific treatments. The nanofiltration experiments were carried out with model solutions and with coke plant ammoniacal wastewaters in a DSS plate-and-frame Lab-Unit M20, equipped with HR-98-PP membranes. The wastewaters concentration till recovery rates of 53% yields a pH variation ranging from 9.4 to 8.8. The decrease to a pH of 9.0 is associated with the preferential permeation of the cyanide ions. Further pH decrease favors the displacement of feed solute equilibria towards positively charged and neutral species and due to electroneutrality requirements the cyanide can no longer permeate through the membrane. The pH of 9.0 is obtained for a recovery rate of 40%, where the cyanide enrichment in the permeates is maximal. Based on the solution-diffusion model a *B* parameter is estimated as being equal to 7.77×10^{-7} (ammonium) and 6.03×10^{-8} m/s (phenol). For the cyanide ions its value varies with the feed composition.

Moeser GD, Roach KA, Green WH, et al. Water-based magnetic fluids as extractants for synthetic organic compounds. Industrial and Engineering Chemistry Research 2002;41(19):4739-49.
URL: http://pubs.acs.org/cgi-bin/abstract.cgi/iecred/2002/41/i19/abs/ie0202118.html
Keywords: Magnetic fluids/ Nanoparticles/ Adsorbents, regeneration/ Organic water pollutants
Abstract: This paper describes a class of water-based magnetic fluids that are specifically tailored to extract soluble organic compounds from water. These magnetic fluids are prepared by precipitation and consist of a suspension of ~7.5 nm magnetite (Fe_3O_4) nanoparticles coated with a ~9 nm bifunctional polymer layer comprised of an outer hydrophilic poly(ethylene oxide) (PEO) region for colloidal stability and an inner hydrophobic poly(propylene oxide) (PPO) region for solubilization of organic compounds. The particles exhibit a high capacity for organic solutes, with partition coefficients between the polymer coating and water on the order of 10^3–10^5, which is consistent with values reported for solubilization of these organics in PEO-PPO-PEO block copolymer micelles. In bench-scale experiments, high-gradient magnetic separation (HGMS) is able to recover the nanoparticles with 98% efficiency. Process options for particle regeneration in water purification applications are discussed.

Mänttäri M, Pekuri T, Nyström M. NF270, a new membrane having promising characteristics and being suitable for treatment of dilute effluents from the paper industry. Journal of Membrane Science 2004;242.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CYNWJB-3&_user=10&_handle=B-WA-A-B-BB-MsSAYWA-UUW-AUEVZWEUUE-AUEWWUEYUE-CZUZECZCU-BB-U&_fmt=summary&_coverDate=07%2F28%2F2004&_rdoc=14&_orig=browse&_srch=%23toc%235257%239999%23999999999%2399999!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=f64c3bd1d2891b0240fa1f9850818b22
Keywords: NF270/ Nanofiltration/ Characterisation/ Paper industry effluents/ Modules
Abstract: A good nanofiltration membrane for the paper mill waters is hydrophilic, having both high retention and high permeability, and it should be resistant to fouling and temperature increase. The membrane should also withstand alkaline and acidic cleaning and mechanical wear. Membranes having all these properties do not exit. Based on laboratory- and pilot-scale experiments, one promising membrane is the NF270 from Dow. The membrane is rather hydrophilic and it has fairly high retention and permeability. However, its resistance to temperature is not sufficient for all applications in the paper industry. By using this membrane or other similar NF membranes in the high-shear cross-rotational CR-filter fluxes above 100

L/(m^2 h) and retentions over 80% for conductivity and total carbon are obtainable with many rather dilute effluents from the paper industry.

Nguyen L, Kho R, Bae W, Mehra RK. Glutathione as a matrix for the synthesis of CdS nanocrystallites. Chemosphere 1999;38(1):155-73.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V74-3VRV0BN-D&_coverDate=01%2F31%2F1999&_alid=199679326&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5832&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5eea74a48b4381f4f0b45b939ad643f5
Keywords: Glutathione (GSH)/ Cadmium sulfide (CdS)/ Semiconductor nanocrystallites (NCs)/ Photocatalysis/ *p*-Nitrophenol
Abstract: GSH-capped CdS nanocrystallites were synthesized by reacting Cd(II)-GSH with aqueous sodium sulfide using specific initial sulfide/Cd(II) ratios. Spectroscopic analyses of fractions obtained from a size exclusion column showed varying absorption spectra indicating a significant dispersion in size-distribution of nanocrystallites at lower sulfide/Cd(II) ratios. However, size distribution of the nanocrystallites was narrower at initial sulfide/Cd(II) ratios that exceeded 1.0. An ethanol precipitation procedure was used to remove free Cd(II)-GSH complexes and selectively isolate GSH-capped nanocrystallites in a very narrow size range. Size exclusion chromatography indicated similar chemical compositions and overlapping spectral profiles of ethanol-precipitated samples suggesting apparent uniformity in both the size and the cap content. All of the GSH-capped CdS nanocrystallites with varying cap contents degraded *p*-nitrophenol upon irradiation at 366 nm. However, photocatalytic degradation of *p*-nitrophenol was significantly higher in samples with higher sulfide/Cd ratio and less capping material. The addition of H_2O_2 enhanced levels of photo-oxidation of *p*-nitrophenol.

Oh JI, Lee SH, Yamamoto K. Relationship between molar volume and rejection of arsenic species in groundwater by low-pressure nanofiltration process. Journal of Membrane Science 2004;234(1-2):167-75.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4BYR5TS-8&_user=10&_handle=B-WA-A-A-WV-MsSAYWA-UUW-AUEVCYUVVW-AUEWAZAWVW-CZUBVDDCB-WV-U&_fmt=summary&_coverDate=05%2F01%2F2004&_rdoc=18&_orig=browse&_srch=%23toc%235257%232004%23997659998%23491217!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=0d2e76b6b7163167f512e5f58c055bcf
Keywords: Arsenite/ Dimethyl arsinic acid/ Arsenate/ Nanofiltration/ Molar volume
Abstract: Rejection of arsenite, dimethyl arsinic acid (DMAA), arsenate, chloride, nitrate and sulfate ion by low-pressure nanofiltration was evaluated by the extended Nernst–Planck model coupled with steric hindrance and Donnan equilibrium. The partition coefficient of K_i for each solute was introduced to Donnan equilibrium. They could be obtained from the curve fitting with experimental rejection of solutes. In the case of anionic solutes such as $H_2AsO_3^-$, $H_2AsO_4^-$, $HAsO_4^-$, $(CH_3)_2AsO_2^-$, NO_3^- and SO_4^{2-}, the partition coefficient K_i was correlated with the molar volume. The empirical equation was obtained from the regression analysis between molar volume (V_A) and partition coefficient (K_i) of anionic solutes for ES10 ($K_i = 3100 V_A^{0.64}$), NTR729HF ($K_i = 930 V_A^{0.44}$) and NTR7250 ($K_i = 1800 V_A^{0.63}$). The effective range of molar volume for the equation was from 0.5×10^{-4} to 1.5×10^{-4} m^3/mol. The gradient value of the

regression line of K_i with molar volume in log scale was close to 2/3 for all membranes used. These results suggest that the interaction between anionic solute and membrane surface was affected mainly by the surface charge density corresponding to molar volume of ionic solute, although another factors need to be considered in order to account for a deviation from the 2/3.

Parmelee MA. Wider horizons. American Water Works Association Journal 2001;93(7):116.
Keywords: Sandia National Laboratories/ Water purification, arsenic removal/ Adsorbents
Abstract: Researchers at the Sandia National Laboratories in New Mexico have designed chemicals called specific anion nanoengineered sorbents (SANS) with arsenic-trapping properties. The new SANS could make the removal of arsenic from drinking water more affordable, especially for smaller communities. Other research at Sandia includes work on a dynamic water budget model, infrastructure security, and desalination.

Passanisi J. Project compares brackish water desalination technologies. Part 1. Water Engineering and Management 2002;149(2):14-7.
Keywords: Saline water conversion/ Water purification/ Reverse-osmosis process/ Nanofiltration
Abstract: The writer describes a project to compare the long-term performance and operating costs of three brackish water desalination technologies operated in Port Hueneme, California. The three technologies used at this state-of-the-art desalination facility are reverse osmosis, nanofiltration, and electrodialysis reversal. The three technologies are operated side-by-side to produce over 3 million gallons per day of high-quality drinking water. During the course of the plant's operation, the Port Hueneme Water Authority will collect data on long-term cost and performance characteristics of the three membrane systems.

Pastagia KM, Chakraborty S, DasGupta S, Basu JK, De S. Prediction of permeate flux and concentration of two-component dye mixture in batch nanofiltration. Journal of Membrane Science 2003;218(1-2):195-210.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-48TMF0H-5&_user=10&_handle=B-WA-A-A-WE-MsSAYWA-UUW-AUEVCDCVED-AUEWACZWED-CZUBAZDUC-WE-U&_fmt=summary&_coverDate=07%2F01%2F2003&_rdoc=15&_orig=browse&_srch=%23toc%235257%232003%23997819998%23436472!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5c01058e21119fda1ee7da8dbbd5320b
Keywords: Batch nanofiltration/ Permeate flux/ Permeate concentration/ Concentration polarization/ Dye separation / Modeling
Abstract: Modeling of separation of two-component dye mixture has been carried out in an unstirred bath cell. Nanofiltration of a two-component industrial dye-house effluent containing reactive black dye (Cibacron Black B, molecular weight 924.5) and reactive red dye (Cibacron Red RB, molecular weight 855.5) has been considered using a 400 molecular weight cut-off (MWCO) membrane. An unsteady-state mass transfer model is developed using an integral method to predict the permeate flux and the permeate concentration of each component. The experimental profiles of permeate concentration and permeate flux are optimized with the calculated profiles to estimate the model parameters. The predicted results using these optimized parameters are in good agreement with the experimental results.

Pastorino L, Disawal S, Nicolini C, Lvov YM, Erokhin VV. Complex catalytic colloids on the basis of firefly luciferase as optical nanosensor platform. Biotechnol Bioeng 2003;84(3):286-91.

URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12968282&dopt=Abstract

Abstract: In the present work, the layer-by-layer nano-assembly technique was used for the development of complex catalytic microparticles on the basis of firefly luciferase (FL). FL films containing 1, 2, or 3 monolayers were assembled on silver electrode QCM-resonators and on 520-nm diameter sulfonated polystyrene latex by alternate adsorption of FL and polycations using electrostatic interactions for the interlayer interaction. The assembly process was studied with quartz crystal microbalance, UV-vis spectroscopy, and microelectrophoresis (surface potential). Structural studies of the resulting multilayers confirmed stepwise deposition of FL and cationic poly(dimethyldiallyl ammonium chloride) with a bilayer thickness of 14 nm; a systematic shift of the surface potential from +28 mV for poly(dimethyldiallyl ammonium chloride) to -14 mV for luciferase outermost layer was established. The functionality and stability of the biocolloids were demonstrated by monitoring the intensity of the light emission. Factors influencing the light emitted upon catalytic activity of FL such as the number of luciferase layers in the film and polyion layer at the outermost layer were studied. Copyright 2003 Wiley Periodicals.

Erratum published in Biotechnol. Bioeng. 2004;86(3):374.

Paugam L, Taha S, Dorange G, Jaouen P, Quéméneur F. Mechanism of nitrate ions transfer in nanofiltration depending on pressure, pH, concentration and medium composition. Journal of Membrane Science 2004;231(1-2):37-46.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4BJX1D3-5&_user=10&_handle=B-WA-A-A-WZ-MsSAYZW-UUW-AUEVCBDYCC-AUEWAAYZCC-CZUABZZEW-WZ-U&_fmt=summary&_coverDate=03%2F01%2F2004&_rdoc=4&_orig=browse&_srch=%23toc%235257%232004%23997689998%23480747!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=038e5ee551015564cabc8ccd09d803ca

Keywords: Nanofiltration/ Nitrate/ Transport mechanism/ Operating pressure/ Ionic composition

Abstract: In this study, the retention of nitrate ions by a commercial nanofiltration membrane is investigated to highlight their transport mechanism. The influence of the operating pressure and the ionic composition (nature of the associated ion, feed concentration, pH and solution complexity) are studied. The separation performance should be the result of dual forces: a global surface force (friction, electrostatic) which retains the solute in the pore and a global convective force directed towards the retentate which depends on the applied pressure. In binary solutions, surface force depends on the hydration energy of the associated cation as well as membrane–solute electrostatic interactions. In ternary mixtures, we underscored the influence of solute–solute interactions (Donnan effect). The observations made with simple nitrated solutions (binary and ternary) were extrapolated and confirmed in experiments made on polluted or nitrate-doped waters.

Peeva LG, Gibbins E, Luthra SS, White LS, Stateva RP, Livingston AG. Effect of concentration polarisation and osmotic pressure on flux in organic solvent nanofiltration. Journal of Membrane Science 2004;236(1-2):121-36.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4C82C1S-1&_user=10&_handle=B-WA-A-A-WD-MsSAYVW-UUA-AUEVCYVEED-AUEWAZCDED-CZUBDCEBY-WD-U&_fmt=summary&_coverDate=06%2F15%2F2004&_rdoc=12&_orig=browse&_srch=%23toc%235257%232004%23997639998%23499913!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b34ee26fb3b6728838fb2991cd6bcd92

Keywords: Solvent nanofiltration/ Concentration polarisation/ Osmotic pressure/ Solution diffusion/ Activity coefficients

Abstract: The separation of molecules present in organic solvents by nanofiltration has potential application in several industries, and organic-solvent-stable nanofiltration (NF) membranes have recently become available. There is a rapidly growing body of information available on the processes controlling solvent fluxes and solute rejections in solvent nanofiltration. However, previous work has mainly been carried out with dilute solutions (<1 wt.% solute in solvent), whereas in actual applications, solutes will be more concentrated (>5 wt.%) and phenomena such as concentration polarisation and osmotic pressure may contribute to the solvent flux, as in aqueous systems. In order to improve our understanding of organic solvent nanofiltration phenomena, experiments were performed in a cross-flow rig in which NF was carried out in a continuous mode. Solutions of different concentrations (up to 20 wt.%) of tetraoctylammonium bromide and docosane in toluene were used. Description of the experimental data, including prediction of solute rejection, was performed using the solution diffusion model for membrane transport and the film theory for liquid mass transfer effects. The results show that the organic systems cannot always be described by a simple osmotic pressure model. The flux through the membrane is affected by the cross-flow velocity, indicating that concentration polarisation induces mass transfer limitations. The fit between the model and the experimental data is markedly improved by allowing the activities of the solution components to vary, indicating that these systems are non-ideal.

Peng W, Escobar IC. Rejection efficiency of water quality parameters by reverse osmosis and nanofiltration membranes. Environmental Science and Technology 2003;37(19):4435-41.

Keywords: Water quality, statistical methods/ Nanofiltration/ Water purification, reverse-osmosis process

Abstract: The objective of this study was to evaluate the effectiveness of reserve osmosis (RO) and nanofiltration (NF) membranes, under various solution chemistries, on water quality. The effects of organic carbon, divalent and monovalent cations, bacteria, and permeate drag on the rejection efficiencies of three different membranes were investigated through a series of laboratory bench-scale experiments. Quantitative models were successfully developed to predict the rejection of turbidity, divalent and monovalent cations, ultraviolet absorbance at 253.7 nm (UV254), and dissolved organic carbon (DOC) by membrane filtration. It was found that mechanical sieving (measured as molecular weight cutoff, MWCO) and electrostatic interactions were the most significant parameters since they were found to be important in nearly all models developed. For negatively charged membranes, under high ionic strength solution environments that repress electrostatic interaction between charged compounds and membranes, passage of compounds was mainly a function of size exclusion (i.e. MWCO). Further, of the feedwater parameters tested, bacteria concentration was observed to be the most significant influence on UV254, divalent cation and monovalent cation rejections. The developed models revealed that interactions between feedwater composition and membrane

properties impacted the rejection efficiency of membranes as significantly as water composition and membrane properties individually. Reprinted by permission of the publisher.

Platt S, Nyström M, Bottino A, Capannelli G. Stability of NF membranes under extreme acidic conditions. Journal of Membrane Science 2004;239(1):91-103.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CC7W4G-2&_user=10&_handle=B-WA-A-W-AD-MsSAYZA-UUW-AUEVZWYZZE-AUEWWUEVZE-CZUZEWBYU-AD-U&_fmt=summary&_coverDate=08%2F01%2F2004&_rdoc=10&_orig=browse&_srch=%23toc%235257%232004%23997609998%23506761!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=1b1f21f94f3ddb1da312bd2dae34be6e
Keywords: Commercial nanomembrane/ Nanomembrane, companies
Abstract: Two commercial nanofiltration (NF) membranes (FilmTec NF-45 and Desal-5 DK) and two new NF-1 membranes made by BPT (Bio Pure Technology) for the purpose of a European Union funded research project (RENOMEM) were tested under extreme acidic conditions. The polyethersulphone (PES) ultrafiltration (UF) supports used for casting the BPT-NF-1 membranes were also tested under similar conditions. The 006 and 015 UF supports were found to be stable in 5% nitric acid at 20 and 80 C for 4 and 3 months, respectively. Both supports (006 and 015) showed a significant reduction in flux after immersion in sulphuric acid at both temperatures. The BPT-NF-1 membranes showed excellent resistance to 20% sulphuric acid for up to 4 months at 20 C but were attacked by the nitric acid solution. The resistance of the two commercial membranes in 20% sulphuric acid at 20 C was generally lower than that of the BPT-NF-1 membranes. The NF-45 membrane was slightly more stable in 5% nitric acid at 20 C. Degradation of the membrane occurred only after 2 months while both the Desal-5 DK and BPT-NF-1 membranes degraded during the first month. At the higher temperature of 80 C in 5% nitric acid all membranes degraded in the first month. The cause of membrane degradation was attributed to oxidation of the thin NF selective skin layer in nitric acid and to acid-catalysed hydrolysis of this layer in sulphuric acid. Knowing the cause of membrane degradation is a step forward in developing a better and more stable nanofiltration membrane.

Ponder SM, Darab JG, Mallouk TE. Remediation of Cr(VI) and Pb(II) aqueous solutions using supported, nanoscale zero-valent iron. Environmental Science and Technology 2000;34(12):2564-9.
Keywords: Chromium reduction/ Lead reduction/ Zero-valent-iron technology
Abstract: Borohydride reduction of an aqueous iron salt in the presence of a support material gives supported zero-valent iron nanoparticles that are 10-30 nm in diameter. The material is stable in air once it has dried and contains 22.6% iron by weight. The supported zero-valent iron nanoparticles ("Ferragels") rapidly separate and immobilize Cr(VI) and Pb(II) from aqueous solution, reducing the chromium to Cr(III) and the Pb to Pb(0) while oxidizing the Fe to goethite (α-FeOOH). The kinetics of the reduction reactions are complex and include an adsorption phase. About 10% of the iron in the material appears to be located at active surface sites. Once these sites have been saturated, the reduction process continues but at a much lower rate, which is likely limited by mass transfer. Rates of remediation of Cr(VI) and Pb(II) are up to 30 times higher for Ferragels than for iron filings or iron powder on a (Fe) molar basis. Over 2 months, reduction of Cr(VI) was 4.8 times greater for Ferragels than for an equal weight of

commercial iron filings (21 times greater on the basis of moles of iron present). The higher rates of reaction, and greater number of moles of contaminant reduced overall, suggest that Ferragels may be a suitable material for in situ remediation.

Reisch MS. Essential minerals. Chemical and Engineering News 2003;81(13):13-4.
URL: http://pubs.acs.org/subscribe/journals/cen/81/i13/toc/toc_i13.html
Keywords: Titanium oxides, analysis/ Nanoparticles/ Filler materials
Abstract: Although manufacturers already use titanium dioxide (TiO_2) to make products as diverse as paper, plastics, lipstick, toothpaste, and pharmaceutical tablets, nanosized particles of TiO_2 in the 10 to 50 nm range take on unusual properties that chemists and chemical engineers are attempting to exploit, with varying degrees of success. These chemists have imagined and produced self-cleaning window glass, air and water purification systems, and antibacterial coatings by exploiting the photocatalytic properties of such partides. Moreover, engineers have modified them to remove nitrogen oxides from powerplant exhausts, and they are examining ways to use these environmental catalysts to treat diesel vehicle emissions. The market for titanium dioxide is examined.

Reynolds TK, Breeze DA, Thompson CM. Improving water quality by desalinating brackish groundwater. Public Works 1997 Apr;128:44-5.
Keywords: Saline water conversion/ Groundwater remediation technologies
Abstract: The Port Hueneme Water Agency in California has developed a cost-effective approach that will allow desalinated groundwater to be blended with imported surface water, thereby providing area residents with a high-quality water supply. The main component of this approach is a desalination plant that uses three different desalination technologies to treat brackish local groundwater. The use of these reverse osmosis, nanofiltration, and electrodialysis reversal technologies in parallel will result in the production of 3 mgd [million US gallons per day] of high-quality water.

Robinson JP, Tarleton ES, Millington CR, Nijmeijer A. Solvent flux through dense polymeric nanofiltration membranes. Journal of Membrane Science 2004 ;230(1-2):29-37.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4BFPDNT-1&_user=10&_handle=B-WA-A-A-WC-MsSAYZA-UUW-AUEVZWEEVZ-AUEWWAUDVZ-CZUDUVZDZ-WC-U&_fmt=summary&_coverDate=02%2F15%2F2004&_rdoc=4&_orig=browse&_srch=%23toc%235257%232004%23997699998%23476875!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=cd34da9fe2191a8c8bce6b0cafea9745
Keywords: Nanofiltration/ Membrane/ PDMS/ Organic solvents
Abstract: This work examines the flux performance of organic solvents through a polydimethylsiloxane (PDMS) composite membrane. A selection of *n*-alkanes, *i*-alkanes and cyclic compounds were studied in deadend permeation experiments at pressures up to 900 kPa to give fluxes for pure solvents and mixtures between 10 and 100 L m^{-2} h^{-1}. Results for the chosen alkanes and aromatics, and subsequent modelling using the Hagen–Poiseuille equation, suggest that solvent transport through PDMS can be successfully interpreted via a predominantly hydraulic mechanism. It is suggested that the mechanism has a greater influence at higher pressures and the *modus operandi* is supported by the non-separation of binary solvent mixtures and a dependency on viscosity and membrane thickness. The effects of

swelling that follow solvent–membrane interactions show that the relative magnitudes of the Hildebrand solubility parameter for the active membrane layer and the solvent(s) are a good indicator of permeation level. Solvents constituting a group (e.g. all *n*-alkanes) induced similar flux behaviours when corrections were made for viscosity and affected comparable swelling properties in the PDMS membrane layer.

Rodriguez AFR, Oliveira AC, Rabelo D, Lima ECD, Morais PC. Magnetic susceptibility investigation of magnetic nanoparticles in styrene-divinylbenzene mesoporous template. Journal of Magnetism and Magnetic Materials 2002 Nov;252:77-9 .
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TJJ-46NX4GV-18&_coverDate=11%2F30%2F2002&_alid=198261652&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5312&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=e48e0f1acbff4cfa35374facb7c4f295
Keywords: Composites/ Magnetite/ Susceptibility
Abstract: In this study, dynamical susceptibility (DS) was used to investigate magnetite-based composites. The field dependence of peaks observed in the DS curves was analyzed within the picture of an asymmetric double well potential for the relaxation of the magnetic moment associated with the magnetite nanoparticle. Parameters obtained from the analysis of the DS data indicate that a different magnetite structure, build up from isolated nanoparticles, explains the features observed in the susceptibility curves.

Sato Y, Kang M, Kamei T. Performance of nanofiltration for arsenic removal. Water Research 2002;36(13):3371-7.
Keywords: Drinking water, contamination/ Water purification, arsenic removal/ Nanofiltration/ Sand filters, design
Abstract: Performance of rapid sand filtration inter-chlorination system was compared with nanofiltration (NF) to reduce the arsenic health risk of drinking water. It was found that rapid sand filtration with inter-chlorination is not effective in removing arsenic. If total arsenic concentration in raw water is below 50 mg/L regardless of the turbidity of raw water, arsenic can be removed below WHO guideline value of 10 mg/L by conventional coagulation (polyaluminum chloride dosage is about 1.5 mg Al /L). However, if the raw water arsenic concentration exceeds 50 mg/L, more coagulant dosage or enhanced coagulation is needed. To adopt optimum coagulant dosage for arsenic removal, it needs to monitor raw water arsenic concentration, but it is difficult because arsenic measurement is time consuming. In addition, if raw water contains As(III), it is difficult for rapid sand filtration inter-chlorination system to meet an arsenic maximum contaminant level of 2 mg/L, which would achieve reduction of cancer risk below 10^{-4} . On the other hand, the NF membrane (NaCl rejection 99.6%) could remove over 95% of As(V) under relatively low-applied pressure (<1.1MPa). Furthermore, more than 75% of As(III) could be removed using this membrane without any chemical additives, while trivalent arsenic could not be removed by rapid sand filtration system without pre-oxidation of As(III) to As(V). Because both As(V) and As(III) removals by NF membranes were not affected by source water composition, it is suggested that NF membrane can be used in any types of waters. Copyright 2002 Elsevier Science Ltd.

Sawamoto S, Ohya H, Yanase K, Semenova SI, Aihara M, Takeuchi T, et al. Nanotechnological method to control pore diameter of organic–inorganic composite membrane: Part II.

Molecular-wise vapor polymerization (MVP). Journal of Membrane Science 2000;174(2):151-9.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-40J1FCY-1&_coverDate=07%2F31%2F2000&_alid=193098832&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=46fa6f57ad4c34457f92f4961b105902
Keywords: Nanotechnology/ Organic–inorganic composite membrane/ Polyimide/ Molecular-wise vapor polymerization/ Gas
Abstract: Polyimide-alumina composite membranes were fabricated by the molecular-wise vapor polymerization (MVP) technique of copolymer which has a constant repeating unit chemically bound by primer on the wall and/or surface of the porous ceramic support. By changing the flow rate of N_2 carrier gas and the repeating number (*n*), the fabricated pyromellitic dianhydride (PMDA)–diaminodiphenylether (ODA) composite membranes have separation factor $\alpha_{CO2/CH4}$ in the range 0.87–16.0. The estimation of pore diameter was carried out by N_2 permeance and estimated pore diameter was controlled in the range 38–263 nm.

Scarpello JT, Nair D, Freitas dos Santos LM, White LS, Livingston AG. The separation of homogeneous organometallic catalysts using solvent resistant nanofiltration. Journal of Membrane Science 2002;203(1-2):71-85.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-44SK79S-5&_coverDate=06%2F30%2F2002&_alid=195994880&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=00f176dbcf9aaf749e7ebeceba79311e
Keywords: Solvent resistant nanofiltration/ Waste minimisation/ Catalyst recycle/ Membrane separation/ Catalyst separation
Abstract: The non-destructive separation of homogeneous catalysts from organic solutions, allowing catalyst recycle, would be of considerable interest in commercial organic synthesis. Many of the catalysts are of high value, and the destructive separation methods currently employed often generate substantial amounts of waste. A study designed to test the potential of solvent resistant nanofiltration to achieve such separations is reported. An investigation was conducted into the nanofiltration of three organometallic catalysts commonly used in commercial organic synthesis (the Jacobsen catalyst, the Wilkinson catalyst and Pd-BINAP) from a selection of organic solvents (ethyl acetate, tetrahydrofuran and dichloromethane) using a range of polymeric solvent resistant membranes (W.R. Grace, STARMEM™ series; Osmonics, Desal-5; Koch Membrane Systems, MPF-50). The compatibility of the solvent–membrane combinations (membrane stability in solvent plus non-zero solvent flux at 2.0 MPa) was assessed. The solvent flux and membrane rejection of catalyst was then determined for each compatible catalyst–solvent–membrane combination in a dead-end pressure cell. Good catalyst rejection (>0.95) coupled with good solvent fluxes (>50 L m^{-2} h^{-1} at 2.0 MPa) were obtained in the majority of systems tested, indicating that the technology has considerable potential in this area. An extension of the investigation to assess the effect of pressure, temperature, and catalyst concentration was conducted on a selection of the most successful catalyst–solvent–membrane systems. Trends in the variation of solvent flux and catalyst rejection with variation of these parameters were identified. Increasing pressure substantially improved both solvent flux and catalyst rejection, whilst increasing catalyst concentration was found to be beneficial in terms of substantial increases in catalyst rejection without

significantly affecting solvent flux. Increasing temperature generally resulted in improved solvent fluxes but lower catalyst rejection.

Seiss M., Gahr A., Niessner R. Improved AOX degradation in UV oxidative waste water treatment by dialysis with nanofiltration membrane. Water Research 2001;35(13):3242-8.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-447G39N-W&_coverDate=09%2F30%2F2001&_alid=242568984&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b9edca2a6c9f86d502bf880bdea9117d
Keywords: Advanced oxidation process/ UV/ Ozone/ Photochemical degradation/ Wastewater/ Adsorbable organic halogenated compounds (AOX)/ Nanofiltration/ Total organic compounds (TOC)
Abstract: In this article, the wastewater treatment by UV oxidation with and without preceding desalination is compared. The influence of different chloride concentrations on the TOC degradation and AOX concentration is analyzed. Nanofiltration membrane dialysis is used to separate the chloride ions from wastewater. It is demonstrated that a reduction of the chloride concentration leads to a faster TOC degradation compared to the treatment of non-desalinated wastewater. Furthermore, the additional formation of AOX during the process could be avoided, in effect leading to a significant degradation of native AOX.

Sharma RR, Agrawal R, Chellam S. Temperature effects on sieving characteristics of thin-film composite nanofiltration membranes: Pore size distributions and transport parameters. Journal of Membrane Science 2003;223(1-2):69-87.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-49H1MXG-2&_user=10&_handle=B-WA-A-A-WB-MsSAYWW-UUA-AUEVCDCAAZ-AUEWACCEAZ-CZUBAVABY-WB-U&_fmt=summary&_coverDate=09%2F15%2F2003&_rdoc=7&_orig=browse&_srch=%23toc%235257%232003%23997769998%23462829!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=c8dbea100aaad52bef8b0adc83d2792d
Keywords: Thin-film composite membranes/ Nanofiltration/ Transport phenomena
Abstract: Cossflow filtration experiments were performed to measure transport of water and hydrophilic neutral organic solutes spanning a range of molecular sizes across two commercial thin-film composite nanofiltration (NF) membranes in the temperature range 5–41 C. Non-viscous contributions to activation energies of pure water permeation across these polymeric membranes were calculated to be 3.9 and 6.4 kJ mol^{-1}. Analysis of solute rejection using a phenomenological model of membrane transport revealed that sizes of pores that contributed to rejection followed a lognormal distribution at any given temperature. Additionally, increasing temperature increased mean pore radii and the molecular weight cutoff suggesting changes in the structure and morphology of the polymer matrix comprising the membrane barrier layer. Consistent with the free volume theory of activated gas transport, activation energies of neutral solute permeability in aqueous systems also increased with Stokes radius and molecular weight indicating their hindered diffusion in membrane pores. All activation energies for pore diffusion calculated in this study were greater than just the viscous contribution to bulk diffusion demonstrating hindered transport across the nanofiltration membranes. Finally, similar to gas transport across zeolites and rubbers, the activation energy and the Arrhenius pre-exponential factor for hindered diffusion coefficients increased with solute size and were

highly correlated with each other.

Shetty GR, Chellam S. Predicting membrane fouling during municipal drinking water nanofiltration using artificial neural networks. Journal of Membrane Science 2003;217(1-2):69-86.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-48F5KBJ-1&_user=10&_handle=B-WA-A-A-BB-MsSAYVA-UUW-AUEVCDCCEC-AUEWACZBEC-CZUBADBBD-BB-U&_fmt=summary&_coverDate=06%2F01%2F2003&_rdoc=8&_orig=browse&_srch=%23toc%235257%232003%23997829998%23433144!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5f02c7efaf53b554f116a66b4a7e08c7
Keywords: Water treatment/ Nanofiltration/ Fouling/ Neural networks/ Modeling
Abstract: A robust artificial neural network (ANN) model, requiring minimal training, closely predicted membrane fouling during nanofiltration (NF) of ground and surface water. Neural networks accurately simulated the total resistance to water permeation across NF membranes during bench-scale experiments with flat membrane sheets, tests with single spiral-wound elements, as well as pilot- and full-scale tests with multiple spiral-wound elements arranged in two stages. ANN inputs included physically meaningful and independent variables, including flow rates and feed water quality parameters (pH, UV_{254}, and total dissolved solids (TDS)) that are commonly monitored during water treatment, thereby facilitating their implementation. Therefore, under the experimental conditions investigated, colloidal fouling and biofouling appeared to be negligible because accurate ANN predictions were possible without using feed water turbidity and bacteria concentrations as inputs. One emphasis during this work was to minimize the data employed for ANN training while simultaneously performing simulations in purely predictive mode for entire cycles (experiments). Cumulatively, using only 10% of experimental data for ANN training allowed prediction of 93% of them with <5% absolute relative error. Hence, simple-to-implement ANNs are capable of capturing changes in feed water quality, flux, and recovery and can successfully overcome difficulties associated with mechanistic models to accurately predict long-term fouling during municipal drinking water nanofiltration.

Shetty GR, Malki H, Chellam S. Predicting contaminant removal during municipal drinking water nanofiltration using artificial neural networks. Journal of Membrane Science 2003;212(1-2):99-112.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4778D7B-4&_user=10&_handle=B-WA-A-A-BU-MsSAYZA-UUW-AUEVZVVVYD-AUEWWWCWYD-CZUEUEZUD-BU-U&_fmt=summary&_coverDate=02%2F15%2F2003&_rdoc=9&_orig=browse&_srch=%23toc%235257%232003%23997879998%23377582!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=aefcfc8ccbd2e2c4cac8fdc630ac3cd4
Abstract: An artificial neural network model for steady-state contaminant removal during nanofiltration of ground and surface waters under conditions typical of drinking water treatment is derived and validated. Operating conditions such as flux, feed water recovery, and element recovery (surrogate for cross-flow velocity), and feed water quality parameters including pH, total dissolved solids concentration (surrogate for ionic strength), target contaminant concentration, and where possible the diffusion coefficient were used as inputs to predict the ratio of permeate to feed concentration of the target contaminant. Contaminants

reported herein include dissolved organic carbon, precursors to total organic halide, four trihalomethanes and nine haloacetic acids containing chlorine and bromine, hardness, alkalinity, and total dissolved solids. Additionally, source waters from seven different locations and two commercial thin-film composite membranes operating in a wide range of permeate fluxes and feed water recoveries were considered. Deterministic and pseudostochastic simulations showed that artificial neural networks closely predicted permeate concentrations of each one of these organic and inorganic contaminants. Therefore, neural networks can be used to circumvent difficulties associated with formulating and solving the highly non-linear Nernst–Planck equation to calculate solute removal from multi-component solutions at high recovery. Moreover, neural networks can predict the transport of heterogeneous and difficult to characterize water treatment contaminants such as natural organic matter and disinfection by-product precursors, whose physicochemical properties are unknown. Such models can be used to screen membranes prior to conducting expensive large-scale tests as well as in the better design and interpretation of data obtained from site-specific water treatment nanofiltration studies conducted in support of plant design.

Song W, Ravindran V, Koel BE, Pirbazari M. Nanofiltration of natural organic matter with H_2O_2/UV pretreatment: Fouling mitigation and membrane surface characterization. Journal of Membrane Science 2004;241(1):143-60.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CY0209-6&_user=10&_handle=B-WA-A-W-AZ-MsSAYVA-UUW-AUEVZWAUAV-AUEWWUAYAV-CZUZWEYEY-AZ-U&_fmt=summary&_coverDate=09%2F15%2F2004&_rdoc=12&_orig=browse&_srch=%23toc%235257%232004%23997589998%23512135!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b79f4af92428c380ea560100d14076c3
Keywords: Nanofiltration/ Membrane fouling/ Surface characterization/ Hydrogen peroxide/ Ultraviolet radiation/ Natural organic matter/ Advanced oxidation
Abstract: This research investigated the application of H_2O_2/UV oxidation for source water pretreatment, and membrane cleaning to improve the performance of nanofiltration processes. It further examined the nature and mechanisms of membrane fouling by natural organic matter (NOM), and membrane cleaning using different chemical agents, by employing several surface characterization techniques. These techniques included attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR), X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), and scanning electron microscopy (SEM). The study revealed that significant improvement could be achieved in the efficiency and economics of nanofiltration for removing NOM and synthetic organic chemicals (SOCs) by employing source water pretreatment and membrane cleaning strategies. The H_2O_2/UV oxidation of source water prior to nanofiltration showed potential for the following: (i) mitigation of flux decline due to membrane fouling, (ii) removal of the pesticide alachlor and hydrogen sulfide, and (iii) improvement in membrane cleanability. Nonetheless, careful control of the preoxidation conditions was exercised to arrive at a reasonable compromise between fouling mitigation and NOM rejection.

Stanton BW, Harris JJ, Miller MD, Bruening ML. Ultrathin, multilayered polyelectrolyte films as nanofiltration membranes. Langmuir 2003;19(17):7038-42.
URL: http://pubs.acs.org/cgi-bin/abstract.cgi/langd5/2003/19/i17/abs/la034603a.html

Abstract: This study shows that alternating polyelectrolyte deposition on porous supports can yield nanofiltration membranes that allow high water flux along with selective ion transport. Membranes composed of 4.5-5 layer pairs of poly(styrene sulfonate)/poly(allylamine hydrochloride) (PSS/PAH) on porous alumina allow water fluxes of 1-2 m^3 m^{-2} day^{-1} at 4.8 bar while exhibiting $MgSO_4$ rejections of 96%. Rejections of $CaCl_2$ and Na_2SO_4 depend on polyelectrolyte deposition conditions and the composition of the outer layer of the membrane. In general, divalent-ion rejection increases when the charge of the outer layer of the membrane has the same sign as the divalent ion being rejected. Increasing the concentration of the supporting electrolyte present during deposition of the terminating PSS layer of PSS/PAH membranes results in a higher surface charge, and hence higher Na_2SO_4 rejections (up to 95%). Nanofiltration with mixed solutions of NaCl and Na_2SO_4 yields Cl^-/SO_4^{2-} selectivities of about 30 when the top layer of PSS/PAH membranes is deposited from a solution of high ionic strength. Capping PSS/PAH films with a layer of PAA increases Cl^-/SO_4^{2-} selectivities to values as high as 80. Interestingly, Cl^-/SO_4^{2-} selectivities in mixed solutions are higher than those determined from single-salt measurements, presumably because diffusion potentials are different in the two cases. The high selectivities, water fluxes, and ion rejections of PSS/PAH membranes make them potentially attractive for applications in water and salt purification.

Suratt WB, Brown DR, St. John G. At work in drinking water plants: Membrane technology, Part 2. Public Works 1998;129(1):65-7.
Keywords: Water filtration/ Membrane filters
Abstract: Case studies showing the application of membrane technology in treating domestic water are presented. The San Jose Water Company in California installed a microfiltration plant to treat highly variable and often high-turbidity flows. Virginia's Newport News Waterworks is constructing a reverse osmosis facility to treat brackish groundwater from two deep confined aquifers. Indian River County in Florida has installed a second nanofiltration plant to remove hardness, color, and disinfection by-products.

Tan TTY, Yip CK, Beydoun D, Amal R. Effects of nano-Ag particles loading on TiO_2 photocatalytic reduction of selenate ions. Chemical Engineering Journal 2003;95(1-3):179-86.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFJ-48S39WW-1&_coverDate=09%2F15%2F2003&_alid=197930806&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5228&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ca917e78b4947de81087a1e7fc9d23a5
Keywords: Nano-silver/ Photocatalysis/ Reduction/ Titanium dioxide/ Selenate
Abstract: The photocatalytic reduction of selenate Se(VI) ions was studied using unmodified TiO_2 and Ag-loaded TiO_2 (Ag-TiO_2) photocatalysts. In the presence of formic acid, both the TiO_2 and Ag-TiO_2 photocatalysts were effective in reducing Se(VI). The reaction proceeded through the reduction of Se(VI) ions to elemental selenium Se and then to hydrogen selenide gas (H_2Se). When unmodified TiO_2 photocatalyst was used, the Se formed from the reduction of Se(VI) was further reduced to Se^{2-} in the form of H_2Se upon the exhaustion of Se(VI) in solution. In the presence of the Ag-TiO_2 photocatalysts, hydrogen selenide gas was generated simultaneously with the reduction of Se(VI). It was found that the maximum Se(VI) reduction rate occurred at pH 3.5 and at a 0.5 at.% Ag loading while the maximum hydrogen selenide gas generation occurred at pH 3.5 and at 2.0 at.% Ag loading. The simultaneous reduction of Se(VI) to hydrogen selenide gas can be attributed to efficient charge separation due to the

mediation of photogenerated electrons by the Ag particles. A mechanism is proposed in terms of the TiO_2-Ag-Se electronic interaction during UV irradiation.

Torres-Martínez CL, Kho R, Mian OI, Mehra RK. Efficient photocatalytic degradation of environmental pollutants with mass-produced ZnS nanocrystals. J Colloid Interface Sci 2001;240(2):525-32.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6WHR-45S4DBB-2S&_coverDate=08%2F15%2F2001&_alid=198262132&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=6857&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5c8f9861b16229838238eec3a9e41abf
Keywords: Semiconductor/ Nanocrystals/ Quantum dot/ Photocatalysis/ Textile dye
Abstract: Photocatalytic degradation of water pollutants using nanometer-sized semiconductor colloids is an emerging area of environmental remediation. The synthesis of semiconductor nanocrystals (NCs), however, can be costly and result in low product yields. For large-scale photocatalytic application in environmental remediation, cost-effective production of the semiconductor NCs would be ideal. Demonstrated in this report is the efficient photocatalytic degradation of *p*-nitrophenol (pNP) and Acid Orange 7 (AO7) using ZnS nanocrystals (~3 to 5 nm diameter) produced in gram quantities with >50% product yield. The pNP half-life in ZnS nanocrystal photocatalyzed reactions was about 1.95 to 2.45 min, whereas in comparable TiO_2 reactions, the pNP half-lives were in the range of 12 to 15 min. Absorption spectra of the photocatalysis reactions suggested the decolorization of pNP without any noticeable formation of phenolic intermediates, implying a mechanism that involves a pNP ring opening via a radical-mediated attack. Likewise, the degradation of AO7 was suggested to occur via an oxidative pathway involving hydroxyl radicals formed at the photocatalyst/liquid interface. Optimum conditions for AO7 degradation such as pH, photocatalyst-to-AO7 ratio, and photocatalyst surface passivation were similar to those for pNP. By demonstrating efficient mineralization of these model pollutants using mass-produced ZnS nanocrystals, we hope to lay the foundations necessary for development of large-scale, field-applicable systems.

Trau D, Yang W, Seydack M, Caruso F, Yu NT, Renneberg R. Nanoencapsulated microcrystalline particles for superamplified biochemical assays. Anal Chem 2002;74(21):5480-6.
URL: http://www.bioeng.nus.edu.sg/people/trau/Papers/Trau%20et%20al_Crystal%20Label_AnalChem_74_21_5480_2002.pdf
Abstract: We report on the preparation and utilization of a novel class of particulate labels based on nanoencapsulated organic microcrystals with the potential to create highly amplified biochemical assays. Labels were constructed by encapsulating microcrystalline fluorescein diacetate (FDA; average size of 500 nm) within ultrathin polyelectrolyte layers of poly(allylamine hydrochloride) and poly(sodium 4-styrenesulfonate) via the layer-by-layer technique. Subsequently, the polyelectrolyte coating was used as an “interface” for the attachment of anti-mouse antibodies through adsorption. A high molar ratio of fluorescent molecules present in the microcrystal core to biomolecules on the particle surface was achieved. The applicability of the microcrystal-based label system was demonstrated in a model sandwich immunoassay for mouse immunoglobulin G detection. Following the immunoreaction, the FDA core was dissolved by exposure to organic solvent, leading to the release of the FDA molecules into the surrounding medium. Amplification rates of 70-2000-fold (expressed as an increase in assay sensitivity) of the microcrystal label-based assay

compared with the corresponding immunoassay performed with direct fluorescently labeled antibodies are reported. Our approach provides a general and facile means to prepare a novel class of biochemical assay labeling systems. The technology has the potential to compete with enzyme-based labels as it does not require long incubation times, thus speeding up bioaffinity tests.

Trebouet D, Schlumpf JP, Jaouen P, Quemeneur F. Stabilized landfill leachate treatment by combined physicochemical–nanofiltration processes. Water Research 2001;35(12):2935-42.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-43CJX46-G&_coverDate=08%2F31%2F2001&_alid=195999670&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=16ca25ff16ce1bc7002955a7f0049f97
Keywords: **N**anofiltration/ Coagulation/ Landfill leachate/ COD/ Adsorption/ Fouling
Abstract: Landfill leachate is a complex wastewater in which the composition and concentration of contaminants are influenced by the type of waste deposited and the age of landfill. In the last years, several processes or process combinations were developed and tested to reach requirements for the discharge of leachate. Among the new processes, membrane processes are considered as promising: reverse osmosis is one of the most widely used treatment in the Northwestern European countries and nanofiltration is gained in popularity during the last five years. Successful application of membrane technology for the treatment of landfill leachates requires efficient control of membrane fouling. Two organic membranes of nanofiltration were used for pilot-scale testing. Leachates were subject to several pretreatments (pH modification, prefiltration and coagulation with $FeCl_3$) to remove potential foulants, including dissolved organic and inorganic substances as well as colloidal and suspended particles. These pretreatments do not enhance the performances (retention and permeation flux) of membranes because the pH range and the presence of Fe^{3+} ions contribute greatly to change the characteristics of organic matter and the surface charges of membranes. However, the results show that nanofiltration is sufficient to eliminate refractory COD: the permeates have a COD lower than the requirements for discharge.

Tsui EM, Cheryan M. Characteristics of nanofiltration membranes in aqueous ethanol. Journal of Membrane Science 2004;237(1-2):61-9.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CBVT0K-5&_user=10&_handle=B-WA-A-W-WE-MsSAYVW-UUW-AUEVCVYAZW-AUEWAWYEZW-CZUAYVBBY-WE-U&_fmt=summary&_coverDate=07%2F01%2F2004&_rdoc=7&_orig=browse&_srch=%23toc%235257%232004%23997629998%23502297!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d57c1c06eb84d99316a70f14710aa592
Keywords: Organic separation/ Nanofiltration membranes, commercial and prototype
Abstract: Twelve commercial and prototype nanofiltration membranes were evaluated for their stability and performance in aqueous ethanol. Performance was better if membranes were preconditioned by gradual solvent exchange. Flux in ethanol solutions was lower than in water. Viscosity and molar volume of the ethanol solutions could partly account for differences in solvent flux with some membranes. The molecular weight cut-off (MWCO) of a membrane varies with different solutes and solvents. Rejection studies with sugars, glycols and lipids indicate that the MWCO of the DK membrane is higher in aqueous ethanol solutions than in

water.

Tungittiplakorn W., Lion L.W., Cohen C, Kim J.Y. Engineered polymeric nanoparticles for soil remediation. Environ Sci Technol 2004;38(5):1605-10.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15046367
Abstract: Hydrophobic organic groundwater contaminants, such as polynuclear aromatic hydrocarbons (PAHs), sorb strongly to soils and are difficult to remove. We report here on the synthesis of amphiphilic polyurethane (APU) nanoparticles for use in remediation of soil contaminated with PAHs. The particles are made of polyurethane acrylate anionomer (UAA) or poly(ethylene glycol)-modified urethane acrylate (PMUA) precursor chains that can be emulsified and cross-linked in water. The resulting particles are of colloidal size (17-97 nm as measured by dynamic light scattering). APU particles have the ability to enhance PAH desorption and transport in a manner comparable to that of surfactant micelles, but unlike the surface-active components of micelles, the individual cross-linked precursor chains in APU particles are not free to sorb to the soil surface. Thus, the APU particles are stable independent of their concentration in the aqueous phase. In this paper we show that APU particles can be engineered to achieve desired properties. Our experimental results show that the APU particles can be designed to have hydrophobic interior regions that confer a high affinity for phenanthrene (PHEN) and hydrophilic surfaces that promote particle mobility in soil. The affinity of APU particles for contaminants such as PHEN can be controlled by changing the size of the hydrophobic segment used in the chain synthesis. The mobility of colloidal APU suspensions in soil is controlled by the charge density or the size of the pendent water-soluble chains that reside on the particle surface. Exemplary results are provided illustrating the influence of alternative APU particle formulations with respect to their efficacy for contaminant removal. The ability to control particle properties offers the potential to produce different nanoparticles optimized for varying contaminant types and soil conditions.

Van der Bruggen B, De Vreese I, Vandecasteele C. Water reclamation in the textile industry: Nanofiltration of dye baths for wool dyeing. Industrial and Engineering Chemistry Research 2001;40(18):3973-8.
Keywords: Dyes, recycling/ Nanofiltration/ Water reuse
Abstract: The textile industry is a large water consumer: dyeing, rinsing, and follow-up treatment of textiles use large amounts of freshwater. As regulations become more and more stringent and the cost of freshwater increases, reclamation of wastewater becomes more and more attractive. This paper explores the possibility of using nanofiltration to improve the wastewater quality to the standards that are used for the dyeing of wool. Four different samples from the wastewater treatment sequence of a textile factory were filtrated with three different nanofiltration membranes (NF70, UTC-20, and NTR 7450). The samples were a used and untreated metal complex dye bath, a used and untreated acid dye bath, a sample from the storage tank (containing a diluted mixture of the previous baths), and the effluent of the biological treatment. Nanofiltration was possible for all samples, but the biologically treated dye baths showed a more efficient color removal. For direct nanofiltration of us! ed dye baths, two membrane passages would be needed to provide the required permeate quality. Flux decline due to adsorption of organic material on the membrane decreased the membrane capacity by up to 73%, but the process water flux reached a stable value in all experiments.

The flux decline was less important for the biologically treated water. The effect of flux decline was only partly reversible; the effect of osmotic pressure on the process water flux is fully reversible. It was found that flux decline is largely concentration-dependent: higher concentrations of organic compounds always caused lower process water fluxes.

Van der Bruggen B, Hawrijk I, Cornelissen E, Vandecasteele C. Direct nanofiltration of surface water using capillary membranes: Comparison with flat sheet membranes. Separation and Purification Technology 2003;31(2):193-201.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THJ-47RBSVY-2&_coverDate=05%2F01%2F2003&_alid=193755073&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5284&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=9b22bb8de651b5f187edc95d44d5fdc9
Keywords: Nanofiltration/ Fouling/ Capillary membranes/ Direct nanofiltration/ Surface water
Abstract: This article explores the possibilities of a new capillary nanofiltration membrane (manufactured by Stork/X-Flow, The Netherlands), designed to reduce membrane fouling and thus allowing to omit or reduce the extensive pretreatment usually required for the implementation of nanofiltration in drinking water production. In the laboratory, the membrane performance (flux decline and flux recovery) during nanofiltration of surface water from the river Dijle, Flanders, Belgium, was compared with that of a series of nine commercial flat sheet membranes. All membranes showed flux decline to some extent. For the capillary membrane, the water flux could, however, easily be increased and maintained at a stable level by a combination of forward flushing and airflushing, which is not possible with the flat sheet membranes. Furthermore, the water permeability for the capillary membrane was three to 15 times higher than for the commercial flat sheet membranes, which leads to lower operating pressure and a correspondingly lower energy consumption. For the capillary membrane rejections of organic and inorganic compounds were satisfactory to reach for COD and conductivity standards in one step starting from the Dijle water. Rejections for most flat sheet membranes were comparable to the rejections obtained with the capillary membrane, but the rejection of ions was usually higher, except for the N30F and NF PES 10 membranes (Nadir, Germany). Low ion rejections are advantageous for drinking water production because demineralization is avoided.

Van der Bruggen B, Kim JH, DiGiano FA, Geens J, Vandecasteele C. Influence of MF pretreatment on NF performance for aqueous solutions containing particles and an organic foulant. Separation and Purification Technology 2004;36(3):203-13.
Keywords: Microfiltration/ Nanofiltration/ Organic fouling/ Particles/ Flux decline
Abstract: The influence of microfiltration (MF) pretreatment on nanofiltration (NF) performance was studied for synthetic solutions of fluorescent monodisperse latex particles of 0.1 and 1 μm diameter and an organic foulant (benzyl alcohol) in water. Samples were microfiltered in the dead-end mode using a membrane with a pore size of 0.22 μm, and subsequently nanofiltered using five flat sheet nanofiltration membranes in parallel: UTC-20 (Toray Ind. Inc.), Desal 5 DL and Desal 51 HL (Osmonics), NF-PES-10 and N30F (Nadir). Both the particles and the organic foulant were found to cause flux decline in NF. The extent of fouling depended on the NF membrane used; hydrophobic materials were found to cause more flux decline by particles and the organic foulant. Particle fouling was visualized using SEM images of the NF membranes after filtration of the 0.1 μm as well as the 1 μm particles

by MF membranes. Smaller particles led to higher flux decline in MF due to more compact cake formation and higher specific cake resistance in the dead-end mode; 0.1 µm particles caused more internal fouling in the membrane than 1 µm particles. However, without MF pretreatment, the flux decline in NF was more severe for solutions containing the larger particles (1 µm) than the smaller particles (0.1 µm), due to slower back diffusion from the membrane surface to the bulk solution. An additional influence of the NF spacer material was observed, due to the formation of a local dead-end volume between the fine meshes of the spacer net. When a microfiltration pretreatment was applied, flux decline was limited to the effect of organic fouling of the membrane. Thus, MF pretreatment is effective in avoiding a large fraction of the fouling in NF, although an effect of organic fouling may remain. Furthermore, a lower rejection of benzyl alcohol in NF was found after MF pretreatment than for NF without pretreatment.

Van der Bruggen B, Koninckx A, Vandecasteele C. Separation of monovalent and divalent ions from aqueous solution by electrodialysis and nanofiltration. Water Research 2004;38(5):1347-53.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-4BDM1WD-1&_coverDate=03%2F31%2F2004&_alid=196232175&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=01c0453f520233a9ad145be46ab99bb2
Keywords: Ion separation/ Electrodialysis/ Nanofiltration, companies / Nanomembranes, commercial
Abstract: The possibilities of separating monovalent and multivalent ions by electrodialysis (ED) and nanofiltration (NF) are explored. Five synthetic single salt solutions were applied to ED and NF: NaCl, Na_2SO_4, $MgCl_2$, $MgSO_4$ and $NaNO_3$. Two combinations of anionic and cationic exchange membranes were evaluated for ED (AMV/CMV Selemion membranes and ACS/CMS Tokuyama membranes), and two membranes were evaluated for NF (NTR 7450 and UTC-60). The separation was evaluated using an alternative parameter, the separation efficiency, in order to compare ED and NF. The separation efficiency ranges from 0% (no separation) to 100% (perfect separation). Both NF membranes had a good separation efficiency for the separation of monovalent and divalent anions (ca. 60%); the ED membranes performed worse. For the separation of monovalent and divalent cations, the UTC-60 membrane was the best for the considered separation because of size exclusion effects for the larger divalent ion. The ACS/CMS membranes had a similar separation efficiency (ca. 60%); the NTR 7540 membrane and AMV/CMV ED membranes showed only a small separation.

Van der Bruggen B, Schaep J, Maes W, Wilms D, Vandecasteele C. Nanofiltration as a treatment method for the removal of pesticides from ground waters. Desalination 1998;117(1-3):139-47.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-3W2SBV1-G&_coverDate=09%2F20%2F1998&_alid=195974132&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=302ec2090e652c888ca91243623eb1f9
Keywords: Nanofiltration/ Pesticides/ Triazines/ Ureum compounds/ Molecular size/ Polarity
Abstract: A major problem in the drinking water production is the presence of pesticides in raw water, not only in surface waters but also in ground waters. Concentrations of several g/L have been found. Traditionally, pesticides are removed using granular or powdered activated carbon, which is an expensive process. The cost is enhanced by competition of pesticides and

natural organic matter (NOM) for adsorption sites on the activated carbon. Nanofiltration (NF) can be a valuable alternative for the removal of pesticides. Moreover, pesticides and hardness can be removed in one step. In this paper, the retention of four pesticides (atrazine, simazine, diuron, isoproturon) was determined experimentally for four NF membranes: NF-70 (Dow/Film Tec), NF-45 (Dow/Film Tec), UTC-20 (Toray Inc.) and NTR-7450 (Nitto-Denko). The experimental retentions indicate that NF-70 is a suitable membrane for removal of pesticides. The experimental retentions were related to structural properties of the molecules. The size of the molecule is the most important parameter, and may be represented by molecular weight, or more accurately by a molecular diameter calculated from the molecular structure. Furthermore, a comparison with retentions of a series of saccharides confirms the earlier found effect of the dipole moment: a higher dipole moment results in a lower retention. No effect of the pesticide concentration was found. The matrix of the ground waters caused an increase of the pesticide retention, together with a decrease of the water flux through the membrane.

Van der Bruggen B, Vandecasteele C. Distillation vs. membrane filtration: Overview of process evolutions in seawater desalination. Desalination 2002;143(3):207-18.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFX-46FS8S9-1&_coverDate=06%2F10%2F2002&_alid=193756084&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5238&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=a21799446cdfb545df45b6553b7a1c53
Keywords: Seawater/ Reverse osmosis/ MSF/ MED/ Electrodialysis/ Pretreatment/ Environmental impact/ Hybrid processes/ Fouling
Abstract: The worldwide need for fresh water requires more and more plants for the treatment of non-conventional water sources. During the last decades, seawater has become an important source of fresh water in many arid regions. The traditional desalination processes [reverse osmosis (RO), multi stage flash (MSF), multi effect distillation (MED), electrodialysis (ED)] have evolved into reliable and established processes; current research focuses on process improvements in view of a lower cost and a more environmentally friendly operation. This paper provides an overview of recent process improvements in seawater desalination using RO, MSF, MED and ED. Important topics that are discussed include the use of alternative energy sources (wind energy, solar energy, nuclear energy) for RO or distillation processes, and the impact of the different desalination process on the environment; the implementation of hybrid processes in seawater desalination; pretreatment of desalination plants by pressure driven membrane processes (microfiltration, ultrafiltration and nanofiltration) compared to chemical pretreatment; new materials to prevent corrosion in distillation processes; and the prevention of fouling in reverse osmosis units. These improvements contribute to the cost effectiveness of the desalination process, and ensure a sustainable production of drinking water on long terms in regions with limited reserves of fresh water.

Van der Bruggen B, Lejon L, Vandecasteele C. Reuse, treatment, and discharge of the concentrate of pressure-driven membrane processes. Environmental Science and Technology 2003;37(17):3733-8.
Keywords: Landfills/ Recycling/ Membrane separation
Abstract: Application of pressure-driven membrane processes (microfiltration, ultrafiltration, nanofiltration, and reverse osmosis) results in the generation of a large concentrated waste

stream, the concentrate fraction, as a byproduct of the purification process. Treatment of the concentrate is a major hurdle for the implementation of pressure-driven membrane processes since the concentrate is usually unusable and has to be discharged or further treated. This paper reviews possibilities to treat or discharge the concentrate: (i) reuse, (ii) removal of contaminants, (iii) incineration, (iv) direct or indirect discharge in surface water, (v) direct or indirect discharge in groundwater, and (vi) discharge on a landfill. General guidelines are given for the choice of a proper method as a function of the origin and composition of the water treated. Next, the further treatment of the concentrates in four application areas of pressure-driven membrane processes (drinking water industry, leather industry, and membrane treatment of landfill leachates and of textile process waters) is discussed.

Vinodgopal K, Kamat PV. Electrochemically assisted photocatalysis using nanocrystalline semiconductor thin films. Solar Energy Materials and Solar Cells 1995;38(1-4):401-10.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V51-3YN9DG7-1B&_coverDate=08%2F31%2F1995&_alid=199682497&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5773&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=221397168c295a15eef608b6f0e25e24
Abstract: The principle and usefulness of electrochemically assisted photocatalysis has been illustrated with the examples of 4-chlorophenol and Acid Orange 7 degradation in aqueous solutions. Thin nanocrystalline semiconductor films coated on a conducting glass surface when employed as a photoelectrode in an electrochemical cell are effective for degradation of organic contaminants. The degradation rate can be greatly improved even in the absence of oxygen by applying an anodic bias to the TiO_2 film electrodes. A ten-fold enhancement in the degradation rate was observed when TiO_2 particles were coupled with SnO_2 nanocrystallites at an applied bias potential of 0.83 V versus SCE.

Wade N, Callister K. Desalination: The state of the art. Water and Environmental Management Journal 1997;11:87-97.
Keywords: Water purification, reverse-osmosis process/ Saline water conversion/ Distillation apparatus
Abstract: A review of the technology available for the process of water desalination is presented. The multi-stage flash process is the one mainly used for seawater desalination. This process is used for most of the main Middle East plants, with unit capacities up to 55,000 m^3/d. Multiple-effect distillation is being used more and more for smaller and medium-sized applications. Reverse osmosis is now used in some large and many small seawater desalination plants. It is competitive with distillation as long as the process and pretreatment equipment is correctly designed and operated for the feedwater conditions at the site. Desalination technology could provide a viable alternative to some of the other options for coping with recent water shortages in the UK, even though it is likely to be more expensive than traditional water supplies.

Wang C-B, Zhang W-X. Synthesizing nanoscale iron particles for rapid and complete dechlorination of TCE and PCBs. Environmental Science and Technology 1997;31(7):2154-6.
URL: http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/1997/31/i07/abs/es970039c.html
Keywords: Zero-valent-iron technology/ Chlorocarbons/ Dechlorination
Abstract: Transformation of halogenated organic compounds (HOCs) by zero-valent iron

represents one of the latest innovative technologies for environmental remediation. For example, iron can be used to construct a reactive wall in the path of a contaminated groundwater plume to degrade HOCs. In this paper, an efficient method of synthesizing nanoscale (1-100 nm) iron and palladized iron particles is presented. Nanoscale particles are characterized by high surface area to volume ratios and high reactivities. BET specific surface area of the synthesized metal particles is 33.5 m^2/g. In comparison, a commercially available Fe powder (<10 µm) has a specific surface area of just 0.9 m^2/g. Batch studies demonstrated that these nanoscale particles can quickly and completely dechlorinate several chlorinated aliphatic compounds and a mixture of PCBs at relatively low metal to solution ratio (2-5 g/100 mL). Surface-area-normalized rate constants (K_{SA}) are calculated to be 10-100 times higher than those of commercially available iron particles. The approach presented offers unique opportunities for both fundamental research and technological applications of zero-valent metals. For example, a potential application of the nanoscale particles is to inject the metal particles directly into contaminated aquifers instead of building iron walls. Copyright 1997, American Chemical Society.

Wang XL, Zhang C, Ouyang P. The possibility of separating saccharides from a NaCl solution by using nanofiltration in diafiltration mode. Journal of Membrane Science 2002;204(1-2):271-81.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-45C022G-4&_coverDate=07%2F15%2F2002&_alid=195992096&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5257&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=2513f97ab406ba8f8204fae40b81e443
Keywords: Membrane separation/ Nanofiltration/ Diafiltration/ Desalination/ Concentration/ Oligosaccharide
Abstract: In this article, the permeation experiments by using a NF membrane were carried out for single component solutions of inorganic electrolytes (NaCl, KCl, $MgCl_2$, Na_2SO_4 and $MgSO_4$) and neutral organic solutes (glycerin, glucose, sucrose and raffinose) and a mixture solution of NaCl and glucose or sucrose. The effects of applied pressure and feed concentration and the coupling interaction between glucose or sucrose and NaCl on the separation performance (observed rejection and permeation flux) were investigated for single and mixture solutions, respectively. NF45 membrane is a negative charged membrane with the molecular weight (MW) cut-offs of about 300 Da, and it is available for the separation of saccharides or bivalent anion electrolytes and univalent anion electrolytes. An overall diafiltration process with a batch-wise mode was simulated for a model solution of soybean whey wastewater containing some saccharides and salts (such as NaCl), and the feasibility of the concentration of oligosaccharides and the removal of salts was also discussed.

Wang YC, Fan SC, Lee KR, Li CL, Huang SH, Tsai HA, et al. Polyamide/SDS–clay hybrid nanocomposite membrane application to water–ethanol mixture pervaporation separation. Journal of Membrane Science 2004;239(2):219-26.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CKFKMF-3&_user=10&_handle=B-WA-A-W-AE-MsSAYWW-UUW-AUEVCDZAAV-AUEWACZEAV-CZUBWUZEV-AE-U&_fmt=summary&_coverDate=08%2F15%2F2004&_rdoc=8&_orig=browse&_srch=%23toc%235257%232004%23997609997%23506872!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=27ed704a4284acee66d547374cc06bbd

Keywords: Polyamide/ SDS–clay hybrid/ Nanocomposite membrane/ Pervaporation
Abstract: A polyamide/clay hybrid nanocomposite membrane was utilized in the pervaporation of aqueous ethanol mixtures. The polyamide/clay hybrid polymers were prepared by direct polycondensation of 4,4'-methylenedianiline (MDA) and 4,4'-hexafluoroisopropylidenedibenzoic acid (6FDAc) in the presence of organo-modified montmorillonite (organo-clay) in *N*-methyl-2-pyrrolidinone (NMP). The organo-clay (SDS–clay) was prepared using an ion-exchange reaction between the montmorillonite silicate layers and the sodium dodecyl sulfate (SDS, intercalating agent). The as-synthesized polyamide/clay hybrid membranes were characterized using wide-angle X-ray diffraction (XRD) and transmission electron microscopy (TEM). The SDS–clay was intercalated and exfoliated into the polyamide matrix. Compared with the pure polyamide membrane, the polyamide/SDS–clay hybrid nanocomposite membrane showed improved thermal stability and mechanical properties. The glass transition temperature of polyamide/SDS–clay nanocomposite was higher than that for the pure polyamide. The SDS–clay content, feed composition and swelling effects on the pervaporation performances of aqueous ethanol mixtures through the polyamide/SDS–clay nanocomposite membranes were also investigated.

Wasan DT, Nikolov AD. Spreading of nanofluids on solids. Nature 2003;423(6936):156-9.
URL: http://www.nature.com/doifinder/10.1038/nature01591
Abstract: Suspensions of nanometre-sized particles (nanofluids) are used in a variety of technological contexts. For example, their spreading and adhesion behaviour on solid surfaces can yield materials with desirable structural and optical properties. Similarly, the spreading behaviour of nanofluids containing surfactant micelles has implications for soil remediation, oily soil removal, lubrication and enhanced oil recovery. But the well-established concepts of spreading and adhesion of simple liquids do not apply to nanofluids. Theoretical investigations have suggested that a solid-like ordering of suspended spheres will occur in the confined three-phase contact region at the edge of the spreading fluid, becoming more disordered and fluid-like towards the bulk phase. Calculations have also suggested that the pressure arising from such colloidal ordering in the confined region will enhance the spreading behaviour of nanofluids. Here we use video microscopy to demonstrate both the two-dimensional crystal-like ordering of charged nanometre-sized polystyrene spheres in water, and the enhanced spreading dynamics of a micellar fluid, at the three-phase contact region. Our findings suggest a new mechanism for oily soil removal--detergency.
Comment in Nature 2003;423(6936):131-2.

Wasay SA, Parker WJ, Van Geel PJ. Contamination of a calcareous soil by battery industry wastes. II. Treatment. Canadian Journal of Civil Engineering 2001;28(3):349-54.
Keywords: Soil washing/ Soils, lead content/ Ethylenediamine tetraacetic acid
Abstract: This study evaluated treatment of a soil that was heavily contaminated by the disposal of waste from a Pb battery industry. The site was of interest from a remediation point of view, since the soil contained substantial quantities of calcareous material. Treatment involved extraction of the metals from the soil using aqueous solutions of EDTA (ethylenediaminetetraacetic acid). The impact of pH, EDTA concentration, and reaction time on the extent of leaching of Pb was evaluated. The leaching efficiency was found to be independent of pH over a range of values from 4 to 8.2. The leaching of Pb and Ca increased with EDTA concentration with 99% of the Pb removed at an EDTA dosage of 3.2 M/kg soil.

The removal efficiencies of Cu, Cr, Cd, Ni, and Zn were consistently less than that of Pb; however, with their lower initial concentrations, acceptable levels were achieved for all metals except Cd. A two-reaction model was successfully used to describe the results of a batch extraction test. The results indicated relatively rapid extraction kinetics for a substantial fraction of the Pb contamination. Treatment of the liquid effluent from the soil treatment process with nano-level filtration indicated that both the EDTA and Pb were consistently removed at efficiencies greater than 98%. The nano-filtration process was not affected by pH over a range of values from 4.8 to 7.6.

Waypa JJ, Elimelech M, Hering JG. Arsenic removal by RO and NF membranes. American Water Works Association Journal 1997;89(10):102-14.
Keywords: Water supply, arsenic content/ Water purification, reverse-osmosis process/ Nanofiltration
Abstract: Bench-scale experiments were carried out to evaluate the effectiveness of reverse osmosis and treatment with nanofiltration membranes in removing arsenic from synthetic freshwater and source water. In particular, the effects of operational conditions and solution chemical composition were examined. The removal of arsenic from source water that was achieved using these techniques was found to be comparable to that obtained with synthetic freshwater, despite the presence of turbidity, natural organic matter, and a variety of co-occurring solutes in the source water.

Wilcoxon JP, Thurston TR, Martin JE. Applications of metal and semiconductor nanoclusters as thermal and photo-catalysts. Nanostructured Materials [Fourth Int Conf on Nanostructured Materials (NANO '98)] 1999;12(5-8):993-7.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TXK-3XK1GWH-84&_coverDate=12%2F31%2F1999&_alid=199680026&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5593&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=bdc7b8175cf5d42dd3923ac2eed40976
Abstract: We discuss studies of photo and thermally driven reactions that illustrate the unique catalytic features of nanoclusters which may be of great technical utility. The application of photocatalysts of nanosize MoS_2 to oxidize organic pollutants to CO_2 is discussed. Nanosize MoS_2 shows improved rates of oxidation of organics, such as phenol, compared to alternative bulk powders such as TiO_2 or ZnO. Selective hydrogenation of pyrene using both dispersed and supported nanoclusters of Rh, Pt, and Pd is also discussed.

Wilczak A, Hoover LL, Lai HH. Effects of treatment changes on chloramine demand and decay. American Water Works Association Journal 2003;95(7):94-106 .
Keywords: Chloramine/ Water purification, chlorination
Abstract: A study of factors affecting combined chloramine demand and decay, using practical experiences gained at the East Bay Municipal Utility District in California and from the published literature, is presented. The importance of the presence of a stable chloramine residual in the distribution system in minimizing system maintenance is emphasized. The effects of using granular activated carbon adsorption or nanofiltration, ozonation with or without hydrogen peroxide, and free chlorine or chlorine dioxide applied to the filter effluent prior to chloramine formation are considered.

Wu JCS, Chen CH. A visible-light response vanadium-doped titania nanocatalyst by sol-gel method. Journal of Photochemistry and Photobiology A: Chemistry 2004;163(3):509-15.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGY-4C1FDPY-G&_coverDate=05%2F21%2F2004&_alid=197907136&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5267&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=98308a03203c3dc658db0ef88c98a26d

Keywords: Titania/ Vanadium doping/ Visible-light photocatalyst/ Sol-gel

Abstract: A series of vanadium-doped TiO_2 catalysts were synthesized by two modified sol-gel methods. V-doped TiO_2 was found to be mainly preserved in its anatase phase after calcination at 400 C. The TEM micrographs showed the sizes of primary particles were in the range of 6–20 nm. The increase of vanadium doping promoted the particle growth, and enhanced the "red-shift" in the UV-Vis absorption spectra. The XPS (X-ray photoelectron spectroscopy) could not detect vanadium, indicating negligible vanadium on the surface of catalysts; furthermore, there were also no peaks of vanadium oxide in the XRD patterns. XAS (X-ray absorption spectroscopy) analysis indicated V^{4+} instead of V^{5+} and thus implied that vanadium either substituted at the Ti^{4+} site or embedded in the vacancy of TiO_2 structure. Therefore, vanadium was concluded to be highly dispersed inside the TiO_2 structure. The photocatalytic activity was evaluated by the degradation of crystal violet (CV) and methylene blue (MB) under visible light irradiation. The degradation rates of CV and MB on V-doped TiO_2 were higher than those on pure TiO_2. The results indicated that V-doped TiO_2 possessed better absorption ability of visible light.

Wu M, Sun DD, Tay JH. Effect of operating variables on rejection of indium using nanofiltration membranes. Journal of Membrane Science 2004;240(1-2):105-11.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4CPD85T-1&_user=10&_handle=B-WA-A-W-BU-MsSAYZA-UUW-AUEVCVWWDY-AUEWAWBUDY-CZUACDAZZ-BU-U&_fmt=summary&_coverDate=09%2F01%2F2004&_rdoc=10&_orig=browse&_srch=%23toc%235257%232004%23997599998%23510566!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=841c933727aba58f6dcd1ec5d2bd30e2

Keywords: Electrochemistry/ Indium phosphide/ Nanofiltration/ Semiconductor/ Wastewater

Abstract: Indium and its compounds exhibit excellent semiconductor properties; however, they are suspected to be carcinogenic to human beings. For the first time, we applied nanofiltration (NF) technology to the separation of indium from a synthetic wastewater, as a literature review revealed little information on the treatment of such a waste. In this research, three types of nanofiltration membranes, NTR7450, ES10 and ES10C, were employed to compare their performances under various operating conditions. With increasing indium concentration in the feed solution, the rejection rates decreased in all the membranes, which could be ascribed to concentration polarization and ion-shielding effects. The changes of indium concentration in the permeate (C_p) were then correlated to the concentration factor (CF) during nanofiltration of the feed solution. The experimental results were well predicted by the theoretical analysis. Increase of operating pressure enhanced their rejection rates of indium, which might be attributed to the "dilute effect". The real rejection (f_r) of indium by nanofiltration was found to be permeate flux dependent. Based on the results obtained, the nanofiltration mechanisms of multivalent cations such as In^{3+} were delineated and discussed. It was found that most of the models developed from nanofiltration of univalent and divalent cations were still valid for the nanofiltration process of trivalent cations. However, the strong chemical potential of trivalent cations to form complexes in the solution around neutral pH exerted a significant impact on indium rejection rates of the NF membranes. The experimental results suggest a stable performance of nanofiltration when applied to the semiconductor wastewater; however, acidic conditions should be avoided.

Yaroshchuk AE. The role of imperfections in the solute transfer in nanofiltration. Journal of Membrane Science 2004;239(1):9-15.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4C8NKSM-2&_user=10&_handle=B-WA-A-W-AD-MsSAYZA-UUW-AUEVZWYZZE-AUEWWUEVZE-CZUZEWBYU-AD-U&_fmt=summary&_coverDate=08%2F01%2F2004&_rdoc=3&_orig=browse&_srch=%23toc%235257%232004%23997609998%23506761!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=9592f0b7de0c9a6731a33f16b2297c20
Keywords: Nanofiltration/ Imperfection/ Reflection coefficient/ Solute permeability/ Feed concentration
Abstract: It is shown that the introduction of imperfections into the model of nanofiltration helps to explain an apparent contradiction between the moderate reflection coefficients and rather large initial slopes of rejection versus transmembrane volume flow curves often observed in nanofiltration. Within the scope of conventional models with no account of imperfections, this mismatch between the reflection coefficient and the solute permeability automatically brings about either strongly reduced diffusivities of solutes in pores or unphysically large effective active layer thicknesses. The model can also explain the relatively weak dependencies of salt rejections on the feed concentrations especially often observed for the salts with multiple-charge co-ions.

Yu D, Cai R, Liu Z. Studies on the photodegradation of rhodamine dyes on nanometer-sized zinc oxide . Spectrochim Acta A Mol Biomol Spectrosc 2004;60(7):1617-24.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VNG-4BDY974-6&_coverDate=06%2F30%2F2004&_alid=197905560&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=6178&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=608008ea14d26f04116db00a78ec7d39
Keywords: Nanometer-sized ZnO/ Rhodamine dyes/ Photodegradation/ Dynamic molecular spectra
Abstract: The nanometer-sized ZnO was prepared through the sol-gel method. Its average particle diameter, determined by TEM, was 20–30 nm. The specific surface area was determined to be 22 m^2 g^{-1} by BET. The photodegradation mechanism of rhodamine dyes on nanometer-sized ZnO was studied by dynamic molecular spectra, and the results showed that the photodegradation of rhodamine dyes obeyed the rules of a pseudo first-order kinetic reaction. The rate constant k of the degradation of rhodamine B (RB) and butyl-rhodamine (BR) were 0.0128 and 0.0154 min^{-1}, respectively, and the half period $t_{1/2}$ were 60 and 52 min, respectively. The photodegradation reaction conditions were optimized. After intermixing with silver, the photodegradation efficiency was greatly improved. A life-span test showed that nanometer-sized ZnO had a long life-span.

Yu JC, Yu J, Zhang L, Ho W. Enhancing effects of water content and ultrasonic irradiation on the

photocatalytic activity of nano-sized TiO_2 powders. Journal of Photochemistry and Photobiology A: Chemistry 2002;148(1-3):263-71.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGY-45BCR51-5&_coverDate=05%2F31%2F2002&_alid=199316307&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5267&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=c8c43796d9d2af4e78a9808c2020508b
Keywords: TiO_2 nano-sized powders/ Sol-gel method/ Ultrasonic/ Water content/ Photocatalytic activity
Abstract: A simple method for preparing highly photoactive nano-sized TiO_2 photocatalyst with anatase and brookite phase was developed by hydrolysis of titanium tetraisopropoxide in pure water or the EtOH/H_2O mixed solution under ultrasonic irradiation. The prepared TiO_2 powders were characterized by differential thermal analysis (DTA), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), transmission electron microscopy (TEM) and BET surface areas. The photocatalytic activity was evaluated by the photocatalytic oxidation of acetone in air. The results showed that the photocatalytic activity of TiO_2 powders prepared by this method from pure water or the EtOH/H_2O mixed solutions with the molar ratio of EtOH/H_2O = 1 exceeded that of Degussa P-25. The molar ratios of EtOH/H_2O obviously influenced the crystallization, crystallite size, BET surface areas and photocatalytic activity of the prepared TiO_2 powders. Ultrasonic irradiation obviously enhanced the photocatalytic activity of TiO_2 powders whether the solvent is pure water or the EtOH/H_2O mixed solutions. This may be ascribed to the fact that ultrasonic irradiation enhances hydrolysis of titanium alkoxide and crystallization of TiO_2 gel.

Zhang WX. Nanoscale iron particles for environmental remediation: An overview. Journal of Nanoparticle Research 2003;5(3-4):323-32.
URL: http://www.ingentaconnect.com/content/klu/nano/2003/00000005/F0020003/05142765
Keywords: Nanoparticles/ Iron/ Palladium/ Nanotechnology/ Groundwater/ Remediation
Abstract: Nanoscale iron particles represent a new generation of environmental remediation technologies that could provide cost-effective solutions to some of the most challenging environmental cleanup problems. Nanoscale iron particles have large surface areas and high surface reactivity. Equally important, they provide enormous flexibility for *in situ* applications. Research has shown that nanoscale iron particles are very effective for the transformation and detoxification of a wide variety of common environmental contaminants, such as chlorinated organic solvents, organochlorine pesticides, and PCBs. Modified iron nanoparticles, such as catalyzed and supported nanoparticles have been synthesized to further enhance the speed and efficiency of remediation. In this paper, recent developments in both laboratory and pilot studies are assessed, including: (1) synthesis of nanoscale iron particles (10–100 nm, >99.5% Fe) from common precursors such as Fe(II) and Fe(III); (2) reactivity of the nanoparticles towards contaminants in soil and water over extended periods of time (e.g., weeks); (3) field tests validating the injection of nanoparticles into aquifer, and (4) *in situ* reactions of the nanoparticles in the subsurface.

Zhang WX, Wang CB, Lien HL. Treatment of chlorinated organic contaminants with nanoscale bimetallic particles. Catalysis Today 1998;40(4):387-95.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFG-3SY2JJS-C&_coverDate=05%2F14%2F1998&_alid=199681613&_rdoc=1&_fmt=&_orig=search&_qd

=1&_cdi=5226&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=31f5a219fa9c8a1bb0309cdf23ddefae

Keywords: Chlorinated organic contaminants/ Dechlorination/ Nanoscale bimetallic particles/ Trichloroethene/ Tetrachloroethene/ Iron/ Palladium

Abstract: Nanoscale bimetallic particles (Pd/Fe, Pd/Zn, Pt/Fe, Ni/Fe) have been synthesized in the laboratory for treatment of chlorinated organic pollutants. Specific surface areas of the nanoscale particles are tens of times larger than those of commercially available microscale metal particles. Rapid and complete dechlorination of several chlorinated organic solvents and chlorinated aromatic compounds was achieved by using the nanoscale bimetallic particles. Evidence observed suggests that within the bimetallic complex, one metal (Fe, Zn) serves primarily as electron donor while the other as catalyst (Pd, Pt). Surface-area-normalized reactivity constants are about 100 times higher than those of microscale iron particles. Production of chlorinated byproducts, frequently reported in studies with iron particles, is notably reduced due to the presence of catalyst. The nano-particle technology offers great opportunities for both fundamental research and technological applications in environmental engineering and science.

Zhang Y, Van der Bruggen B, Chen GX, Braeken L, Vandecasteele C. Removal of pesticides by nanofiltration: Effect of the water matrix. Separation and Purification Technology 2004;38(2):163-72.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THJ-4BK2K4R-2&_user=10&_handle=B-WA-A-W-AU-MsSAYZW-UUA-AAUEEZUVBA-AAUDCVAWBA-YECBZBCBC-AU-U&_fmt=summary&_coverDate=08%2F31%2F2004&_rdoc=6&_orig=browse&_srch=%23toc%235284%232004%23999619997%23505621!&_cdi=5284&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ab60ce0940372edb9ead8e7bfd4e4aa5

Keywords: Nanofiltration/ Water matrix/ Pesticides/ Drinking water production

Abstract: This study explores the removal of two pesticides (atrazine and simazine) from different water matrices (distilled water, tap water and river water) by nanofiltration (NF), using four types of nanofiltration membranes (DESAL 51 HL, DESAL 5 DL, UTC-20, UTC-60). Atrazine or simazine was added to the different water matrices at a concentration of 5 mg/L and 100 g/L. Rejection of pesticides and the water flux were measured. The rejection of atrazine was always higher than the rejection of simazine; the highest rejections were obtained with UTC-20. The rejection of pesticides was higher in river water and tap water than in distilled water, but the water flux was lower. This was mainly explained by ion adsorption inside the membrane pores. Narrower pore size counteracted the effect of presence of natural organic matter (NOM). The NOM was assumed to enhance the adsorption of pesticides onto membranes surface, increased the size exclusion and electrostatic repulsion also appeared during the transport. Additionally, there was a small effect of NOM on rejection and flux. No significant effect of the pesticides concentration was observed. The rejections were the highest at pH 8 and decreased at higher and lower pH. Considerable rejections of nitrate and organic matter (measured as COD and UV absorbance at 254 nm) were observed, in particular for the membrane with the smallest pores (UTC-20). This confirms the assumption that pore narrowing by ion adsorption influences the rejections and water fluxes.

Zhang Y, Weidenkaff A, Reller A. Mesoporous structure and phase transition of nanocrystalline TiO_2.

Materials Letters 2002;54(5-6):375-81.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TX9-44DYF1G-1&_coverDate=06%2F30%2F2002&_alid=199315223&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5585&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=13a58490979938f51c9394fbfa781a5e
Keywords: Nanoparticle/ Titanium dioxide/ Mesoporous/ Sol-gel
Abstract: Mesoporous nanocrystalline titanium dioxide with narrow pore size distribution was prepared by a sol-gel technique. Butanediol mixed with tetrapropylothotitanate was used as a precursor. The aging time for the synthesis has an evident influence on the phase transition of TiO_2 and the nucleation process. A very fine network texture made from uniform nanoparticles was revealed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) analyses. The mesoporous structures as-prepared titania were maintained after a heat treatment at 350 and 400 C for 1 h, exhibiting a significant thermal stability. Four titania crystal phases (amorphous, anatase, anatase–rutile, rutile) were observed at different calcination temperatures.

Zhao ZP, Li J, Zhang DX, Chen CX. Nanofiltration membrane prepared from polyacrylonitrile ultrafiltration membrane by low-temperature plasma. I. Graft of acrylic acid in gas. Journal of Membrane Science 2004;232(1-2):1-8.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGK-4BP3M5B-6&_user=10&_handle=B-WA-A-A-WW-MsSAYZA-UUA-AUEVZWCUEV-AUEWWUCYEV-CZUZZAUCE-WW-U&_fmt=summary&_coverDate=03%2F15%2F2004&_rdoc=1&_orig=browse&_srch=%23toc%235257%232004%23997679998%23482526!&_cdi=5257&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=466bbd7c41fa8e5f87124a8664dbbfb3
Keywords: Low-temperature plasma/ Graft modification/ Polyacrylonitrile ultrafiltration membrane/ Acrylic acid/ Nanofiltration
Abstract: Low temperature plasma-induced grafting modifications of polyacrylonitrile (PAN) ultrafiltration membrane were studied to prepare hydrophilic nanofiltration membranes. By argon (Ar) treating and subsequent grafting reaction, a hydrophilic monomer, acrylic acid, was introduced onto the PAN membrane. Fourier transform infrared attenuated total reflection (FTIR-ATR) spectroscopy, X-ray photoelectron spectroscopy (XPS), field emission scanning electron microscopy (FESEM) and differential scanning calorimetry (DSC) were employed to characterize the chemical and physical changes of modified membranes. FTIR-ATR spectra suggested that the CN bonds were not broken during Ar plasma irradiation. One can infer Ar plasma irradiation caused the scission of C–H bonds for subsequent graft reaction on PAN membrane surface. Results from DSC measurements demonstrated that the pores in the modified membranes became smaller and the distribution of pores narrowed. However, prolonged irradiation time caused surface etching from plasma, which resulted in an increase of pore size. For a surface hydrophilization with an improved permeability change, short graft reaction time (~10 min) is recommended. Longer graft time (e.g., 20 min, 36 W) caused the saccharose solution flux of the QH2 PAN membrane to decrease from 82 to 18 kg/(m^2 h) at 2 MPa. Saccharose retention of this nanofiltration membrane is 76%.

Ziolli RL, Jardim WF. Photocatalytic decomposition of seawater-soluble crude-oil fractions using high surface area colloid nanoparticles of TiO_2. Journal of Photochemistry and Photobiology A:

Chemistry 2002;147(3):205-12.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TGY-44B1YD4-1&_coverDate=04%2F26%2F2002&_alid=199317340&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5267&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=4eff4f13c8ecb52ba190ba09b0af53c6

Keywords: Crude oil/ TiO_2/ Water-soluble fraction (WSF)/ Heterogeneous photocatalysis/ Microtox®

Abstract: Photocatalytic destruction of the water-soluble crude oil fraction, WSF, was conducted using TiO_2/UV-VIS. Infrared studies were carried out to investigate the transformations of crude oil compounds during the photolytic and heterogeneous photocatalytic processes. Although no mineralization occurred due to photolysis, important chemical changes were verified. However, when in the presence of TiO_2, degradation reached 90% (measured as dissolved organic carbon, DOC) in waters containing 9–45 mg C /L of seawater-soluble crude oil compounds after 7 days of artificial light exposure. Inorganic peroxides were photo-generated in a concentration of up to 8.0 μmol/L upon illumination, but total destruction of these peroxides occurred during heterogeneous photocatalysis. Toxicity studies before and after irradiation of the WSF using the *Vibrio fischeri* (Microtox®) were performed. During light exposure of the WSF, transient intermediates which showed higher toxicity than the initial compounds were observed, but were subsequently destroyed. Heterogeneous photocatalysis using TiO_2 was shown to be a promising process to minimize the impact of crude oil compounds on contaminated waters.

C3. Bibliography of Nanotechnology and Sensors: Selected Reviews and News Articles from 1995 to 2004

Biosensors for environmental monitoring. TrAC Trends in Analytical Chemistry 1997;16(7):VIII-IX.
URL: http://www.sciencedirect.com/science/article/B6V5H-49347VG-5/2/0a440725a9970bdacd20e3cb4c3d9f46

Adrian P. Nanosensors targeted at the right markets could generate big business opportunities. 2003.
URL: http://www.sensorsmag.com/resources/businessdigest/sbd0703.shtml

Allan R. The future of sensors. Electronic Design 2004;52(15):51-4.
Keywords: Wireless telecommunication systems/ Automotive industry/ Medical applications/ Consumer electronics/ Fiber optics/ Nanotechnology/ Technological forecasting/ Accident prevention/ Costs/ Sensors
Abstract: The future developments in the field of sensors are predicted. Besides greater penetration in the automotive, medical, and industrial arenas, sensor manufacturers also anticipate a multitude of applications in wireless communications and consumer electronics. Rising concerns for safety, convenience, entertainment, and efficiency factors, coupled with worldwide government mandates, will see sensor usage swell to unprecedented levels. The industry needs to develop nanotemplates as nanomanufacturing tools for nanodevices and sensors as bare minimum before the technology can fluorish.

Anscombe N. MEMS are on the move in Europe. Photonics Spectra 2003;37(12):66-76.
Keywords: Nanotechnology/ Infrared radiation/ Sensors/ Investments/ Waveguides/ Microelectromechanical devices
Abstract: Although much hype is being made of the idea of nanomachines, researchers worldwide are still trying to make micromachines a reality. While the US remains a hot spot for development of microtechnology, European firms appear to be building up for a potential market lead.

Arnold JO, Venktapathy E. Developments in nanotechnology and implications for future atmospheric entry probes. International Workshop: Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science. European Space Agency, (Special Publication) ESA SP; Lisbon, Portugal. European Space Agency, 2004: 253-65.
URL:
http://www.mrc.uidaho.edu/entryws/presentations/Papers/arnold%20nanotechnology.doc
Keywords: Space research/ Nanotechnology/ Sensors/ Planets/ Environmental impact/ Isotopes/ Inert gases/ Interplanetary spacecraft/ Information analysis/ Solar system
Abstract: Two subjects which portend an exciting future for Solar System exploration are reviewed: A blueprint for science and technology needs outlined in the 2002 National Research Council (NRC) New Frontiers Report, and a forecast of remarkable advances in sensors and electronic devices from the emerging field of nanotechnology. The New Frontiers report calls for increased science capability, using less mass and power while meeting more stringent environmental conditions. In cosmochemistry, atmospheric planetary science requires reliable information (beyond that available today) on volatiles including H_2O, NH_3, CH_4, SO_2,

CO_2, H_2S, SO_2; H, He, O, C, N, S; isotopic mixing ratios of O; the noble gases and their isotopes. Examples of advances, already demonstrated for nanotechnology are discussed. Technology drivers for smaller atmospheric entry probes enabled by nanotechnology and implications for new missions are addressed. Finally, an approach to hasten the use of nanotechnology in Solar System exploration is recommended.

Bailey RE, Smith AM, Nie S. Quantum dots in biology and medicine. Physica E: Low-Dimensional Systems and Nanostructures 2004;25(1):1-12.
URL: http://www.robertbaileyphd.org/publications/PhysicaE01.pdf
Keywords: Quantum dots/ Photoluminescence / Biological physics/ Chemical sensors/ Low-dimensional structures
Abstract: Semiconductor quantum dots (QDs) are nanometer-sized crystals with unique photochemical and photophysical properties that are not available from either isolated molecules or bulk solids. In comparison with organic dyes and fluorescent proteins, these quantum-confined nanoparticles are brighter, more stable against photobleaching, and can be excited for multicolor emission with a single light source. Recent advances have shown that nanometer-sized semiconductor particles can be covalently linked with biorecognition molecules such as peptides, antibodies, nucleic acids, or small-molecule ligands for use as biological labels. High-quality QDs are also well suited for optical encoding and multiplexing applications due to their broad excitation profiles and narrow/symmetric emission spectra. In this article, we discuss recent developments in QD synthesis and bioconjugation, their applications in molecular and cellular imaging, as well as promising directions for future research. [Review]

Bakker E, Telting-Diaz M. Electrochemical sensors. Anal Chem 2002;74(12):2781-800.
Keywords: Electrochemistry/ Voltammetry/ Biosensors, design/ Fluidic devices/ Gas detectors, design
Abstract: Part of a special issue reviewing recent developments in analytical chemistry. Recent trends in modern electrochemical sensors research are reviewed. In many ways, chemical sensors research is among the most productive, exciting, and interdisciplinary areas of research in analytical chemistry. The all-important trend of miniaturization in the physical sciences is very evident in the area of chemical sensors, and the use of micro- and nanoelectrodes and microtechnological strategies for fabricating sensors highlight the strong link between chemistry, physics, and engineering in the field. However, the field also effectively interfaces with materials and polymer research, with organic chemistry and biological chemistry for chemical recognition development, and with basic electrochemistry for probing mechanistic questions. Topics covered are potentiometric and voltammetric sensors, electrochemical biosensors, the use of electrochemical sensors and detectors in fluidic systems, and electrochemical gas sensors.

Ballato A. Modeling piezoelectric and piezomagnetic devices and structures via equivalent networks. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 2001;48(5):1189-240.
Keywords: Piezoelectric transducers/ Cantilever beams/ Optical sensors/ Actuators/ Resonators/ Equivalent circuits
Abstract: A history of equivalent circuit modeling of acoustic structures is presented. This is

followed by a tutorial development of their use to represent piezoelectric (PE) and piezomagnetic (PM) plate transducers and bimorph cantilever beams for the purpose of facilitating transition of modern micro/nanotechnology creations to practical sensor, actuator, and transducer applications. Circuit approximations of various types are derived from the more general networks.

Bastani B, Fernandez D. Intellectual property rights in nanotechnology. Thin Solid Films 2002;420-421:472-7.

Keywords: Intellectual property/ Communication systems/ Sensors/ Patents and inventions/ Nanotechnology

Abstract: Intellectual property (IP) rights are essential in today's technology-driven age. Building a strategic IP portfolio is economically important from both an offensive and defensive standpoint. After an introduction to intellectual property rights and acquisitions, we provide an overview of current efforts in nanotechnology. Research into nano-scale materials and devices and requirements for their efficient mass production are outlined, with focus on the applicable IP rights and strategies. We present current and future applications of nanotechnology to such fields as electronics, sensors, aerospace, medicine, environment and sanitation, together with the IP rights that can be brought to bear in each. Finally, some challenging issues surrounding the acquisition of intellectual property rights in nanotechnology are presented. Copyright 2002 Elsevier Science B.V. All rights reserved.

Basu S. Smart materials and structures for chemical sensors. Smart Materials, Structures, and Systems. Proceedings of SPIE - The International Society for Optical Engineering; Bangalore, India. The International Society for Optical Engineering, 2002: 83-92.

Keywords: Chemical sensors/ Vapors/ Microelectromechanical devices/ Nanotechnology/ Chemical analysis/ Intelligent materials

Abstract: The latest development of materials and technology for building smart chemical sensors has been presented. Different kinds of chemical sensors working on the principle of chemical and physical transductions have been individually discussed. The sensor mechanism in each case of detection of inorganic and organic vapours has been indicated. The merits and demerits of different materials and sensors structures have been mentioned. Finally the strategic applications of some innovative chemical sensors have been clearly cited.

Baughman RH, Zakhidov AA, de Heer WA. Carbon nanotubes: The route toward applications. Science 2002;297(5582):787-92.

Keywords: Carbon nanotubes/ Hydrogen, storage/ Electrochemical apparatus, design

Abstract: Many potential applications have been proposed for carbon nanotubes, including conductive and high-strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; hydrogen storage media; and nanometer-sized semiconductor devices, probes, and interconnects. Some of these applications are now realized in products. Others are demonstrated in early to advanced devices, and one, hydrogen storage, is clouded by controversy. Nanotube cost, polydispersity in nanotube type, and limitations in processing and assembly methods are important barriers for some applications of single-walled nanotubes. Reprinted by permission of the publisher.

Beaver ER, Tanzil D. Application of sustainability tools to nanotechnology. 2004 AIChE Spring

National Meeting, Conference Proceedings. 2004 AIChE Spring National Meeting, Conference Proceedings; New Orleans, LA, USA. American Institute of Chemical Engineers, New York, USA, 2004: 3006-13.
Keywords: Sustainable development/ Drug products plants/ Sensors/ Cells/ Health risks/ Environmental impact/ Costs/ Nanotechnology
Abstract: As each new technology emerges, there are implications which often are unforeseen. Surprises tend to be at least 50% negative. Using tools such as sustainability screen, sustainability metrics, life cycle assessment, and "Total Benefit and Cost Assessment" provide mechanisms for identifying and examining the surprises in advance. This paper will report the work done by Practical Sustainability, LLC and BRIDGES to Sustainability™ to identify and prioritize the issues surrounding the realm of nanotechnology. The excitement, in particular the interest by the US federal government, provides incentives for accelerating the growth of the field. Researchers actively involved in the field have no reason raise red flags; and yet the earlier those flags are raised, the more thoroughly they can be explored, the odds and magnitude of problems can be reduced, and the benefits of new technology can be maximized.

Blaeser G, Ruehl Th, Diehl C, Ulrich M, Kohl D. Nanostructured semiconductor gas sensors to overcome sensitivity limitations due to percolation effects. Physica A: Statistical Mechanics and Its Applications [Proceedings of the 1998 International Conference on Percolation and Disordered Systems: Theory and Applications, Giessen, Germany, July 14-17, 1998] 1999;266(1-4):218-23.
Keywords: Semiconductor devices/ Percolation (solid state)/ Nanostructured materials/ Crystal lattices/ Charge carriers/ Nanotechnology/ Grain boundaries/ Quantum theory/ Chemical sensors
Abstract: Semiconductor gas sensors are widespread in applications to detect toxic or explosive gases. Their gas-sensitive layer consists of a polycrystalline metal oxide film. The gas-detection principle is based on variations of the depletion layer at the grain boundaries in presence of reducing or oxidizing gases which leads to variations in the height of the energy barriers for free charge carriers (e.g. electrons in case of SnO_2). The presence of a gas reduces the height of these barriers thus leading to an increased conductivity of the sensing material. The lower detection limit for gases is given by the fact that no (at least single) connected path exists between the reading electrodes below a certain gas concentration. The sensitivity of a gas sensor as well as its dynamic range can be improved significantly when nano technology methods are used to allow for parallel reading of shorter paths.

Bogue RW. Nanotechnology: What are the prospects for sensors? Sensor Review 2004;24(3):253-60.
Keywords: Microsensors/ Chemical sensors/ Biosensors/ Carbon nanotubes/ Chemical vapor deposition/ Electrolysis/ Ionization/ DNA/ Photocatalysis/ Photolithography/ Charge transfer/ Assembly/ Microelectromechanical devices/ Fluorescence/ Gas chromatography/ Scanning electron microscopy/ Nanotechnology
Abstract: The developments made in the field of nanosensors and its prospects in nanotechnology were discussed. The sensors, which were based on carbon nanotubes (CNT), were highly sensitive and able to detect gas concentrations down to 10^{-7} moles per litre. The sensors were also used as the detector in a gas chromatograph (GC). Sensors based on arrays of multi-walled CNTs are also being used to detect DNA and other biomolecules. The

integration of nanostructures and nanomaterials with MEMS technology and microelectronics had led to yield an intelligent, sensitive and inexpensive sensors.

Buck SM, Xu H, Brasuel M, Philbert MA, Kopelman R. Nanoscale probes encapsulated by biologically localized embedding (PEBBLEs) for ion sensing and imaging in live cells. Talanta 2004;63(1):41-59.

Keywords: Nanotechnology/ Cells/ Dyes/ Fluorescence/ Electrodes/ Sensitivity analysis/ Engineering research/ Sensors

Abstract: This review discusses the development and recent advances of probes encapsulated by biologically localized embedding (PEBBLEs), and in particular the application of PEBBLEs as ion sensors. PEBBLEs allow for minimally intrusive sensing of ions in cellular environments due to their small size (20 to 600 nm in diameter) and protect the sensing elements (i.e. fluorescent dyes) by encapsulating them within an inert matrix. The selectivity and sensitivity of these nanosensors are comparable to those of macroscopic ion selective optodes, and electrodes, while the response time and absolute detection limit are significantly better. This paper discusses the principles guiding PEBBLE design including synthesis, characterization, diversification, the advantages and limitations of the sensors, cellular applications and future directions of PEBBLE research. Copyright 2004 Elsevier B.V. All rights reserved.

Bunt G, Wouters FS. Visualization of molecular activities inside living cells with fluorescent labels. International Review of Cytology. Volume 237 ed. Academic Press, 2004:205-77.

URL: http://www.sciencedirect.com/science/article/B7CTY-4DC6ST0-7/2/34d80cca54463b15629a3de6553aff7b

Keywords: FRET/ GFP/ Protein–protein interactions/ Biosensors/ Fluorescence/ Microscopy

Abstract: The major task of modern cell biology is to identify the function and relation of the many different gene products, discovered by genomics and proteomics approaches, in the context of the living cell. To achieve this goal, an increasing toolbox of custom-designed biosensors based on fluorescent labels is available to study the molecular activities of the cellular machinery. An overview of the current status of the young field of molecular-cellular physiology is presented that includes the application of fluorescent labels in the design of biosensors and the major detection schemes used to extract their sensing information. In particular, the use of the photophysical phenomenon of Forster resonance energy transfer (FRET) as a powerful indicator of cellular biochemical events is discussed. In addition, we will point out the challenges and directions of the field and project the short-term future for the application of fluorescence-based biosensors in biology.

Carrillo DL. Nanosensors' Niche in Nanotechnology. Chemical Engineering Progress 2003;99(11):44-5.

Keywords: Sensors/ Chemical industry/ Thermal conductivity/ Carbon nanotubes/ Self assembly/ Alumina/ Tumors/ Zeolites/ Nanotechnology

Abstract: The work done in nanosensor development, which has been notable in the areas of nanomaterials, nanoparticles and nanodevices for biotechnological, chemical and gas applications is discussed. Nanosensors made of nanostructured particles are typically used to design microdevices, such as optical biosensors, DNA detection sensors, ethanol detection sensors and photodetectors. Nanodevices have demonstrated the capability to track the movement of metal ions in and out of cells, a process that is crucial to basic functions like muscle contraction.

Cassell A, Delzeit L, Nguyen C, Stevens R, Han J, Meyyappan M. Carbon nanotubes by CVD and applications. Journal De Physique IV [Proceedings of EUROCVD 13: Thirteenth European Conference on Chemical Vapor Deposition, Glyfada, Athens, Greece, August 26-31, 2001] 2001;11(3):401-10.
Abstract: Carbon nanotube (CNT) exhibits extraordinary mechanical and unique electronic properties and offers significant potential for structural, sensor, and nanoelectronics applications. An overview of CNT, growth methods, properties and applications is provided. Single-wall, and multi-wall CNTs have been grown by chemical vapor deposition. Catalyst development and optimization has been accomplished using combinatorial optimization methods. CNT has also been grown from the tips of silicon cantilevers for use in atomic force microscopy.

Castelvetro V, De Vita C. Nanostructured hybrid materials from aqueous polymer dispersions. Adv Colloid Interface Sci 2004 May;108-109:167-85.
URL: http://www.sciencedirect.com/science/article/B6V5F-4B668D3-2/2/0a12dbc52f3fcfd53d125bea8b260369
Keywords: Organic–inorganic hybrid/ Nanoparticle/ Emulsion polymerization/ Reactive latex/ Sol-gel
Abstract: Organic-inorganic (O-I) hybrids with well-defined morphology and structure controlled at the nanometric scale represent a very interesting class of materials both for their use as biomimetic composites and because of their potential use in a wide range of technologically advanced as well as more conventional application fields. Their unique features can be exploited or their role envisaged as components of electronic and optoelectronic devices, in controlled release and bioencapsulation, as active substrates for chromatographic separation and catalysis, as nanofillers for composite films in packaging and coating, in nanowriting and nanolithography, etc. A synergistic combination or totally new properties with respect to the two components of the hybrid can arise from nanostructuration, achieved by surface modification of nanostructures, self-assembling or simply heterophase dispersion. In fact, owing to the extremely large total surface area associated with the resulting morphologies, the interfacial interactions can deeply modify the bulk properties of each component. A wide range of starting materials and of production processes have been studied in recent years for the controlled synthesis and characterization of hybrid nanostructures, from nanoparticle or lamellar dispersions to mesoporous materials obtained from templating nanoparticle dispersions in a continuous, e.g. ceramic precursor, matrix. This review is aimed at giving some basic definitions of what is intended as a hybrid (O-I) material and what are the main synthetic routes available. The various methods for preparing hybrid nanostructures and, among them, inorganic-organic or O-I core-shell nanoparticles, are critically analyzed and classified based on the reaction medium (aqueous, non-aqueous), and on the role it plays in directing the final morphology. Particular attention is devoted to aqueous systems and water-borne dispersions which, in addition to being environmentally more acceptable or even a mandatory choice for any future development of large output applications (e.g. in paint, ink and coating industry), can provide the thermodynamic drive for self-assembling of amphiphilics, adsorption onto colloidal particles or partitioning of the hybrid's precursors between dispersed nanosized reaction loci, as in emulsion or miniemulsion free-radical

polymerization. While nanoencapsulation and self-assembling processes are already exploited as commercially viable fabrication methods, a newly developed technique based on two-stage sol-gel and free-radical emulsion polymerization is described, which can grant a versatile synthetic approach to hybrid O-I nanoparticles with tailor-made composition of both the organic core and the silica or organosilica shell, and good control on morphology, size and heterophase structure in the 50-500 nm range. Styrene or acrylate homo- and copolymer core latex particles need to be modified with a reactive comonomer, such as trimethoxysilylpropyl methacrylate, to achieve efficient interfacial coupling with the inorganic shell. Accurate control over pH and process conditions is required to avoid latex coagulation or, in case of organic particles with uniform composition, incipient intraparticle crosslinking.

Colbert DT. Single-wall nanotubes: A new option for conductive plastics and engineering polymers. Plastic Additives and Compounding 2003.
URL: http://cnanotech.com/download_files/PAC_Jan-Feb_2003_CNI.pdf
Abstract: Since their discovery in the 1980s, single-wall nanotubes have largely been confined to the chemists' laboratory. However, applications in the plastics industry are now starting to emerge—particularly as an additive for conductive plastics. Daniel T. Colbert of Carbon Nanotechnologies Inc. explains the background to single-wall carbon nanotubes and where the current technical development is leading.

Dagani R. Carbon nanotube Achilles' heel. Chem Eng News 2000;78(11):8-9.
URL: http://pubs.acs.org/cgi-bin/bottomframe.cgi?7811notw1
Keywords: Carbon nanotubes, oxidation/ Electric properties
Abstract: There is growing evidence that the chemical environment of a single-walled carbon nanotube (SWNT) can exert a crucial influence on the SWNT's electronic properties. The latest evidence comes from physics professor Alex Zettl's group at the University of California, Berkeley, and Lawrence Berkeley National Laboratory, where Zettl and coworkers have discovered that the electronic properties of SWNTs are highly sensitive to oxygen in the air. They argue that the electronic characteristics of nanotubes can be reversibly tuned by remarkably small concentrations of adsorbed gases and that an apparently semiconducting nanotube may be converted into one that is apparently metallic (conducting) through the same exposure. The results show that nanotubes could be used as sensitive chemical sensors for such gases as oxygen and indicate that many of the electronic properties that researchers measured and believed were intrinsic to nanotubes may instead be due to such extrinsic factors as gas exposure. For years, theorists have argued that the electronic properties of a SWNT depend on its diameter and the arrangement of carbon hexagons making up the tube wall.

Dempsey P. A fantastic voyage. New Electronics 2004;37(12):19-20.
Keywords: Medical applications/ Nanotechnology/ Surgery/ Implants (surgical)/ Patient monitoring/ Sensors/ Communication systems/ Health care/ Semiconductor devices
Abstract: Nanotechnology's impact on healthcare has changed the National Health Service's (NHS) attitude to the treatment of several chronic diseases. The sensor and monitoring technologies in electronics has enabled the use of communication systems that can transmit medical data from within the patient. The companies, on the other hand, are coming up with innovative ways to disrupt the technologies in medicine. Texas Instruments is working on dsp enabled artificial vision and AMI Semiconductor has developed asic specified implantable

diabetes monitor.

Ebbesen TW. Squeezing light through tiny holes. Electrochemical Society Interface 2003;12(1):15-6.
Keywords: Color/ Particles (particulate matter)/ Surface plasmon resonance/ Optical films/ Light transmission/ Magnetic storage/ Quantum cryptography/ Nanotechnology/ Scanning electron microscopy/ Nanostructured materials
Abstract: An overview is given on data demonstrating the possibility of making miniature novel optical devices using surface plasmons. Surface plasmon photonics is presently being tested for applications in areas such as optomagnetic data storage, quantum cryptography, near-field microscopy, sensors, and optical circuitry. Modern nanofabrication techniques allow to tailor the structure of metals and thereby the properties of surface plasmons offering a multitude of possibilities to explore.

George T. Overview of MEMS/NEMS technology development for space applications at NASA/JPL. Smart Sensors, Actuators, and MEMS. Proceedings of SPIE - The International Society for Optical Engineering; Maspalonas, Gran Canaria, Spain. The International Society for Optical Engineering, 2003: 136-48.
Keywords: Nanotechnology/ Space applications/ Interplanetary flight/ Robotics/ Electric power supplies to apparatus/ Consumer electronics/ Bolometers/ Gyroscopes/ Spectrometers/ Actuators/ Chemical sensors/ Electroplating/ Microelectromechanical devices
Abstract: This paper highlights the current technology development activities of the MEMS Technology Group at JPL. A diverse range of MEMS/NEMS technologies are under development, that are primarily applicable to NASA's needs in the area of robotic planetary exploration. MEMS/NEMS technologies have obvious advantages for space applications, since they offer the promise of highly capable devices with ultra low mass, size and power consumption. However, the key challenge appears to be in finding efficient means to transition these technologies into "customer" applications. A brief description of this problem is presented along with the Group's innovative approach to rapidly advance the maturity of technologies via insertion into space missions. Also described are some of the major capabilities of the MEMS Technology Group. A few important examples from among the broad classes of technologies being developed are discussed, these include the "spider web bolometer", high-performance miniature gyroscopes, an electron luminescence X-ray spectrometer, a MEMS-based "Knudsen" thermal transpiration pump, MEMS inchworm actuators, and nanowire-based biological/chemical sensors.

Gopel W. Nanosensors and molecular recognition. Microelectronic Engineering 1996;32(1-4):75-110.
Keywords: Nanotechnology/ Design/ Nanostructured materials/ Molecular structure/ Pattern recognition/ Chemical sensors
Abstract: A survey is given on "top-down" and "bottom-up" approaches to the design of nanostructured sensors which monitor different physical and chemical quantities. Particular emphasis is put on new materials and transducers for molecular recognition by chemical sensors. They convert chemical information into electronic signals by making use of suitable "key-lock" structures. This requires the control of atomic structures of chemically sensitive materials under either thermodynamically or kinetically controlled conditions. This in turn requires the molecular understanding of sensor mechanisms which is deduced from comparative microscopic, spectroscopic, and sensor test studies on "prototype materials".

Selected examples illustrate typical mechanisms of molecular recognition with electron conductors, ion conductors, mixed conductors, molecular cages, polymers, and biomolecular function units.

Gopel W. Chemical imaging: I. Concepts and visions for electronic and bioelectronic noses. Sensors and Actuators B: Chemical 1998;52(1-2):125-42.
URL: http://www.sciencedirect.com/science/article/B6THH-3VHW509-R/2/22e51d1dfff657ae7b6f8cf4d59916d7
Keywords: Chemical sensor systems/ Sensor arrays/ Electronic noses/ Bioelectronic noses/ Pattern recognition/ Basic concepts
Abstract: Perfect 'chemical imaging' aims at the time- and spatially-resolved recording of many chemical species. Comparison of results from 'chemical imaging' with calibration data may also be trained towards an identification of odor impressions, environmental or medical conditions (such as toxicity), process control parameters etc. This 'chemical imaging' can be approached by either using the well-established techniques of analytical chemistry or by using a large number of calibrated sensors and sensor systems. The latter are sometimes denoted 'electronic noses', provide an electronic approach to artificial olfaction and are considered in this paper. They offer a variety of principal advantages including the fact that calibration efforts and sizes can be minimized systematically for specific applications by fine-tuning individual components of the sensor system. The paper describes a systematic to design such sensor systems. In the traditional application of chemical sensors the output of an individual chemical sensor is recorded as one 'feature'. The first aim towards perfect 'chemical imaging' is to determine a large number of independent features, which span a large 'hyperspace of chemical features'. The second aim is then to extract information from this hyperspace by optimizing a feature extraction procedure towards four application-specific goals. (a) The first goal concerns to record certain chemical species quantitatively and hence aims at perfect 'chemical imaging' as defined above. (b) Alternative goals concern the recording of odor impressions, (c) environmental or medical conditions, (d) and process control parameters. Different kinds of calibration are wanted to extract the wanted information from the data represented in the hyperspace of chemical sensor features. Hence, four different strategies are required to compare the features monitored by the chemical sensor systems with independent calibration standards from (a) instruments in analytical chemistry, (b) human odor panels, (c) (micro-)biological or medical tests, (d) and process parameter measurements. This adjustment of measured sensor features to calibration standards determines a specific type of feature extraction and pattern recognition for a specific application. This pattern recognition of experimentally recorded features is of key importance not only for these 'electronic' noses but occurs in the same way in all real 'biological' noses. Hence, formal analogies between the technical and biological world of noses are obvious. It is therefore expected, that our current studies on chemical sensor systems will also lead to a deeper understanding of signal processing in biological sensor systems and vice versa. Expected synergies of comparative studies concern in particular the molecular scale understanding of (a) the elementary processes of chemical sensing, (b) human odor perception, and (c) interactions between the environment and biological organisms. In this context, biolectronics becomes an increasingly important discipline. By taking advantage of characteristic similarities and differences of components in technical and biological systems, high-performance hybrid systems will be developed in the future.

Greene JE. Transitioning from the art to the science of thin films: 1964 to 2003. J Vac Sci Technol B: Microelectronics and Nanometer Structures 2003;21(5 SUPPL):71-3.

Keywords: Surface structure/ Film growth/ Transmission electron microscopy/ Surfaces/ Morphology/ Nanotechnology/ Molecular beam epitaxy/ Molecules/ Etching/ Thin films

Abstract: Thin film science and technology remain vital and exciting. Unanticipated new results continue to lead to unpredictable branch points launching the field into dramatically different pathways. This is driven by nanotechnology, the increasing number of chemists entering the field, the desire to take one- and two-dimensional self-organization to higher orders, and interest in such areas as photonic bandgap materials, nano-electro-mechanical systems-based sensors, organic thin film devices, biocompatible materials, nanofluidics, etc. Clearly, the field of thin films remains dynamic, challenging, and highly interdisciplinary.

Hamilton J. Potential of Micro Electro Mechanical Systems and Nanotechnology for the U.S. Army. Final rept. US Government, 2001 May. Report No.: A768193.

URL: http://www.stormingmedia.us/76/7681/A768193.html

Abstract: Developments in Micro Electrical Mechanical Systems (MEMS) are reviewed. MEMS-based systems for Army applications are described, including safing and fusing devices, reconnaissance and surveillance sensors, machine interfaces, inertial measurement systems, and environmental sensors. Nanotechnology is described and developments in molecular electronics and nanostructured materials are discussed.

Handley J. Stretching the wire frontier. Anal Chem 2002;74(7):196A-9A.

Keywords: Nanowires

Abstract: Recent developments on sensors built with nanowires (NW), mesowires, or carbon nanotubes are described. The tiny size of these wires make them useful for miniaturizing analysis and possibly for intracellular analysis in biological systems. Researchers at the University of California-Irvine have discovered that palladium mesowires unexpectedly exhibit higher conductivity in the presence of hydrogen. Reginald Penner and his group are now investigating the commercial possibilities of using this sensor to monitor the fuel and effluent of hydrogen-powered vehicles. Nongjian Tao and his group at Arizona State University have fabricated copper and gold nanowires that are sensitive to chemical molecules. Harvard University's Yi Cui and Charles Lieber have developed boron-doped silicon NWs with different biological adducts that they believe could be used for real-time measurements of protein concentrations. Finally, single-walled carbon nanotubes can be useful for analyzing automobile exhaust, industrial work environments and effluents, and even for monitoring breathable air in homes, according to Hongjie Dai of Stanford University.

Heinrich B. Magnetic nanostructures: From physical principles to spintronics. Can J Phys 2000;78:161-99.

URL: http://article.pubs.nrc-cnrc.gc.ca/ppv/RPViewDoc?_handler_=HandleInitialGet&journal=cjp&volume=78&calyLang=eng&articleFile=p00-017.pdf

Keywords: Nanostructured materials, magnetic properties/ Spintronics/ Magnetic random-access semiconductor memories

Abstract: A summary of the principals that govern ultrathin film magnetic nanostructures and magnetoelectronics is presented. The presentation is based on intuitive concepts as opposed to complex physical and mathematical models in order to bring this new field to as wide an audience as possible. Some of the most recent developments in magnetic sensors and magnetic RAM are outlined to emphasize the importance of spintronics in the new technologies of the 21st century.

Hsu SM. Nano-lubrication: Concept and design. Beijing, China. Elsevier Ltd, 2004: 537-45.

Keywords: Microelectromechanical devices/ Sensors/ Actuators/ Nanotechnology/ Friction/ Surface properties/ Hard disk storage/ Adhesion/ Oxidation/ Lubrication

Abstract: The advent of micro-electromechanical devices (MEMs), sensors, actuators, microsystems, and nanotechnology have called to attention the effect of friction on moving parts in nano/micro devices. To take full advantage of the opportunity to sense, compute, and actuate in real time, fast-moving parts are often necessary or desirable. As the scales of the components shrink, adhesion, stiction, friction, and wear become a significant technological barrier for the successful deployment of durable devices. Most current devices in production avoid such contacts. The nature of the surface contacts, as component scale moves from macro to micro to nano, is dominated by surface forces that normally are dwarfed by mechanical loading. Therefore nanolubrication needs to take into account different factors than conventional lubrication concepts. This paper compares traditional lubrication concepts and those necessary for nanolubrication and proposes various nanometer scale thick lubricating film designs as a means to control the surface properties of surfaces at nano/micro scales. Many of the concepts derive their origin from studies and observations from the magnetic hard disk technology where a "monolayer" of lubricant protects the system and has proven to be robust and safe. Examples from magnetic hard disks will be used to illustrate some of the concepts. Copyright 2003. Published by Elsevier Ltd.

Huang GT. Singapore center sets ambitious goals. Technol Rev 2004;107(3):28.

Keywords: Biomedical engineering/ Biosensors/ Diagnostic products/ Blood/ Glucose/ Diseases/ Supercomputers/ Tumors/ Pulmonary diseases/ Chemical engineering/ Investments/ Nanotechnology

Abstract: Singapore's Institute of Bioengineering and Nanotechnology which is a hub for nano-based biosensors and diagnostic devices is discussed. This nanotech institute, which is part of Singapore's new Biopolis biomedical research center, has applied for a dozen patents in 2003. The institute reflects heavy nanotech investments by several governments in Asia and aims to produce everything from extremely sensitive diagnostics to superfast computers. One of the nearer-term efforts at the Singapore center is a new blood glucose sensor that allows people with diabetes to draw one-tenth the amount of blood required by conventional home systems and get readings in 5 seconds.

Iqbal SS, Mayo MW, Bruno JG, Bronk BV, Batt CA, Chambers JP. A review of molecular recognition technologies for detection of biological threat agents. Biosens Bioelectron 2000;15(11-12):549-78.

URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=11213217&dopt=Abstract

Keywords: Antibodies/ DNA probes/ Aptamers/ Biological pathogens/ Biorecognotion molecules/ Biological warfare agents

Abstract: The present review summarizes the state of the art in molecular recognition of biowarfare agents and other pathogens and emphasizes the advantages of using particular types of reagents for a given target (e.g. detection of bacteria using antibodies versus nucleic acid probes). It is difficult to draw firm conclusions as to type of biorecognition molecule to use for a given analyte. However, the detection method and reagents are generally target-driven and the user must decide on what level (genetic versus phenotypic) the detection should be performed. In general, nucleic acid-based detection is more specific and sensitive than immunological-based detection, while the latter is faster and more robust. This review also points out the challenges faced by military and civilian defense components in the rapid and accurate detection and identification of harmful agents in the field. Although new and improved sensors will continue to be developed, the more crucial need in any biosensor may be the molecular recognition component (e.g. antibody, aptamer, enzyme, nucleic acid, receptor, etc.). Improvements in the affinity, specificity and mass production of the molecular recognition components may ultimately dictate the success or failure of detection technologies in both a technical and commercial sense. Achieving the ultimate goal of giving the individual soldier on the battlefield or civilian responders to an urban biological attack or epidemic, a miniature, sensitive and accurate biosensor may depend as much on molecular biology and molecular engineering as on hardware engineering. Fortunately, as this review illustrates, a great deal of scientific attention has and is currently being given to the area of molecular recognition components. Highly sensitive and specific detection of pathogenic bacteria and viruses has increased with the proliferation of nucleic acid and immuno-based detection technologies. If recent scientific progress is a fair indicator, the future promises remarkable new developments in molecular recognition elements for use in biosensors with a vast array of applications.

Jager G, Manske E, Hausotte T, Fussl R, Grunwald R , Buchner H, et al. Miniature interferometers for applications in microtechnology and nanotechnology. Recent Developments in Traceable Dimensional Measurements II. Proceedings of SPIE - The International Society for Optical Engineering; San Diego, CA, USA. The International Society for Optical Engineering, 2003: 185-92.
Keywords: Nanotechnology/ Lasers/ Optical resolving power/ Mirrors/ Scanning/ Microscopes/ Signal processing/ Velocity measurement/ Acceleration/ Pressure effects/ Force measurement/ Interferometers
Abstract: An initial description of the design and operation of compact miniature interferometers that employ fiberoptic lightguides for all of their optical couplings and are suitable for general-purpose use is followed by a metrological analysis of their mode of operation and examples of their broad applicability, based on several typical instrumental setups.

Jayaraman K, Kotaki M, Zhang Y, Mo X, Ramakrishna S. Recent advances in polymer nanofibers. J Nanosci Nanotechnol 2004;4(1-2):52-65.
URL: http://www.ingentaconnect.com/content/asp/jnn/2004/00000004/F0020001/art00004
Keywords: Applications/ Characterization techniques/ Nanofiber mats / Polymer nanofibers/ Processing methods
Abstract: Polymer nanofibers, with diameters in the nanometer range, possess larger surface areas per unit mass and permit easier addition of surface functionalities compared with polymer microfibers. Hence, polymer nanofiber mats are being considered for use as filters,

scaffolds for tissue engineering, protective clothing, reinforcement in composite materials and sensors. Although some of these applications are in the development stage, a few have been commercially exploited. Research on polymer nanofibers, nanofiber mats, and their applications has seen a remarkable growth over the last few years. However, a review of the various issues related to these nanofibers has not been published. This article presents a review of the recent trends in the processing methods and characterization techniques for polymer nanofibers. Research challenges and future trends in the processing and characterization of polymer nanofibers are discussed in the article. Five processing methods have been examined in this review, namely drawing, template synthesis, phase separation, self-assembly, and electrospinning. Among these methods, electrospinning has been used to convert a large variety of polymers into nanofibers and may be the only process that has the potential for mass production. The structure, morphology, and geometry of nanofibers and the porosity and tensile properties of nanofiber mats can be investigated through conventional techniques and instruments. But new techniques are needed for the mechanical testing of single nanofibers. Although measurement of mechanical properties such as tensile modulus, strength, and elongation is difficult because of the small diameters of the fibers, these properties are crucial for the proper use of nanofiber mats. [103 Refs; In English]

Kaminorz Y, Heinze L. Nanotechnology in microsystems for sensor applications. VDI Berichte 2004;(1829):625-33.

Keywords: Nanotechnology/ Chemical industry/ Accelerometers/ Health care/ Atmospheric humidity/ Energy utilization/ Research and development, management/ Optimization/ Optical sensors

Abstract: Sensor applications are important almost everywhere in our life. Artificial noses, sensors to control processes in chemical industry, or accelerometers in automotive applications are of increasing importance for safety, health and convenience reasons. Therefore, sensor development is an important and innovative field of research and development. This comprises not just chemical sensors for gas or humidity, but also optical and imaging sensors. Almost every day there are new announcements of progress in improving sensitivity or selectivity. Even if it is difficult to maintain an overview over all different evolutions, because of the rapid development, it seems that sensor development is in general still based on systematic optimisation of conventional materials and technologies. But a new approach becomes more and more relevant: the use of nanotechnology. In this paper an overview over several approaches arising from nanotechnology to improve microsystems with attached importance to sensor applications will be given. The addressed attempts ranges from new functional materials, to analysing techniques to selected physical attempts. It will be shown, that nanotechnology will open new opportunity for concept developments and innovative approaches to solve problems of conventional sensors like energy consumption, selectivity and miniaturisation. Exemplification will illustrate the benefit of combining nanotechnology with microsystems technology.

Karlsson M, Davidson M, Karlsson R, Karlsson A, Bergenholtz J, Konkoli Z, et al. Biomimetic nanoscale reactors and networks. Annu Rev Phys Chem 2004;55:613-49.

Keywords: Nanotubes/ Self assembly/ Nanotechnology/ Biological membranes/ Chemical sensors/ Kinetic theory/ Topology/ Biomimetic materials

Abstract: Methods based on self-assembly, self-organization, and forced shape transformations to form synthetic or semisynthetic enclosed lipid bilayer structures with several properties similar to biological nanocompartments are reviewed. The procedures offer unconventional micro- and nanofabrication routes to yield complex soft-matter devices for a variety of applications for example, in physical chemistry and nanotechnology. In particular, we describe novel micromanipulation methods for producing fluid-state lipid bilayer networks of nanotubes and surface-immobilized vesicles with controlled geometry, topology, membrane composition, and interior contents. Mass transport in nanotubes and materials exchange, for example, between conjugated containers, can be controlled by creating a surface tension gradient that gives rise to a moving boundary or by induced shape transformations. The network devices can operate with extremely small volume elements and low mass, to the limit of single molecules and particles at a length scale where a continuum mechanics approximation may break down. Thus, we also describe some concepts of anomalous fluctuation-dominated kinetics and anomalous diffusive behaviours, including hindered transport, as they might become important in studying chemistry and transport phenomena in these confined systems. The networks are suitable for initiating and controlling chemical reactions in confined biomimetic compartments for rationalizing, for example, enzyme behaviors, as well as for applications in nanofluidics, bioanalytical devices, and to construct computational and complex sensor systems with operations building on chemical kinetics, coupled reactions and controlled mass transport.

Knauth P, Tuller HL. Solid-state ionics: Roots, status, and future prospects. J Am Ceram Soc 2002;85(7):1654-80.
Keywords: Ionic conductivity/ Impedance spectroscopy/ Crystal defects
Abstract: This review represents the authors' view of the evolution of solid-state ionics over approximately the past 100 years. A brief history, introducing milestones of the development of this discipline, is followed by a short summary of the theory of ionic conduction in the bulk and the more recently developed theory of ionic conduction at interfaces. The central part of the article gives examples of ionic-conducting materials systems with structures ranging from one- to three-dimensional disorder. Important experimental techniques for analyzing ionic conduction, including alternating-current impedance spectroscopy, direct-current coulometry, and direct-current current-voltage measurements with blocking electrodes, are also summarized. The main technological applications, that is, batteries, solid-oxide fuel cells, electrochemical sensors, electrochromic windows, and oxygen-separation membranes, are reviewed. Finally, new concepts in solid-state ionics are presented, including the investigation of new materials (such as nanostructured phases), the study of boundaries (for example, using microelectrodes), the development of computational techniques, and the connections with other classes of materials (notably magnetic and semiconducting materials).

Lang HP, Hegner M, Meyer E, Gerber C. Nanomechanics from atomic resolution to molecular recognition based on atomic force microscopy technology. Nanotechnology 2002;13(5):29-36.
URL: http://monet.physik.unibas.ch/nose/na25r2.pdf
Keywords: Atomic force microscopy/ Vapors/ Adsorption/ Molecules/ Chemical sensors/ Biosensors/ Nanotechnology
Abstract: Atomic force microscopy (AFM) is a technique to image surfaces with unprecedented vertical and lateral resolution. Many related techniques have been derived from AFM, taking advantage of local interactions between a tip on a cantilever and a surface.

However, cantilevers can also be used for sensing applications. These so-called nanosensors feature extreme sensitivity for the detection of chemical vapours or adsorption of molecules. Upon adsorption to the cantilever surface, the molecules cause the cantilever to bend. Thus physical, chemical or biochemical processes are directly transduced into nanomechanical motion. We show that measurement of the deflection of a single cantilever might be misleading. Reliable information can only be obtained by using a sensor cantilever and at least one reference cantilever integrated into an array. We have built an electronic nose using polymer layers as partially selective cantilever coatings to recognize chemical vapours and odours by evaluating the cantilevers' bending pattern. Major applications lie in the fields of process and quality control, biosensing, medical diagnostics, molecular recognition and proteomics.

Leonard P, Hearty S, Brenna J, Dunne L, Quinn J, Chakraborty T, et al. Advances in biosensors for detection of pathogens in food and water. Enzyme Microb Technol 2003;32(1):3-13.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TG1-475BFWJ-1&_user=10&_handle=B-WA-A-W-BU-MsSAYZA-UUA-AAAUVCUEYU-AAUYUBADYU-EUZDVBWYW-BU-U&_fmt=summary&_coverDate=01%2F02%2F2003&_rdoc=2&_orig=browse&_srch=%23toc%235241%232003%23999679998%23368770!&_cdi=5241&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=8430503294559ca48acad85393f2ce30
Keywords: Biosensor/ Surface plasmon resonance (SPR)/ Piezoelectric/ Amperometric/ Potentiometric
Abstract: While most microbes play an important role in nature, certain potentially harmful microbes can contaminate food and water, and cause a plethora of infectious diseases in both animals and humans. Conventional methods for detecting microbial contamination have primarily relied on time-consuming enrichment steps, followed by biochemical identification, having a total assay time of up to 1 week in certain cases. Over the last decade, a great deal of research has focused on the development of biological sensors for the detection of micro-organisms, allowing rapid and "real-time" identification. This paper reviews some of the most commonly used biosensor systems based on their transducer properties, which include surface plasmon resonance (SPR), amperometric, potentiometric, and acoustic wave sensors and their applications for the detection of pathogens in food and water. It also highlights some of the limitations of applying biosensors for the detection of pathogens, such as sensitivity, cost and the need for sample pre-treatment.

Lieber CM. Nanoscale science and technology: Building a big future from small things. MRS Bulletin 2003;28(7):486-91.
URL: http://cmliris.harvard.edu/publications/2003/mRSBull28_486.pdf
Keywords: Nanotechnology/ Carbon nanotubes/ Chemical sensors/ Biosensors/ Light emitting diodes/ Materials science
Abstract: The following article is an edited transcript based on the MRS Medalist presentation given by Charles M. Lieber of Harvard University on December 4, 2002, at the Materials Research Society Fall Meeting in Boston. Lieber received the Medal "for controlled synthesis of nanowire and nanotube materials." This presentation begins With an introduction to the bottom-up paradigm of nanoscience and nanotechnology. The key concepts of this paradigm are explored through studies outlining progress toward meeting the challenge of

nanocomputing through the assembly of functional nanowire elements. The richness of the bottom-up paradigm and nanowire building blocks is then illustrated with the development of chemical and biological nanosensors. Finally, the uniqueness of nanowires is exemplified through discussion of the assembly of nanophotonic devices, including the demonstration of multicolor and addressable nanoscale light-emitting diodes, nanowire injection lasers, and assembled arrays of these nanophotonic sources. Challenges and goals for reallzing nanotechnologies in the future are discussed in the conclusion.

Lieber CM. Nanowires as building blocks for nanoelectronics and nanophotonics. IEEE Int Electron Devices Mtg. Technical Digest - International Electron Devices Meeting; Washington, DC, USA. Institute of Electrical and Electronics Engineers Inc., 2003: 300-2.
Keywords: Nanotechnology/ Field-effect semiconductor devices/ Single crystals/ Electric properties/ Composition/ Doping (additives)/ Heterojunctions/ Low temperature effects/ Temperature measurement/ Silicon/ Transport properties/ Proteins / Chemical sensors/ Tumors/ Optical pumping/ Optoelectronic devices/ Nanostructured materials
Abstract: The bottom-up paradigm for nanoscale science and technology enabled by using semiconductor nanowires as building blocks was discussed. The growth and structural properties of single crystal nanowire building blocks were also analyzed. The electrical transport properties of individual nanowires and nanowire heterostructures were described. The optical and opto-electronic properties of compound semiconductor nanowires and nanowire heterostructures were also discussed.

Liz-Marzan LM. Nanometals: Formation and color. Materials Today 2004;7(2): 26-31.
Keywords: Optical properties/ Synthesis (chemical)/ Nanotechnology/ Tissue/ Sensors/ Color/ Solvents/ Gold/ Silver/ Ethylene/ Thin films/ Resonance/ Nanostructured materials
Abstract: Metal nanoparticles are very attractive because of their size- and shape-dependent properties. From the plethora of existing procedures for the synthesis of metal nanoparticles, the most widely used wet-chemical methods are briefly discussed, which are suitable for production of both spherical and anisometric (rod-like or prismatic) nanoparticles. The optical properties of these nanoparticles are spectacular and, therefore, have promoted a great deal of excitement during the last few decades. The basics of the origin of such optical properties are described and some of the theoretical methods accounting for them are briefly presented. Examples are shown of the color variations arising from changes in the composition, size, and shape of nanoparticles, as well as from the proximity of other metal nanoparticles. All rights reserved.

Madan R, Kumar S, Bagga E, Bajpai RP, Bharadwaj LM. Smart sensor chip based on BioMEMS. BioMEMS and Nanotechnology. Proceedings of SPIE - The International Society for Optical Engineering; Perth, WA, Australia. The International Society for Optical Engineering, 2004: 197-203.
Keywords: Biosensors/ Chemical sensors/ Intelligent networks/ Diseases/ Diagnosis/ Simulation/ Enzymes/ Microorganisms/ Antibodies/ Antigens/ Detectors/ Nanotechnology
Abstract: The smart sensor chip for simultaneous detection of a large number of disease markers is the most recent interest in the field of nanobiotechnology. Potential applications include miniaturized sensors to detect biological agents and diseases, biocompatible and improved systems for drug delivery. They are the simplest biomicroelectromechanical system

(BioMEMS) devices that offer a very promising future to the development of novel physical, chemical and biological sensors. They can simultaneously detect a large number of antigens, antibodies, DNA molecules, trace metals, hormones, proteins, gases, microorganisms, toxins, chemical warfare agents, explosives etc. in gaseous, vacuum and liquid medium. Smart sensor chips would be of greater use in intensive care units (ICUs) where multiple disease markers are to be assessed precisely in very less time. These sensors employ highly specific biochemical reactions between complementary biomolecules in the same way that nature has used in our body to detect, diagnose and treat various types of diseases. They have aroused considerable interest because of their high specificity, ultra-high sensitivity, simplicity, low cost, less analyte requirement (in µL), less steps involved, non-hazardous procedure, quick response, low power requirement and a unique capability of detecting a large number of analytes simultaneously in a single step.

Martin JI, Nogues J, Liu K, Vicent JL, Schuller IK. Ordered magnetic nanostructures: Fabrication and properties. J Magnetism Magnetic Mater 2003;256(1-3):449-501.
URL: http://www.sciencedirect.com/science/article/B6TJJ-46WVPR6-3/2/87002e9e87e121847ee8e8b1b9424c7b
Keywords: Magnetic nanostructures/ Nanofabrication/ Magnetic properties
Abstract: The fabrication methods and physical properties of ordered magnetic nanostructures with dimensions on the submicron to nanometer scale are reviewed. First, various types of nanofabrication techniques are described, and their capabilities and limitations in achieving magnetic nanostructures are discussed. Specifically, we address electron beam lithography, X-ray lithography, laser interference lithography, scanning probe lithography, step growth methods, nanoimprint, shadow masks, radiation damage, self-assembled structures, and the use of nanotemplates. Then the magnetic properties of these nanostructures are reviewed, including properties of single dots, magnetic interactions in arrays, dynamic effects, magnetic behavior of nanostructured lines and wires, giant magnetoresistance effect, and properties of films with arrays of holes. Finally, the physical properties in hybrid systems, where the magnetic arrays interact with superconducting and semiconducting layers, are summarized.

Menezes AJ, Kapoor VJ, Goel VK, et al. Within a nanometer of your life. Mech Engineering-CIME 2001 Aug;54-8.
URL: http://www.memagazine.org/backissues/aug01/features/nmeter/nmeter.html
Keywords: Artificial implants, materials/ Nanostructured materials
Abstract: The advance in semiconductor technology down to the nanometer scale is enabling new cures and treatments to be developed. Research includes biomechanical materials for novel drug deliveries, implantable sensors, textured bandages, orthopedic implants, imaging technologies, brain neurochips, and microbe and viral detectors.

Moraru CI, Panchapakesan CP, Huang Q, Takhistov P, Liu S, Kokini JL. Nanotechnology: A new frontier in food science. Food Technology 2003;57(12):24-9.
URL: http://www.ift.org/publications/docshop/ft_shop/12-03/12_03_pdfs/12-03-moraru.pdf
Keywords: Nanotechnology/ Molecular structure / Macromolecules/ Carbon nanotubes/ Tissue/ DNA/ Polysaccharides/ Chemical bonds/ Oils and fats/ Nondestructive examination/ Bacteria/ Viruses/ Antigens/ Atomic force microscopy/ Food processing
Abstract: The implementation of nanotechnology in food science is discussed. The

developments include the incorporation of miniscule carbon nanotubes into polymer substrates developed into electrically conductive membranes that can minimize the energy losses that occur when the feedstock is heated, and limit the detrimental effects of prolonged heating on the nutritional and sensory properties of the food. Chip-based sensing for rapid detection of biological pathogens is another new area with potential for application in food handling, processing, and in early warning regarding exposure to bacteria, viruses and other antigens. The applications of atomic force microscopy in nondestructive topographical analysis of delicate biomaterials are also elaborated.

Moreland J. Micromechanical instruments for ferromagnetic measurements. J Phys D: Appl Phys 2003;36:R39-R51.
URL: http://www.boulder.nist.gov/div818/81803/current/Nanoprobe/Assets/PDFs/Micromech.%20Instr.%20for%20Ferromagnetic%20Meas.pdf
Keywords: Magnetometers/ Mechatronics/ Ferromagnetic materials, testing
Abstract: I review some of the novel methods for measuring ferromagnetic properties of thin films based on micromechanical magnetometers and put them into context relative to current research on nanomagnetism. Measurements rely on the detection of mechanical forces or torques on thin films deposited onto microcantilevers. Displacements of the cantilever are detected by optical methods similar to those developed for atomic force microscopy. High sensitivities are achieved by integrating the sample with the detector, allowing magnetic measurements of samples with a total magnetic moment smaller than that detectable with conventional magnetometers. Cantilevers with low spring constants and high mechanical Q are essential for these measurements. Sensitivities better than 105 mB are possible at room temperature with the potential for single spin detection below 1 K, where the thermomechanical noise of micromechanical sensors is substantially reduced.

Oda S, Moore DF, Milne WI. Nanostructuring of materials for device and sensor applications. Eng Sci Educ J 1999;8(6):281-5.
Keywords: Lithography/ Microsensors/ Micromachining/ Thin film devices/ Microelectronic processing/ Microelectromechanical devices/ Nanotechnology
Abstract: The recent developments in nanotechnology are reviewed, with particular emphasis on its application in microsystem technology where increased reliability is achieved by integrating the sensor and the readout electronics on the same substrate. New applications may be possible using integrated micromechanical clips to connect optic fibers and components in integrated silicon systems. Some of the key developments in enabling technologies are also described, including the control of thin film deposition, nanostructuring to tailor the properties of thin film, silicon micromachining to make sensors, and microclips for the low-cost assembly of integrated optical microsystems.

Peckerar M, Perkins FK, Hodge-Miller A, Ehrlich R, Fertig S, Tender L. Sensor sensitivity training. IEEE Circuits Devices Mag 2003;19(2):17-24.
URL: http://ieeexplore.ieee.org/xpl/abs_free.jsp?arNumber=1191434
Keywords: Macromolecules/ Diseases/ Bioassay/ Chemically sensitive field-effect transistors/ Biomimetic materials/ Time domain analysis/ DNA/ Chemical sensors/ Acoustic surface wave, devices/ Nanotechnology/ Threshold voltage/ Capacitance/ Biosensors
Abstract: The basic principles of a number of emerging macromolecular sensor technologies

are reviewed. Such sensors can be used in the area of biological warfare threat mitigation and as tools in disease diagnosis. The emphasis is on newer technologies, which make use of a variety of physical principles that range from "catastrophic" changes in the electron density of states on attachment of a single macromolecule, to exploitation of capacitance change of surface in solution.
Published abstract: In this article, we review recent progress in the area of biological macromolecular sensors and we present several research activities aimed at achieving such a device. Here we distinguish sensors from assays - the former describing devices capable of continuous monitoring and real-time detection, the latter describing devices and techniques for analysis of a single sample. We give examples of both types of detector below. We conclude by focusing on a specific device we are developing in our laboratory, based upon imparting molecular recognition to a field-effect transistor as an example of current development strategies in the field.

Purvis G. The compound weather-vanes of nanotechnology. III-Vs Review 2004;17(4):42-6.
Keywords: Semiconductor device manufacture/ Biotechnology/ Sensors/ Drug therapy/ Diagnosis/ Plasma etching/ Investments/ Strategic planning/ Optoelectronic devices/ Magnetic fields/ Thermal effects/ Biomedical engineering/ Transmission electron microscopy/ Nanotechnology
Abstract: Merrill Lynch's Nanotech Index (NNZ) is discussed. The initial list of 25 companies was spread through semiconductors, biotechnology, instrumentation, sensors, diagnostics, drug delivery and development. A range of emerging technologies and markets, optoelectroniocs, photonics, RF, bio, packaging, display and high speed devices all have a requirement for nanolithography. Lithography has become a part of the device, and can change device characteristic, such as conductance, mechanical strength or color. Texas-based Molecular Imprints Inc.'s step and flash imprint lithography (S-FIL) process has been included in the International Technology Roadmap for Semiconductors, as a potential alternative to optical lithography at the 32 nm node.

Rodriguez-Mozaz S, Lopez de Alda MJ, Marco M-P, Barcelo D. Biosensors for environmental monitoring: A global perspective. Talanta 2005;65(2):291-7.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THP-4D20070-9&_user=10&_handle=B-WA-A-W-VD-MsSAYWA-UUW-AAAUVBVBEZ-AAUYUACAEZ-EUZVZCVEB-VD-U&_fmt=summary&_coverDate=01%2F30%2F2005&_rdoc=1&_orig=browse&_srch=%23toc%235288%232005%23999349997%23528350!&_cdi=5288&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=0fbd1cbb2553cbe61352134f5534bfa3
Keywords: Environmental monitoring/ Biosensors/ European projects/ Commercial
Abstract: The intention of this article is to reflect the advances and describe the trends on biosensors for environmental applications. Biosensors are useful analytical tools for environmental monitoring, capable of providing results in real time, simple to use, portable and cost-effective. Some examples of biosensors in advanced stage of development, which have been applied to real samples, as well as of commercial devices, are given. Biosensors designed for measurement of either specific chemicals or their biological effects, such as toxicity biosensors and endocrine effect biosensors, are discussed. This overview also addresses the support provided by public institutions for biosensor research in the USA, Japan and,

especially, in Europe. Future prospects of biosensor technology, with special emphasis in the development of new sensing elements, are foreseen.

Ruffin PB. Nanotechnology for missiles. Quantum Sensing and Nanophotonic Devices. Proceedings of SPIE - The International Society for Optical Engineering; San Jose, CA, USA. Int Soc Opt Eng, Bellingham, WA, USA, 2004: 177-87.
URL: http://spiedl.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PSISDG005359000001000177000001&idtype=cvips&gifs=yes
Keywords: Nanotechnology/ Optical coatings/ Thin films/ Microelectromechanical devices/ Turbines/ Carbon nanotubes/ Schottky barrier diodes/ Missiles
Abstract: Nanotechnology development is progressing very rapidly. Several billions of dollars have been invested in nanoscience research since 2000. Pioneering nanotechnology research efforts have been primarily conducted at research institutions and centers. This paper identifies developments in nanoscience and technology that could provide significant advances in missile systems applications. Nanotechnology offers opportunities in the areas of advanced materials for coatings, including thin-film optical coatings, light-weight, strong armor and missile structural components, embedded computing, and "smart" structures; nano-particles for explosives, warheads, turbine engine systems, and propellants to enhance missile propulsion; nano-sensors for autonomous chemical detection; and nano-tube arrays for fuel storage and power generation. The Aviation and Missile Research, Development, and Engineering Center (AMRDEC) is actively collaborating with academia, industry, and other Government agencies to accelerate the development and transition of nanotechnology to favorably impact Army Transformation. Currently, we are identifying near-term applications and quantifying requirements for nanotechnology use in Army missile systems, as well as monitoring and screening research and developmental efforts in the industrial community for military applications. Combining MicroElectroMechanical Systems (MEMS) and nanotechnology is the next step toward providing technical solutions for the Army's transformation. Several research and development projects that are currently underway at AMRDEC in this technology area are discussed. A top-level roadmap of MEMS/nanotechnology development projects for aviation and missile applications is presented at the end.

Saxton E, Marsh P. Building a bioelectronic interface. New Electronics 1996;29(3):18-20.
Keywords: Biotechnology/ Nanotechnology/ Biological materials/ Electrodes/ Electrochemical sensors/ Piezoelectric devices/ Optical sensors/ Acoustic surface wave devices/ Enzymes/ Biomedical engineering/ Biosensors
Abstract: Hand-held biosensor devices are finding many potential applications, especially in health care which is starting to see a potential revolution in these devices for diagnosing and monitoring disease. The technology has already found reasonable success in blood glucose measuring kits for diabetic patients. In the food industry, the same technology could be used to construct a sensitive electronic device to detect nuances in the taste of wine or beer during production. This capability also promises to impact environmental monitoring, allowing easier detection of substances such as heavy metals, industrial residues and nitrates in water supplies.

Schmedake TA, Stout GF, Fiddy MA. Nanoscale design of optical materials. VDI Berichte 2003;(1803):131-4.
Keywords: Optical materials/ Chemical sensors/ Chemisorption/ Refractive index/

Transducers/ Thin films/ Porous silicon/ Reflection/ Fluorescence/ Electromagnetic fields/ Boundary conditions/ Remote sensing/ Nanotechnology

Abstract: The nanoscale design of optical materials with dimensions on the order of or even less than the wavelength of light is discussed. Nanoscale design elements improve functionality in optically transduced chemical sensors. Adsorption of chemicals in the nanosized pores leads to a change in the refractive index of the bulk material. The incorporation of molecular dyes into submicron optical cavities leads to strong perturbations in the vaccum electromagnetic field. Nanoscale morphology results in different macroscopic properties, as in the difference between a standard light emitting dode and a laser diode.

Seal S, Shukla S. Nanocrystalline SnO gas sensors in view of surface reactions and modifications. JOM 2002;54(9):35-8, 60.

URL: [First page only] http://doc.tms.org/ezMerchant/prodtms.nsf/ProductLookupItemID/JOM-0209-35/$FILE/JOM-0209-35F.pdf?OpenElement

Keywords: Nanostructured materials/ Gas detectors/ Tin oxides, electric properties

Abstract: The gas-sensing mechanism of an n-type semiconductor (tin dioxide) gas sensor is reviewed in this paper. It is demonstrated that very high sensitivity can be obtained only when the crystallite size is less than 10 nm. Various mechanisms involving the surface and the bulk modifications of the semiconductor oxide gas sensors are discussed to improve the gas sensitivity. Current challenges and problems in nanocrystalline oxide gas sensors are also presented.

Seeman NC. Nanotechnology and the double helix. Sci Am 2004;290(6):64-75.

Keywords: DNA/ Biochemistry/ Nanostructured materials/ Biotechnology/ Genes/ Catalyst activity/ RNA/ Proteins/ Drug products/ Crystal structure/ Crystalline materials/ Chemical bonds/ X-ray crystallography/ Nanotechnology

Abstract: The nonbiological uses of the double-helix structure oF DNA in the building of structures and devices whose essential elements and mechanisms range from 100 nanometers in size are discussed. Regular lattices made of DNA can hold copies of large biological molecules in an ordered array for X-ray crystallography to determine their structure. Alternatively, the lattices can serve as scaffolding for nanoelectronic components, either as a working device or as a step in the manufacture of a device. DNA machines with moving parts can be employed as nanomechanical sensors, switches and tweezers as well as for more elaborate robotic functions.

Service RF. Atom-scale research gets real. Science 2000;290:1524-31.

Keywords: Nanotechnology/ Scientific research

Abstract: The field of nanotechnology has enormous potential but faces many challenges. The promise of this field has attracted funding, with the creation of about a dozen nanotech research centers in U.S. universities alone. However, transforming this promise into reality will mean overcoming some major obstacles. Apart from manipulating atoms, nanoscientists must devise ways to mass-produce nanosized objects and integrate them with the larger, human-scale systems around them. In addition, researchers will need to work out how to position nanocomponents on structures so that they can be used as components in electronic devices, sensors, and the like.

Shapiro B. Control challenges in micro fluidic systems and nanoscale transport phenomena. 42nd IEEE Conf on Decision and Control. Proceedings of the IEEE Conference on Decision and Control; Maui, HI, USA. Institute of Electrical and Electronics Engineers Inc., 2003: 2126-31.

Keywords: Nanotechnology/ Actuators/ Sensors/ Surface tension/ DNA/ RNA/ Switching/ Electrodes/ Integration/ Optimization/ Fluidics

Abstract: Over the last three decades, the number of available micro devices, actuators, and sensors has grown in leaps and bounds. Moreover, newly emerging nano-technology and nanosized patterning techniques are enabling even more capabilities in micro fluidic systems. The micro community is now moving from component creation to system design, optimization, and control. Hence there is a real opportunity for controls researchers, who are well versed in system dynamics and control, to contribute to the maturing field of micro systems, and also to the emerging field of nano systems. This paper presents some brief examples of my groups research efforts in this direction, and outlines our perspective on the available control opportunities and emerging system integration and control challenges.

Shelley S. Carbon nanotubes: a small-scale wonder. Chem Engineering 2003 Jan;27-9.

URL: http://www.cnanotech.com/download_files/Chemical_Engineering_Carbon_02_03.pdf

Keywords: Carbon nanotubes

Abstract: The industrial application of nanotube technology is examined. Single-wall and multi-wall configurations offer distinct sets of material characteristics and are currently used as key components in the production of high-strength composites, advanced sensors, electronic and optical devices, batteries, catalysts, and fuel cells. Although the market value shows significant potential for improvement, full-scale viability will be predicated on the ability of manufacturers to closely control repeatability and purity and reduce production costs.

Shelley S, Ondrey G. Nanotechology - the sky's the limit. Chem Engineering 2002;23-7, 72.

URL: http://www.chemshowdaily.com/pdf/23-2772ce1202.pdf

Keywords: Nanostructured materials/ Chemical-mechanical polishing/ Gas detectors

Abstract: The writer describes how nanotechnology has sweeping implications for many optical, electronic, magnetic, catalytic, and medical-therapeutic applications. Nanomaterials are currently being employed to yield composite materials with improved electroconductivity and catalytic activity, hardness, scratch resistance and self-cleaning capabilities. A discussion on how they are being exploited to improve the performance of gas sensors and other devices, the way drugs reach targets in the human body, and the aesthetic appeal and efficacy of consumer products is included.

Sheu F-S, Ye J-S. Advances in electrochemical sensors using multi-walled carbon nanotubes. Mater Technol 2004;19(1):11-2.

Keywords: Electrochemical sensors/ Electric conductivity/ Nanotechnology/ Electronic properties/ Catalysis/ Oxidation/ Single crystals/ Adsorption/ Bonding/ Electronic structure/ Carbon nanotubes

Abstract: Carbon nanotubes are cylindrical nanostructures with nanometer diameter, high electrical conductivity, chemical stability, and extremely high mechanical strength and modulus. These special properties of both single-walled and multi-walled carbon nanotubes (SWNTs and MWNTs) have attracted much attention in the research field of nanotechnology. Recently, significant advances have been made by using carbon nanotubes as sensors for the

detection of biomolecules.

Shi J, Zhu Y, Zhang X, Baeyens WRG, Garcia-Campana AM. Recent developments in nanomaterial optical sensors. TrAC Trends in Analytical Chemistry 2004;23(5):351-60.
URL: http://166.111.26.226/cams/zxr005.pdf
Abstract: The application of nanomaterials in the field of optical sensors has become a new, growing area of interest in recent years. We review chemical sensors that apply the optical principles of nanomaterials to the determination of chemical and biochemical analytes. We mainly focus on the changes of spectral absorbance, photoluminescence (PL) and chemiluminescence (CL) phenomena induced by the interaction between nanomaterials and various analytes.

Sinnott SB. Chemical functionalization of carbon nanotubes. J Nanosci Nanotechnol 2002;2(2):113-23.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12908295&dopt=Abstract
Abstract: There are many reasons why one would want to form chemical attachments to the walls or ends of carbon nanotubes: these chemical bonds might be used to tailor the interaction of the nanotube with other entities, such as a solvent, a polymer matrix, or other nanotubes. The chemically functionalized nanotube might have mechanical or electrical properties that are different from those of the unfunctionalized nanotube and thus might be used as a chemical sensor or a nanometer-scale electronic device. The challenge is to find a way to reproducibly and reliably chemically alter carbon nanotubes that, like graphite, are fairly unreactive. The various methods used to date and the possible application of the resulting functionalized nanotubes is discussed in this review paper. [Review; 124 Refs; In English]

Smith S, Nagel DJ. Nanotechnology-enabled sensors: Possibilities, realities, and applications. Sensors (Peterborough, NH) 2003;20(11):22-8.
URL: http://www.sensorsmag.com/articles/1103/22/main.shtml
Keywords: Microsensors/ Carbon nanotubes/ Printed circuit boards/ Microelectronics/ Microprocessor chips/ Cost effectiveness/ Electrometers/ Chemical sensors/ Biosensors/ Microelectromechanical devices/ Nanotechnology
Abstract: Nanotechnology is certain to improve existing sensors and be a strong force in developing new ones. The field is progressing, but considerable work must be done before its full impact is seen. Among the obvious challenges are reducing the cost of materials and devices, improving reliability, and packaging the devices into useful products.

Srivastava D, Menon M, Cho K. Computational nanotechnology with carbon nanotubes and fullerenes. Computing in Science and Engineering 2001;3(4):42-55.
Abstract: The authors envision computational nanotechnology's role in developing the next generation of multifunctional materials and molecular-scale electronic and computing devices, sensors, actuators, and machines. They briefly review computational techniques and provide a few recent examples derived from computer simulations of carbon nanotube-based molecular nanotechnology. The four core areas are: molecular-scale, ultralightweight, extremely strong, functional or smart materials; molecular-scale or nanoscale electronics with possibilities for quantum computing; molecular-scale sensors or actuators; and molecular machines or motors with synthetic materials. The underlying molecular-scale building blocks in all four areas are

fullerenes and carbon nanotube-based molecular materials. Only the different aspects of their physical, chemical, mechanical, and electronic properties create the many applications possible with these materials in vastly different areas.

Tan W, Kopelman R, Barker SLR. Ultrasmall optical sensors for cellular measurements. Anal Chem 1999;71(17):606A-12A.
Keywords: Biosensors/ Nanotechnology
Abstract: A new device called the nanoscopic optical biochemical sensor (NOBS) is discussed. The NOBS employs the high biochemical selectivity of optically sensitive dye molecules or biomolecules, such as enzymes, antibodies, DNA molecules, or living cells, to recognize substances of interest in complex media. It has dimensions in the micrometer-to-nanometer range, and thus offers both fast response times and excellent biochemical sensitivity. Furthermore, the small size of the device makes it ideal for cellular and subcellular applications. The preparation of optical sensors, intracellular ion sensors, fluorophore-labeled biomolecule sensors, enzyme-based biosensors, photobleaching, single cell measurements, monitoring biochemical species, advantages of the NOBS over a microscope, developments in the elucidation of molecular nanostructure, and future prospects of the NOBS concept are examined. [Review]

Taniguchi I. Electrochemical sensors: Key products for our technological future. Electrochemistry 2003;71(6):386.
Keywords: Electrochemistry/ Chemical warfare/ Nanotechnology/ Chemical sensors
Abstract: Electrochemical sensors are discussed. These sensors can be used for detecting chemical and biological poisons and weapons, monitoring safety and origin of chemicals, daily foods and mental care. The possible use of various techniques at the atomic and molecular levels in the development of electrochemical sensors was also discussed.

Teresko J. Electronics: A voyage of discovery. Industry Week 2003;252(5):24-30.
Keywords: Information technology/ Computer hardware/ Product development/ Data storage equipment/ Machine tools/ Maintenance/ Nanotechnology
Abstract: A review on trends in nanotechnology that foster a revolution in information technology hardware, rivaling the microelectronics revolution is presented. It is stated that nano-based breakthroughs would shrink data storage costs, redefine equipment maintenance and change the fundamental challanges of new-product development. Nanoscience solutions combining with nanoelectronic sensors are capable of determining quality levels by interacting with nanoparticles. It is suggested that nanoelectronic based sensors would be a critical benefit for machine tools as builders continue to add diagnostic capabilities.

Teresko J. Production equipment of the future. Industry Week 2004;253(8):18.
Keywords: Machine tools/ Gages/ Actuators/ Sensors/ Assembly machines/ Nanotechnology/ Materials handling/ Milling (machining)/ Computer aided design/ Mathematical models/ Production engineering
Abstract: The development of smart machines, micro-machine tools for micro factories, nanomaterials and wireless sensor networking, is discussed. The Emerging Technology Center (ETC), foretells the Smart Machine, production equipment which will be able to make the first part correctly. The objective is to eliminate wasted time and material which accompanies

traditional cut-and-try approach to new part configurations. At ETC, Georgia Tech will display smaller machine operating with a 2X improvement in resolution and accuracy.

Thayer AM. Firms find a new field of dreams. Chem Eng News 2000 Oct;78(42):36-8.
URL: http://pubs.acs.org/cen/nanotechnology/7842/7842business.html
Keywords: Market research/ New products/ Nanotechnology
Abstract: Part of a special section on nanotechnology discusses the emerging nanomaterials market. Current plans for commercializing nanotechnology range from the development of nanoscale electronics and computing applications to the development of molecular machines and manufacturing capabilities at the nanometer level. However, most companies involved in this area fall in the materials area, producing organic, inorganic, and metal nanomaterials. Many of these firms have restricted production capabilities for research-scale or perhaps development-scale quantities, but they are collaborating with partners or working alone to develop new applications for nanomaterials. These applications range from those used in polymers, batteries, electronics, cosmetics, sensors, fuel cells, and catalysis to coatings on metals and computer screens and other displays. Other firms are manufacturing nanoparticles for such biological applications as drug delivery, discovery, screening, and diagnosis. A number of companies involved in nanomaterials development and production are discussed.

Tiefenauer L, Ros R. Biointerface analysis on a molecular level: New tools for biosensor research. Colloids and Surfaces B: Biointerfaces 2002;23(2):95-114.
URL: http://www.aapspharmaceutica.com/search/view.asp?ID=24348
Keywords: Biointerface/ Analysis/ Biosensor/ Nanotechnology/ AFM
Abstract: In the last decade various techniques have been developed to investigate biointerfaces on a molecular level. Here, their impact for biointerface analysis is reviewed with emphasis on biosensor research. In order to demonstrate the power and limitations of local probe methods the imaging and force spectroscopy on single molecules are presented in details.

Tsukruk VV. Assembly of supramolecular polymers in ultrathin films. Prog Polymer Sci 1997;22(2):247-311.
URL: http://www.sciencedirect.com/science/article/B6TX2-3SPD364-6/2/ea2ddef8c89311d821f7f9c10b47a26a
Abstract: This review presents a sketch of the current status and trends in the field of organized assemblies from supramolecular polymeric systems. Among various classes of polymeric systems used to fabricate organized films, we select supramolecular polymers able to self-organize or be organized in complicated superlattices in the bulk state and/or at an interface with low-dimensional ordering. We focus on the microstructural behavior in different classes of polymers and their abilities to form various organized superstructures at surfaces and interfaces. Among the supramolecular polymers discussed are: mesomorphic polymers with chromophore and non-linear optic fragments, chiral and amphotropic polymers, systems with hydrogen bonding and discotic compounds, hairy-rod and electroactive macromolecules, block-polymers and fullerene-based systems, dendritic and latex nanocomposites, organic-inorganic organized composites and biomolecular complexes. The variation of molecular shapes, architecture of polymer backbones and specific intermolecular interactions are very effective tools for tailoring supramolecular organization of these materials in ultrathin films.

We discuss the merits of various fabrication techniques as applied to ultrathin organized films, such as Langmuir-Blodgett, self-assembly and forced solvent removal methods, as well as some characterization techniques. The physical properties of these films are discussed briefly with emphasis on optical, electric, transport, sensing and nanomechanical behavior. Finally, some thoughts about the future development in this field are presented.

U.S. Environmental Protection Agency. Biosensors for environmental monitoring: Research efforts through the National Exposure Research Laboratory at Las Vegas [Web Page]. 2004; Available at http://www.epa.gov/heasdweb/edrb/biochem/env-monit.htm.
Abstract: One of the approaches for reducing uncertainties in the assessment of human exposure is to better characterize the hazardous wastes that contaminate our environment. A significant limitation to this approach, however, is that sampling and laboratory analysis of contaminated environmental and biological samples, can be slow and expensive; thus, limiting the number of samples that can be analyzed within time and budget constraints. In cases where indicator compounds can be identified, faster, more cost-effective field screening and monitoring methods can increase the amount of information available concerning the location, source and concentration of pollutants which may impact human health and the environment. The Biosensors Research Group at the EPA's National Exposure Research Laboratory-Las Vegas is conducting research to develop scientifically sound approaches to assess and characterize risks to human health.

Varghese OK, Grimes CA. Metal oxide nanoarchitectures for environmental sensing. J Nanosci Nanotechnol 2003;3(4):277-93.
URL: http://www.ee.psu.edu/grimes/publications/JNN.OKV.CAGrimes.pdf.pdf
Keywords: Nanotubes/ Nanowires/ Metal oxide/ Gas sensing/ Hydrogen/ Humidity/ Sensor
Abstract: Metal oxide materials are widely used for gas sensing. Capable of operating at elevated temperatures and in harsh environments, they are mechanically robust and relatively inexpensive and offer exquisite sensing capabilities, the performance of which is dependent upon the nanoscale morphology. In this paper we first review different routes for the fabrication of metal oxide nanoarchitectures useful to sensing applications, including mesoporous thin films, nanowires, and nanotubes. Two sensor test cases are then presented. The first case examines the use of highly uniform nanoporous Al_2O_3 for humidity sensing; we find that such materials can be successfully used as a wide-range humidity sensor. The second test case examines the use of TiO_2 nanotubes for hydrogen sensing. Going from a nitrogen atmosphere to one containing 1000 ppm of hydrogen, at 290 C, 22 nm diameter titania nanotubes demonstrate a 10^4 change in measured resistance with no measurement hysteresis. [Review; 144 Refs; In English]

Walt DR. Nanomaterials: Top-to-bottom functional design. Nature Materials 2002;1(1):17-8.
Keywords: Sensors/ Hydrophobicity/ Self assembly/ Coatings/ Electron tunneling/ Nanotechnology
Abstract: A discussion about functional materials prepared by self assembly is presented. A macroscopic substrate serves as a template on which nanomaterials self-assemble in a predictable fashion to form a sensor. The best analytical sensors are small devices that can measure a multitude of substances continuously.

Warneke BA, Pister KSJ. Exploring the limits of system integration with Smart Dust. 2002 ASME Int Mech Eng Congress and Exposition. American Society of Mechanical Engineers, Micro-Electromechanical Systems Division Publication (MEMS); New Orleans, LA, USA. American Society of Mechanical Engineers, 2002: 621-5.

Keywords: Optical sensors/ Optical communication/ Carbon nanotubes/ Nanotechnology/ Unmanned vehicles/ Energy management/ Computer networks/ Project management/ Remote sensing

Abstract: The Smart Dust project aims to explore the limits of system integration by packing an autonomous sensing, computing, and communication node into a cubic millimeter mote that will form the basis of massive distributed sensor networks, thus demonstrating that a complete system can be integrated into 1 mm^3. Effectively exploring this space requires new approaches to design that emphasize energy and volume constraints over all others. To this end a 16 mm^3 autonomous solar-powered sensor node with bi-directional optical communication has been demonstrated, with smaller nodes forthcoming. System integration limits will shrink even further as carbon nanotube technology matures.

Watson GS, Watson JA. Natural nano-structures on insects: Possible functions of ordered arrays characterized by atomic force microscopy. Appl Surface Sci 2004;235(1-2):139-44.

URL: http://www.sciencedirect.com/science/article/B6THY-4CWSW95-2/2/5008afa3b3e07b9b4b603e6e4d760a92

Keywords: Atomic force microscopy/ Insect nano-structure/ Natural analogues/ Smart structures/ Anti-reflection

Abstract: Naturally occurring nano-structures is a much neglected, but potentially rich, source of products that meet specifications imposed by natural selection. While the pharmaceutical industry has long recognized the value of natural compounds, the emerging industries based on nanotechnology have so far made little use of 'free' technology that has been 'invented' over evolutionary time-scales and driven by the imperatives of species survival. Ordered hexagonal packed array structures on cicada (e.g., *Pflatoda* [*Psaltoda*? Ed.] *claripennis)* and termite (e.g., family Rhinotermitidae) wings have been investigated in this study. The spacings range from 200 to 1000 nm. The structures tend to have a rounded shape at the apex and protrude some 150-350 nm out from the surface plane. Wing structures with spacings at the lower end of the range are most likely optimized to serve as an anti-reflective coating (natural 'stealth technology') but may also act as a self-cleaning coating (the Lotus effect). Structures with spacings at the upper end of the range may provide mechanical strength to prevent load failure under flight and/or aid in the aerodynamic efficiency of the insect. This study demonstrates the multi-purpose design of natural structures.

Weber A. Nanotech: Small products, big potential. Assembly 2004;47(2):54-9.

Keywords: Assembly/ Electric conductivity/ Strength of materials/ Fullerenes/ Carbon nanotubes/ Self assembly/ Optical properties/ Magnetic properties/ Hardness/ Friction/ Sensors/ Transistors/ Fiber-reinforced plastics / Strategic planning/ Nanotechnology

Abstract: Nanotechnology, which transforms the way products are designed and assembled, and enhances the materials's natural properties, is discussed. Nanotechnology enhances material strength, electrical conductivity, optical properties, magnetic properties, and thermal properties. Nanotubes and bucky balls which are based on nanotechnology are also discussed. Nanomanipulation, which create customized materials molecule by molecule, atom layer by atom layer, and producing new effects, is classified into nanofabrication and self-assembly. The technology is used to develop sensors, coatings, films and membranes, and also revolutionize the battery industry.

Whatmore RW. Ferroelectrics, microsystems and nanotechnology. Proc 1997 IEE Colloq on Electro-Technical Ceramics: Processing, Properties and Applications. IEE Colloquium (Digest); London, UK. IEE, Stevenage, Engl, 1997: 1.
Keywords: Ferroelectric materials/ Semiconductor devices/ Thin films/ Thick films/ Pyroelectricity/ Piezoelectricity/ Nanostructured materials
Abstract: The term 'nanotechnology' was first coined by Taniguchi in 1974 to describe the precision manufacture of mechanical parts with finishes and tolerances in the nanometer region. However, the term has now expanded in its meaning to cover the definition and exploitation of entities (materials, devices, etc.) in which there is a dimension of less than 100 nm which is critical to their performances or behaviour. It covers a wide range of activities from ultra-precision engineering and fine-line lithography through nanostructured materials to the use of microsystems for fabricating and manipulating materials on the nanoscale. This talk will review the subject of nanotechnology and explore how new materials can be used to integrate sensing and actuation functions onto semiconductor chips, with the ultimate objective of permitting nanoscale fabrication and information storage. Ferroelectric materials offer a wide range of properties which can be used in such microsystems and nanotechnology, particularly the pyroelectric effect for thermal infra-red detection and imaging and the piezoelectric effect for sensors (sound, acceleration, etc.), and for actuators (motors, pumps). The potential for ferroelectric thin and thick films to contribute to these fields will be discussed, and problems reviewed, especially from the aspect of materials and process integration. Specific examples of the factors critical to the growth and behaviour of the materials will be given and novel processed for the fabrication of thin and thick films of ferroelectrics discussed.

Wouters D, Schubert US. Nanolithography and nanochemistry: Probe-related patterning techniques and chemical modification for nanometer-sized devices. Angewandte Chemie - Int Ed 2004;43(19):2480-95.
Keywords: Electronic equipment/ Nanostructured materials/ Photolithography/ Oxidation / Molecular dynamics/ Scanning/ Nanotechnology
Abstract: The size regime for devices produced by photolithographic techniques is limited. Therefore, other patterning techniques have been intensively studied to create smaller structures. Scanning-probe-based patterning techniques, such as dip-pen lithography, local force-induced patterning, and local-probe oxidation-based techniques are highly promising because of their relative ease and widespread availability. The latter of these is especially interesting because of the possibility of producing nanopatterns for a broad range of chemical and physical modification and functionalization processes; both the production of nanometer-sized electronic devices and the formation of devices involving (bio)molecular recognition and sensor applications is possible. This review highlights the development of various scanning probe systems and the possibilities of local oxidation methods, as well as giving an overview of state-of-the-art nanometer-sized devices, and a view of future development.

Zhao J, Xie R-H. Electronic and photonic properties of doped carbon nanotubes. J Nanosci Nanotechnol

2003;3(6):459-78.

URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15002124&itool=iconabstr

Abstract: The idea of doping carbon nanotubes is attractive since it provides various possibilities for controlling the physical properties of carbon nanotubes. In this review, we have summarized recent progress on the experimental and theoretical studies of carbon nanotubes doped with nonmetals, alkali metals, transition metals, and clusters. The doping effects on the electronic, magnetic, transport, and optical properties of carbon nanotubes are reviewed. The related applications of carbon nanotubes in nanoelectronics, battery, field emission, spintronics, nonlinear optics, and chemical sensors are discussed. [Review; 234 Refs; In English]

C4. Bibliography of Nanotechnology and Sensors: Selected Research Articles and Reports from 1995 to 2004

Aardahl CL, Grate JW, Hartman JS, Zheng F, Alexander ML, and Shin Y. Preconcentration of organic signatures based on carbon nanotube composites [Web Page]. 2003; Available at http://www.pnl.gov/nano/projects/organicsignatures.pdf.

Abstract: This work is focused on the fundamental understanding of the interactions of carbon nanotubes with vapor species and the development of novel preconcentration platforms for trace chemical detection based on that understanding.

Addleman RS, Fryxell GE, Zemanian TS, and Egorov O. Highly selective monolayer sorbents for advanced analytical applications [Web Page]. 2003; Available at http://www.pnl.gov/nano/projects/monolayersorbents.pdf.

Abstract: This research focuses on the synthesis and understanding of novel nanostructures and monolayers. The work will provide highly effective materials for preconcentration, separation, sensing, and spectroscopy, enabling the development of a wide range of novel measurement technologies for the detection of trace levels of chemical and nuclear materials.

Alvarez M, Carrascosa LG, Tamayo J, Calle A, Lechuga LM. Nanomechanics for specific biological detection. Nanotechnology. Proceedings of SPIE - The International Society for Optical Engineering; Maspalomas, Gran Canaria, Spain. The International Society for Optical Engineering, 2003: 197-206.

Keywords: Biosensors/ DNA/ Molecules/ Fluorescence/ Nucleic acids/ Pesticides/ Self assembly/ Bioassay/ Biosynthesis/ Antibodies/ Herbicides/ Genetic engineering/ Nanotechnology

Abstract: Nanomechanical biosensors have emerged as a promising technology for measurement of biomolecular interactions. Among the advantages are direct detection without need of labelling with fluorescent or radioactive molecules, small sensor area, high sensitivity and suitability for integration using silicon technology. Here we present two important applications: i) study of DNA immobilization for nucleic acid detection and ii) direct detection of the harmful pesticide dichlorodiphenyltrichloroethane (DDT). Single-stranded oligonucleotides were derivatized with thiol molecules for self-assembly on the gold-coated side of a microcantilever. The geometry of the binding and the surface density were studied and controlled by mixing derivatized oligonucleotides with spacer self-assembled monolayers. The hybridization signals were smaller than 10% of the immobilization signal. The molecular mechanisms responsible of the nanomechanical response due to hybridization are discussed. On the other hand, herbicide DDT was detected by performing competitive assays, in which the cantilever was coated with a synthetic DDT hapten, and it was exposed to different ratios between the monoclonal antibody and the DDT. The relevance of this technique in functional genomics and environmental control will be discussed.

Anderson G, Mauro M, Mattoussi H, Banahalli R. Luminescent Nanoparticles for High Sensitivity Biosensing. Final rept. 28 Mar 2000-30 Sep 2001. Washington, DC: Naval Research Lab, 2000. Report No.: A365993.

URL: http://www.stormingmedia.us/36/3659/A365993.html

Keywords: Optical detectors/ Quantum dots (QD)/ Nanoparticles/ Immunoassays/ Biosensors

Abstract: Water-soluble luminescent nanoparticles have been fabricated with suitable surface chemistry to attach biomolecules, engineered to attach via spontaneous self-assembly. The resulting bio-conjugates have been characterized and the effects of pH and ionic strength on stability examined. Additionally, methods to improve bacterial expression and purification of the fusion proteins have been developed. QDs coated with protein G, which binds antibody, have been utilized in developing sensitive immunoassays. Finally, viral capsids, which are made of repeating subunits, are being utilized as signal amplifiers, enhancing the sensitivity of optical sensors with the goal of detecting single molecular events.

Anrather D, Smetazko M, Saba M, Alguel Y, Schalkhammer T. Supported membrane nanodevices. Journal of Nanoscience and Nanotechnology 2004;4(1-2):1-22.

URL: http://www.ingentaconnect.com/content/asp/jnn/2004/00000004/F0020001/art00001

Keywords: Membranes/ Nanodevices/ Lipid membranes/ Membrane support

Abstract: Supported membrane nanodevices are based on natural or artificial ion channels embedded in a lipid membrane deposited on a chip wafer. Membrane conductance is modulated by biorecognitive events, with the use of intrinsic binding sites of the ion channel or via artificial sites fused to the channel protein. Artificial ion gates are constructed by coupling a specific ligand for the analyte near the channel entrance or a site important to triggering channel conformation. The binding event leads to the closure of the ion channel or induces a conformational change of the channel, reducing the ion flux. The signal transduced from the device is the decrease in the ion flux-induced electron current at a silver-silver chloride electrode at ultimate single-molecule sensitivity. Among the natural ion channels, gramicidin A, a transport antibiotic, was found to be most suitable, and thus was used by AMBRI, Australia, to set up prototypes of membrane biochips, using self-association of the dimer. Covalent dimerization-based devices, developed by the Vienna group, make use of the down-regulation of the permanently open membrane-spanning bisgramicidine ion channel. The reactive group at the C-terminus, a hydroxy group, allows precise coupling of the analyte-binding moiety in gramicidin as well as bisgramicidin. The device is set up with bilayer membranes deposited on apertures of a hydrophobic frame structure produced via microlithography, facing an aqueous or hydro-gel micro-environment on both sides, constructing black lipid membranes or patch-clamp devices "on chip." The setup of the device needs gel membrane supports that allow membrane formation and contribute to the stability of the bilayer by exposure of functional groups that promote electrostatic interaction and formation of hydrogen bridges and enable the introduction of covalent spacers and anchors. Photo-cross-linked polyvinylpyrrolidone and polyacrylamide, electropolymerized polydiaminobenzene and coated agarose, as well as various chemical modifications of these polymers, were employed as membrane supports. With optimized assemblies, the membrane support did allow the formation of stable bilayer membranes, proved by "gigaseal" (electrical sealing with giga-ohm resistance) to be free of any point defects in the lipid assembly. Supports with and without hydrophilic and hydrophobic anchors were studied with reference to promoting the formation of a self-assembled membrane, to their electric resistance, and to the capability to insert functional ionophores. All components, including novel chemically engineered ion channels, novel amphiphilic lipids, a microlithographically designed chip, isolating polymer frames, and a hydrogel membrane support, are combined in the new bionanodevice. Sensitivity and specificity were proved, for example, with the use of an antibody-antigen couple down-regulating the ion flux through the membrane channel. Single ion channels incorporated in the supported lipid bilayer gave stable signals at an operational stability of several hours, which is already sufficient to test and screen for membrane receptors but still insufficient to use this device as a sensor for off-site application. Further optimization to increase operational and storage stability is done by a number of groups to allow a broad application of these devices. [45 Refs; In English]

Arbiol J, Cabot A, Morante JR, et al. Distributions of noble metal Pd and Pt in mesoporous silica. Appl Phys Lett 2002;81(18):3449-51.
URL: http://www.prism.gatech.edu/~ml44/02_Cabot_APL.pdf
Keywords: Nanostructured catalysts/ Porous silica
Abstract: Mesoporous silica nanostructures were synthesized and loaded with Pd and Pt catalytic metals. Pd was found to form small nanoclusters of 3-5 nm in diameter on the surface of the mesoporous structure, while Pt impregnation resulted in the inclusion of Pt nanostructures within the silica hexagonal pores. These materials were found to have high catalytic properties for CO-CH_4 combustion. Results showed that the Pt and Pd dispersed in mesoporous silica were catalytically active as a selective filter for gas sensors.

Arnold MS, Avouris P, Pan ZW. Field-effect transistors based on single semiconducting oxide nanobelts. J Phys Chem B 2003;107:659-63.
URL: http://www.nanoscience.gatech.edu/zlwang/paper/2003/03_JPC_1.pdf
Keywords: Field effect transistors/ Zinc oxides/ Conductometric analysis
Abstract: We have fabricated field-effect transistors (FETs) based on single SnO_2 and ZnO nanobelts of thicknesses between 10 and 30 nm. Switching ratios as large as 6 orders of magnitude and conductivities as high as 15 $(Q\ cm)^{-1}$ are observed. Annealing SnO_2 nanobelt FETs in an oxygen-deficient atmosphere produces a negative shift in gate threshold voltage, indicating doping by the generation of surface oxygen vacancies. This treatment provides an effective way of tuning the electrical performance of the nanobelt devices. The ability of SnO_2 FETs to act as gas sensors is also demonstrated. SnO_2 FETs with lengths of about 500 nm or less show an anomalous behavior where the conductance cannot be modulated by the gate. ZnO nanobelt FETs are sensitive to ultraviolet light. Both photogeneration of electron-hole pairs and doping by UV induced surface desorption contribute to the conductivity.

Arregui FJ, Liu Y, Lenahan K, Holton C, Matias IR , Claus RO. Optical fiber humidity sensor formed by the ionic self-assembly monolayer process. Proceedings of SPIE - The International Society for Optical Engineering [Proceedings of the 1999 13th International Conference on Optical Fiber Sensors (OFS-13) and Workshop on Device and System Technology Toward Future Optical Fiber Communication and Sensing, Kyongju, South Korea, Apr. 12-16, 1999] 1999;3746:236-9.
Keywords: Atmospheric humidity/ Remote sensing/ Electrostatics/ Electric charge/ Nanotechnology/ Industrial applications/ Optical fibers/ Optical multilayers/ Fiber optic sensors
Abstract: The Ionic Self-Assembly Monolayer (ISAM) process was utilized to fabricate a novel optical fiber humidity sensor based on a nano interferometric cavity. This sensor operates from 23% RH to 100% RH with a maximum variation of 2.25 dB.

Arregui FJ, Matias IR, Claus RO. Optical fiber sensors based on nanoscale self-assembly. Transducing Materials and Devices. Proceedings of SPIE - The International Society for Optical Engineering; Brugge, Belgium. The International Society for Optical Engineering, 2002: 17-24.

Keywords: Nanotechnology/ Nanostructured materials/ Electrostatic devices/ Deposition/ Optical coatings/ Optical glass/ Silicon/ Polymers/ Prisms/ Optical instrument lenses/ Optical fibers/ Volatile organic compounds/ Fiber optic sensors

Abstract: The Electrostatic Self-Assembly (ESA) method is a new process that has been successfully tested for the deposition of coatings on glass, silicon, polymer or metallic substrates. This technique allows to control the individual layer composition and the thickness of the coatings on the nanometer scale and has been already proved on substrates with different sizes and shapes such as prisms, curve lens or fibers. The molecular species of the nanolayered structures and the long-range physical order of the layers determine the resulting coating properties. Combining the proper materials it is possible to build up sensitive coatings onto optical fibers for the measurement of humidity, harmful gases, volatile organic compounds or pH. These sensitive films can have thicknesses from 1 nanometer to 1 micron. Here, a review of the different optical fiber sensors fabricated up-to-date using the the ESA process is presented. The promising results obtained as well as the new possibilities opened by the synthesis of the new multilayered materials using the ESA method are also studied.

Baker JR, Balogh L, Majoros I, Keszler B, Myc A, et al. Biosensors for Real-Time Monitoring of Radiation-Induced Biologic Effects in Space. Monthly Report, 26 Jun.-25 Jul. 2002. Washington, DC, USA: National Aeronautics and Space Administration, 2002. Report No.: NAS2-02069-3.

Abstract: This proposal seeks to develop cellular biosensors based on dendritic polymers. Nanoscale polymer structures less than 20 nm in diameter will be used as the basis of the sensor/actuators. The structures will be designed to target into specific cells of an astronaut and be able to monitor health issues such as the exposure to radiation or infectious agents. Multiple components can be assembled on the polymers including target directors, analytical devices (such as molecular probes), magnetic particles and metals, and imaging agents. The design and assembly of these devices has been pioneered at the Center for Biologic Nanotechnology in the University of Michigan. These molecules would also be able to administer therapeutics in response to the needs of the astronaut, and act as actuators to remotely manipulate an astronaut as necessary to ensure their safety. The reporting will be accomplished either through fluorescence signal monitoring, with the use of multispectral analysis for signal interpretation, or through functional MRI. These nanosensors coupled to NEMS devices could facilitate the success and increase the safety of extended space flight.

Baker JR, Balogh L, Majoros I, Keszler B, Myc A, et al. Biosensors for Real-Time Monitoring of Radiation-Induced Biologic Effects in Space. Monthly Report, 26 Jul.-25 Aug. 2002. Washington, DC, USA: National Aeronautics and Space Administration, 2002. Report No.: NAS2-02069-4.

Abstract: This work seeks to develop cellular biosensors based on dendritic polymers. Nanoscale polymer structures less than 20 nm in diameter will be used as the basis of the biosensors. The structures will be designed to target into specific cells of an astronaut and be able to monitor health issues such as exposure to radiation. Multiple components can be

assembled on the polymers including target directors, analytical devices (such as molecular probes), and reporting agents. The reporting will be accomplished through fluorescence signal monitoring, with the use of multispectral analysis for signal interpretation. These nanosensors could facilitate the success and increase the safety of extended space flight. The design and assembly of these devices has been pioneered at the Center for Biologic Nanotechnology in the University of Michigan. This period, synthesis of the test-bed biosensors continued. Studies were performed on the candidate fluorescent dyes to determine which might be suitable for the biosensor under development. Development continued on producing an artificial capillary bed as a tool for the use in the production of the fluorescence signal monitor. Work was also done on the in vitro multispectral analysis system, which uses the robotic microscope.

Ballato J, Carroll D, Foulger SH. Novel light detection and sensing devices based on optical nanocomposites. Quantum Sensing: Evolution and Revolution from Past to Future, Jan 27-30 2003. Proceedings of SPIE - The International Society for Optical Engineering; San Jose, CA, USA: The International Society for Optical Engineering, 2003: 70-7.

Keywords: Elastomers / Photons/ Chemical sensors/ Photocurrents/ Quantum efficiency/ Photovoltaic cells/ Doping (additives)/ Nanostructured materials

Abstract: The promise, some fact and some fanciful, of nanotechnology has led to a well funded global race to develop new materials, components, and devices for use in a remarkably diverse range of applications. Towards the true realization of commercial- and defense-relevant devices, this paper focuses on passive and active optical detecting and sensing devices whose performance is markedly improved, with respect to traditional analogs, through the use of nanocomposite materials. Specifically to be discussed are efficient organic photovoltaics (OPVs) fabricated using doped and undoped carbon nanotube-containing conjugated polymers. All-organic photonic crystals based on ordered arrays of nanoparticles encapsulated in elastomeric matrices also are discussed. These nanocomposites exhibit bandstops that are highly tunable though strain generated by mechanical forces (mechano-chromism) or chemical affinity (chemo-chromism) which opens new doors for optical beam steering and chemical sensing.

Balogh L, Tomalia DA, Hagnauer GL. A revolution of nanoscale proportions. Chemical Innovation 2000;30(3):19-26.

Keywords: Nanostructured materials/ Dendrimers/ Encapsulation/ Size determination/ Interfaces (materials)/ Macromolecules/ DNA/ Transmission electron microscopy/ Spectroscopic analysis/ Quantum theory/ Continuum mechanics/ Nanotechnology

Abstract: The potential to construct and control objects of nanoscale proportions were discussed. The ability of dendrimers nanocomposites (DNC) to construct and control nanoscale objects and structures was addressed. The structure of organic-inorganic materials was demonstrated using polyamidoamine (PAMAM) DNCs of elemental metals. Sophisticated template structures were modified and assembled into novel compositions, shapes and sizes to study their physical and biological activity. Potential applications investigated include antimicrobial nanocomposites, fire-suppression agents, fire-retardant materials, electro-optical devices, sensors, ultrasoft magnets, single-site crystals and therapeutical nanodevices.

Barker SLR, Kopelman R, Meyer TE, Cusanovich MA. Fiber-optic nitric oxide-selective biosensors and nanosensors. Anal Chem 1998;70(5):971-6.

Keywords: Fiber optic sensors/ Nitrogen oxides/ Binding energy/ Cells/ Fluorescence/ Bacteria/ Nanotechnology/ Signal to noise ratio/ Biosensors

Abstract: Fiber-optic biosensors that are selective for nitric oxide and do not respond to most potential interferents have been prepared with cytochromes c prime. Both micro- and nanosensors have been prepared, and their response is fast (less than 1 s), reversible, and linear up to 1 mM nitric oxide. The detection limit is 20 μM, making the sensor useful for some biological samples, such as the macrophages studied here. While sensors have been prepared based on the fluorescence of the cytochromes c prime, optodes with greatly enhanced signal-to-noise ratios have been made by labeling the cytochrome c prime with a fluorescent dye. Comparisons of cytochromes c prime from three species of bacteria as well as of two matrixes were performed and the optimum sensor configuration is described.

Barker SLR, Thorsrud BA, Kopelman R. Nitrite- and chloride-selective fluorescent nano-optodes and in vitro application to rat conceptuses. Anal Chem 1998;70(1):100-4.

Keywords: Nitrites, analysis/ Biological specimens, analysis/ Chlorides in the body

Abstract: Nitrite- and chloride-selective, ion-correlation-based, nano-optodes have been prepared for application in vitro. These fluorescent, liquid polymer based sensors have theoretically predictable responses to anion activities and good selectivity. The nitrite sensor, prepared with a vitamin B12 derivative ionophore, would be useful for determination of oxidized nitric oxide. Chloride nano-optodes, as well as micro-optodes, prepared with an indium porphyrin ionophore, were utilized to determine chloride levels both on the surface and inside the visceral yolk sac of organogenesis-stage rat conceptuses. Copyright 1998, American Chemical Society.

Barron JA, Rosen R, Jones-Meehan J, Spargo BJ, Belkin S, Ringeisen BR. Biological laser printing of genetically modified *Escherichia coli* for biosensor applications. Biosens Bioelectron 2004;20(2):246-52.

URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15308228&itool=iconabstr

Abstract: One of the primary requirements of cell- or tissue-based sensors is the placement of cells and cellular material at or near the sensing elements of the device. The ability to achieve precise, reproducible and rapid placement of cells is the focus of this study. We have developed a technique, biological laser printing or BioLP, which satisfies these requirements and has advantages over current technologies. BioLP is capable of rapidly depositing patterns of active biomolecules and living cells onto a variety of material surfaces. Unlike ink jet or manual spotting techniques, this process delivers small volume (nl to fl) aliquots of biomaterials without the use of an orifice, thus eliminating potential clogging issues and enabling diverse classes of biomaterials to be deposited. This report describes the use of this laser-based printing method to transfer genetically-modified bacteria capable of responding to various chemical stressors onto agar-coated slides and into microtiter plates. The BioLP technology enables smaller spot sizes, increased resolution, and improved reproducibility compared to related technologies.

Bauer G, Voinov S, Sontag G, Leitner A, Aussenegg FR, Pittner F, et al. Optical nanocluster microchips for human diagnostics. Proceedings of SPIE - The International Society for Optical Engineering [Proceedings of the 1999 Micro- and Nanofabricated Structures and Devices for

Biomedical Environmental Applications II, San Jose, CA, USA, Jan. 25-26, 1999] 1999;3606:40-5.

Keywords: Medical applications/ Nanotechnology/ Optical systems/ Microoptics/ Light absorption/ Diagnosis/ Electronic medical equipment/ Biosensors

Abstract: Metal clusters excited by light exhibit high local field enhancement and nanoscale resonant behavior. Absorptive properties of these metal clusters bound to a surface are the basis of various new and highly promising setups to transduce biorecognitive interactions into an optical signal. Multilayered highly resonant systems had been proposed and recently demonstrated employing a metal mirror, a nanometric polymer distance layer, a biomolecule interaction layer and biorecognitively bound metal nano clusters. The optochips clearly exhibit strong reflection minima induced by the resonant behavior of the metal cluster layer. At least one narrow reflection minimum can be shifted to the red or infra red spectral range and therefore far away from spherical gold colloids (less than 520 nm) and human plasma absorption. The setup enabled us to replace conventional binding assays (like ELISA) overcoming the various technological limits as there are multiple incubation steps, harmful reagents and spatial resolution. A modified setup (the metal island coated swelling polymer over mirror system) employing an optical thin-layer system consisting of a metal mirror, an active analyte-induced swelling polymer, and a metal cluster (island) film as the topmost layer was used to transduce human plasma ion concentrations.

Bayley H, Conlan S. Genetically Engineered Pores Sensing Metal Ions. Final rept. 1 Jun 1997-31 May 2000. US Government, 2000 Oct. Report No.: A314383.

URL: http://www.stormingmedia.us/31/3143/A314383.html

Keywords: Peptides/ Metals/ Genetics/ Proteins/ *Escherichia coli*/ Fouling/ Poreforming/ Stochastic processes/ Hemolysins/ Ions/ Chemical reactions

Abstract: Stochastic sensing with pore-forming proteins has been established as a means for sensing metal ions by using engineered forms of alpha-hemolysin as the sensor elements. The alpha-hemolysin pore is a heptamer, which has disadvantages for certain manipulations in protein engineering. Therefore a single-chain protein pore was sought. In this work, the *Escherichia coli* outer membrane protein, OmpG, was shown to be a monomeric, single-chain molecule. The availability of milligram amounts of this porin will be useful for membrane protein engineering studies that will yield stochastic sensing elements more diverse than those previously accessible. Analyte-responsive pores are an inherently powerful technology for the real-time quantification of nanomolar levels of essential or toxic metal ions. Genetically engineered pores can be tailored for sensitivity, selectivity, resistance to fouling and other important characteristics. For many metal ions, the response time is limited only by analyte diffusion.

Bayley H, Martin CR. Resistive-pulse sensing: From microbes to molecules. Chem Rev 2000;100(7):2575-94.

Keywords: Single molecule detection/ Electrochemical analysis/ Membrane separation/ Ion channels

Abstract: The authors discuss issues related to a chemical sensing paradigm known as the resistive-pulse method. The topics discussed include resistive-pulse detection of cells and small particles, using biological channels for sensing, and the use of gold nanotubule membranes as molecule and ion sensors and molecular filters.

Behrend CJ, Anker JN, Kopelman R. Brownian modulated optical nanoprobes. Appl Phys Lett 2004;84(1):154-6.

URL: http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=APPLAB000084000001000154000001&idtype=cvips&gifs=yes

Keywords: Brownian movements/ Optical measurements/ Nanodevices

Abstract: The use of Brownian modulated optical nanoprobes (MOONs) as nanoviscometers through the modulation of the fluorescent signal at various characteristic rates in solutions of varying viscosity is discussed. The unique time signature produced by the random Brownian motion enables the signal to be separated from the background. These MOONs have the potential to enhance sensitivity and reduce complexity for current immunoassay procedures and for intracellular chemical sensors.

Published **Abstract:** Brownian modulated optical nanoprobes (Brownian MOONs) are fluorescent micro- and nanoparticles that resemble moons: one hemisphere emits a bright fluorescent signal, while an opaque metal darkens the other hemisphere. Brownian motion causes the particles to tumble and blink erratically as they rotate literally through the phases of the moon. The fluctuating probe signals are separated from optical and electronic backgrounds using principal components analysis or images analysis. Brownian MOONs enable microrheological measurements on size scales and timescales that are difficult to study with other methods. Local chemical concentrations can be measured simultaneously, using spectral characteristics of indicator dyes embedded within the MOONs.

Bergaud C, Cocheteau E, Guirardel M, Nicu L, Belier B. Design and fabrication of arrays of nanoelectromechanical resonators for parallel detection of biomolecular interactions. 8th International Conference on Emerging Technologies and Factory Automation (ETFA 2001). IEEE Symposium on Emerging Technologies and Factory Automation, ETFA; Antibes Juan-les-Pins, France. Institute of Electrical and Electronics Engineers Inc., 2001: 305-8.

Keywords: Nanotechnology/ Electromechanical devices/ Resonators/ Biotechnology/ Micromachining/ Microsensors/ Microactuators/ Factory automation

Abstract: The recent achievements of surface and bulk micro and nanomachining techniques combined with the fabrication techniques of integrated circuits have led to the development of miniaturized sensors and actuators exhibiting unprecedented sensitivity. This work is dedicated to the design and fabrication of nanoelectromechanical resonators for parallel detection of biomolecular interactions. The aim is to obtain piezoresistive nanoresonators with a high mechanical quality factor and a high force sensitivity to detect the mass loading induced by specific biomolecular interactions (ligand-receptor, antibody-antigen, hybridization of complementary DNA strands).

Bettotti P, Cazzanelli M, Dal Negro L, Danese B, Gaburro Z, Oton CJ, et al. Silicon nanostructures for photonics. Journal of Physics Condensed Matter 2002;14(35):8253-81.

Keywords: Silicon/ Optical materials/ Nanotechnology/ Amplification/ Nonlinear optics/ Photons/ Plasma confinement/ Electron traps/ Chemical sensors/ Nanostructured materials

Abstract: Nanostructuring silicon is an effective way to turn silicon into a photonic material. In fact, low-dimensional silicon shows light amplification characteristics, non-linear optical effects, photon confinement in both one and two dimensions, photon trapping with evidence of light localization, and gas-sensing properties.

Blaeser G, Ruehl Th, Diehl C, Ulrich M, Kohl D. Nanostructured semiconductor gas sensors to overcome sensitivity limitations due to percolation effects. Physica A: Statistical Mechanics and Its Applications [Proceedings of the 1998 International Conference on Percolation and Disordered Systems: Theory and Applications, Giessen, Germany, July 14-17, 1998] 1999;266(1-4):218-23.

Keywords: Semiconductor devices/ Percolation (solid state)/ Nanostructured materials/ Crystal lattices/ Charge carriers/ Nanotechnology/ Grain boundaries/ Quantum theory/ Chemical sensors

Abstract: Semiconductor gas sensors are widespread in applications to detect toxic or explosive gases. Their gas-sensitive layer consists of a polycrystalline metal oxide film. The gas-detection principle is based on variations of the depletion layer at the grain boundaries in presence of reducing or oxidizing gases which leads to variations in the height of the energy barriers for free charge carriers (e.g. electrons in case of SnO_2). The presence of a gas reduces the height of these barriers thus leading to an increased conductivity of the sensing material. The lower detection limit for gases is given by the fact that no (at least single) connected path exists between the reading electrodes below a certain gas concentration. The sensitivity of a gas sensor as well as its dynamic range can be improved significantly when nano technology methods are used to allow for parallel reading of shorter paths.

Borman S. Red signals lead. Chem Eng News 2003;81(21):6.

URL: http://pubs.acs.org/cen/topstory/8121/8121notw2.html

Keywords: Colorimeters/ Lead-based paint, analysis

Abstract: A sensitive and selective colorimetric sensor developed by chemists at the University of Illinois at Urbana-Champaign may provide a simple test for lead in paint. The DNAzyme-nanoparticle sensor is made up of gold nanoparticles and a DNAzyme that catalyzes cleavage of a substrate DNA only when activated by lead. When the substrate is cleaved, aggregate formation is inhibited and the more highly separated nanoparticles appear red, with the intensity of the red color indicating the amount of lead present. Sensors made with DNAzymes activated by other substances may also be useful in the detection and measurement of other metals, nonmetals, and compounds in such applications as household and environmental monitoring, developmental biology, and clinical toxicology.

Bradley K, Gabriel J-CP, Star A, Gruener G. Short-channel effects in contact-passivated nanotube chemical sensors. Appl Phys Lett 2003;83(18):3821-3.

Keywords: Single-walled carbon nanotubes/ Surface passivation/ Field-effect transistors

Abstract: The authors present a design for carbon nanotube FETs that allows the testing of the nanotube depletion length. The metal contacts and adjacent nanotubes were coated with impermeable silicon oxide, while the central region of nanotubes was left exposed. The devices were tested by measuring sensitivity to NH_3 and poly(ethylene imine). NH_3 led to similar responses in passivated devices and in normal, nonpassivated devices. In this way, the device design passivates the metal-nanotube contacts while maintaining chemical sensor characteristics. Poly(ethylene imine) generated negative threshold shifts of tens of volts, despite being in contact with only the center region of the devices. It was concluded that the length scale of the covered nanotubes in the structure under investigation was comparable to the decay length of the depletion charge in nanotube transistors.

Brasuel M, Kopelman R, Miller TJ, et al. Fluorescent nanosensors for intracellular chemical analysis: Decyl methacrylate liquid polymer matrix and ion-exchange-based potassium PEBBLE sensors with real-time application to viable rat C6 glioma cells. Anal Chem 2001;73(10):2221-8.

URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=11393844&dopt=Abstract

Keywords: Biosensors/ Tumors

Abstract: Fluorescent spherical nanosensors, or PEBBLEs (probes encapsulated by biologically localized embedding), in the 500 nm to 1 µm size range have been developed using decyl methacrylate as a matrix. A general scheme for the polymerization and introduction of sensing components creates a matrix that allows for the utilization of the highly selective ionophores used in poly(vinyl chloride) and decyl methacrylate ion-selective electrodes. We have applied these optically silent ionophores to fluorescence-based sensing by using ion-exchange and highly selective pH chromoionophores. This allows the tailoring of selective submicrometer sensors for use in intracellular measurements of important analytes for which selective enough fluorescent probes do not exist. The protocol for sensor development has been worked out for potassium sensing. It is based on the BME-44 ionophore (2-dodecy1-2-methyl-1,3-propanediylbis[*N*-[5'nitro(benzo-15-crown-5)-4'-yl]carbamate]). The general scheme should work for any available ionophore used in PVC or decyl methacrylate ion-selective electrodes, with minor adjustments to account for differences in ionophore charge and analyte binding constant. The reversible and highly selective sensors developed have a subsecond response time and an adjustable dynamic range. Applications to live C6 glioma cells demonstrate their utility; the intracellular potassium activity is followed in real time upon extracellular administration of kainic acid. Reprinted by permission of the publisher.

Bright VM, Raj R, Daily JW, Dunn ML. Injectable Ceramic Microcast Silicon Carbonitride (SiCN) microelectromechanical System (MEMS) for Extreme Temperature Environments with Extension: Micro Packages for Nano-Devices. Final rept. Aug 1999-Aug 2003. US Government, 2004. Report No.: A413124.

URL: http://www.stormingmedia.us/41/4131/A413124.html

Abstract: MEMS that can survive ultrahigh-temperatures and corrosive environments are important in a variety of unique applications. This work develops an innovative microfabrication technology for high temperature MEMS: microcasting of injectable polymer-derived SiCN ceramic materials. The techniques allow realization of MEMS with complex, three-dimensional and multilayer geometry useable to 1500 C. Our approach is easy and low cost. Several MEMS were realized and evaluated. The objectives of the extension research project are to investigate a new micro-packaging technology to create a high-vacuum, sealed environment for nano-devices integrated with other electronic or RF circuits. The process fits standard manufacturing infrastructure, and can be scaled to package MEMS or nano devices. Such a micro- package will be critical to the advancement of devices such as nano sized resonators that require high vacuum and clean environment to maintain Q's on the order of 10,000 or higher, or very advanced RF MEMS where packaging can greatly affect performance. Two challenges were identified in the initial proposal: the precision creation of the micro -cap, and the deposition of glass droplets in vacuum. The final deliverable for this project was to demonstrate a MEMS sensor hermetically sealed in vacuum. The sensors performance was measured as a function of time to demonstrate the vacuum and hermetic sealing levels.

Brolo AG, Gordon R, Leathem B, Kavanagh KL. Surface plasmon sensor based on the enhanced light transmission through arrays of nanoholes in gold films. Langmuir 2004;20(12):4813-5.
Keywords: Gold/ Refractive index/ Nanotechnology/ Lithography/ Permittivity/ Surface plasmon resonance/ Light transmission/ Thin films
Abstract: Arrays of nanoholes in a gold film were used to monitor the binding of organic and biological molecules to the metallic surface. This technique is particularly sensitive to surface binding events because it is based upon the resonant surface plasmon enhanced transmission through the array of nanoholes. The sensitivity was found to be 400 nm per refractive index unit, which is comparable to other grating-based surface plasmon resonance (SPR) devices. The array of nanoholes is well suited for dense integration in a sensor chip. Furthermore, the optical geometry is collinear, which simplifies the alignment with respect to the traditional Kretschmann (reflection) arrangement for SPR sensing.

Brown JQ, Guice KB, Caldorera ME, McShane MJ. Fabrication and deployment of nanoscale fluorescent intracellular probes. A New Beginning for Human Health: Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society . Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings; Cancun, Mexico. Institute of Electrical and Electronics Engineers Inc., 2003: 3384-7.
Keywords: Fluorescence/ Nanostructured materials/ Nanotechnology/ Chemical sensors/ Toxicity/ Potassium/ Real-time systems/ Polyelectrolytes/ Pressure transducers/ Physiology/ Cell culture/ Biomedical engineering
Abstract: Nanofabrication is an attractive tool for precise construction of micro/nanostructures to realize fluorescence sensors that may overcome problems related to use of free dyes for biological analysis. Sensor films deposited on optically-functional nanotemplates (less than or equal to 300 nm) are proposed as intracellular chemical sensors that provide an internal standard and stable separation of host from toxic foreign materials. Fluorescent nanoparticles were used as templates and intensity references for an oxygen-sensitive fluorophore Ru(dpp) and a potassium-binding dye (PBFI). Nanoassembled films on particles were characterized in terms of response to target analytes, and an efficient method of delivery to cytosol was developed using a polycationic coating. These findings suggest that self-assembled nanoparticle sensors may be easily produced and employed as useful tools for real-time cellular analysis.

Brown JQ, McShane MJ. Nanoengineered polyelectrolyte micro- and nano-capsules as fluorescent potassium ion sensors. IEEE Eng Med Biol Mag 2003;22(5):118-23.
Keywords: Nanotechnology/ Potassium/ Ion-selective electrodes, design
Abstract: The application of nanoengineered polyelectrolyte micro- and nano-capsules as ion sensors was studied. A potassium ion sensor was constructed using nanocomposite polymeric carriers, which were fabricated by the layer-by-layer method and contained potassium-binding benzofuran isophthalate as their anionic fluorescent K^+ indicator. The potassium sensitivity, reversibility, and stability of the sensors was determined. It was concluded that this simple fabrication technology can be used to produce other ion-type sensors for the study of ion occurrence at the cellular level.

Bubb DM, McGill RA, Honwitz JS, et al. Laser-based processing of polymer nanocomposites for chemical sensing applications. J Appl Phys 2001;89(10):5739-46.
Keywords: Nanocomposites/ Gas detectors, manufacture
Abstract: The use of pulsed laser deposition to fabricate polymer/carbon nanocomposite thin films for use as chemical sensors is presented. Depending on the chemistry, a given polymer absorbs and concentrates a given analyte, which swells the volume of the insulating material between the carbon particles and increases the electrical resistance of the film. Ethylene vinyl acetate films were deposited using a 193 nm ArF excimer laser at fluences from 150 to 300 mJ/cm^2.

Chafin D, Murante R, Greco RJ, Hainon J, Seabridge S, VanDerMeid K, et al. Fluidic engineering challenges in the development of an electronic-based DNA identification system. Proceedings of the Second International Conference on Microchannels and Minichannels (ICMM2004). Proceedings of the Second International Conference on Microchannels and Minichannels (ICMM2004); Rochester, NY, United States. New York, NY 10016-5990, USA: American Society of Mechanical Engineers, 2004: 1-6.
Keywords: DNA/ Flow of fluids/ Microelectronics/ Adhesives/ Diseases/ Antibiotics/ Marketing/ Nanotechnology
Abstract: Integrated Nano-Technologies, LLC (INT) has spent the last three and a half years developing a novel electronic based DNA identification system. In addition to combining DNA with microelectronics to form sensors that respond to, and identify DNA sequences in target organisms; this system relies heavily on the manipulation and delivery of small volumes of fluids. These fluids facilitate both the biological and chemical reactions required by the device's processes. The company has encountered fluidic engineering challenges throughout the development of the system including pump accuracy and delivery, material incompatibilities, adhesive intrusion, reaction waste collection, and micro mixing/channel design In this presentation, the challenges and the approaches taken to overcome them will be presented, as well as a device overview.

Chen Z, Lai JKL, Shek CH, Chen H. Synthesis and structural characterization of rutile SnO_2 nanocrystals. J Mater Res 2003;18(6):1289-92.
URL: http://www.mrs.org/publications/jmr/jmra/2003/jun/001.html
Keywords: Nanocrystals, manufacture/ Tin dioxide, crystallography
Abstract: Nanocrystalline tin dioxide (SnO_2) thin films were prepared on glass substrate by pulse laser deposition for the first time. The thin films were characterized for their composition, morphology, and crystalline structure by X-ray diffraction, transmission electron microscopy, and high-resolution transmission electron microscopy. It was found that the thin films consisted only of the tetragonal phase SnO_2 with no structural change, and they were well crystallized during deposition. In most cases, SnO_2 particles were overlapped, predominantly grown on preferred (101) plane, and connected with two or three neighbors through necks. The average grain size of the as-prepared thin films was about 12 nm. These facts are of great importance for sensor characteristics, since smaller grains and preferred orientation properties provide higher gas sensitivity to the whole thin films. Our findings indicate that the n-type wide-band-gap semiconductor nanocrystalline thin films can be manipulated by using pulse laser deposition techniques, offering new opportunities to control material fabrication.

Cho Y, Ivanisevic A. SiO_X surfaces with lithographic features composed of a TAT peptide. Journal of Physical Chemistry B 2004;108(39):15223-8.

Keywords: Lithography/ Proteins/ RNA/ Biochemistry/ DNA/ Arrays/ Nanotechnology/ Network protocols/ Atomic force microscopy/ X-ray photoelectron spectroscopy/ Silicon compounds

Abstract: Synthetic TAT peptides designed to contain an arginine-rich basic unit can bind to RNA with an affinity and specificity of a full-length TAT protein. Therefore, deducing strategies to immobilize such short peptides to surfaces can enable one to study their unique recognition properties in various types of sensor platforms. In this paper, we present a strategy to immobilize a 15-residue TAT peptide (CGISYGRKKRRQRRR) in the form of nanoscopic features on SiO_X surfaces. The protocol is based on dip-pen nanolithography that results in the formation of a covalent attachment of the peptide to a SiO_X surface rather than immobilization via electrostatic interactions or patterning on metal surfaces. The nanolithography was characterized by atomic force microscopy (AFM) and X-ray photoelectron spectroscopy. Critical parameters identified by this report include roughness quality and chemical composition of the surface prior to patterning, high humidity conditions, and concentration of ink solution needed to modify the AFM tip. Furthermore, the nanoscopic features were successfully used in recognition experiments where an RNA sequence with a loop structure, known for its specific interaction with the peptide, was tested. The results in this report indicate that one can use nanolithographic strategies to pattern chemically modified "soft" SiO_X surfaces and therefore provide a proof-of-concept experiment that can be transferred in complex microfabricated semiconductor architectures. Developing such patterning methodologies, along with the reported surface characterization protocol, is essential for precise and selective multicomponent placement of biologically active molecules on microcantilever based devices or other types of bio-MEMS platforms.

Chopra S, Pham A, Gaillard J, et al. Carbon-nanotube-based resonant-circuit sensor for ammonia. Appl Phys Lett 2002;80(24):4632-4.

Keywords: Gas detectors/ Remote sensing/ Ammonia

Abstract: The authors present highly sensitive and fast-responsive microwave resonant sensors for monitoring the presence of ammonia gas. The sensors are composed of a circular-disk electromagnetic resonant circuit coated with adsorbed-gas-sensitive carbon nanotubes. The electrical resonant frequency of the sensor exhibits a dramatic downshift of 4.375 MHz when exposed to ammonia. The sensors exhibit recovery and response times of approximately 10 minutes.

Chovin A, Garrigue P, Vinatier P, Sojic N. Development of an ordered array of optoelectrochemical individually readable sensors with submicrometer dimensions: Application to remote electrochemiluminescence imaging. Anal Chem 2004;76(2):357-64.

Keywords: Chemiluminescence / Electroluminescence / Fiber optic sensors, design

Abstract: A novel array of optoelectrochemical submicrometer sensors for remote electrochemiluminescence (ECL) imaging is presented. This device was fabricated by chemical etching of a coherent optical fiber bundle to produce a nanotip array. The surface of the etched bundle was sputter-coated with a thin layer of indium tin oxide in order to create a transparent and electrically conductive surface that is insulated eventually by a new electrophoretic paint except for the apex of the tip. These fabrication steps produced an ordered array of optoelectrochemical sensors with submicrometer dimensions that retains the optical fiber bundle architecture. The electrochemical behavior of the sensor array was independently characterized by cyclic voltammetry and ECL experiments. The steady-state current indicates that the sensors are diffusively independent. This sensor array was further studied with a co-reactant ECL model system, such as Ru-$(bpy)_3^{2+}$/TPrA. We clearly observed an ordered array of individual ECL micrometer spots, which corresponds to the sensor array structure. While the sensors of the array are not individually addressable electrochemically, we could establish that the sensors are optically independent and individually readable. Finally, we show that remote ECL imaging is performed quantitatively through the optoelectrochemical sensor array itself.

Chowdhuri A, Gupta V, Sreenivas K, et al. Response speed of SnO_2-based H_2S gas sensors with CuO nanoparticles. Appl Phys Lett 2004;84(7):1180-2.
Keywords: Copper catalysts/ Poisonous gas detectors/ Tin oxides
Abstract: The authors examined the response speed of SnO_2-based H_2S gas sensors with CuO nanoparticles. It was found that the CuO nanoparticles on sputtered SnO_2 thin-film surface displayed fast response and recovery time for trace-level H_2S gas detection. The sensitivity of the sensor, about 2.06×10^3, was found to be high even at a low operating temperature of 130 C. CuO nanoparticles on SnO_2 permitted the effective removal of excess adsorbed oxygen from the uncovered SnO_2 surface via the spillover of hydrogen dissociated from the H_2S-CuO interaction.

Chung J, Lee K-H, Lee J. Microfabricated glucose sensor based on single-walled carbon nanotubes. 17th IEEE International Conference on Micro Electro Mechanical Systems (MEMS): Maastricht MEMS 2004 Technical Digest. Proceedings of the IEEE International Conference on Micro Electro Mechanical Systems (MEMS); Maastricht, Netherlands. Piscataway, NJ, USA: Institute of Electrical and Electronics Engineers Inc., 2004: 617-20.
Keywords: Glucose sensors/ Microelectrodes/ Microelectromechanical devices/ Nanotechnology/ Electrometers/ Semiconductor materials/ Sensitivity analysis/ Carbon nanotubes
Abstract: This paper describes a novel glucose sensor that uses the hydrogen-specific gas sensing capability of single walled carbon nanotubes (SWCNTs) assembled on microelectrodes. Highly specific glucose sensing was demonstrated using buffered sample solutions with clinically significant concentrations. The proposed approach enables a simple but powerful bio-sensor reliably operating with a completely new principle, and opens up novel device applications where functional nano-components are integrated into a bioMEMS device.

Clark HA, Barker SLR, Brasuel M, Miller MT, Monson E, Parus S, et al. Subcellular optochemical nanobiosensors: Probes encapsulated by biologically localised embedding (PEBBLEs). Sensors and Actuators B: Chemical 1998;B51 [Proceedings of the 1998 4th European Conference on Optical Chemical Sensors and Biosensors, EUROPT(R)ODE IV. Munster, Germany, Mar. 29-Apr. 1, 1998](1-3):12-6.
Keywords: Biosensors/ Nanotechnology/ Probes/ Cells/ Permselective membranes/ Fiber optic sensors
Abstract: Described here are arguably the world's smallest stand-alone devices/sensors,

consisting of multicomponent nano-spheres with radii as small as 10 nm, occupying approximately 1 ppb of a typical mammalian cell's volume. The probe is prepared from up to seven ingredients and is optimised for selective and reversible analyte detection, as well as sensor stability and reproducibility. Such a sensor probe encapsulated by biologically localised embedding (PEBBLE), is delivered into a cell by a variety of minimally-invasive techniques, including a pico-injector, a gene gun, liposomal incorporation and natural ingestion. These remote nano-optodes (PEBBLEs) have been prepared for pH, calcium, magnesium, potassium and oxygen. The sensor PEBBLEs can be inserted into a cell individually, in clusters (single analyte), in sets (multi-analyte) or in ensembles (single analyte, multiple locations).

Clark HA, Hoyer M, Philbert MA, Kopelman R. Optical nanosensors for chemical analysis inside single living cells: 1. Fabrication, characterization, and methods for intracellular delivery of PEBBLE sensors. Anal Chem 1999;71(21):4831-6.

Keywords: Fiber optic sensors/ Nanostructured materials/ Cells

Abstract: Spherical optical nanosensors, or PEBBLEs (probes encapsulated by biologically localized embedding), have been produced in sizes including 20 and 200 nm in diameter. These sensors are fabricated in a microemulsion and consist of fluorescent indicators entrapped in a polyacrylamide matrix. A generalized polymerization method has been developed that permits production of sensors containing any hydrophilic dye or combination of dyes in the matrix. The PEBBLE matrix protects the fluorescent dye from interference by proteins, allowing reliable in vivo calibrations of dyes. Sensor response times are less than 1 ms. Cell viability assays indicate that the PEBBLEs are biocompatible, with negligible biological effects compared to control conditions. Several sensor delivery methods have been studied, including liposomal delivery, gene gun bombardment, and picoinjection into single living cells.

Clark HA, Kopelman R, Tjalkens R, Philbert MA. Optical nanosensors for chemical analysis inside single living cells: 2. Sensors for pH and calcium and the intracellular application of PEBBLE sensors. Anal Chem 1999;71(21):4837-43.

Keywords: Fiber optic sensors/ Nanostructured materials/ pH sensors/ Calcium, analysis

Abstract: Optical nanosensors, or PEBBLEs (probes encapsulated by biologically localized embedding), have been produced for intracellular measurements of pH and calcium. Five varieties of pH-sensitive sensors and three different calcium-selective sensors are presented and discussed. Each sensor combines an ion-selective fluorescent indicator and an ion-insensitive internal standard entrapped within an acrylamide polymeric matrix. Calibrations and linear ranges are presented for each sensor. The photobleaching of dyes incorporated into PEBBLEs is comparable to that of the respective free dye that is incorporated within the matrix. These PEBBLE sensors are fully reversible over many measurements. The leaching of fluorescent indicator from the polymer is less than 50% over a 48-h period (note that a typical application time is only a few hours). The PEBBLE sensors have also been applied to intracellular analysis of the calcium flux in the cytoplasm of neural cells during the mitochondrial permeability transition. Specifically, a distinct difference is noted between cells of different types (astrocyte vs neuron-derived cells) with respect to their response to the toxicant m-dinitrobenzene (DNB). Use of PEBBLE sensors permits the quantitative discrimination of subtle differences between the ability of human SY5Y neuroblastoma and C6 glioma to respond to challenge with DNB. Specifically, measurement of intracellular calcium, the precursor to cell death, has been achieved.

Comini E, Faglia G, Sberveglieri G, et al. Stable and highly sensitive gas sensors based on semiconducting oxide nanobelts. Appl Phys Lett 2002;81(10):1869-71.
URL: http://www.nanoscience.gatech.edu/zlwang/paper/2002/02_APL_5.pdf
Keywords: Nanostructured materials/ Gas detectors/ Ohmic contacts
Abstract: The authors describe gas sensors fabricated using single-crystalline SnO_2 nanobelts. It was found that the contacts are ohmic and the nanobelts are sensitive to environmental polluting species, including CO and NO_2, as well as to ethanol for breath analyzers and food control applications. The sensor response is 4,160% for 250 ppm of ethanol and -1,550% for 0.5 ppm NO_2 at 400 C. The findings show the potential of fabricating nanosized sensors using the integrity of a single nanobelt with a sensitivity at the level of a few ppb.

Cricenti A, Generosi R, Scarselli MA, et al. Morphological, chemical and electrical characterization of Pt-SnO_2 thin film grown on rough and mechanically polished Al_2O_3 substrates. J Phys D: Appl Phys 1996;29:2235-9.
URL: http://www.iop.org/EJ/abstract/0022-3727/29/9/003
Keywords: Tin oxide films, sputtering techniques/ Platinum/ Atomic force microscopy
Abstract: Surface chemical composition and topography of Pt-SnO_2 thin films grown by radiofrequency (rf) reactive sputtering on two different Al_2O_3 substrates (rough and mechanically polished) were investigated by X-ray photoemission spectromicroscopy (XPSM) and atomic force microscopy (AFM). XPSM measurements showed, for both substrates, a homogeneous chemical composition of the Pt-SnO_2 films. The only difference was the observation of different charging in different areas of the film grown on rough alumina substrates, due, presumably, to a non-continuous Pt-SnO_2 film. AFM showed large topographical variations (several hundred nanometres) for the Pt-SnO_2 film grown on a rough alumina substrate, due to structures already present on the substrate. The estimated roughness of the sensor was 20% larger for the Pt-SnO_2 film grown on a rough alumina substrate. The response to carbon monoxide was 30% higher for the sensor grown on rough alumina than that on polished alumina, reflecting the larger exposed sensor area.

Cui Y, Wei Q, Park H, Lieber CM. Nanowire nanosensors for highly sensitive and selective detection of biological and chemical species. Science 2001 Aug;293:1289-92.
URL: http://cmliris.harvard.edu/publications/2001/science293_1289.pdf
Keywords: Nanowires/ Biosensors
Abstract: Boron-doped silicon nanowires (SiNWs) were used to create highly sensitive, real-time electrically based sensors for biological and chemical species. Amine- and oxide-functionalized SiNWs exhibit pH-dependent conductance that was linear over a large dynamic range and could be understood in terms of the change in surface charge during protonation and deprotonation. Biotin-modified SiNWs were used to detect streptavidin down to at least a picomolar concentration range. In addition, antigen-functionalized SiNWs show reversible antibody binding and concentration-dependent detection in real time. Lastly, detection of the reversible binding of the metabolic indicator Ca^{2+} was demonstrated. The small size and capability of these semiconductor nanowires for sensitive, label-free, real-time detection of a wide range of chemical and biological species could be exploited in array-based screening and in vivo diagnostics. Copyright 2001 by the AAAS.

Cui Z, Dong L. On the gas sensing properties of α-Fe_2O_3 prepared by the plasma method. Gongneng Cailiao/Journal of Functional Materials [Chongqing, China] 1995;26(4):321-3.

Keywords: Nanotechnology/ Iron oxides/ Sensors/ Plasma applications/ Nanostructured materials

Abstract: The nanometer α-Fe_2O_3 particles were prepared by using the arc plasma method and their gas sensitivity was studied also. The results show that even under the condition of no doping, the nanometer α-Fe_2O_3 particles still have good gas sensitivity which comes from their large specific-surface area and high ratio of crystal boundary. Hence their adsorption and diffusion ability of gas are high. Besides, their mechanism of gas sensitivity was studied by using the in situ XRD method, and the results show that the gas sensitivity mechanism of nanometer α-Fe_2O_3 particles is of the surface controlled type rather than the phase transformation controlled type.

Dahne L, Leporatti S, Donath E, Mohwald H. Fabrication of micro reaction cages with tailored properties. J Am Chem Soc 2001;123(23):5431-6.

Keywords: Polyelectrolytes/ Microencapsulation/ Copolymerization

Abstract: Hollow polyelectrolyte capsules in micro- and submicrometer size were prepared. Their interior was functionalized by a "ship in bottle" synthesis of copolymers. While the monomers permeated the capsule wall easily, the formed polymers remained in the capsule cage. The physicochemical properties of the capsule interior such as ion strength, pH, light absorption, and fluorescence could be controlled independently from the surrounding solvent by means of the chemical nature of the captured polymer. In case of polyelectrolytes the osmotic pressure of the counterions led to a swelling of the capsules which can be important for micromechanics. The functionalization with light-sensitive materials allowed selective photoreactions inside the capsules. Synthesis of polyelectrolytes at high concentration resulted in an intertwining of the capsule wall with the polymer. The modified walls behaved like ion exchange membranes and showed selectivity toward adsorption and permeation of organic ions. The modified capsules offer many possibilities for novel applications as containers for controlled precipitation, as nanoreactors for catalyzed reactions, or as sensors.

Danelon C, Lindemann M, Borin C, Fournier D, Winterhalter M. Channel-forming membrane proteins as molecular sensors. IEEE Transactions on Nanobioscience 2004;3(1):46-8.

Keywords: Proteins/ Nanotechnology/ Molecular physics/ Molecules/ Kinetic theory/ Diffusion/ Electric conductance/ Biosensors

Abstract: Membrane channels are typically around or less than 1 nm in diameter and a description of the flow through them requires a molecular approach called nanofluidic. The ion current through channels is extremely sensitive to pore sizes. It is tempting to use the ion current to probe conformational changes of the channel or, for a fixed channel conformation, the current can be used to follow binding of molecules to the pore surfaces. Here we show the sensitivity of this method. It is possible to observe the passage of single isolated molecules through the channel and it is possible to discriminate between different passing molecules. Bioengineering allows us to modify channel surfaces and the affinity to different host molecules. Combining engineered proteins with the appropriated detection technique will allow a new type of molecular sensor.

Datskos PG, Sepaniak MJ. Final Progress Report: Detection and Characterization of Chemicals Present in Tank Waste [Rept. for 15 Sep 1998-14 Sep 2001]. U. S. Department of Energy, Evironmental Management Science Program, 2001 . Report No.: Project number 653540, Grant number DE-FG07-98ER62718.

URL: http://emsp.em.doe.gov/EMSPprojects1996_2003/completed/65340.pdf

Abstract: A multifaceted, interdisciplinary research program has served to provide fundamental insights and practical technological advances toward the development of miniaturized, highly-sensitive, tunably-selective sensors for monitoring chemical constituents in complex vapor and liquid matrices. The aim of this work is to support high-level waste management by improving methodologies and technologies for low cost, safe, and effective measurements of the chemical, physical, and radiological characteristics of DOE storage tanks as well as samples from surrounding areas. Specifically, the focus has been on magnifying, controlling, and augmenting the chemi-mechanical responses of microcantilever (MC) sensors. Key advances have resulted from modifying the structures of these MCs with unique geometries and nanostructured surfaces that provide higher surface area for the binding of analyte and analyte-recognizing receptors.

Datskos PG, Thundat T. Nanocantilever signal transduction by electron transfer. Journal of Nanoscience and Nanotechnology 2002;2(3-4):369-73.

URL: http://www.mnl.ornl.gov/Publications/Datskos-2002.pdf

Keywords: Nanocantilevers/ Resonance frequency/ Focused ion beam/ Micromachining / Electron transfer

Abstract: Microfabricated cantilever beams promise to bring about a revolution in the field of chemical, physical, and biological sensor development. The resonance frequency of a microfabricated cantilever shifts sensitively because of mass loading from molecular adsorption. The minimum detectable adsorbed mass on a cantilever sensor can be increased by orders of magnitude by changing the dimensions of the device; smaller and thicker cantilevers offer higher resonance frequency and therefore better mass detection sensitivity. Here we describe micromachined silicon cantilevers that are 0.5 to 4 microns in length, fabricated with the use of a focused ion beam (FIB). In addition, we demonstrate a technique for detection of the cantilever resonance frequency that is based on electron transfer.

Davidson M, Karlsson M, Sinclair J. Nanotube-vesicle networks with functionalized membranes and interiors. J Am Chem Soc 2003;125(2):374-8.

Keywords: Nanotubes/ Membranes, biology

Abstract: We describe nanotube-vesicle networks with reconstituted membrane protein from cells and with interior activity defined by an injection of microparticles or molecular probes. The functionality of a membrane protein after reconstitution was verified by single-channel ion conductance measurements in excised inside-out patches from the vesicle membranes. The distribution of protein, determined by fluorescence detection, in the network membrane was homogeneous and could diffuse via a nanotube connecting two vesicles. We also show how injecting small unilamellar protein-containing vesicles can differentiate the contents of individual containers in a network. The combination of membrane activity and interior activity was demonstrated by ionophore-assisted accumulation, and internal Calcium Green-mediated detection, of Ca^{2+} within a single network container. This system can model a variety of biological functions and complex biological multicompartment structures and might serve as a platform for constructing complex sensor and computational devices.

Davis SR, Wilson A, Wright JD. Flammable gas sensors based on sol-gel materials. IEEE Proc Circuits Devices Syst 1998;145(5):379-82.

Keywords: Flammable mixtures/ Sol-gel processes/ Gas detectors, manufacture

Abstract: The sol-gel route to the fabrication of metal oxide thin film gas sensors offers promising advantages over traditional manufacturing technologies. In particular, the low temperature fabrication process and reliable doping procedure allows the production of high surface area, high porosity materials. Metal alkoxide and metal chloride precursors have been used to prepare high surface area SnO_2 materials; Pt and Pd catalysts were added to the surface by evaporation of the appropriate metal salt. X-ray powder diffraction studies have shown these materials to be nanocrystalline with an average particle size of 2–3 nm. The use of polyacrylic acid as an organic template has been explored to improve the porosity of the materials. The authors present preliminary results of a study into the detection of mixtures of low ppm concentrations of flammable gases and vapours. Initial studies of the response of unmodified SnO_2 to simple binary mixtures of vapours and gases have shown that the response is not easily interpreted in terms of the individual gas responses and there is some evidence of interference effects. The response of Pt or Pd modified SnO_2 materials to gas mixtures does, however, show additive effects. This can be attributed to the complete oxidation of the gases and hence the removal of interfering reaction intermediates. However, reductions in response are observed due to the increased competition for active catalytic sites on the surface. The materials are capable of selectively detecting carbon monoxide in the presence of high concentrations of methane at very low temperatures (< l00 C), making them suitable for use as inexpensive domestic CO sensors.

Dechow J, Forchel A, Lanz T, Haase A. Fabrication of NMR microsensors for nanoliter sample volumes. Microelectronic Engineering [25th International Conference on Micro- and Nano-Engineering, Rome, Italy, Sept. 21-23, 1999] 2000;53(1):517-9.

Keywords: Semiconductor device, manufacture/ Nuclear magnetic resonance spectroscopy/ Nanotechnology/ Glass/ Electric coils/ Semiconducting gallium compounds/ Substrates/ Photoresists/ Masks/ Microsensors

Abstract: The fabrication of micro-sensors for NMR-spectroscopy on both glass and GaAs is presented. Planar coils with inner diameter from 50 µm to 400 µm including a coplanar wave-guide leading to the bonding pads were combined with a chamber for liquid samples of 200-500 µm diameter on the backside of the substrate. The microcoil served as a receiver in a ^{1}H-NMR experiment at 11 T (500 MHz). In initial experiments, the spectrum of 60 nl volumes of pure silicone oil were detected by the microcoil.

Di Francia G, Dalla Noce M, La Ferrara V, et al. Nanostructured porous silicon for gas sensor applications. Mater Sci Technol 2002;18(7):767-71.

Keywords: Oxygen sensors/ Porous silicon

Abstract: The response of two different types of nanostructured gas sensor to oxygen has been investigated. The first (optical) is based on the photoluminescence quenching effect of a porous silicon sample, the second on the changes of the electrical conductance vs. environment of a porous silicon free standing membrane on an insulating neutral substrate. The response of both the devices to oxygen have been measured and compared. The optical based gas sensor exhibits a quenching following the Stern-Volmer model. The corresponding reactivity rate constant is found to depend on a characteristic nanodimension of the wire. The electrically operated sensor is more sensitive to oxygen and shows an opposite behavior if exposed to a reducing environment.

Dias AF, Dernick G, Valero V, Yong MG, James CD, Craighead HG, et al. An electrochemical detector array to study cell biology on the nanoscale. Nanotechnology 2002;13(3):285-9.
Keywords: Electrochemical sensors/ Cell culture/ Biological materials/ Membranes/ Plasmas/ Electric currents/ Electrodes/ Nanotechnology
Abstract: Nanobiotechnology is a field that utilizes the techniques of nano- and microfabrication to study biosystems or to use biological material and principles to build new devices. As an example we discuss the development of a nanofabricated electrochemical detector array that reveals the spatio-temporal dynamics of exocytosis in single chromaffin cells. In a quantal release event a single vesicle fuses with the plasma membrane releasing its contents through the fusion pore. The time-resolved amperometric currents measured by the individual electrodes detecting different fractions of the released molecules allow determination of the time course as well as localization of quantal events. Such a device may be applicable to study the correlation of exocytotic events with signalling events that could be simultaneously monitored by fluorescence microscopy.

Dill K. Nanode Array Sensor Microchips. Final rept. 30 June-30 Dec. 1999. US Government, 2000 Jan. Report No.: A484814.
URL: http://www.stormingmedia.us/48/4848/A484814.html
Abstract: The phase I SBIR grant had two primary objectives. The first objective was to demonstrate the fabrication of large arrays of individually addressable, nanometerscale ultramicroelectrodes (nanodes). The second objective was to develop model immunochemical assays that can be monitored by electrochemical means for a wide range of chemical and biological warfare agents. Attaining these technical objectives would demonstrate the feasibility of using integrated circuit sensor devices for multiplexed assays. We developed the CombiMatrix ArrayChip for use in biowarfare agent detection and determined the feasibility of monitoring multiplexed assays on the chip surface using new electrochemical techniques that are in development.

Dill K. Nanode Array Sensor Microchips. Phase 2. Final rept. 26 Jan. 2000-15 Jul. 2002. US Government, 2002 Jul. Report No.: A841714.
URL: http://www.stormingmedia.us/84/8417/A841714.html?categoryID=44&categoryPageCount=&addToCart=1
Abstract: The funded proposal had several objectives. The first objective is to expand the fabrication and utilization of large arrays of individually addressable, nanometerscale ultramicroelectrodes (nanodes). The second objective was to expand on the current suite of immunochemical assays that can be monitored by electrochemical, visible, or fluorescent means for a wide range of chemical and biological warfare agents. Thirdly, we were to determine if various particle size (viral, spore, cell) can be detected on the ArrayChip. Lastly, limits of detection were determined for all analytes mentioned in this proposal. Attaining these technical objectives will demonstrate the commercialization of using integrated circuit sensor devices for multiplexed assays.

Duchesne TA, Brown JQ, Guice KB, Lvov YM, McShane MJ. Encapsulation and stability properties of

nanoengineered polyelectrolyte capsules for use as fluorescent sensors. Sensors and Materials 2002;14:293-308.
URL: http://www.myu-inc.jp/myukk/S&M/archives/pdf/S&M0491.pdf
Keywords: Fluorescent sensors/ Layer-by-layer electrostatic self assembly/ Nanoparticles/ Polyelectrolytes
Abstract: This is the first report about a novel fluorescence sensor technology based on hollow micro- and nanoscale polyelectrolyte capsules. The nanostructured shells were constructed using the electrostatic layer-by-layer assembly process to deposit multilayer polyion films onto microtemplates (melamine formaldehyde microspheres). The latex cores were subsequently dissolved and removed, leaving hollow shells. The capsules were then loaded with a model fluorescent assay consisting of a sodium-sensitive dye and a reference fluorophore. Fluorescence spectroscopy was used to analyze properties of the capsules with respect to their potential application as biosensors. The results show that multiple dye molecules can be introduced into the interior of the capsules with excellent control over relative levels, and the capsules retain >99% of fluorescence during 30 days of storage in a buffer. The findings also demonstrate that the capsules are mechanically robust, and only extremes in solvent pH cause significant leaching of fluorophores from the interior of the shells. Finally, results from sodium sensitivity experiments suggest that capsules have excellent potential for use as sensors, with a highly linear response over a broad range (0–100 mM).

Dutta P, Tipple CALNV, et al. Enantioselective sensors based on antibody-mediated nanomechanics. Anal Chem 2003;75(10):2342-8.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12918975&dopt=Abstract
Keywords: Biosensors design/ Cantilever devices, miniaturization/ Antigens and antibodies
Abstract: The use of microfabricated cantilevers as bioaffinity sensors was investigated. Since many bioaffinity interactions involve proteins as receptors, we conducted studies of the magnitude, kinetics, and reversibility of surface stresses caused when common proteins interact with microcantilevers (MCs) with nanostructured (roughened) gold surfaces on one side. Exposure of nanostructured, unfunctionalized MCs to the proteins immunoglobulin G and bovine serum albumin (BSA) resulted in reversible large tensile stresses, whereas MCs with smooth gold surfaces on one side produced reversible responses that were considerably smaller and compressive. The response magnitude for nanostructured MCs exposed to BSA is shown to be concentration dependent, and linear calibration over the range of 1–200 mg/L is demonstrated. Stable, reusable protein bioaffinity phases based on unique enantioselective antibodies are created by covalently linking monoclonal antibodies to nanostructured MC surfaces. The direct (label-free) stereoselective detection of trace amounts of an important class of chiral analytes, the α-amino acids, was achieved based on immunomechanical responses involving nanoscale bending of the cantilever. The temporal response of the cantilever (Δ deflection/Δ time) is linearly proportional to the analyte concentration and allows the quantitative determination of enantiomeric purity up to an enantiomeric excess of 99.8%. To our knowledge, this is the first demonstration of chiral discrimination using highly scalable microelectromechanical systems.

Efremov MY, Olson EA, Zhang M, et al. Ultrasensitive, fast, thin-film differential scanning

calorimeter. Rev Sci Instrum 2004;75(1):179-91.
URL: http://www.lps.umontreal.ca/~schiette/articles/RevSciInst_nanocal.pdf
Keywords: Differential scanning calorimetry/ Thin films
Abstract: The equipment for an ultrasensitive, fast, thin-film differential scanning calorimetry [(TDSC) or nanocalorimetry] technique is described. The calorimetric cell (~0.30 cm^2) operates by applying a short (~10 ms) dc current pulse (~10 mA) to a thin (~50 nm) patterned metal strip, which is supported by a thin (~50 nm) SiN_X membrane. The calorimeter operates at high heating rates (15–200 K/ms) and is very sensitive (30 pJ/K). The design of the calorimeter, the timing/synchronization methods, as well as the choice of key components of the instrument are discussed. Comparisons are made between two dc pulsing circuits that generate the current, a battery powered system and a system based on discharge of an assembly of charged capacitors (recommended). Design concepts for the differential as well as a simplified nondifferential technique are discussed and evaluated via experiments on thin films of indium. The differential design shows an increase in sensitivity, making it suitable for small samples. The custom made electronic circuits are also described, including the design of a preamplifier with low (28×) and high (700×) gain options, which are also compared using experimental data. Noise considerations are critical for the method. Simple models which describe noise levels in the calorimetric data are given and methods for reducing noise are discussed in detail. The sources of noise in the instrument are discussed in terms of both fundamental factors such as Johnson noise of the metal strip, as well as the limiting attributes of the sensing and pulsing circuits and instrumentation. These limiting attributes include spurious signals generated by desorption of ambient gases from the sensor, ground loops, switching regulators, and missing codes in analog-to-digital converter instruments. Examples of the experimental data of heat capacity Cp(T) of various thin films of indium, tin, and polystyrene are presented. A complete data set of raw experimental values is included for a 20 nm sample of Sn which shows the values of current and voltage of both the sample and reference sensors, as well as the differential voltage and the final values of the heat capacity.

Elibol OH, Morisette D, Akin D. Integrated nanoscale silicon sensors using top-down fabrication. Appl Phys Lett 2003;83(22):4613-15.
URL: http://www.ece.purdue.edu/~bashir/projects/papers/Elibol_APL_2003.pdf
Keywords: Nanodevices, manufacture/ Chemical sensors/ Semiconductor devices
Abstract: A method for fabricating silicon nanowires at precise locations using recent advances in microelectronic fabrication techniques is presented. The technique allows for the realization of fully integrated sensors for use in the production of dense arrays. The sensitivity of these devices to ambient gas atmospheres of varying composition is demonstrated.

Fasching RJ, Tao Y, Hammerick K, Prinz FB. A pencil probe system for electrochemical analysis and modification in nanometer dimensions. Smart Sensors, Actuators, and MEMS. Proceedings of SPIE - The International Society for Optical Engineering; Maspalonas, Gran Canaria, Spain. The International Society for Optical Engineering , 2003: 128-35.
Keywords: Probes/ Electrochemical sensors/ Nanotechnology/ Reactive ion etching/ Silicon nitride/ Platinum/ Gold/ Electrochemical electrodes/ Scanning electron microscopy/ Microelectronic processing/ Atomic force microscopy/ Microelectrodes/ Transducers
Abstract: A pencil-shaped electrochemical transducer system for analysis or surface modification in nanometer dimensions has been developed. High aspect ratio tip structures are

shaped, combining isotropic and anisotropic deep reactive etch processes, forming the body of the transducer. In this way, an aspect ratio of greater than 20 with a tip radius of smaller than 50 nm can be achieved. Subsequently, a three-layer system (an isolation layer: silicon nitride, a metal layer: platinum or gold and an isolation layer: silicon nitride) is deposited on the tip structure. Planarization of this structure in combination with an etch-back process enables precise exposure of the buried metal layer producing an electrode dimension of 100 nm at the tip. Electrochemical and impedance spectroscopic characterization shows electrochemical functionality of the transducer system. Due to the high aspect ratio topography, this probe is particularly well suited for Scanning Electrochemical Microscope (SECM) methodologies. Furthermore, this technology promises a feasible production possibility for both arrays of electrochemical probes and probes on cantilevers.

Favier F, Waltzer EC, Zach MP, et al. Hydrogen sensors and switches from electrodeposited palladium mesowire arrays. Science 2001;293(21):2227-31.
URL: http://chem.ps.uci.edu/~rmpenner/PDFs/63_Science_293(2001)2227.pdf
Keywords: Nanowires, synthesis/ Palladium, electrotechnical uses/ Hydrogen sensors
Abstract: Hydrogen sensors and hydrogen-activated switches were fabricated from arrays of mesoscopic palladium wires. These palladium "mesowire" arrays were prepared by electrodeposition onto graphite surfaces and were transferred onto a cyanoacrylate film. Exposure to hydrogen gas caused a rapid (less than 75 milliseconds) reversible decrease in the resistance of the array that correlated with the hydrogen concentration over a range from 2 to 10%. The sensor response appears to involve the closing of nanoscopic gaps or "break junctions" in wires caused by the dilation of palladium grains undergoing hydrogen absorption. Wire arrays in which all wires possessed nanoscopic gaps reverted to open circuits in the absence of hydrogen gas. Copyright 2001 by the AAAS.

Ferguson JA, Steemers FJ, Walt DR. High-density fiber-optic DNA random microsphere array. Anal Chem 2000;72(22):5618-24.
URL: http://www.math.unm.edu/~andriese/Walt_Anal_Chem.pdf
Keywords: DNA chips/ Fiber optics
Abstract: A high-density fiber-optic DNA microarray sensor was developed to monitor multiple DNA sequences in parallel. Microarrays were prepared by randomly distributing DNA probe-functionalized 3.1 µm diameter microspheres in an array of wells etched in a 500 µm diameter optical imaging fiber. Registration of the microspheres was performed using an optical encoding scheme and a custom-built imaging system. Hybridization was visualized using fluorescent-labeled DNA targets with a detection limit of 10 fM. Hybridization times of seconds are required for nanomolar target concentrations, and analysis is performed in minutes.

Fuller LF, Vega R, Manley R, Hwang VC, Jaeger D, Pham A, et al. An interdigitated electrode detector for the identification of a single specific DNA molecule fragment. 15th Biennial University/Government/Industry Microelectronics Symposium. Biennial University/Government/Industry Microelectronics Symposium - Proceedings; Boise, ID, USA. Institute of Electrical and Electronics Engineers Inc., 2003: 200-2.
Keywords: Electrodes/ DNA/ Molecules/ Bacteria/ Viruses/ Probability/ Nanotechnology
Abstract: The detection of a single specific DNA molecule fragment will allow for the

identification of bacteria and viruses that could be harmful if not detected quickly. DNA probes attached to the sensor electrodes have a specific molecular sequence that results in a billion to one or better probability that any DNA that hybridizes with the probe is the DNA to be detected. The DNA is coated with a metal, resulting in a large decrease in the measured electrical resistance between the sensor electrodes. Thus the electrical detection of a specific single DNA molecule fragment is very easy.

Germanenko IN, Li S, El Shall MS. Decay dynamics and quenching of photoluminescence from silicon nanocrystals by aromatic nitro compounds. J Phys Chem 2001;105(1):59-66.
Keywords: Photoluminescence quenching, kinetics/ Nitro compounds/ Silicon/ Nanostructured materials
Abstract: The decay dynamics and the quenching of the photoluminescence (PL) from Si nanocrystals are investigated. Electron acceptors whose reduction potentials lie below the conduction band (CB) edge of the Si nanocrystals quench the red emission from the Si nanocrystals. The quenching rate constants obtained from Stern-Volmer analyses for 3,5-dinitrobenzonitrile, 4-nitrophthalonitrile, 1,4-dinitrobenzene, 4-nitrobenzonitrile, 2,3-dinitrotoluene, 3,4-dinitrotoluene, 2,4-dinitrotoluene, and 2,6-dinitrotoluene are in the range of 106-107 M^{-1} s^{-1}. The quenching mechanism occurs via an electron transfer from the CB band of the Si nanocrystals to the vacant orbitals of the quenchers. The PL decay profiles of the Si nanocrystals, in the presence and absence of the quencher, are well described by the stretched exponential decay law. The band gap of the Si nanocrystals estimated from the present study is larger than the PL peak energy. The results are consistent with a quantum-confinement model, where recombination of electrons and holes occurs in a surface state. The ability of nitrotoluenes to quench the PL from Si nanocrystals could be used to develop a sensor based on Si nanostructures for the detection of explosives.

Giakos GC, Meehan K, Tuma M. Exploitation of enhanced fluorescence via cross-coupling principles toward the design of an optical integrated thin-film sensor for nanotechnology and biomedical applications. IEEE Transactions on Instrumentation and Measurement 2002;51(5):970-5.
Keywords: Integrated optoelectronics/ Thin films/ Fluorescence/ Optical design/ Nanotechnology/ Biomedical engineering/ Signal to noise ratio/ Surface plasmon resonance/ Mathematical models/ Optical sensors
Abstract: A novel fluorescence thin-film integrated sensor has been proposed that retains the beneficial selectivity characteristics typical of optical and electronic sensors, while improving the signal-to-noise ratio in a miniature geometry. The sensor can be tuned to measure a wide variety of biological species by varying its thin-film corrugation period. The optical properties of the sensor are determined, in large part, by optical cross coupling through a corrugated metal film and enhanced fluorescence. The surface plasmon to surface plasmon cross coupling was theoretically modeled and experimentally tested. Finally, prospective applications of this sensor in the key areas of nanotechnology and bioengineering are discussed.

Glynou K, Ioannou PC, Christopoulous TK. Oligonucleotide-functionalized gold nanoparticles as probes in a dry-reagent strip biosensor for DNA analysis by hybridization. Anal Chem 2003;75(16):4155-60.
Keywords: Biosensors, design/ DNA, analysis/ Gold nanoparticles
Abstract: The highly specific molecular recognition properties of oligonucleotides are

combined with the unique optical properties of gold nanoparticles for the development of a dry-reagent strip-type biosensor that enables visual detection of double stranded DNA within minutes. The assay does not require instrumentation and avoids the multiple incubation and washing steps performed in most current assays. Gold nanoparticle reporters with oligo(dT) attached to their surface form an integral part of the strip. Biotinylated PCR products (233 bp or 495 bp) are hybridized (5 min) with a poly(dA)-tailed oligo and applied on the strip, which is then immersed in the appropriate buffer. As the buffer migrates upward, it rehydrates the nanoparticles that are linked to the target DNA through poly(dA)/(dT) hybridization. Capture of the hybrids by immobilized streptavidin in the test zone of the strip generates a characteristic red band. A second red band is formed, by hybridization, in the control zone of the strip to indicate proper test performance. The sensor offers at least 8 times higher detectability than ethidium bromide staining of agarose gels and provides confirmation of the amplified fragments. Quantitative data are obtained by densitometric analysis of the bands. As low as 2 fmol of amplified DNA were detectable by the strip sensor. Also, 500 copies of prostate-specific antigen cDNA were detected by combining PCR and the strip sensor. The sensor was used successfully for detection of hepatitis C virus in plasma samples from 20 patients. The strip detected 16 out of 16 positive samples and gave no signal for 4 samples that were negative for the virus. To our knowledge, this is the first dry-reagent system that makes use of oligonucleotide-conjugated gold nanoparticles as probes.

Goldoni A, Larciprete R, Petaccia L. Single-wall carbon nanotube interaction with gases: Sample contaminants and environmental monitoring. J Am Chem Soc 2003;125(37):11329-33.
Keywords: Single-walled carbon nanotubes, testing/ Gas detectors
Abstract: Here, we show that residual contaminants in purified single-wall carbon nanotube bundles may be responsible for the reported sensitivity of the electronic and transport properties to oxygen. Removal of these contaminants makes the electronic spectra insensitive to O_2, CO, H_2O, and N_2, while a strong sensitivity to NO_2, SO_2, and NH_3 is observed, confirming the possible application of single-wall nanotubes as powerful sensors capable of measuring environmentally significant levels of toxic gases.

Golovchenko JA, Branton D. Electrical Properties of Solid-State Nanopore Sensors. Final rept. 17 Apr 2001-31 Aug 2002. US Government, 2003. Report No.: A970714.
URL: http://www.stormingmedia.us/97/9707/A970714.html
Abstract: This final report documents support from ONR in developing a solid state single molecule sensor. The sensor uses a voltage biased nanopore in an insulating membrane that separates two pools of conducting salt water. The biased nanopore attracts and translocates charged biopolymers like DNA. The ionic current that flows through the pore is sensitive to the presence of single molecules and can be used to measure their passage. In this work we demonstrate the process using solid state pores for the first time.

Grant P, Barnidge M, McShane M. Spectroscopic fiber probes for chemical sensing based on LbL self-assembled ultra-thin films. Second IEEE International Conference on Sensors: IEEE Sensors 2003. Proceedings of IEEE Sensors; Toronto, ON, Canada. Institute of Electrical and Electronics Engineers Inc., 2003: 895-8.
Keywords: Self assembly/ Chemical sensors/ Polyelectrolytes/ Resonators/ Colloids/ Enzymes/ Nanotechnology/ pH effects/ Resonance/ Fluorescence/ Luminescence/ Cladding

(coating)/ Ultrathin films
Abstract: Electrostatic Layer-by-Layer self-assembly (LbL) is an attractive method for depositing films, composed of charged molecules, on a wide variety of charged substrates. This report describes progress toward development of LbL as a platform for fabrication of fluorescent sensors based on nanocomposite multilayer ultra-thin films. Two types of fiber probes have been fabricated to demonstrate this concept: oxygen sensing ruthenium-based multilayer films with additional reference fluorophore allowing ratiometric measurements, and multilayer films containing a pH-sensitive fluorophore assembled on imaging fiber bundles. This work provides a basis for development of sensors for numerous biomedical sensing applications, including fiber-optic probes for research and clinical measurements and implantable micro/nanoparticle based sensors for in vitro or in vivo monitoring.

Grate JW, Nelson DA, Skaggs R. Sorptive behavior of monolayer-protected gold nanoparticle films: Implications for chemical vapor sensing. Anal Chem 2003;75(8):1868-79.
Keywords: Gold films, chemical vapor deposition/ Adsorption/ Nanoparticles
Abstract: Monolayer-protected gold nanoparticle materials were synthesized and characterized for use as sorptive layers on chemical sensors. Thiols investigated as monolayer-forming molecules included dodecanethiol, benzenethiol, 4-chlorobenzenethiol, 4-bromobenzenethiol, 4-(trifluoromethyl)benzenethiol, 4-hydroxybenzenethiol, and 4-aminobenzenethiol. Films of selected monolayer-protected nanoparticle (MPN) materials were deposited on thickness shear mode devices and vapor uptake properties were measured at 298 K. Many, but not all, MPN-based sensing layers demonstrated rapid and reversible uptake of vapors, and sorptive selectivity varies with the monolayer structure. The mass of vapor sorbed per mass of sorptive material was determined and compared with poly(isobutylene) and poly(epichlorohydrin) as examples of simple sorptive polymers that have been used on vapor sensors. The nanoparticle-based films considered here were less sorptive than the selected polymers on a per mass basis. Partition coefficients, which measure the mass of vapor sorbed per volume of the sorptive phase, were estimated for these MPN materials and found to be comparable to or less than those of the polymer layers. Implications for the roles of sorption and transduction in determining the performance of chemical sensors coated with nanoparticle-based films are discussed.

Guice KB, Lvov YM, McShane MJ. Nanoengineered microcapsules for the fluorescent sensing of oxygen. Proceedings of the 2002 IEEE Engineering in Medicine and Biology 24th Annual Conference and the 2002 Fall Meeting of the Biomedical Engineering Society (BMES / EMBS). Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings; Houston, TX, USA. Institute of Electrical and Electronics Engineers Inc., 2002: 1712-3.
Keywords: Nanotechnology/ Oxygen sensors/ Fluorescence/ Dyes/ Electrostatics/ Self assembly/ Polyelectrolytes/ Cell culture/ Biochemical engineering
Abstract: Self-assembled microcapsules allow for the encapsulation of fluorescent dyes capable of the detection of many biochemicals. The stability and detection range of these sensors might make them optimal for use in microgravitational environments. A microencapsulated fluorescent oxygen sensor was developed for the detection of O_2 in fluidic and cultured systems. This sensor provides real-time response for differing O_2 concentration in a useable range.

Guilinger TR, Kelly MJ, Follstaedt DM, et al. Final report on LDRD Project: Quantum confinement and light emission in silicon nanostructures. Sandia National Labs., Albuquerque, NM, USA, 1995. Report No.: SAND--94-3248.
URL: http://www.osti.gov/bridge/product.biblio.jsp?osti_id=71362
Abstract: Electrochemically formed porous silicon (PS) was reported in 1991 to exhibit visible photoluminescence. This discovery could lead to the use of integrated silicon-based optoelectronic devices. This LDRD addressed two general goals for optical emission from Si: (1) investigate the mechanisms responsible for light emission, and (2) tailor the microstructure and composition of the Si to obtain photoemission suitable for working devices. PS formation, composition, morphology, and microstructure have been under investigation at Sandia for the past ten years for applications in silicon-on-insulator microelectronics, micromachining, and chemical sensors. The authors used this expertise to form luminescent PS at a variety of wavelengths and have used analytical techniques such as in situ Raman and X-ray reflectivity to investigate the luminescence mechanism and quantify the properties of the porous silicon layer. Further, their experience with ion implantation in Si lead to an investigation into alternate methods of producing Si nanostructures that visibly luminesce.

Gupta A, Akin D, Bashir R. Single virus particle mass detection using microresonators with nanoscale thickness. Appl Phys Lett 2004;84(11):1976-8.
URL: http://dynamo.ecn.purdue.edu/~bashir/ee526_bme581_fall2004/APL%20Virus.pdf
Keywords: Lab-on-a-chip/ Silicon-on-insulator devices/ Cantilever beams
Abstract: The authors investigated the detection of the mass of individual virus particles using arrays of silicon cantilever beams as microresonator sensors with nanoscale thickness. Virus particles of the vaccinia virus, a member of the Poxviridae family and the basis of the smallpox vaccine, were used. The frequency spectra of the cantilever beams were recorded by means of a laser Doppler vibrometer under ambient conditions. The detection scheme was based on alterations in resonant frequency as a function of the virus particle mass binding on the cantilever beam surface. A single vaccinia virus particle with an average mass of 9.5 fg was detected.

Haes AJ, Van DRP. Highly sensitive and selective surface-enhanced nanobiosensor. Mater Res Soc Conf Proc. Materials Research Society, 2002: O3.1.1-O3.1.6.
URL: http://www.chem.northwestern.edu/~vanduyne/pdf/MRS_723_O311-0316_2002.pdf
Abstract: Nanosphere lithography (NSL) derived triangular Ag nanoparticles were used to create an extremely sensitive and specific optical biological and chemical nanosensor. Using simple UV-vis spectroscopy, biotinylated surface-confined Ag nanoparticles were used to detect streptavidin down to one picomolar concentrations. The system was tested for nonspecific binding interactions with bovine serum albumin and was found to display virtually no adverse results. The extremely sensitive and selective response of the Ag nanoparticle sensor indicates an exciting use for biological and chemical sensing.

Haes AJ, van Duyne RP. Nanosensors enable portable detectors for environmental and medical applications. Laser Focus World 2003;39(5):153-6.
URL: http://www.chem.northwestern.edu/~vanduyne/pdf/LFW39_153-156_2003.pdf
Keywords: Biosensors/ Surface plasmon resonance/ Silver clusters/ Nanoparticles
Abstract: Localized surface-plasmon resonance (LSPR) spectroscopy with silver

nanoparticles can be used to produce ultrasensitive portable biosensors for use in environmental and medical applications. From the instrumentation point of view, LSPR nanosensors can be implemented using extremely simple, small, light, robust, and inexpensive equipment for unpolarized, UV-visible extinction spectroscopy in transmission or reflection geometry. Calculations suggest that in the future it will be possible to reach sensitivities of a few molecules per nanoparticle sensor element.

Haynes CL, Van Duyne RP. Nanosphere lithography: A versatile nanofabrication tool for studies of size-dependent nanoparticle optics. J Phys Chem B 2001;105(24):5599-611.
Keywords: Lithography/ Nanotechnology / Nanostructured materials/ Particle size analysis/ Synthesis (chemical)/ Surface plasmon resonance/ Chemical sensors/ Biosensors/ Particle optics
Abstract: Nanosphere lithography (NSL) is an inexpensive, simple to implement, inherently parallel, high throughput, materials general nanofabrication technique capable of producing an unexpectedly large variety of nanoparticle structures and well-ordered 2D nanoparticle arrays. This article describes our recent efforts to broaden the scope of NSL to include strategies for the fabrication of several new nanoparticle structural motifs and their characterization by atomic force microscopy. NSL has also been demonstrated to be well-suited to the synthesis of size-tunable noble metal nanoparticles in the 20–1000 nm range. This characteristic of NSL has been especially valuable for investigating the fascinating richness of behavior manifested in size-dependent nanoparticle optics. The use of localized surface plasmon resonance (LSPR) spectroscopy to probe the size-tunable optical properties of Ag nanoparticles and their sensitivity to the local, external dielectric environment (viz., the nanoenvironment) is discussed in detail. More specifically, the effects of nanoparticle size, shape, interparticle spacing, nanoparticle-substrate interaction, solvent, dielectric overlayers, and molecular adsorbates on the LSPR spectrum of Ag nanoparticles are presented. This systematic study of the fundamentals of nanoparticle optics promises to find application in the field of chemical and biological nanosensors; herein, the initial data demonstrate that LSPR spectroscopy of Ag nanoparticles can be used to sense specifically bound analytes with zeptomole per nanoparticle detection limits and no detectable nonspecific binding.

Heilmann A, Teuscher N, Kiesow A, Janasek D, Spohn U. Nanoporous aluminum oxide as a novel support material for enzyme biosensors. J Nanosci Nanotechnol 2003;3(5):375-9.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=14733146&dopt=Abstract
Keywords: Anodic oxidation/ Nanoporous alumina/ Enzyme sensors/ Amperometric detection
Abstract: To construct novel amperometric sensors for the detection of hydrogen peroxide and pyruvate, peroxidase and pyruvate oxidase were immobilized in self-supporting nanoporous alumina membranes those made by anodic oxidation. Pyruvate oxidase and other enzymes were enclosed in poly(carbamoylsulfonate) hydrogel and sucked into the nanoporous alumina structure before polymerization. The alumina membranes were investigated by scanning electron microscopy before and after the enzyme immobilization. In an amperometric flow detector cell, pyruvate and hydrogen peroxide were detected under flow injection analysis conditions in concentration ranges from 1 microM to 100 microM and 5 microM to 500 microM, respectively. The achieved operational stability showed that alumina membranes can be used to construct enzyme-modified electrodes.

Heo YW, Kaufman M, Pruessner K, Norton DP, Ren F, Chisholm MF, et al. Optical properties of $Zn_{1-X}Mg_XO$ nanorods using catalysis-driven molecular beam epitaxy. Solid-State Electronics 2003;47(12):2269-73.

URL: http://www.sciencedirect.com/science/article/B6TY5-48WJKYT-5/2/5955ec376bcb855a4a82ed083f538f00

Keywords: ZnMgO/ Nanorods/ Photoluminescence/ Molecular beam epitaxy

Abstract: We report on the optical properties of (Zn,Mg)O nanorods grown by catalyst-driven molecular beam epitaxy. The process is site-specific, as single crystal (Zn,Mg)O nanorod growth is realized via nucleation on Ag films or islands that are deposited on a SiO_2-terminated Si substrate surface. Growth occurs within a flux of Zn, Mg, and O_2/O_3 mixture at substrate temperatures of 400–500 C. With the addition of Mg, the nanorod morphology becomes more uniform relative to the pure ZnO nanomaterials synthesized under similar conditions. The (Zn,Mg)O nanorods are cylindrical, exhibiting diameters of 15–40 nm and lengths in excess of 1 μm. The (Zn,Mg)O nanorods exhibit a strong photoluminescence response, showing a slight shift to shorter wavelengths due to Mg incorporation.

Hilmi A, Luong JHT. Electrochemical detectors prepared by electroless deposition for microfabricated electrophoresis chips. Anal Chem 2000;72(19):4677-82.

Keywords: Detectors/ Electrochemical analysis/ Electrophoretic microchips

Abstract: Microfabricated capillary electrophoresis (CE) chips with integrated electrochemical detection have been developed on glass substrates. An electroless deposition procedure was used to deposit a gold film directly onto the capillary outlet to provide high-sensitivity electrochemical detection for catechol and several nitroaromatic explosives. Scanning electron microscopy revealed that the electroless gold film contains nanoscopic gold aggregates (100–150 nm) with an average thickness of 79 nm. The electroless deposition procedure can be easily and routinely performed in any wet-chemistry laboratory, and electroless gold can be deposited onto complex and internal surfaces. Intimate coupling of electrochemical detection and CE chips obviates the need for a coupling mechanism or tedious alignment procedures. With nitroaromatic compounds as a working model, microchip capillary electrophoresis equipped with electroless gold has proven to provide high sensitivity and fast response times for sensor applications. The CE microchip system was capable of separation and determination of explosive compounds including TNT in less than 130 s with detection limits ranging from 24 to 36 μg/L, i.e., 4-fold enhancements in detection efficiency in comparison to thick-film technology.

Hrapovic S, Liu Y, Male KB. Electrochemical biosensing platforms using platinum nanoparticles and carbon nanotubes. Anal Chem 2004;76(4):1083-8.

Keywords: Hydrogen peroxide, analysis/ Biosensors, manufacture/ Single-walled carbon nanotubes/ Platinum films, electrodeposition

Abstract: Platinum nanoparticles with a diameter of 2–3 nm were prepared and used in combination with single-wall carbon nanotubes (SWCNTs) for fabricating electrochemical sensors with remarkably improved sensitivity toward hydrogen peroxide. Nafion, a perfluorosulfonated polymer, was used to solubilize SWCNTs and also displayed strong interactions with Pt nanoparticles to form a network that connected Pt nanoparticles to the electrode surface. TEM and AFM micrographs illustrated the deposition of Pt nanoparticles on carbon nanotubes whereas cyclic voltammetry confirmed an electrical contact through

SWCNTs between Pt nanoparticles and the glassy carbon (GC) or carbon fiber backing. With glucose oxidase (GOx) as an enzyme model, we constructed a GC or carbon fiber microelectrode-based biosensor that responds even more sensitively to glucose than the GC/GOx electrode modified by Pt nanoparticles or CNTs alone. The response time and detection limit (S/N = 3) of this biosensor was determined to be 3 s and 0.5 mM, respectively.

Huang J, Virji S, Weiller BH. Polyaniline nanofibers: Facile synthesis and chemical sensors. J Am Chem Soc 2003;125(2):314-15.
Keywords: Nanostructured materials/ Polyaniline/ Conductive polymers, optical properties
Abstract: A facile chemical route to high-quality polyaniline nanofibers under ambient conditions is described. The synthesis is based on the well-known chemical oxidative polymerization of aniline in a strongly acidic environment with ammonium peroxydisulfate as the oxidant, which allows the by-products to be separated according to their solubility in the organic and aqueous phases. The nanofibers have almost uniform diameters between 30 and 50 nm; lengths range from 500 nm to several micrometers. Gram-scale products can be prepared that contain almost exclusively nanofibers. Films of the polyaniline nanofibers hold promise for sensor applications because they possess much faster gas phase doping/dedoping times compared with conventional cast films.

Hughes RC, Boyle TJ, Gardner TJ. Thin film porous membranes for catalytic sensors. Int. Conf. on Solid State Sensors and Actuators: Transducers '97. Chicago, IL, USA. 1997: 581-4.
Abstract: This paper reports on new and surprising experimental data for catalytic film gas sensing resistors coated with nanoporous sol-gel films to impart selectivity and durability to the sensor structure. This work is the result of attempts to build selectivity and reactivity to the surface of a sensor by modifying it with a series of sol-gel layers. The initial sol-gel SiO_2 layer applied to the sensor surprisingly showed enhanced O_2 interaction with H_2 and reduced susceptibility to poisons such as H_2S.

Hughes RC, Patel SV, Jenkins MW, Boyle TJ, Gardner TJ, Brinker CJ. Thin film porous membranes based on sol-gel chemistry for catalytic sensors. Sandia National Labs., Albuquerque, NM, USA, 1998. Report No.: SAND--97-3124C; CONF-980727-- .
URL: http://www.osti.gov/bridge/product.biblio.jsp?osti_id=658200
Abstract: Nanoporous sol-gel based films are finding a wide variety of uses including gas separations and supports for heterogeneous catalysts. The films can be formed by spin or dip coating, followed by relatively low temperature annealing. The authors used several types of these films as coatings on the Pd alloy thin film sensors they had previously fabricated and studied. The sol-gel films have little effect on the sensing response to H_2 alone. However, in the presence of other gases, the nanoporous film modifies the sensor behavior in several beneficial ways. (1) They have shown that the sol-gel coated sensors were only slightly poisoned by high concentrations of H_2S while uncoated sensors showed moderate to severe poisoning effects. (2) For a given partial pressure of H_2, the signal from the sensor is modified by the presence of O_2 and other oxidizing gases.

Hughes WL, Wang ZL. Nanobelts as nanocantilevers. Appl Phys Lett 2003;82(17):2886-8.
URL: http://www.nanoscience.gatech.edu/zlwang/paper/2003/03_APL_3.pdf
Keywords: Cantilever devices/ Mechatronics / Zinc oxides

Abstract: The authors sectioned and manipulated semiconducting oxide nanobelts of ZnO using an atomic force microscopy probe to facilitate their use in microelectromechanical systems. The modified nanobelts demonstrated significant potential for use in nanocantilever-based technologies. The devices' dimensions were approximately 30 to 1,800 times smaller than conventional cantilevers, and it was concluded that they would possess better physical, chemical, and biological sensitivities for scanning probe, microscopy, and sensor applications.

Israel LB, Kariuki NN, Han L, Maye MM, Luo J, Zhong CJ. Electroactivity of Cu^{2+} at a thin film assembly of gold nanoparticles linked by 11-mercaptoundecanoic acid. J Electroanal Chem 2001;517(1-2):69-76.
Keywords: Nanostructured thin film assembly/ Gold nanoparticles/ Carboxylic acid/ Electrochemistry/ Copper ion/ Heavy metal
Abstract: Core-shell nanoparticles are emerging advanced materials for developing novel electroanalytical platforms. This paper describes the results of an investigation of the electroactivity of Cu^{2+} ions on electrodes coated with thin films assembled from thiolate-encapsulated gold nanoparticles of 2 nm core size (Au_{2nm}) and a carboxylic functionalized alkyl thiol linker, i.e. 11-mercaptoundecanoic acid (MUA). The high surface-to-volume ratio and the 3-D ligand network properties are potentially useful as sensitive and selective nanomaterials for the monitoring and removal of environmental heavy metals. The nanostructured MUA–Au_{2nm} film is sensitive to Cu^{2+} below 1 ppm. The selectivity of the electroactivity is also probed using mixed-metal systems such as Cu^{2+} and Fe^{3+} and Cu^{2+} and Zn^{2+}. Issues related to the electrochemical activity of these metal ions are also discussed.

Jacobson A. Nanotechnology meets marine biology. Computing in Science & Engineering [Also IEEE Computational Science and Engineering] 2002;4(4):10-1.
URL: http://ieeexplore.ieee.org/xpl/abs_free.jsp?isNumber=21843&prod=JNL&arnumber=1014973&arSt=10&ared=11&arAuthor=Jacobson%2C+A.&arNumber=1014973&a_id0=1014972&a_id1=1014973&a_id2=1014974&a_id3=1014976&a_id4=1014977&a_id5=1014978&a_id6=1014979&a_id7=1014980&a_id8=1014981&a_id9=1014982&a_id10=1014983&a_id11=1014985&a_id12=1014987&a_id13=1014988&a_id14=1014989&count=15
Keywords: Marine biology/ Nanodevices/ Microrobots
Abstract: The National Science Foundation has given a $1.5 million grant to researchers at the University of Southern California School of Engineering to create millions of sensor-equipped microscopic robots that would search the seafloor for potentially dangerous microorganisms. It is estimated that it will take at least a decade before the first nanorobots take to the water. The bacteria-sized robots will be able to propel themselves, sense microbes, communicate using electronic signals, and carry out restricted computations.

Jiang L, Ruan H, Chen Y, Liu Y, Claus RO. Measurement of water content of oil downhole using fiber optic sensors and nanotechnology. 32nd Annual Offshore Technology Conference: OTC 2000. Proceedings of the Annual Offshore Technology Conference; Houston, TX, USA. Offshore Technology Conference, USA, 2000: 195-8 .
Keywords: Crude petroleum/ Water/ Fiber optic sensors/ Electrostatics/ Nanostructured materials/ Enhanced recovery/ Offshore oil wells/ Offshore boreholes
Abstract: Since water occurs naturally in petroleum formation, and is used in the secondary recovery of oil from wells, it is particularly desirable to be able to measure the water content of

oil (watercut) during the exploration, drilling, production and transmission of oil and gas. In general, oil/water/gas cut measurements have been traditionally carried out by taking samples from wells or pipes, separating the oil, water and gas, and measuring the volumes of the separated components. As the water content of the oil flow is nonhomogeneous and changes over time in a pipe, there is no guarantee that a sample is representative. A new method for measuring the borehole watercut is given in this paper. It uses fiber-optic evanescent wave sensing (FOEWS) technology and nanotechnology based on the electrostatic self-assembly monolayer (ESAM) method. The watercut measured by this sensor ranges from 0% to 100% and its precision is lower than 2%. The characteristics of this sensor are analyzed.

Jimenez I, Centeno MA, Scotti R. NH_3 interaction with catalytically modified nano-WO_3 powders for gas sensing applications. J Electrochem Soc 2003;150(4):H72-H80.
Keywords: Tungsten oxides/ Poisonous gas detectors/ Ammonia, analysis
Abstract: Nanocrystalline powders of WO_3, pure and with catalytic additives such as copper and vanadium, for ammonia gas detection are analyzed in detail. Material was annealed at two different temperatures (400 and 700 C) and catalytic additives were introduced in two different concentrations (0.2 and 2%) in order to study the gas sensor performances of these WO_3-based materials. Crystalline structure characterization shows that a mixture of triclinic and monoclinic structure was present in the materials analyzed. Additive characterization reveals that catalytic metals were located as cations in the matrix lattice. Thick-film gas sensors based on pure WO_3 show an abnormal sensor response, which is attributed to a complex process originated by the oxidation of ammonia to NO. On the other hand, catalyzed WO_3-based gas sensors show a more direct and simple sensor response. Interaction of ammonia with WO_3 was studied by diffuse reflectance infrared spectroscopy. Only pure WO_3 presented a W=O overtone band decrease and some nitrosil bands. In this case, NH_3 would react with the surface oxygen of terminal W=O bonds and would lead to the formation of NO. Catalyzed WO_3 avoided this reaction and so the unselective catalytic oxidation of NH_3, improving sensor response. Influence of introduced additives on ammonia oxidation and thus on sensor response is discussed.

Kalkan AK, Li H, O'Brien CJ, Fonash SJ. A rapid-response, high-sensitivity nanophase humidity sensor for respiratory monitoring. IEEE Electron Device Lett 2004;25(8):526-8.
Keywords: Thin film devices/ Nanostructured materials/ Nanotechnology/ Plasma devices/ Hygrometers/ Electric conductance / Miniature instruments/ Digital integrated circuits/ Semiconductor device manufacture/ Semiconducting polymers/ Biomedical engineering/ Computer simulation/ Silicon sensors
Abstract: A novel ionic-type humidity sensor based on a plasma-deposited nanophase Si thin film was developed. Detection of relative humidity cycles between 20% and 90% was possible in less than or equal to 0.2 s with ~ 5 orders of magnitude variation in conductance. Such superior performance is attributable to the unique arrayed column-void network structure and ultrafine thickness (e.g., 50 nm) of the Si film as well as to the lateral electrode configuration. Our sensor can be miniaturized, integrated with signal processing circuits, and fabricated on plastics. A crucial implementation, where our sensor would be very suitable and beneficial, is respiratory monitoring. Copyright 2004 IEEE.

Kameoka J, Craighead HG. Nanofabricated refractive index sensor based on photon tunneling in

nanofluidic channel. Sensors and Actuators B: Chemical 2001;77(3):632-7.
Keywords: Refractive index/ Nanotechnology/ Composition effects/ Surface plasmon resonance/ Photons/ Optical sensors
Abstract: We have fabricated and tested a refractive index sensor based on photon tunneling in a nanofluidic system. The device comprises an extremely thin fluid chamber formed between two optically transparent layers. It can be used to detect changes in refractive index due to chemical composition changes of a fluid in the small test volume. Because the physical property measured is a refractive index change, no staining or labeling is required. We tested the device with five samples, water and water with 1% ethanol, 2% ethanol, 5% ethanol and 10% ethanol. The sensing was done by measuring the intensity of a reflected laser beam incident on the sensing element at around the critical angle. The measured response agrees well with the calculated reflectance. Copyright 2001 Elsevier Science B.V.

Kaul S, Chinnayelka S, McShane MJ. Self-assembly of polymer/nanoparticle films for fabrication of fiber-optic sensors based on SPR. Progress in Biomedical Optics and Imaging: Optical Fibers and Sensors for Medical Applications IV. Proceedings of SPIE - The International Society for Optical Engineering; San Jose, CA, USA. International Society for Optical Engineering, Bellingham, WA 98227-0010, United States, 2004: 224-33.
Keywords: Macromolecules/ Adsorption/ Surface plasmon resonance/ Interferometry/ Refractive index/ Electrostatics/ Biosensors/ Fabrication/ Ellipsometry/ Permittivity/ Nanotechnology/ Ultrathin films/ Optical fibers
Abstract: Surface Plasmon Resonance (SPR) is an optical phenomenon which can be used for the sensitive detection of macromolecular interactions at a sensor surface by detecting small changes in refractive index resulting from adsorbed species. Previous work toward fiber-optic SPR sensors has employed metal films sputtered or evaporated onto waveguides. In this work, a novel nanofabrication approach using a combination of self-assembled monolayers (SAMs) and electrostatic layer-by-layer (LbL) self assembly was investigated toward precise deposition of metal nanomaterials onto fibers, which could enable excellent control over surface properties as well as provide an enhanced plasmon signal due to the roughened metal surfaces. Furthermore, nanoassembly allows production of nanocomposite materials that may possess attractive optical properties. To study this possibility, ultrathin films with architecture $\{Au/polymer\}_n$ (n = 1–10) were deposited on flat silica substrates, then on optical fibers. Physical measurements of deposited mass were performed with quartz crystal microbalance (QCM). The influence of particle size, number of layers, and distance from surface on the magnitude of optical signals was investigated by measuring the absorption spectrum for each configuration. In addition, sequential and simultaneous bimetallic (Au/Ag) film layering and testing was also completed to assess the effect of nanocomposite metal films on SPR signals. Fluorescent anti-Immunoglobulin G (IgG) antibody was deposited on the outside surface, which was then exposed to IgG for observation of shifting resonance peak due to target binding. The results show that nanoassembly is a promising approach to precise yet cost-effective fabrication of optical biosensors.

Khlebtsov NG. Optical models for conjugates of gold and silver nanoparticles with biomacromolecules. J Quant Spectroscopy Radiative Transfer 2004;89(1-4):143-53.
URL: http://www.sciencedirect.com/science/article/B6TVR-4CPW4TX-C/2/a643b4b8706a39d62888e450160cebd6

Keywords: Gold and silver nanoparticles/ Plasmon resonance/ Biosensors/ Light scattering/ Multilayer Mie solution

Abstract: We discuss optical models for gold and silver nanoparticle bioconjugates that consist of a metal core and a polymer shell formed by recognizing and target molecules. A universal dependence of the normalized spectral shift of the extinction maximum on the shell/core thickness ratio has been found in the dipole approximation. Using Mie's theory for multilayer spheres, we have calculated the extinction and static light-scattering spectra (at 90 degrees), as well as the differential spectra related to the adsorption of recognizing and target molecules. The differential spectra possess a characteristic resonance that is red-shifted as compared with the known resonance of gold particles. Having in mind an optimization of conjugate-nanosensors, we have studied the following problem: what particle size is optimal for the transduction of polymer adsorption events into variations of recorded optical signals? The maximal values of the differential resonance are observed for gold particles with diameters of about 40–60 nm (extinction) or 70–90 nm (scattering). In the case of silver particles, the corresponding optimal diameters are equal to 20–40 nm for extinction and 30–50 nm for scattering.

Kling J. Multipurpose nanopore sensors. Anal Chem 2001;73(11):306A.

Keywords: Ion channels/ Polymers

Abstract: A report in the May 15 issue should make nanopore sensors easier to construct and more powerful in scope. The use of cell-like membrane channels to detect analytes in solution could, in principle, allow ready analysis with minimal sample preparation, but such systems are difficult to engineer. Kasianowicz and colleagues may have found an answer by fusing a binding site to a polymer that could thread freely through the channel rather than directly to the ion channel. The interactions of the channel, the polymer, and the analyte yield useful diagnostic information and allows for the simultaneous measurement of multiple analytes.

Kong J, Franklin NR, Zhou C. Nanotube molecular wires as chemical sensors. Science 2000;287:622-5.

URL: http://www.stanford.edu/dept/chemistry/faculty/dai/group/Reprint/22.pdf

Keywords: Carbon nanotubes/ Gas detectors/ Molecular wires

Abstract: Chemical sensors based on individual single-walled carbon nanotubes (SWNTs) are demonstrated. Upon exposure to gaseous molecules such as NO_2 or NH_3, the electrical resistance of a semiconducting SWNT is found to dramatically increase or decrease. This serves as the basis for nanotube molecular sensors. The nanotube sensors exhibit a fast response and a substantially higher sensitivity than that of existing solid-state sensors at room temperature. Sensor reversibility is achieved by slow recovery under ambient conditions or by heating to high temperatures. The interactions between molecular species and SWNTs and the mechanisms of molecular sensing with nanotube molecular wires are investigated. Copyright 2000 by the AAAS.

Koo YEL, Cao Y, Kopelman R. Real-time measurements of dissolved oxygen inside live cells by organically modified silicate fluorescent nanosensors. Anal Chem 2004;76:2498-505.

Keywords: Oxygen sensors/ Cells, analysis

Abstract: Optical PEBBLE (probes encapsulated by biologically localized embedding) nanosensors have been developed for dissolved oxygen using organically modified silicate (ormosil) nanoparticles as a matrix. The ormosil nanoparticles are prepared via a sol-gel-based process, which includes the formation of core particles with phenyltrimethoxysilane as a precursor followed by the formation of a coating layer with methyltrimethoxysilane as a precursor. The average diameter of the resultant particles is 120 nm. These sensors incorporate the oxygen-sensitive platinum porphyrin dye as an indicator and an oxygen-insensitive dye as a reference for ratiometric intensity measurement. Two pairs of indicator dye and reference dye, respectively, platinum(II) octaethylporphine and 3,3'-dioctadecyloxacarbocyanine perchlorate, and platinum-(II) octaethylporphine ketone and octaethylporphine, were used. The sensors have excellent sensitivity with an overall quenching response of 97%, as well as excellent linearity of the Stern-Volmer plot ($r^2 = 0.999$) over the whole range of dissolved oxygen concentrations (0–43 ppm). In vitro intracellular changes of dissolved oxygen due to cell respiration were monitored, with gene gun injected PEBBLEs, in rat C6 glioma cells. A significant change was observed with a fluorescence ratio increase of up to 500% after 1 h, for nine different sets of cells, which corresponds to a 90% reduction in terms of dissolved oxygen concentration. These results clearly show the validity of the delivery method for intracellular studies of PEBBLE sensors, as well as the high sensitivity, which is needed to achieve real-time measurements of intracellular dissolved oxygen concentration.

Koronczi I, Reichert J, Ache H-J, Krause C, Werner T, Wolfbeis OS. Submicron sensors for ion detection based on measurement of luminescence decay time. Sensors and Actuators B: Chemical [5th European Conference on Optical Chemical Sensors and Biosensors, Lyon, France, Apr .16-19, 2000] 2001;74:47-53.
Keywords: Chemiluminescence/ Polymeric membranes/ pH effects/ Nanotechnology/ Resonance/ Protons/ Phase modulation/ Fiber optic chemical sensors
Abstract: Submicron optochemical sensors for pH and chloride were developed by coating silanised optical fibre tips of ~300 nm diameter and aluminium-coated SNOM fibres of ~50 nm aperture with polymeric membranes containing luminescent indicators. Luminescence decay time was measured using a phase-modulation technique. Changes in decay time are induced by resonance energy transfer from a ruthenium complex (the donor) to the pH indicator bromothymol blue (the acceptor). The donor-acceptor ion pair was immobilised in a hydrogel membrane and undergoes a change in decay time with pH. The chloride sensor was made by combining the ion pair for optical transduction with the chloride-carrier tridodecylmethylammonium chloride in a plasticised PVC membrane. Chloride ions present in the solution are carried into the membrane. In order to maintain electroneutrality, an equivalent molar quantity of protons is coextracted into the membrane where the dye is protonated. Both sensors are suitable for measurements in physiological fluids. Copyright 2001 Elsevier Science B.V.

Kossek S, Padeste C, Tiefenauer LX, Siegenthaler H. Localization of individual biomolecules on sensor surfaces. Biosens Bioelectron 1998;13(1):31-43.
Keywords: Surfaces/ Molecules/ Nanotechnology/ Microscopic examination/ Immunosensors
Abstract: Scanning probe microscopy techniques have been used to investigate biosensor surfaces. Complementarily, the surfaces have been characterized using immunoanalytical and radioanalytical methods which average over a large number of biomolecules. This combination of local probe and averaging techniques provides detailed information about the density, the homogeneity and the functionality of biomolecules immobilized on surfaces. Surface analysis at molecular resolution is especially important for the development of sensor surfaces,

designed at nanometer scale.

Kwoun SJ, Lec RM, Han B, Ko FK. A novel polymer nanofiber interface for chemical sensor applications. 2000 IEEE 54th Annual Frequency Control Symposium. Proceedings of the Annual IEEE International Frequency Control Symposium; Kansas, MO, USA. Institute of Electrical and Electronics Engineers Inc., 2000: 52-7.
Keywords: Interfaces (materials)/ Nanotechnology/ Semiconducting polymers/ Chemical sensors/ Piezoelectric devices/ Acoustic properties/ Viscoelasticity/ Thin films
Abstract: Thin films are often employed in sensors in order to improve their performance. It is well known that the sensitivity of a film is proportional to the surface area of the film per unit mass. Thin films made of nanofibers (NF) have surface area approximately one to two orders of the magnitude larger than continuous films, and therefore their sensitivities are potentially as large. In this paper we report preliminary results on the use of nanofiber films as a sensing interface for the thickness shear mode (TSM) piezoelectric sensors. The TSM sensors coated with nanofiber films made of poly-lactic acid co-glycolic acid (PLAGA) polymers were studied under various ambient conditions and the important operating parameters have been determined. Applications of the TSM-NF sensors for gas and liquid detection have been discussed.

Lad RJ, Tripp CJ, Frederick BG, DeSisto W. Development of a Prototype Chemical Agent Detector System Based on Semiconducting Metal Oxide (SMO) Thin Film Technology. Final rept. 1 Jun 2001–30 Jun 2002. US Government, 2003 Mar . Report No.: A519414.
URL: http://www.stormingmedia.us/51/5194/A519414.html
Abstract: This research grant focused on carrying out 6.1 research activities to advance the development a next generation chemical agent detector system based on semiconducting metal oxide (SMO) technology. The tasks and the resulting findings described in detail in this report, emphasize strategies to improve the selectivity, sensitivity, and miniaturization of the SMO detector system. Experiments were performed using organophosphonates and various alcohols as target gases Results are reported concerning (i) selective concentration of organophosphonates on nano-sized WO_3 powders (ii) selective filtering and detection of decomposition products using catalyst-modified silica membranes (iii) kinetic signatures and decomposition reaction products associated with reactions of organophosphonates, alcohols and ethers on WO_3 surfaces (iv) heteroepitaxial WO_3 sensing films grown on BaF_2/Si(100) substrates and (vi) a dosiometer sensor based on poisoning of dispersed copper oxide nanoparticles on WO_3 films.

Lang HP, Hegner M, Meyer E, Gerber C. Nanomechanics from atomic resolution to molecular recognition based on atomic force microscopy technology. Nanotechnology 2002;13(5):29-36.
URL: http://monet.physik.unibas.ch/nose/na25r2.pdf
Keywords: Atomic force microscopy/ Vapors/ Adsorption/ Molecules/ Chemical sensors/ Biosensors/ Nanotechnology
Abstract: Atomic force microscopy (AFM) is a technique to image surfaces with unprecedented vertical and lateral resolution. Many related techniques have been derived from AFM, taking advantage of local interactions between a tip on a cantilever and a surface. However, cantilevers can also be used for sensing applications. These so-called nanosensors feature extreme sensitivity for the detection of chemical vapours or adsorption of molecules.

Upon adsorption to the cantilever surface, the molecules cause the cantilever to bend. Thus physical, chemical or biochemical processes are directly transduced into nanomechanical motion. We show that measurement of the deflection of a single cantilever might be misleading. Reliable information can only be obtained by using a sensor cantilever and at least one reference cantilever integrated into an array. We have built an electronic nose using polymer layers as partially selective cantilever coatings to recognize chemical vapours and odours by evaluating the cantilevers' bending pattern. Major applications lie in the fields of process and quality control, biosensing, medical diagnostics, molecular recognition and proteomics.

Lee W, Oh BK, Bae YM, Paek S.H., Won HL, Choi JW. Fabrication of self-assembled protein A monolayer and its application as an immunosensor. Biosens Bioelectron 2003;19(3):185-92.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=14611753&dopt=Abstract
Abstract: The self-assembled layer of modified protein A was fabricated. In order to modify protein A, the surface group of protein A was substituted with thiol (–SH) functionality by using *N*-succinimidyl-3-(2-pyridyldithio)propionate (SPDP) and dithiothreitol (DTT). The formation of a self-assembled protein A layer on a Au substrate and its increased binding capacity to antibody were confirmed by surface plasmon resonance (SPR) spectroscopy. The surface structure of self-assembled protein A layer, and the binding status of anti-bovine serum albumin (anti-BSA) and BSA were determined by atomic force microscopy (AFM). Treatment on the self-assembled protein A layer with a detergent, such as Tween 20, increased the binding capacity of anti-BSA, because protein A aggregation was reduced significantly by the detergent; this was confirmed by SPR spectroscopy. The self-assembled layer of chemically modified protein A with enhanced binding capacity can be used for immunosensor fabrication.

Lee WC, Cho Y-H. Nanomechanical protein detectors using electrothermal nano-gap actuators. 17th IEEE International Conference on Micro Electro Mechanical Systems (MEMS): Maastricht MEMS 2004 Technical Digest. Proceedings of the IEEE International Conference on Micro Electro Mechanical Systems (MEMS); Maastricht, Netherlands. Institute of Electrical and Electronics Engineers Inc., Piscataway, United States, 2004: 629-32.
URL: http://www.ieeexplore.ieee.org/xpl/abs_free.jsp?arNumber=1290663
Keywords: Nanotechnology/ Actuators/ Resonant tunneling/ Electrochemistry/ Chemical sensors/ Electric conductivity/ Proteins
Abstract: This paper presents a new method and device for protein presence and size detection based on the coordinate shift of the rigidity changing points due to proteins. Compared to the conventional resonant method, the present nanomechanical method shows higher precision. The present method also offers simple and inexpensive protein detection by removing labeling process and optical components. We design and fabricate the nanomechanical protein detector using an electrothermal actuator and a nano-gap. In experimental study, we measure two rigidity changing points and their coordinate shift between two cases (without/with target protein). The fabricated device detects the protein presence and size of 14.0 ± 7.4 nm from this coordinate shift of rigidity changing points. We experimentally verify the protein sensing capability of the nanomechanical protein detector, applicable to high-precision protein detection.

Li C, Lei B, Zhang D. Chemical gating of In_2O_3 nanowires by organic and biomolecules. Appl Phys Lett 2003;83(19):4014-16.

Keywords: Biomolecules/ Nanowires, testing/ Current-voltage characteristics

Abstract: The chemical gating effect of organic molecules and biomolecules with amino or nitro groups was investigated using In_2O_3 nanowire transistors. Amino groups in organic molecules were found to improve carrier concentrations and conductance by donating electrons to the nanowires, whereas molecules with nitro groups made the nanowires less conductive by withdrawing electrons. Intrananowire junctions produced by partial exposure of the nanowire device to butyl nitrite achieved marked rectifying current-voltage characteristics. The interaction of amino groups in low-density lipoprotein cholesterol indicated that the nanowires could act as a sensor for this agent of heart disease.

Li C, Zhang D, Liu X. In_2O_3 nanowires as chemical sensors. Appl Phys Lett 2003;82(10):1613-15.

Keywords: Gas detectors/ Nanowires/ Indium oxides

Abstract: The authors describe the use of individual In_2O_3 nanowire transistors as room-temperature chemical sensors. Upon exposure to a small amount of NO_2 or NH_3, the nanowire transistors exhibit a reduction in conductance of up to 5 or 6 orders of magnitude and also significant shifts in the threshold gate voltage. These devices show a significantly better chemical sensing performance than existing solid-state sensors. Furthermore, by illuminating the devices with UV light in vacuum, the recovery time of these devices can be shortened to just 30 s.

Li YY, Cunin F, Link JR. Polymer replicas of photonic porous silicon for sensing and drug delivery applications. Science 2003;299:2045-7.

URL: http://mtel.ucsd.edu/publications/Li_Polymer_Replicas_Science_2003.pdf

Keywords: Molecular templates/ Porous silicon/ Photonic crystals

Abstract: Elaborate one-dimensional photonic crystals are constructed from a variety of organic and biopolymers, which can be dissolved or melted, by templating the solution-cast or injection-molded materials in porous silicon or porous silicon dioxide multilayer (rugate dielectric mirror) structures. After the removal of the template by chemical dissolution, the polymer castings replicate the photonic features and the nanostructure of the master. We demonstrate that these castings can be used as vapor sensors, as deformable and tunable optical filters, and as self-reporting, bioresorbable materials.

Liu CC, Wal RV, Hunter G. Microchemical and Gaseous Sensors Using Carbon Nanotubes and MEMS Fabrication Technology. Cleveland, Ohio: National Aeronautics and Space Administration, 2003 Apr. Report No.: NASA TM-2003-212209.

URL: http://gltrs.grc.nasa.gov/reports/2003/TM-2003-212209.pdf

Abstract: This research is a joint effort between the researchers in the Electronics Design Center at Case Western Reserve University and the National Center of Microgravity Research (NCMR)/Universities Space Research Association at NASA Glenn Research Center. The overall objective is to advance nanosensor technology for gaseous detection in propulsion and power systems for aerospace applications. The underpinning technology of this research is a combination of silicon-based microfabrication and micromachining processes and carbon nanotube technology. In this research, photolithography and thin film metallization techniques were used to produce the basic sensor structure. This metallic sensor structure also served as the catalytic precursor for the formation of carbon nanotubes. Metals such as Fe, Ni and Co were the candidates for the catalytic precursor. An ion beam sputtering system was used to carry out the metallic thin film deposition.

Liu J, Lu Y. Adenosine-dependent assembly of aptazyme-functionalized gold nanoparticles and its application as a colorimetric biosensor. Anal Chem 2004;76(6):1627-32.

Keywords: Biosensors, manufacture/ Gold nanoparticles, synthesis

Abstract: Previous work has shown that DNAzyme-directed assembly of gold nanoparticles can be utilized to make effective colorimetric biosensors. However, the method is restricted to analytes that are directly involved in phosphodiester cleavage. To expand the methodology to a broader range of analytes, a colorimetric adenosine biosensor based on the aptazyme-directed assembly of gold nanoparticles is reported here. The aptazyme is based on the 8-17 DNAzyme with an adenosine aptamer motif that can modulate the DNAzyme activity through allosteric interactions depending on the presence of adenosine. In the absence of adenosine, the aptazyme is inactive and the substrate strands can serve as linkers to assemble DNA-functionalized 13 nm diameter gold nanoparticles, resulting in a blue color. However, the presence of adenosine activates the aptazyme, which cleaves the substrate strand, disrupting the formation of nanoparticle aggregates. A red color of separated gold nanoparticles is observed. Concentrations of adenosine of up to 1 mM can be measured semiquantitatively by the degree of blue to red color changes or quantitatively by the extinction ratio at 520 and 700 nm. Under the same conditions, 5 mM guanosine, cytidine, or uridine resulted in a blue color only, indicating good selectivity of the sensor. The color difference can be clearly observed by the naked eye by spotting the resulting sensor solution onto an alumina TLC plate. Since aptamers that can target many classes of important analytes have already been selected, they can be adapted into aptazyme systems through rational design or further selection. Thus, colorimetric biosensors for many analytes of interest can be designed using the method presented here, regardless of whether the analytes are directly involved in the cleavage reaction or not.

Lu F, Chen S, Peng S, Wang X. Ultrafine SnO_2 used as low-temperature gas-sensing material. Gongneng Cailiao/J Functional Mater 1995;26(4):298-301.

Keywords: Nanotechnology/ Tin compounds/ Sensors/ Nanostructured materials

Abstract: The supercritical fluid drying technique (SCFDT) was used here to prepare the nanometer-sized SnO_2 powders, and their gas-sensing properties were examined. Our results show that (1) after simply adding additives into the SnO_2 powders, their working temperature for detecting CO and H_2 can be reduced to about 30 C and 120 C respectively, hence both the energy consumption, the sensing-element duration, and danger of causing explosion are reduced when it works; (2) the temperature of sintering to obtain high mechanical strength can be cut down 100–200 C as compared to the sintering temperature of ordinary SnO_2 sensors, hence the energy-consumption can also be reduced even in the preparation of the sensing-element.

Luebbers DW. How to measure pO_2 of tissue sealed in a transparent chamber: Development and construction of the first optrodes/optodes. Sensors and Actuators B: Chemical [Proceedings of the 1998 4th European Conference on Optical Chemical Sensors and Biosensors, EUROPT(R)ODE IV, Munster, Germany, Mar. 29-Apr. 1, 1998] 1998;B51(1-3):5-11.

Keywords: Tissue/ Oxygen/ Permselective membranes/ Organic solvents/ Nanotechnology/ Fiber optic sensors

Abstract: To measure tissue pO_2 in a sealed transparent chamber we tried to use dissolved pyrene butyric acid as fluorescence indicator but, using the in vitro calibration curve in the tissue, we obtained distinct misreadings in vivo. By studying the measuring conditions, together with N. Opitz, it was found that the microenvironment within the tissue had a strong effect on the quenching reaction and was responsible for the misreadings. Therefore, we worked out a setup by which the sensor reaction was separated from the medium to be measured by a suitable membrane which was permeable for the analyte. These new optical sensors with such an analytical and optical separation of the sensor reaction were called optrodes or, etymologically more correct, optodes. In the following development we demonstrated that many analytes could be measured with sufficient exactitude (e.g. blood gases, enzyme optodes, ionic strength). For special applications it was possible to construct fiberoptic optodes by applying the sensor membranes to optical fibers and nanooptodes by including the indicator into capsules of a diameter of 100–500 nm.

Ma A, Rosenzweig Z. Submicrometric lipobead-based fluorescence sensors for chloride ion measurements in aqueous solution. Anal Chem 2004;76(3):569-75.

Keywords: Chlorides, analysis/ Dimethyl biacridine

Abstract: This paper describes the preparation and optimization of the analytical properties of fluorescence-based submicrometric chloride ion sensing lipobeads. Fluorescence sensing lipobeads are polystyrene nanoparticles that are coated with a phospholipid membrane that contains a fluorescent indicator for a targeted analyte. In this study, the halide-specific fluorescence dye, lucigenin, was immobilized into the phospholipid membrane of the lipobeads to enable chloride ion detection. The fluorescence intensity of lucigenin decreases with increasing chloride ion concentration due to dynamic quenching. Lipobeads that contained only lucigenin were ineffective as chloride ion sensors due to poor partition of the water-soluble lucigenin molecules into the phospholipid membrane and high leakage rate of immobilized lucigenin molecules to the aqueous solution. To stabilize the chloride ion sensing lipobeads we coimmobilized hexadecanesulfonate molecules into the phospholipid membrane. The formation of ion pairs between hexadecanesulfonate and lucigenin decreased the hydrophilicity of the dye, increased its partition rate into the membrane, increased the brightness of the particles, and significantly decreased the leakage rate of the hydrophobic ion pair from the membrane to the solution. To further improve their chloride ion sensitivity, we also immobilized the chloride ionophore [9]mercuracarborand-3 into the lipobead membrane. The study resulted in a unique submicrometric chloride ion sensor, which is suitable for chloride ion measurements in biological fluids.

Manalis SR, Cooper EB, Indermuhle PF. Microvolume field-effect pH sensor for the scanning probe microscope. Appl Phys Lett 2000;76(8):1072-4.

URL: http://content.aip.org/APPLAB/v76/i8/1072_1.html

Keywords: pH sensors, miniaturization/ Cantilever devices/ Potentiometers

Abstract: A microfabricated cantilever with an integrated field-effect sensor is used to profile the pH of laminar streams in a microfluidic channel array. The combined system is scalable and acts as a high-resolution tool for the direct synthesis, switching, and examination of nanoliter volumes in several discrete solutions. The scanning probe potentiometers have potential in imaging pH gradients produced by individual cells as well as the charge distribution from patterned arrays of biomolecules such as DNA and protein.

Manobianco J, Evans RJ, Pister KSJ, Manobianco DM. GEMS: A revolutionary system for environmental monitoring. 2004 NSTI Nanotechnology Conference and Trade Show - NSTI Nanotech 2004. 2004 NSTI Nanotechnology Conference and Trade Show - NSTI Nanotech 2004; Boston, MA, USA. Nano Science and Technology Institute, Cambridge, MA 02139, USA, 2004: 422-5.
Keywords: Sensors/ Nanotechnology/ Systems analysis/ Particulate emissions/ Data acquisition/ Carbon dioxide/ Aerodynamics/ Microelectromechanical devices
Abstract: This paper describes a revolutionary new observing system designed for environmental monitoring that will integrate MicroElectroMechanical Systems (MEMS) and nanotechnologies. The concept, known as Global Environmental MEMS Sensors (GEMS), features an integrated system of airborne probes that will remain suspended in the atmosphere for hours to days and take measurements as they are carried by wind currents. Previous efforts focused on defining the major feasibility issues associated with system design and development in the decadal time frame. The current two-year project focuses on studying the major feasibility issues including costs/benefits and developing a technology roadmap.

Matveeva E, Gryczynski Z, Malicka J, Gryczynski I, Lakowicz JR. Metal-enhanced fluorescence immunoassays using total internal reflection and silver island-coated surfaces. Anal Biochem 2004;334(2):303-11.
URL: http://www.sciencedirect.com/science/article/B6W9V-4DDXNTS-4/2/9816c44824906f67aa02f07ada113bd5
Keywords: Fluorescence immunoassay/ Enhanced fluorescence/ Immunoglobulin/ Nano-size metallic particles/ Silver island films
Abstract: We present a generic immunoassay platform that uses enhanced total internal reflection fluorescence in the proximity of silver island films (SIFs), a surface coating consisting of metal (silver) particles. This platform is used with a model immunoassay where a protein antigen, rabbit immunoglobulin G, was immobilized on the SIF-coated glass surface. The signal from a fluorescent dye-labeled anti-rabbit antibody binding to the surface antigen was detected; different color dyes have been tested. Close placement of the fluorophore to surface-bound silver nanostructures results in dramatic signal enhancement (up to 40-fold) on the SIFs as compared with the glass slides. Use of the total internal reflection mode of excitation has significant advantages (over classic front-face excitation) for practical assay development. The limited evanescent wave excitation volume makes it possible to minimize the background signal and use the immunoassay with no need for any washing steps.

May LM, Russell DA. Novel determination of cadmium ions using an enzyme self-assembled monolayer with surface plasmon resonance. Anal Chim Acta 2003;500(1):119-25(7).
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TF4-49JX8XH-1&_coverDate=12%2F19%2F2003&_alid=245174711&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5216&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b38f31b53faacdf37e618786cb3f47b6
Keywords: Self-assembled monolayer/ Circular dichroism/ SPR/ Cadmium/ Biosensor/ Conformational change

Abstract: The activity of the enzyme urease is known to be inhibited by the heavy metal cadmium. The binding of cadmium to urease and the consequent changes of the enzyme structure are the basis of the surface plasmon resonance (SPR) biosensing system reported herein. To facilitate the formation of a self-assembled monolayer (SAM) of the urease on gold-coated glass SPR sensor disks, the enzyme has been modified with *N*-succinimidyl 3-(2-pyridyldithiol) propionate (SPDP). The urease monolayer was exposed to trace levels of cadmium ions and monitored by SPR. From circular dichroism (CD) data, it is believed that the conformation of the active nickel site of the urease changes upon binding of the cadmium ions. It is this change of the enzyme monolayer, measured by SPR, which has been related to the cadmium ion concentration in the range of 0–10 mg L^{-1}. These data are the first report of a SPR biosensor capable of detecting metal ions.

McShane MJ. Multilayer nanoengineering techniques for fabrication of opto-chemical probes. Second Int Conf on Sensors: IEEE Sensors 2003. Proceedings of IEEE Sensors; Toronto, ON, Canada. Institute of Electrical and Electronics Engineers Inc., 2003: 689-93.

Keywords: Nanotechnology / Optical fibers/ Self assembly/ Adsorption/ Probes/ Energy transfer/ Macromolecules/ Precipitation (chemical)/ Fluorescence/ Surface plasmon resonance/ Spectroscopic analysis/ Optical sensors

Abstract: This report presents a succession of theoretical and experimental work on sensors using the LbL technique to produce spectroscopic devices on optical fibers and micro/nano carriers using fluorescence and surface plasmon resonance interactions as specific biosensors. Examples of engineering opto-chemical transducers for in vitro, in vivo, and intracellular biochemical analysis are given to demonstrate the versatility of the process.

McShane MJ. Nanoengineering of fluorescence-based chemical sensors using electrostatic self-assembly: Thin films and micro/nanoshells. First IEEE Int Conf on Sensors - IEEE Sensors 2002. Proceedings of IEEE Sensors; Orlando, FL, USA. Institute of Electrical and Electronics Engineers Inc., 2002: 293-7 .

Keywords: Fluorescence/ Nanotechnology/ Thin films/ Electrostatics/ Self assembly/ Nanostructured materials/ Sensors/ Deposition/ Sodium/ Potassium/ Oxygen/ Glucose sensors/ Chemical sensors

Abstract: A general strategy for design and fabrication of nanoscale fluorescent sensors using electrostatic layer-by-layer assembly is presented. Using the approach of depositing oppositely-charged species onto colloidal micro/nanotemplates, two sensor systems employing fluorescent indicators and functional biomolecules are proposed: thin sensor films on solid carriers, and micro/nanocapsules containing sensing chemistry. Results demonstrating these concepts are described for ion (sodium and potassium), oxygen, and glucose sensors. The work suggests great potential for layer-by-layer architecture to fabricate nanostructured fluorescent sensors using nanoscale solid carriers and hollow microshells.

McShane MJ, Brown JQ, Guice KB, Lvov YM. Polyelectrolyte microshells as carriers for fluorescent sensors: Loading and sensing properties of a ruthenium-based oxygen indicator. J Nanosci Nanotechnol 2002;2(3-4):411-6.

URL: http://www.ingentaconnect.com/content/asp/jnn/2002/00000002/F0020003/art00021 and for a related paper, see http://www.coes.latech.edu/ifm/nsfnirt0210298.pdf

Keywords: Layer-by-layer self assembly/ Biosensors/ Fluorescene spectroscopy
Abstract: A strategy for the design and fabrication of microcapsule-based fluorescent biosensors containing indicators and internal references is described. The rationale for this work is the physical immobilization and chemical separation of assay chemistry for use in biological environments. Using the general approach of depositing oppositely charged species on colloidal micro/nanotemplates, a sensor system employing polyelectrolyte microshells for uptake of functional molecules is proposed, and experiments to demonstrate the feasibility of nanoengineering the sensor properties are described in the context of an oxygen sensor. Methods for immobilization and entrapment of fluorescent indicator and reference dyes are shown, along with the pH dependence of this process. Embedded dyes are shown to be stable and retain their function, as demonstrated with oxygen-sensitivity experiments of loaded microcapsules. Although oxygen sensitivity is presented as an example of a specific application, the overall strategy is likely more generally useful. The work suggests that polyelectrolyte microshells may be used as a platform to develop novel sensors by entrapment of functional materials.

Mirsky VM. New electroanalytical applications of self-assembled monolayers. TrAC Trends in Analytical Chemistry 2002;21(6-7):439-50.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V5H-467JYKW-4&_coverDate=06%2F07%2F2002&_alid=245166474&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5787&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=630c42f28141fd23ec13b2a9df748728
Abstract: New applications of self-assembled monolayers of thiol compounds on gold electrodes are reviewed. They include: (i) exploitation of electrical control of self-assembly of thiol compounds for electrically-addressable immobilization of receptor molecules onto sensor arrays; (ii) a spreader-bar technique for formation of stable nanostructures; and, (iii) use of self-assembled monolayers as selective filters for chemical sensors.

Misiakos K, Kakabakos SE, Petrou PS. A monolithic silicon optoelectronic transducer as a real-time affinity biosensor. Anal Chem 2004;76(5):1366-73.
Keywords: Biosensors/ Optoelectronicdevices, design/ Lab-on-a-chip/ Silicon
Abstract: An optical real-time affinity biosensor, which is based on a monolithic silicon optoelectronic transducer and a microfluidic module, is described. The transducer monolithically integrates silicon avalanche diodes as light sources, silicon nitride optical fibers, and p/n junction detectors and efficiently intercouples these elements through a self-alignment technique. The transducer surface is hydrophilized by oxygen plasma treatment, silanized with (3-aminopropyl)triethoxysilane and bioactivated through adsorption of the biomolecular probes. The use of a microfluidic module allows real-time monitoring of the binding reaction of the gold-nanoparticle-labeled analytes with the immobilized probes. Their binding within the evanescent field at the surface of the optical fiber causes attenuated total reflection of the waveguided modes and reduction of the detector photocurrent. The biotin-streptavidin model assay was used for the evaluation of the analytical potentials of the device developed. Detection limits of 3.8 and 13 pM in terms of gold nanoparticle-labeled streptavidin were achieved for continuous- and stopped-flow assay modes, respectively. The detection sensitivity was improved by silver plating of the immolilized gold nanoparticles, and

a detection limit of 20 fM was obtained after 20 min of silver plating. In addition, two different analytes, streptavidin and antimouse IgG, were simultaneously assayed on the same chip demonstrating the multianalyte potential of the sensor developed.

Moore TL, Aburime SA, Wilson TA, Giannelis EP, Batt CA. Nanofabrication of biodegradable enzyme-based glucose and organophosphorus pesticide biosensors. Proc 2002 Nat Conf on Environmental Science and Technology. Proceeding of the 2002 National Conference on Environmental Science and Technology; Greensboro, NC, USA. Battelle Press, 2002: 225-32.
Keywords: Enzymes/ Nanotechnology/ Biodegradation/ Phosphorus/ Pesticides/ Plastics/ Electrodes/ Gold/ Sol-gels/ Etching/ Tensile testing/ Photolithography/ Evaporation/ Approximation theory/ Glucose sensors
Abstract: The nanofabrication of biodegradable enzyme-based glucose and organophosphorus pesticide biosensors was discussed. The biosensors were constructed by using polyhydroxyalkanoate (PHA), a biodegradable plastic, as a base material, for detecting organophosphorous pesticide that were as durable and effective as synthetic plastics. A degradation study and tensile test were performed to test PHA for durability. The PHA substrate was found to be degrade at an average rate of approximately 0.1434 g per day during the first 28 days. The PHA was patterned with a nanofabricated interdigitated (IDA) gold electrode using a combination of thermal evaporation, photolithography and etching processes.

Mor GK, Carvalho MA, Varghese OK, et al. A room-temperature TiO_2-nanotube hydrogen sensor able to self-clean photoactively from environmental contamination. J Mater Res 2004 ;19(2):628-34.
Keywords: Hydrogen sensors/ Nanotubes
Abstract: Described is a room-temperature hydrogen sensor comprised of a TiO_2-nanotube array able to recover substantially from sensor poisoning through ultraviolet (UV) photocatalytic oxidation of the contaminating agent; in this case, various grades of motor oil. The TiO_2 nanotubes comprising the sensor are a mixture of both anatase and rutile phases, having nominal dimensions of 22 nm inner diameter, 13.5 nm wall thickness, and 400 nm length, coated with a 10 nm thick noncontinuous palladium layer. At 24 C, in response to 1000 ppm of hydrogen, the sensors show a fully reversible change in electrical resistance of approximately 175,000%. Cyclic voltammograms using a 1 N KOH electrolyte under 170 mW/cm^2 UV illumination show, for both a clean and an oil-contaminated sensor, anodic current densities of approximately 28 mA/cm^2 at 2.5 V. The open circuit oxidation potential shows a shift from 0.5 V to -0.97 V upon UV illumination.

Motesharei K, Ghadiri MR. Diffusion-limited size-selective ion sensing based on SAM-supported peptide nanotubes. J Am Chem Soc 1997;119:11306-12.
Keywords: Biosensors/ Cyclic peptides/ Nanotubes
Abstract: An approach for the construction of diffusion-limited size-selective sensors is described based on the self-assembly of cyclic peptides into tubular channels in organosulfur self-assembled monolayers on gold films. An eight-residue cyclic peptide of alternating units of D-Leu and L-Trp amino acid residues was incorporated into monolayers of dodecanethiol and octadecyl sulfide and shown to adopt highly oriented tubular structures under specified adsorption conditions. The structural properties of monolayer-supported peptide nanotubes have been analyzed by grazing angle FTIR spectroscopy and their selective ion transport

activities by cyclic voltammetry and impedance spectroscopy. Copyright 1997, American Chemical Society.

Nabok A, Haron S, Ray A. Registration of heavy metal ions and pesticides with ATR planar waveguide enzyme sensors. Appl Surface Sci 2004;238(1-4):423-8.
URL: http://www.sciencedirect.com/science/article/B6THY-4CYGVS0-2/2/e02e00d26a7f55a58977d2ca3ee6e3a1
Keywords: Attenuated total reflection/ Planar waveguide/ Enzyme reactions/ Inhibition of enzyme activity/ Heavy metal ions/ Pesticides
Abstract: The proposed novel type of enzyme optical sensors is based on a combination of $SiO_2/Si_3N_4/SiO_2$ planar waveguide ATR (attenuated total reflection) transducer, fabricated by standard silicon planar technology, with the composite polyelectrolyte self-assembled coating containing both organic chromophores and enzyme molecules. Such devices were deployed to monitor typical industrial and agricultural water pollutants, such as heavy metal ions and pesticides, acting as inhibitors of enzyme reactions. The sensitivity of registration of these pollutants in the range of 1 ppb was achieved. The use of different enzymes in the sensitive membrane provides a background for pattern recognition of the above pollutants.

Narita M, Yamagata T, Ishii H, et al. Simultaneous detection and removal of organomercurial compounds by using the genetic expression system of an organomercury lyase from the transposon TnMERl1. Appl Microbiol Biotechnol 2002;59(1):86-90.
URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=12073137&dopt=Abstract
Keywords: Transposons/ Mercury compounds/ Environmental pollution, indicator organisms
Abstract: A biosensor capable of detecting and removing organo- and inorganic mercurial contamination is presented. The biosensor uses a newly identified organomercury lyase gene expression system from the mercury resistance transposon TnMERI1. The sensor system can detect concentrations of bioaffecting inorganic mercury ranging from several hundred nanomolars to micromolars, and its sensitivity increases in the presence of methylmercury. Published abstract: Using a newly identified organomercury lyase gene (merB3) expression system from Tn MERI1, the mercury resistance transposon first found in Gram-positive bacteria, a dual-purpose system to detect and remove organomercurial contamination was developed. A plasmid was constructed by fusing the promoterless luxAB genes as bioluminescence reporter genes downstream of the merB3 gene and its operator/promoter region. Another plasmid, encoding mer operon genes from merR1 to merA, was also constructed to generate an expression regulatory protein, MerR1, and a mercury reductase enzyme, MerA. These two plasmids were transformed into Escherichia coli cells to produce a biological system that can detect and remove environmental organomercury contamination. Organomercurial compounds, such as neurotoxic methylmercury at nanomolar levels, were detected using the biomonitoring system within a few minutes and were removed during the next few hours.

Navarro Villoslada F, Orellana G, Moreno Bondi MC, et al. Fiber-optic luminscent sensors with composite oxygen-sensitive layers and anti-biofouling coatings. Anal Chem 2001;73(21):5150-6.
Keywords: Fiber optic sensors/ Oxygen sensors/ Marine bacteria

Abstract: Anti-biofouling polymers containing phosphorylcholine (PC)-substituted methacrylate units have been prepared by copolymerization with dodecyl methacrylate and used to coat luminescent oxygen sensors. Nanometer-sized coatings of such materials are shown to reduce significantly the adhesion of marine bacteria (more than 70%) and thrombocytes (more than 90%) to the surface of tris-(4,7-diphenyl-1,10-phenanthroline)ruthenium(II)-doped silicone layers. A thorough analytical characterization of both the PC-coated and the uncoated dyed films has demonstrated that the anti-biofouling layers do not alter dramatically the performance of the fiber-optic oxygen sensors in aqueous media and are mechanically stable for more than one year of continuous immersion. The slope of the linear calibration plots in the 0–8 mg/L oxygen concentration range (ca. 1.0 L/mg) decreases 8–11% after applying the 50 nm protective layer with no change in the sensor precision (1.1–1.9% RSD, n = 6). The response time of the 200 mm O_2-sensitive layers (1.5–6 min) increases up to 2-fold, depending on the nature of the PC polymer used, but the temperature effect on the sensor response (0.020 L mg^{-1} C^{-1}) remains essentially unchanged. Oxygen detection limits as low as 0.04 mg /L have been measured with the coated optodes. The novel biofouling-resistant optosensors have been successfully validated against a commercial oxygen electrode and are shown to respond faster than the electrochemical device for large oxygen concentration changes. The biomimetic coatings will be particularly useful for drift-free long-term operation of environmental optosensors and in vivo fiber-optic oxygen analyzers.

Nayak SR, Guice K, Lvov Y, McShane MJ. Nanoengineered fluorescent sensors containing enzyme assays. Proc 2002 IEEE Engineering in Medicine and Biology 24th Annual Conference and the 2002 Fall Meeting of the Biomedical Engineering Society (BMES / EMBS). Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings; Houston, TX, USA. Institute of Electrical and Electronics Engineers Inc., 2002: 1679-80.

Keywords: Nanotechnology/ Enzymes/ Fluorescence/ Polyelectrolytes/ Biomaterials/ Catalysis/ Encapsulation/ Glucose/ Biosensors

Abstract: This paper describes progress towards the fabrication, calibration and testing of polyelectrolyte microshells being used as sensors for biochemicals, which are either produced or consumed in enzyme-catalyzed reactions. They are nanoengineered using Layer-by-Layer (LbL) assembly. These shells are loaded with the analyte sensitive fluorophore, the reference fluorophore for ratiometric monitoring and the enzyme, which catalyzes the reaction. A potential use of these sensors is to study the transient local changes in both glucose and lactate caused by neuronal activity. A specific application of this project is the study of the brain's response to low glucose. This paper primarily focuses on the work done on enzyme encapsulation. A study of the effect of encapsulation on enzymes as well as the influence of sensor fabrication variables (size, layer thickness, composition) on the response characteristics of the sensors is being investigated. Preliminary work has shown that the enzymes can be encapsulated by a method of aided diffusion and that the enzyme retains its activity after encapsulation. Co-loading of the labeled enzyme and the oxygen sensitive dye has also been demonstrated.

Neubauer A, Pum D, Sleytr UB, Klimant I, Wolfbeis OS. Fibre-optic glucose biosensor using enzyme membranes with 2-D crystalline structure. Biosens Bioelectron 1996;11(3):317-25.

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TFC-3THJ3YG-

1J&_coverDate=12%2F31%2F1996&_alid=245168768&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5223&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=af65148ba95a433df2f0862d7f93af3e
Keywords: Fibre-optic glucose biosensor/ Immobilization matrix/ Bacterial S-layers/ Fluorescence quenching
Abstract: Two-dimensional crystalline bacterial surface layers (S-layers) composed of identical (glyco)protein subunits turned out to be ideal matrices for immobilizing monolayers of functional macromolecules. Due to their crystalline character, S-layers exhibit a characteristic topography with a defined arrangement and orientation of functionalities, which is a prerequisite for a reproducible and geometrically defined binding of biomolecules. The proteinic nature of S-layers provides an adequate microenvironment for immobilized biomolecules, frequently along with the effect of a high retention of biological activity and enhanced stability towards drying. For the development of a fibre-optic glucose biosensor, monomolecular layers of glucose oxidase were covalently immobilized on the surface of S-layer ultrafiltration membranes. During glucose measurements, the enzyme monolayer was attached to the transducer, an oxygen optode containing a ruthenium(II) complex whose fluorescence is dynamically quenched by molecular oxygen. The performance of the sensor, in terms of response time, linear range and stability, is comparable to existing optodes. Given its minute size, the system presented is considered to hold great promise for the development of micro-integrated optical biosensors.

Ng HT, Fang A, Li J, Lia SFY. Flexible carbon nanotube membrane sensory system: A generic platform. J Nanosci Nanotechnol 2001;1(4):375-9.
URL: http://www.ingentaconnect.com/content/asp/jnn/2001/00000001/00000004/art00002
Keywords: Carbon nanotube/ Membrane/ Sensors/ Template growth/ Chemical vapor deposition/ Electrochemistry/ Soft lithography
Abstract: A multi-walled carbon nanotube membrane as obtained from a soft lithography-mediated selective chemical-vapor deposition template approach has been successfully integrated with a flexible elastomeric polydimethylsiloxane framework to fabricate microsensing devices. Two proof-of-concept experiments, namely high-sensitivity chemical gas sensing and electrochemical detection have been performed to demonstrate its potential as a useful generic platform for a general purpose sensory system.

Nicolini C, Erokhin V, Facci P, Guerzoni S, Ross A, Paschkevitsch P. Quartz balance DNA sensor. Biosens Bioelectron 1997;12(7):613-8.
Keywords: DNA/ Langmuir Blodgett films/ DNA sequences/ Enzyme immobilization/ Nanotechnology/ Bioassay/ Fluorescence/ Optical variables, measurement/ Biosensors
Abstract: Single-strand DNA-containing thin films were deposited onto quartz oscillators by the Langmuir-Blodgett technique towards the realization of a device capable of sensing the presence of the complementary DNA sequences which hybridize with the immobilized ones. DNA, once complexed with aliphatic amines, appears as a monolayer in a single-stranded form by X-ray small angle scattering. A quartz nanobalance is then utilized to monitor mass increment related to specific hybridization with a complementary DNA probe. The crystal quartz nanobalance, capable of high sensitivity, indeed appears capable of obtaining a prototype of a device capable of sensing the occurrence of particular genes or sequences in the sample under investigation. The validity of the nanogravimetric assay was confirmed by

independent fluorescence measurements utilizing DAPI and a CCD camera.

Nieto S, Santana A, Delgado R, Hernandez SP, Thomas Chamberlain R, Lareau R, et al. Nanoscaled science and engineering for sensing: Quantum dots fluorescence quenching for organic NO_2 sensing. 2004 NSTI Nanotechnology Conference and Trade Show - NSTI Nanotech 2004. 2004 NSTI Nanotechnology Conference and Trade Show - NSTI Nanotech 2004; Boston, MA, USA. Nano Science and Technology Institute, Cambridge, MA 02139, United States, 2004: 399-401.
Keywords: Nanostructured materials/ Nanotechnology/ Fluorescence/ Nitrogen oxides/ Quenching/ Biosensors/ Electrochemical sensors/ Solutions/ Charge transfer/ Toluene/ Cadmium compounds/ Ultraviolet radiation/ Charge coupled devices/ Semiconductor quantum dots
Abstract: We report on femtosecond laser off-resonance excitation of quantum dots-TNT assemblies in solution. The fluorescence emission from quantum dots shifts toward lower wavelengths and the relative peak intensity decreases with the amount of TNT added to solutions of the dots. A charge transfer mechanism based on charge injection from the photoexcited electrons in the TNT into the conduction band of the nanoscaled semiconductor is proposed to account for the observed results.

Novak JP, Snow ES, Houser EJ, et al. Nerve agent detection using networks of single-walled carbon nanotubes. Appl Phys Lett 2003;83(19):4026-8.
Keywords: Poisonous gas detectors/ Single-walled carbon nanotubes/ Dimethyl methylphosphonate
Abstract: The authors present carbon nanotubes that can be used as sensors for chemical nerve agents. Thin-film transistors obtained from random networks of single-walled carbon nanotubes are able to detect dimethyl methylphosphonate (DMMP), a simulant for the nerve agent sarin. These sensors are reversible, can identify DMMP at sub-ppb concentration levels, and are intrinsically selective against interferent signals from hydrocarbon vapors and humidity. Additional chemical specificity is achieved through the use of filters coated with chemoselective polymer films.

Oh S, Lee JS, Jeong K-H, Lee LP. Minimization of electrode polarization effect by nanogap electrodes for biosensor applications. IEEE 16th Ann Int Conf on Micro Electro Mechanical Systems. Proceedings of the IEEE Micro Electro Mechanical Systems (MEMS); Kyoto, Japan. Institute of Electrical and Electronics Engineers Inc., 2003: 52-5.
Keywords: Biosensors/ Electrodes/ Electromagnetic wave polarization/ Spectroscopy/ Electric impedance/ Capacitance measurement/ Equivalent circuits/ Nanotechnology
Abstract: Nanogap electrodes-based dielectric spectroscopy is introduced to create ultrasensitive biomolecular sensors by minimizing the effects of electrode polarization. The electrode polarization is a major source of error in determining the impedance of biological samples in solution. The unwanted double layer impedance due to the electrode polarization impedance is caused by the accumulation of ions on the surface of electrode. This effect becomes more dominant in low frequency region (less than or equal to 1 kHz). In this paper we describe nanogap-electrodes-based biomolecular measurements that can minimize electrode polarization effects since the double layers overlap and potential drop inside of the electrode gap can be reduced in nanoscale (less than or equal to100 nm) electrode spacing.

Ono T, Li X, Miyashita H. Mass sensing of adsorbed molecules in sub-picogram sample with ultrathin silicon resonator. Rev Sci Instrum 2003;74(3):1240-3.

Keywords: Carbon nanotubes/ Resonators design/ Silicon micromachining/ Silicon/ elemental Semiconductors/ Crystal resonators/ Semiconductor thin films/ Hydrogen economy/ Adsorbed layers/ Chemical sensors/ Mass measurement

Abstract: Ultrathin single-crystalline silicon cantilevers with a thickness of 170 nm as a resonating sensor are applied to mass sensing. The hydrogen storage capacity of a small amount of carbon nanotubes (CNTs), which were mounted on an ultrathin resonator by a manipulator, is measured from the resonant frequency change. The resonator is annealed in ultrahigh vacuum to clean the surface and increase the quality factor, and exposed to oxygen gas to oxidize the surface for long-term stability. The resonator can be electrostatically actuated, and the vibration is measured by a laser Doppler vibrometer in ultrahigh vacuum. The mass of the CNTs is determined by the difference of resonant frequencies before and after mounting the CNTs, and the hydrogen storage capacity is determined from the frequency change after exposure to high-pressure hydrogen as well. The obtained hydrogen storage capacitance is 1.6%–6.0%. The available mass resolution and the achieved stability of the resonance of the 170-nm-thick resonator are below 10^{-18} g and 5 Hz/days, respectively.

Otsuka H, Akiyama Y, Nagasaki Y. Quantitative and reversible lectin-induced association of gold nanoparticles modified with α-lactosyl-Ω-mercapto-poly(ethylene glycol). J Am Chem Soc 2001;123(34):8226-30.

URL: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=11516273&dopt=Abstract

Keywords: Gold nanoparticles/ Dispersion/ Polyethylene glycol

Abstract: Gold nanoparticles (1–10 nm size range) were prepared with an appreciably narrow size distribution by in situ reduction of $HAuCl_4$ in the presence of heterobifunctional poly(ethylene glycol) (PEG) derivatives containing both mercapto and acetal groups (α-acetal-Ω-mercapto-PEG). The α-acetal-PEG layers formed on gold nanoparticles impart appreciable stability to the nanoparticles in aqueous solutions with elevated ionic strength and also in serum-containing medium. The PEG acetal terminal group was converted to aldehyde by gentle acid treatment, followed by the reaction with p-aminophenyl-β-D-lactopyranoside (Lac) in the presence of $(CH_3)_2NHBH_3$. Lac-conjugated gold nanoparticles exhibited selective aggregation when exposed to *Recinus communis* agglutinin (RCA(120)), a bivalent lectin specifically recognizing the β-D-galactose residue, inducing significant changes in the absorption spectrum with concomitant visible color change from pinkish-red to purple. Aggregation of the Lac-functionalized gold nanoparticles by the RCA(120) lectin was reversible, recovering the original dispersed phase and color by addition of excess galactose. Further, the degree of aggregation was proportional to lectin concentration, allowing the system to be utilized to quantitate lectin concentration with nearly the same sensitivity as ELISA. This simple, yet highly effective, derivatization of gold nanoparticles with heterobifunctional PEG provides a convenient method to construct various colloidal sensor systems currently applied in bioassays and biorecognition.

Park EJ, Brasuel M, Behrend C, et al. Ratiometric optical PEBBLE nanosensors for real-time magnesium ion concentrations inside viable cells. Anal Chem 2003;75(15):3784-91.

Keywords: Magnesium in the body/ Biosensors

Abstract: This paper presents the development and characterization of a highly selective magnesium fluorescent optical nanosensor, made possible by PEBBLE (probe encapsulated by biologically localized embedding) technology. A ratiometric sensor has been developed by co-immobilizing a dye that is sensitive to and highly selective for magnesium, with a reference dye in a matrix. The sensors are prepared via a microemulsion polymerization process, which entraps the sensing components inside a polymer matrix. The resultant spherical sensors are ~40 nm in diameter. The Coumarin 343 (C343) dye, which by itself does not enter the cell, when immobilized in a PEBBLE is used as the magnesium-selective agent that provides the high and necessary selectivity over other intracellular ions, such as Ca^{2+}, Na^{+}, and K^{+}. The dynamic range of these sensors was 1–30 mM, with a linear range from 1 to 10 mM, with a response time of < 4 s. In contrast to free dye, these nano-optodes are not perturbed by proteins. They are fully reversible and exhibit minimal leaching and photobleaching over extended periods of time. In vitro intracellular changes in Mg^{2+} concentration were monitored in C6 glioma cells, which remained viable after PEBBLE delivery via gene gun injection. The selectivity for Mg^{2+} along with the biocompatibility of the matrix provides a new and reliable tool for intracellular magnesium measurements.

Park S, Chung TD, Kim HC. Nonenzymatic glucose detection using mesoporous platinum. Anal Chem 2003;75(13):3046-9.
Keywords: Glucose sensors/ Platinum electrodes/ Porous electrodes, design
Abstract: Roughness of nanoscopic dimensions can be used to selectively enhance the faradaic current of a sluggish reaction. Using this principle, we constructed mesoporous structures on the surfaces of pure platinum electrodes responding even more sensitively to glucose than to common interfering species, such as L-ascorbic acid and 4-acetamidophenol. Good sensitivities, as high as 9.6 mA cm^{-2} mM^{-1}, were reproducibly observed in the presence of high concentration of chloride ion. The selectivities, sensitivities, and stabilities determined experimentally have demonstrated the potential of mesoporous platinum as a novel candidate for nonenzymatic glucose sensors.

Pastorino L, Disawal S, Nicolini C, Lvov YM, Erokhin VV. Complex catalytic colloids on the basis of firefly luciferase as optical nanosensor platform. Biotechnol Bioeng 2003;84(3):286-91.
Keywords: Colloids / Biocatalysts/ Optical sensors/ Nanotechnology/ Monolayers/ Polystyrenes/ Silver/ Electrophoresis/ Catalyst activity/ Electrostatics/ Electrodes/ Ultraviolet spectroscopy/ Biotechnology
Abstract: In the present work the layer-by-layer nanoassembly technique was used for the development of complex catalytic microparticles on the basis of firefly luciferase (FL). FL films containing 1, 2, or 3 monolayers were assembled on silver electrode QCM-resonators and on 520 nm diameter sulfonated polystyrene latex by alternate adsorption of FL and polycations using electrostatic interactions for the interlayer interaction. The assembly process was studied with quartz crystal microbalance, UV-vis spectroscopy, and microelectrophoresis (surface potential). Structural studies of the resulting multilayers confirmed stepwise deposition of FL and cationic poly(dimethyldiallyl ammonium chloride) with a bilayer thickness of 14 nm; a systematic shift of the surface potential from +28 mV for poly(dimethyldiallyl ammonium chloride) to -14 mV for luciferase outermost layer was established. The functionality and stability of the biocolloids were demonstrated by monitoring the intensity of the light emission. Factors influencing the light emitted upon catalytic activity

of FL such as the number of luciferase layers in the film and polyion layer at the outermost layer were studied. Copyright 2003 Wiley Periodicals.

Perez GP, Crooks RM. Pore-bridging poly(dimethylsiloxane) membranes as selective interfaces for vapor-phase chemical sensing. Anal Chem 2004;76(14):4137-42.
Keywords: Surface acoustic wave sensors, design/ Chemical sensors/ Methyl siloxanes
Abstract: A new kind of polymer-based sensor is described in which the experimental parameters controlling selectivity and sensitivity are decoupled. The sensor is based on a surface acoustic wave (SAW) gravimetric transducer modified with a high-surface-area, nanoporous alumina coating. A very thin (~40 nm) poly(dimethylsiloxane) (PDMS) coating resides atop the porous alumina structure. In this configuration, the total surface area of the nanoporous alumina coating controls the sensitivity of the device, while the chemical properties of the PDMS membrane control selectivity. In conventional polymer-based sensors, the polymer plays the dual role of controlling both selectivity (via the chemical composition of the coating) and sensitivity (via the volume of the film). In this paper, we show that PDMS acts as a chemically selective gate that absorbs polar and nonpolar VOCs but does not transport these analytes to the underlying pore volume. In contrast, water vapor is absorbed by the PDMS to a very minor extent but is easily transported through it to the underlying walls of the porous substructure. Specifically, there was little difference in the mass-loading response arising from polar and nonpolar VOCs dosed onto planar and nanoporous SAW devices modified with PDMS. In contrast, SAW devices having nanoporous coatings responded up to 24 times more selectively to water than planar sensors modified identically.

Prasad AK, Gouma PI. MoO_3 and WO_3 based thin film conductimetric sensors for automotive applications. J Mater Sci 2003;38:4347-52.
URL: http://www.ic.sunysb.edu/stu/akapalee/academic/JMSC.pdf or http://www.ingentaconnect.com/content/klu/jmsc/2003/00000038/00000021/05253627;jsessionid=98k0r49eh14hn.henrietta
Keywords: Tungsten oxide films, testing/ Automobile engines, emission control systems/ Gas detectors, specifications/ Molybdenum oxides
Abstract: Undoped semiconducting oxides suitable for automotive gas sensor applications have been studied in this work. Thin films of MoO_3 and WO_3 were fabricated by ion beam deposition on alumina substrates with gold interdigitated electrodes. The process pressure inside the deposition chamber was 1.6×10^{-4} torr. The oxygen to argon ratio in the secondary plasma was maintained at 5:5 sccm. A stabilization heat treatment of 500 C for 8 h was performed for each set of films that produced nanocrystalline structures. Gas sensing tests were carried out at 450 C with nitrogen dioxide/ammonia with synthetic air background similar to those realized in diesel automotive exhausts. XRD and electron microscopy studies were performed to understand the microstructure of the thin films following the sensing tests. The MoO_3 films were selective to ammonia whereas the WO_3 films showed high senstitivity towards NO_2 with respect to NH_3. An attempt is made to correlate the structural characteristics to the sensing behavior of the materials.

Prieto F, Sepulveda B, Calle A, Llobera A, Dominguez C, Abad A, et al. An integrated optical interferometric nanodevice based on silicon technology for biosensor applications. Nanotechnology 2003;14(8):907-12.

Keywords: Optical sensors/ Interferometry/ Biosensors/ Semiconductor device manufacture/ Semiconducting silicon/ Optical waveguides/ Water pollution control/ Bioassay/ Nanotechnology

Abstract: Integrated optical sensors have become important in recent years since they are the only technology which allows the direct detection of biomolecular interactions. Moreover, silicon microelectronics technology allows mass production as well as the fabrication of nano-/macrosystems on the same platform by hybrid integration of sources, sensors, photodetectors and complementary metal-oxide semiconductor electronics. For the fabrication of an optical sensor nanodevice with an integrated Mach-Zehnder interferometric (MZI) configuration, the optical waveguides must have two main features: monomode behaviour and a high surface sensitivity. In this paper we present the development of a MZI sensor based on total internal reflection waveguides with nanometre dimensions. The aim is to use these sensors in environmental control to detect water pollutants by immunoassay techniques.

Ram MK, Yavuz O, Lahsangah V, Aldissi M. CO gas sensing from ultrathin nano-composite conducting polymer film. Sensors and Actuators B: Chemical [In press, corrected proof].

URL: http://www.sciencedirect.com/science/article/B6THH-4DN9MXB-1/2/330dc685ddfa21582d81a12635c70161

Keywords: Gas sensor/ CO/ Conducting polymers/ Nanocomposites/ LBL/ In situ self-assembly/ SnO_2/ TiO_2

Abstract: New approaches are needed to solve environmental measurement problems associated with mobile sources for the measurements of CO, NO_X, aromatic hydrocarbons HC and particulates. There is a need to develop fast, rapid, cost effective, low power, and non-intrusive rugged sensors that can be easily installed. In order to be useful as a sensor, the device and technique should be able to detect the emissions from at relevant low concentrations. Our effort has focused on the use of highly organized ultrathin conducting polymer/metal oxide (SnO_2 and/or TiO_2) films for sensing of CO gas for the first time. The supramolecular approach has been utilized to fabricate films of conducting materials via in situ layer-by-layer (LBL) self-assembly technique. We have used UV-vis spectroscopy, atomic force microscopy (AFM), conductivity and AC impedance measurements to quantify the different characteristics of the ultrathin nanocomposite polymer films to ensure reproducibility, stability and reliability in CO sensing.

Ravi Shankaran D., Iimura K.-I., Kato T. A novel metal immobilized self-assembled surface for electrochemical sensing. Sensors and Actuators B: Chemical 2003;96(3):523-6(4).

URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THH-49MF21F-3&_coverDate=12%2F01%2F2003&_alid=245177927&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5283&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=7b878fca8f9dda22f46d5d122e099914

Keywords: Self-assembly/ Sol-gel/ (3-Mercaptopropyl)trimethoxysilane/ Iron/ Electroanalysis/ Hydrogen peroxide

Abstract: A new iron immobilized (3-mercaptopropyl)trimethoxysilane (MPS) self-assembled layer has been developed over a gold electrode surface by a combined sol-gel and self-assembly techniques. The sensor exhibited excellent sensing characteristics for the catalytic reduction as well as oxidation of hydrogen peroxide (H_2O_2) at the potentials of +0.1 and +0.4 V, respectively, with good sensitivity, selectivity and reproducibility. The possible coordination of iron with the functional thiol group of the MPS favored highly stable and leakage free sensing surface. The proposed system is a promising mean for the construction of a variety of new chemical and biosensors.

Ravi Shankaran D, Uehera N, Kato T. Determination of sulfur dioxide based on a silver dispersed functional self-assembled electrochemical sensor. Sensors and Actuators B: Chemical 2002;87(3):442-7(6).
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THH-473M9WG-4&_coverDate=12%2F20%2F2002&_alid=245184258&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5283&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=73fb3d4b0515562a59ed2edf5d601e9c
Keywords: Metal dispersed self-assembly/ (3-Mercaptopropyl)trimethoxysilane/ Silver/ Sulfur dioxide/ Electrocatalysis
Abstract: A new and simple amperometric sensor for sulfur dioxide (SO_2) has been constructed based on the self-assembly of (3-mercaptopropyl)trimethoxysilane (MPS) over a glassy carbon (GC) electrode followed by the complexation with silver. The silver dispersed onto the self-assembled surface exhibited excellent electrocatalytic activity for the determination of sulfur dioxide at a reduced potential (+0.3 V) with good sensitivity in a wide concentration range from 0.6 to 88 ppm with a correlation coefficient of 0.9989. The proposed sensor is easy to fabricate and has the advantages of good stability, reproducibility and rapid response.

Rolinski OJ, Birch DJS, McCartney LJ, Pickup JC. Fluorescence nanotomography using resonance energy transfer: Demonstration with a protein-sugar complex. Physics Medicine Biol 2001;46(9):221-6.
URL: http://www.iop.org/EJ/abstract/0031-9155/46/9/401
Keywords: Tomography/ Fluorescence/ Resonance/ Nanotechnology/ Chemical sensors/ Clinical laboratories/ Energy transfer
Abstract: A new approach to structural sensing, fluorescence resonance energy transfer nanotomography, which interprets fluorescence decay measurement in terms of site density analysis of molecular distributions, has been applied to a glucose sensor based on competitive binding with malachite green labelled dextran to the sugar binding protein concanavalinA labelled with allophycocyanin. Opportunities for structural sensing in clinical medicine are highlighted.

Rothschild A, Komem Y. The effect of grain size on the sensitivity of nanocrystalline metal-oxide gas sensors. J Appl Phys 2004;95(11):6374-80.
Keywords: Nanostructured materials, electric-properties/ Gas detectors, performance/ Carrier density, mathematical models
Abstract: A quantitative model that describes the effect of grain size on the sensitivity of metal-oxide gas sensors with nanosized grains is presented. The model, which uses simulations of the sensitivity as a function of the grain size, is applied to nanocrystalline SnO_2 gas sensors. Results are compared with experimental data.

Ruysschaert T, Germain M, Gomes JFPDS, Fournier D, Sukhorukov GB, Meier W, et al. Liposome-based nanocapsules. IEEE Trans Nanobiosci 2004;3(1):49-55.

Keywords: Biotechnology/ Enzymes/ Enzyme sensors/ Antibodies/ Osmosis/ Polymers/ Hydrophobicity/ Thermal effects/ Nanotechnology

Abstract: Here we present three different types of mechanically stable nanometer-sized hollow capsules. The common point of the currently developed systems in our laboratory is that they are liposome based. Biomolecules can be used to functionalize lipid vesicles to create a new type of intelligent material. For example, insertion of membrane channels into the capsule wall can modify the permeability. Covalent binding of antibodies allows targeting of the capsule to specific sites. Liposomes loaded with enzymes may provide an optimal environment for them with respect to the maximal turnover and may stabilize the enzyme. However, the main drawback of liposomes is their instability in biological media as well as their sensitivity to many external parameters such as temperature or osmotic pressure. To increase their stability we follow different strategies: 1) polymerize a two-dimensional network in the hydrophobic core of the membrane; 2) coat the liposome with a polyelectrolyte shell; or 3) add surface active polymers to form mixed vesicular structures.

Sasaki DY, Waggoner TA. Optical detection of aqueous phase analytes via host-guest interactions on a lipid membrane surface. Ferrari M. Micro- and Nanofabricated Structures and Devices for Biomedical Environmental Applications II. Proceedings of SPIE - The International Society for Optical Engineering; SPIE - The International Society for Optical Engineering, 1999: 46-54.

URL: http://spie.org/scripts/abstract.pl?bibcode=1999SPIE%2e3606%2e%2e%2e46S&page=1&qs=spie

Abstract: The organization and assembly of molecules in cellular membranes is orchestrated through the recognition and binding of specific chemical signals. A simplified version of the cellular membrane system has been developed using a synthetically prepared membrane receptor incorporated into a biologically derived lipid bilayer. Through an interplay of electrostatic and van der Waals interactions, aggregation or dispersion of molecular components could be executed on command using a specific chemical signal. A pyrene fluorophore was used as an optical probe to monitor the aggregational state of the membrane receptors in the bilayer matrix. The pyrene excimer emission to monomer emission (E/M) intensity ratio gave a relative assessment of the local concentration of receptors in the membrane. Bilayers were prepared with receptors selective for the divalent metal ions of copper, mercury, and lead. Addition of the metal ions produced a rapid dispersion of aggregated receptor components at nano- to micromolar concentrations. The process was reversible by sequestering the metal ions with EDTA. Receptors for proteins and polyhistidine were also prepared and incorporated into phosphatidylcholine lipid bilayers. In this case, the guest molecules bound to the membrane through multiple points of interaction causing aggregation of initially dispersed receptor molecules. The rapid, selective, and sensitive fluorescence optical response of these lipid assemblies make them attractive in sensor applications for aqueous phase metal ions and polypeptides.

Shah RR, Abbott NL. Principles for measurement of chemical exposure based on recognition-driven anchoring transitions in liquid crystals. Science 2001;293(5533):1296-9.

Keywords: Liquid crystals/ Environmental pollution testing/ Detectors

Abstract: The competitive binding of a molecule forming a liquid crystal and a targeted analyte to a common molecular receptor presented at a solid surface possessing nanometer-

scale topography is used to trigger an easily visualized surface-driven change in the orientation of a micrometer-thick film of liquid crystal. Diffusion of the targeted analyte from atmosphere to surface-immobilized receptor across the micrometer-thick film of liquid crystal is fast (on the order of seconds), and the competitive interaction of the targeted analyte and liquid crystal with the receptor provides a high level of tolerance to nontargeted species (water, ethanol, acetone, and hexanes). Systems that provide parts-per-billion (by volume) sensitivity to either organoamine or organophosphorus compounds are demonstrated, and their use for imaging of spatial gradients in concentration is reported. This approach does not require complex instrumentation and could provide the basis of wearable personalized sensors for measurement of real-time and cumulative exposure to environmental agents. Copyright 2001 by the AAAS.

Sheble N. Nano mercury monitoring. InTech 2004;51(9):111.
Keywords: Mercury (metal)/ Environmental protection/ Nanostructured materials/ Conductive plastics/ Colloids/ Sensors/ Nanotechnology
Abstract: The US Environmental Protection Agency (EPA) conducted a research project in which novel nanostructured materials were used in ways that might be useful in sensing technologies for the detection, identification and quantitation of metals. The overall objective was to incorporate novel colloidal-metal nanoparticles into a bed of electrically conducting polymers (ECP). The inclusion of the nanoparticles will establish catalytic sites that will facilitate the electrodeposition of the corresponding metal ions of interest. The EPA has been studying the emission of mercury from coal-fired power plants for fourteen years.

Shukla S, Seal S. Room temperature hydrogen gas sensitivity of nanocrystalline pure tin oxide. J Nanosci Nanotechnol 2004;4(1-2):141-5.
URL: http://www.ingentaconnect.com/content/asp/jnn/2004/00000004/F0020001/art00020
Keywords: Nanocrystalline/ Oxygen ion vacancies/ Sensor/ Sol-gel/ Tin oxide
Abstract: Nanocrystalline (6–8 nm) tin oxide (SnO_2) thin film (100–150 nm) sensor is synthesized via sol-gel dip-coating process. The thin film is characterized using focused ion-beam microscopy (FIB) and high-resolution transmission electron microscopy (HRTEM) techniques to determine the film thickness and the nanocrystallite size. The utilization of nanocrystalline pure SnO_2 thin film to sense a typical reducing gas such as hydrogen, at room temperature, is demonstrated in this investigation. The grain growth behavior of nanocrystalline pure SnO_2 is analyzed, which shows very low activation energy (9 kJ/mol) for the grain growth within the nanocrystallite size range of 3–20 nm. This low activation energy value is correlated, via excess oxygen-ion vacancy concentration, with the room temperature hydrogen gas sensitivity of the nanocrystalline pure SnO_2 thin film sensor.

Shukla S, Seal S, Ludwig L, Parish C. Nanocrystalline indium oxide-doped tin oxide thin film as low temperature hydrogen sensor. Sensors and Actuators B: Chemical 2004;97(2-3):256-65.
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THH-49WPP12-8&_user=10&_handle=B-WA-A-W-VU-MsSAYVW-UUW-AAAUCZAVDD-AAUYAVWWDD-EAUBDUUCU-VU-U&_fmt=summary&_coverDate=02%2F01%2F2004&_rdoc=13&_orig=browse&_srch=%23toc%235283%232004%23999029997%23476666!&_cdi=5283&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=3552248a7067a22a786a8d860cfac540
Keywords: Nanocrystalline indium oxide-doped tin oxide/ Pt-sputtered thin film/ Low

temperature hydrogen sensor

Abstract: Hydrogen gas, within the concentration range of 100 ppm–4 vol.%, is successfully sensed at lower operating temperatures, 25 and 50 C, using the Pt-sputtered sol-gel dip-coated nanocrystalline (6–7 nm) 6.5 mol% In_2O_3-doped SnO_2 semiconductor thin (100–150 nm) film sensor. Typically, for 1000 ppm of hydrogen, the maximum sensitivity values of 32 and 1600% are observed at 25 and 50 C, respectively; while for 2 vol.% hydrogen, the maximum sensitivity values of 50 and 70,000% are recorded at 25 and 50 C, respectively. At 25 C, for 4 vol.% (explosive limit as set by NASA) hydrogen, the maximum hydrogen gas sensitivity values of 107,887 and 2083% are observed for the Pt-sputtered thin films calcined at 500 and 600 C, respectively.

Siontorou CG, Nikolelis DP, Krull UJ, Chang K-L. A triazine herbicide minisensor based on surface-stabilized bilayer lipid membranes. Anal Chem 1997;69:3109-14.

Keywords: Herbicides analysis/ Bilayer lipid membranes/ Biosensors

Abstract: This work describes an electrochemical technique that is suitable for rapid and sensitive screening of the triazine herbicides simazine, atrazine, and propazine. Egg phosphatidylcholine and dipalmitoylphosphatidic acid (DPPA) were used for the formation of self-assembled bilayer lipid membranes supported on silver wire (s-BLMs). Evidence that BLMs could form on silver wires was collected by means of ellipsometry which was done to investigate samples consisting of lipids deposited on planar reflective silver films. The interactions of triazines with s-BLMs produced electrochemical ion current increases which reproducibly appeared within ~10 s after exposure of the lipid membranes to the herbicides. The sensitivity of the response was maximized by use of BLMs composed of 35% (w/w) DPPA and by alteration of the phase distribution within membranes by the introduction of 1.0 mM calcium ions in bulk solution. The mechanism of signal generation could be a result of rapid adsorption of the triazine on the surface of s-BLMs with a consequent rapid reorganization of the electrostatics of the membrane. The magnitude of the current signal was linearly related to the herbicide concentration, which could be determined at the nanomolar level. The present triazine minisensor exhibited good mechanical stability and longevity (routinely over 48 h), reproducible response characteristics (i.e., sensitivity and response to a given concentration of triazine in solution), fast response times, and low detection limits. The sensor can be simply and reliably fabricated at low cost. Studies have shown high selectivity for triazines in the presence of insecticides and pesticides. Copyright 1997, American Chemical Society.

Sirkar K, Revzin A, Pishko MV. Glucose and lactate biosensors based on redox polymer/oxidoreductase nanocomposite thin films. Anal Chem 2000;72(13):2930-6.

Keywords: Glucose sensors/ Lactates analysis/ Enzyme electrodes/ Thin films

Abstract: Glucose and lactate enzyme electrodes have been fabricated through the deposition of an anionic self-assembled monolayer and subsequent redox polymer/enzyme electrostatic complexation on gold substrates. These surfaces were functionalized with a negative charge using 11-mercaptoundecanoic acid (MUA), followed by alternating immersions in cationic redox polymer solutions and anionic glucose oxidase (GOX) or lactate oxidase (LAX) solutions to build the nanocomposite structure. The presence of the multilayer structure was verified by ellipsometry and sensor function characterized electrochemically. Reproducible analyte response curves from 2 to 20 mM (GOX) and 2–10 mM (LAX) were generated with the standard deviation between multiple sensors between 12 and 17%, a direct result of the reproducibility of the fabrication technique. In the case of glucose enzyme electrodes, the multilayer structure was further stabilized through the introduction of covalent bonds within and between the layers. Chemical cross-linking was accomplished by exposing the thin film to glutaraldehyde vapors, inducing linkage formation between lysine and arginine residues present on the enzyme periphery with amine groups present on a novel redox polymer, poly[vinyl-pyridine Os(bisbipyridine)$_2$Cl]-co-allylamine. Finally, an initial demonstration of thin-film patterning was performed as a precursor to the development of redundant sensor arrays. Microcontact printing was used to functionalize portions of a gold surface with a blocking agent, typically 1-hexadecanethiol. This was followed by immersion in MUA to functionalize the remaining portions of gold with negative charges. The multilayer deposition process was then followed, resulting in growth only on the regions containing MUA, resulting in a "positive"-type pattern. This technique may be used for fabrication of thin-film redundant sensor arrays, with thickness under 100 angstroms and lateral dimensions on a micrometer scale.

Sohn LL. On the road toward electronic biosensors. Proc 1999 IEEE Engineering in Medicine and Biology 21st Ann Conf and the 1999 Fall Meeting of the Biomedical Engineering Soc (1st Joint BMES / EMBS). Atlanta, GA, USA. Piscataway, NJ, USA: Institute of Electrical and Electronics Engineers Inc., 1999: 1338.
Keywords: Nanotechnology/ DNA/ Proteins/ Electron beam lithography/ Silicon/ Platinum/ Microelectrodes/ Capacitance measurement/ Biosensors
Abstract: Recent advances in nanofabrication technology have allowed for access to length scales in the sub-20 nm regime. Since such length scales are compatible with many biological systems, including DNA and proteins, it is now possible to consider the integration of nanofabrication technology with molecular biology. Using electron-beam lithography and advanced resist technology, we have fabricated electronic sensors on silicon that can detect and manipulate single biomolecules, i.e. DNA and proteins. Specifically, our sensors consist of arrays of platinum nano-electrodes which form channels, 10 nm wide and several microns long. When individually voltage-biased, the nano-electrodes can manipulate single molecules of DNA within a confined geometry. Via capacitance measurements, the nano-electrodes can detect the presence of single molecules and ascertain their length by time-of-flight measurements. The electronic sensors we have fabricated are first-generation. That they can already detect and manipulate single biomolecules—all on silicon—suggest that future devices will be truly hybrid in nature, serving many functions on both the molecular biology and electronic level.

Steele JJ, Brett MJ. Humidity sensors fabricated using nanostructured materials. NanoForum Canada. Edmonton, AB, Canada. 2004.
URL: http://www.physics.mcgill.ca/NanoForum/abs/abs-jjsteele-ece.ualberta.ca.html
Abstract: Porous nanostructured thin films fabricated with an advanced deposition technique known as glancing angle deposition (GLAD) have been used to construct very high-speed capacitive-based humidity sensors. GLAD is a recently developed advanced nano-materials fabrication technique where highly oblique deposition and controlled substrate motion result in high surface area, high porosity films, with nanostructures that can be engineered for various applications. Helices, vertical posts, chevrons and square spirals are examples of the

nanostructures that can fabricated with GLAD. Vertical post oxide films with post diameters on the order of a few hundred nanometers were deposited onto a gold interdigitated electrode structure. Changes in the capacitance as a result of water vapour adsorption and desorption are monitored and correlated to the ambient humidity. Desorption response time measurements were obtained by placing the sensors in a humid (>90% relative humidity) chamber and exposing them to a discharge of dry nitrogen. Desorption response times of 40 milliseconds have been achieved and are reported. This is far superior to commercial high-speed humidity sensors with typical response times on the order of seconds. Several applications would benefit from sub-second response times including pulmonary diagnostics and industrial process control. The fast response times of the sensors can be attributed to the morphology of the GLAD films. The porous, accessible high surface area structure facilitates rapid vapour adsorption and desorption. Thus, these nanostructured films hold promise as rapid response sensors for a variety of gases and vapours.

Stetter JR, Bradley K, Cumings J, Gabriel J-C, Gruner G, Star A. Nano-electronic sensors: Practical device designs for sensors. 2003 Nanotechnology Conference and Trade Show - Nanotech 2003. 2003 Nanotechnology Conference and Trade Show - Nanotech 2003; San Francisco, CA, USA. Computational Publications, Cambridge, MA 02139, United States, 2003: 313-6.
Keywords: Nanotechnology/ Carbon nanotubes/ Field effect transistors/ CMOS integrated circuits/ Hydrogen/ Ammonia/ Chemical vapor deposition/ Atomic force microscopy/ Chemical sensors
Abstract: There is often a large gap between laboratory science and practical products. It will take some years to fathom the overall technical importance of nano-technology and even longer to realize societal benefits through practical products. However, Nanomix has identified a specific nanotechnology, using carbon nanotubes to make devices that can make immediate impacts on the commercial product scene. The initial devices from Nanomix will be several sensor products useful in detection of chemicals in safety, human health, and process applications. The unique electronic characteristics of carbon nanotubes can now be harnessed to provide a platform for the design, fabrication, and commercialization of nano-chemical sensors.

Stich N, Gandhum A, Matyushin V, Raats J, Mayer C, Alguel Y, et al. Phage display antibody-based proteomic device using resonance-enhanced detection. J Nanosci Nanotechnol 2002;2(3):1-7.
URL: http://www.xs4all.nl/~jori/pdf/stich.pdf
Abstract: The combination of phage display antibody arrays with a novel nanotransducer technique based on resonant nanoparticles in a nanosandwiched film enables the sensitive parallel screening of proteins. Using the resonance of nanoparticles with their induced mirror dipoles in a thin-film structure, limitations of fluorophores, such as unspecific background and nonvisibility to the eye, can be overcome, thereby leading to an optical signal significantly more sensitive than that of standard colloid techniques. The signal can be both directly observed as a color change of a microdot at the sensor surface and tuned throughout the visible range of the spectrum. Here we report the application of an optical chip using scFv-antibody-antigen interactions. Artificial scFv antibodies against a variety of proteins, including yeast enzymes and bovine serum albumin (as a standard), were constructed via Phage Display. These scFv-antibodies were then coated onto metal nanoclusters and bound to their antigens that were arrayed as nanodroplets at the resonance layer of the chip. ScFv antibody-antigen

interaction resulted in a visible array of microdots. Using resonance-enhanced absorption, the absorption signal of the spots was amplified by one to two orders of magnitude (compared to colloid-based techniques). For quantitative analysis, either an 8 micron scanner or a CCD camera (resolution 4 microns) was employed to gain direct-reflection spectra rather than unspecific scatter data (prone to dust and unspecific interaction). Our results demonstrate that this device enables high-throughput proteomics to overcome some limitations of fluorescence, enzyme labels, and colloid techniques.

Storm AJ, Chen JH, Ling XS, Zandbergen HW, Dekker C. Fabrication of solid-state nanopores with single-nanometre precision. Nature Materials 2003;2(8):537-40.
URL: http://www.nature.com/nmat/journal/v2/n8/pdf/nmat941.pdf
Keywords: Porosity/ Nanotechnology/ Sensors/ Biological materials/ Proteins/ Thermooxidation/ Etching/ Surface tension/ Molecular dynamics/ Deformation/ Electron energy loss spectroscopy/ Transmission electron microscopy/ Nanostructured materials
Abstract: Single nanometre-sized pores (nanopores) embedded in an insulating membrane are an exciting new class of nanosensors for rapid electrical detection and characterization of biomolecules. Notable examples include α-hemolysin protein nanopores in lipid membranes and solid-state nanopores in Si_3N_4. Here we report a new technique for fabricating silicon oxide nanopores with single-nanometre precision and direct visual feedback, using state-of-the-art silicon technology and transmission electron microscopy. First, a pore of 20 nm is opened in a silicon membrane by using electron-beam lithography and anisotropic etching. After thermal oxidation, the pore can be reduced to a single nanometre when it is exposed to a high-energy electron beam. This fluidizes the silicon oxide leading to a shrinking of the small hole due to surface tension. When the electron beam is switched off, the material quenches and retains its shape. This technique dramatically increases the level of control in the fabrication of a wide range of nanodevices.

Stranik O, McEvoy HM, McDonagh C, MacCraith BD. Plasmonic enhancement of fluorescence for sensor applications. Sensors and Actuators B: Chemical [In press, corrected proof].
URL: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THH-4DVBVFV-3&_user=10&_handle=B-WA-A-W-VVY-MsSAYVW-UUW-AAAUZBZEYZ-AAUYWADDYZ-EAWCWZBWW-VVY-U&_fmt=summary&_coverDate=11%2F21%2F2004&_rdoc=269&_orig=browse&_srch=%23toc%235283%239999%2399999999999%2399999!&_cdi=5283&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=8b979fbe0df0520ed44cf09edc6601f9
Keywords: Metallic nanoislands/ Surface plasmon resonance/ Plasmonics/ Enhanced fluorescence/ Biosensors/ Near-field optics
Abstract: In this work we report on the so-called plasmonic enhancement effect, whereby the presence of metallic surfaces or particles in the vicinity of a fluorophore can dramatically alter the fluorescence emission and absorption properties of a fluorophore. The effect, which is associated with the surface plasmon resonance of the metallic surface, depends on parameters such as metal type, particle size, fluorophore type, and fluorophore-particle separation. This work focuses on the creation of metal nanoparticle arrays by a lithographic process and on optimisation strategies to maximise the fluorescence enhancement of dyes in the vicinity of the nanoparticles, for important applications such as fluorescence-based biochip platforms.Ordered arrays of metallic nano-islands were fabricated on glass substrates by a process of natural

lithography using monodisperse polystyrene nanospheres. The metal particle dimensions were tailored in order to tune the plasmon resonance wavelength to match the spectral absorption of the fluorophore. The fluorophore, Cy5 dye, which is widely used in optical immunoassays and has a medium quantum efficiency (~0.3), was used in this preliminary study of the plasmonic enhancement effect.The morphology of the metallic arrays was investigated using scanning electron microscopy (SEM) and atomic force microscopy (AFM). Absorption and emission spectroscopies were used to elucidate the enhancement effect and its dependence on metal island morphology. Results were correlated with existing theoretical models. The applicability of this important technique to sensor platforms, such as fluorescence-based biochips, is also discussed.

Su M, Li S, Dravid VP. Miniaturized chemical multiplexed sensor array. J Am Chem Soc 2003;125:9930-1.
URL: http://vpd.ms.northwestern.edu/Publications_files/Ming/JACS_125_33_9930_2003.pdf
Keywords: Multiplexing/ Nanolithography/ NO_2/ Volatile organic compounds
Abstract: An efficient technique for constructing miniaturized semiconductor chemical sensors is described. The technique takes advantage of the capabilities of dip-pen nanolithography in site-specific and multiple ink patterning and the versatility of sol-gel synthesis for preparing appropriate sol inks. The technique allows the construction of fast-response and rapid-recovery sensors and a combinatorial array in the search for useful sensor materials. It also represents a step toward an on-chip electronic sensor array that can discriminate between different gaseous species with collective reference responses from all the sensor elements.

Suehiro J, Zhou G, Hara M. Fabrication of a carbon nanotube-based gas sensor using dielectrophoresis and its application for ammonia detection by impedance spectroscopy. J Phys D: Appl Phys 2003;36:L109-L114.
Keywords: Gas detectors design/ Multiwalled carbon nanotubes/ Ammonia/ Dielectrophoresis
Abstract: This paper describes a new method for fabricating a gas sensor composed of multi-wall carbon nanotubes (MWCNTs) using dielectrophoresis (DEP). MWCNTs dispersed in ethanol were trapped and enriched in an interdigitated microelectrode gap under the action of a positive DEP force that drove the MWCNTs to a higher electric field region. During the trapping of MWCNTs, the electrode impedance varied as the number of MWCNTs bridging the electrode gap increased. After the DEP process, the ethanol was evaporated and the microelectrode retaining the MWCNTs was exposed to ammonia (NH3) gas while the electrode impedance was monitored. It was found that the electrode impedance was altered by ppm-levels of ammonia at room temperature. The ammonia exposure decreased the sensor conductance, while the capacitance increased. The sensor showed a reversible response with a time constant of a few minutes. The conductance change was proportional to ammonia concentration below 10 ppm and then gradually saturated at higher concentrations. Effects of the number of trapped MWCNTs on sensor response were also discussed.

Suo H, Wu F, Quan B, Liu G, Xu B, Zhao M. Study on ethanol sensitivity of nanocrystalline $La_{0.7}Sr_{0.3}FeO_3$-based gas sensor. Gongneng Cailiao/J Functional Mater 1998;29(3):274-5.
Keywords: Sensitivity analysis/ Chemical sensors/ Crystalline materials/ Nanotechnology/ Ethanol/ Stability/ Nanostructured materials

Abstract: $La_{0.7}Sr_{0.3}FeO_3$ nanocrystalline materials have been synthesized by using a citrate method. Its grain size is about 10 nm. By measuring the sensitive property of the sensor, it is found that the sensor has good stability, excellent selectivity, short response and recovery times.

Tan W, Shi Z-Y, Kopelman R. Miniaturized fiber-optic chemical sensors with fluorescent dye-doped polymers. Sensors and Actuators B: Chemical 1995;B28(2):157-63.
Keywords: Fiber optic sensors/ Miniature instruments/ Nanotechnology/ Dyes/ Doping (additives)/ Polymers/ Polymerization/ Photochemical reactions/ Chemical sensors
Abstract: Miniaturization of optical-fiber chemical sensors has been achieved by near-field optics and photochemical synthesis. We have generalized this novel nanofabrication technique by using polymers doped with fluorescent dye or fluorescent dextran through photopolymerization. These doped polymers have been successfully used in chemical-sensor fabrication. The new methodologies make it possible to miniaturize further optical-fiber sensors with multiple chemical sensitivities by a multiple-step nanofabrication process.

Tipple CA, Lavrik NV, Culha M. Nanostructured microcantilevers with functionalized cyclodextrin receptor phases: Self-assembled monolayers and vapor-deposited films. Anal Chem 2002;74:3118-26.
URL: http://www.mnl.ornl.gov/Publications/Tipple-2002.pdf
Keywords: Nanostructured materials/ Microcantilevers/ Cyclodextrins analysis/ Molecular self-assembly
Abstract: It is shown that the performance of microcantilver-based chemical sensors in a liquid environment is affected by altering cantilever surface morphology and receptor phase type and thickness. Self-assembled monolayers of thiolated β-cyclodextrin (HM-β-CD) and thin films of vapor-deposited heptakis(2,3-O-diacetyl-6-O-tertbutyl-dimethylsilyl)-β-cyclodextrin (HDATB-β-CD) were studied on smooth and nanostructured (dealloyed) gold-coated microcantilever surfaces. The dealloyed surface contains nanometer-sized features that enhance the transduction of molecular recognition events into cantilever response, as well as increase film stability for thicker films. Improvements in the limits of detection of the compound 2,3-dihydroxynaphthalene as great as 2 orders of magnitude have been achieved by manipulating surface morphology and film thickness. The observed response factors for the analytes studied varied from 0.02–604 nm/ppm, as determined by cantilever deflection. In general, calibration plots for the analytes were linear up to several hundred nanometers in cantilever deflections.

Trau, Yang WJ, Seydack M, Caruso F, Yu NT, Renneberg R. Nanoencapsulated microcrystalline particles for superamplified biochemical assays. Anal Chem 2002;74(21):5480-6.
URL: http://www.bioeng.nus.edu.sg/people/trau/Papers/Trau%20et%20al_Crystal%20Label_AnalChem_74_21_5480_2002.pdf
Abstract: We report on the preparation and utilization of a novel class of particulate labels based on nanoencapsulated organic microcrystals with the potential to create highly amplified biochemical assays. Labels were constructed by encapsulating microcrystalline fluorescein diacetate (FDA; average size of 500 nm) within ultrathin polyelectrolyte layers of poly(allylamine hydrochloride) and poly(sodium 4-styrenesulfonate) via the layer-by-layer technique. Subsequently, the polyelectrolyte coating was used as an "interface" for the

attachment of anti-mouse antibodies through adsorption. A high molar ratio of fluorescent molecules present in the microcrystal core to biomolecules on the particle surface was achieved. The applicability of the microcrystal-based label system was demonstrated in a model sandwich immunoassay for mouse immunoglobulin G detection. Following the immunoreaction, the FDA core was dissolved by exposure to organic solvent, leading to the release of the FDA molecules into the surrounding medium. Amplification rates of 70–2000-fold (expressed as an increase in assay sensitivity) of the microcrystal label-based assay compared with the corresponding immunoassay performed with direct fluorescently labeled antibodies are reported. Our approach provides a general and facile means to prepare a novel class of biochemical assay labeling systems. The technology has the potential to compete with enzyme-based labels as it does not require long incubation times, thus speeding up bioaffinity tests.

Valentini L, Armentano I, Kenny JM, et al. Sensors for sub-ppm NO_2 gas detection based on carbon nanotube thin films. Appl Phys Lett 2003;82(6):961-3.
Keywords: Carbon nanotubes/ Gas detectors/ Nitrogen dioxide
Abstract: Carbon nanotubes (CNTs) deposited by plasma-enhanced chemical vapor deposition on Si_3N_4/Si substrates have been investigated as resistive gas sensors for NO_2. Upon exposure to NO_2, the electrical resistance of the CNTs was found to decrease. The maximum variation of resistance to NO_2 was found at an operating temperature of around 165 C. The sensor exhibited high sensitivity to NO_2 gas at concentrations as low as 10 ppb, fast response time, and good selectivity. A thermal treatment method, based on repeated heating and cooling of the films, adjusted the resistance of the sensor film and optimized the sensor response to NO_2.

Varghese OK, Gong D, Paulose M, et al. Highly ordered nanoporous alumina films: Effect of pore size and uniformity on sensing performance. J Mater Res 2002;17(5):1162-71.
Keywords: Cellular aluminum, testing/ Moisture detectors, testing
Abstract: The authors examine the effect of pore size and uniformity on the sensing performance of highly ordered nanoporous alumina films. The response of the material to humidity is a function of pore size and operating frequency. At 5 kHz, an alumina sensor with an average pore size of 13.6 nm is found to exhibit a well-behaved change in impedance magnitude of 103 over 20 to 90 percent relative humidity. The humidity range over which the sensors have high sensitivity decreases with increasing pore size.
Published abstract: The effect of pore size and uniformity on the humidity response of nanoporous alumina, formed on aluminum thick films through an anodization process, is reported. Pore sizes examined range from approximately 13 to 45 nm, with a pore size standard deviations ranging from 2.6 to 7.8 nm. The response of the material to humidity is a strong function of pore size and operating frequency. At 5 kHz an alumina sensor with an average pore size of 13.6 nm (standard deviation 2.6 nm) exhibits a well-behaved change in impedance magnitude of 10^3 over 20% to 90% relative humidity. Increasing pore size decreases the humidity range over which the sensors have high sensitivity and shifts the operating range to higher humidity values. Cole–Cole plots of 5 to 13 MHz measured impedance spectra, modeled using equivalent circuits, are used to resolve the effects of water adsorption and ion migration within the adsorbed water layer. The presence of impurity ions within the highly ordered nano-dimensional pores, accumulated during the anodization

process, appear highly beneficial for obtaining a substantial variation in measured impedance over a wide range of humidity values.

Varghese OK, Grimes CA. Metal oxide nanoarchitectures for environmental sensing. J Nanosci Nanotechnol 2003;3(4):277-93.
URL: http://www.ee.psu.edu/grimes/publications/JNN.OKV.CAGrimes.pdf.pdf
Keywords: Nanotubes/ Nanowires/ Metal oxide/ Gas sensing/ Hydrogen/ Humidity/ Sensor
Abstract: Metal oxide materials are widely used for gas sensing. Capable of operating at elevated temperatures and in harsh environments, they are mechanically robust and relatively inexpensive and offer exquisite sensing capabilities, the performance of which is dependent upon the nanoscale morphology. In this paper we first review different routes for the fabrication of metal oxide nanoarchitectures useful to sensing applications, including mesoporous thin films, nanowires, and nanotubes. Two sensor test cases are then presented. The first case examines the use of highly uniform nanoporous Al_2O_3 for humidity sensing; we find that such materials can be successfully used as a wide-range humidity sensor. The second test case examines the use of TiO_2 nanotubes for hydrogen sensing. Going from a nitrogen atmosphere to one containing 1000 ppm of hydrogen, at 290 C, 22 nm diameter titania nanotubes demonstrate a 10^4 change in measured resistance with no measurement hysteresis. [Review; 144 Refs; In English]

Villar ID, Matias IR, Arregui FJ. Nanosensor for detection of glucose. Second European Workshop on Optical Fibre Sensors, EWOFS'04. Proceedings of SPIE - The International Society for Optical Engineering; Santander, Spain. International Society for Optical Engineering, Bellingham, WA 98227-0010, USA, 2004: 259-62.
Keywords: Glucose/ Self assembly/ Negative ions/ pH effects/ Drug products/ Oxidation/ Spectroscopy/ Multiplexing/ Monolayers/ Polymerization/ Nanotechnology/ Glucose sensors
Abstract: A novel fibre-optic sensor sensitive to glucose has been designed based on electrostatic self-assembly method. The polycation of the structure is a mixture of poly(allylamine hydrochloride) (PAH) and Prussian Blue, whereas the polyanion is well-known enzyme glucose oxidase (GOx). The range of glucose concentration that can be measured is submilimolar and is located between 0.1 and 2 mM. Measures are based on a new detection scheme based on the slope of the change of signal produced by injection of glucose, yielding to a linear response. The sensor response is in a pH range between 4 and 7.4, which includes the physiological pH of blood. Some rules for estimation of the refractive index of the material deposited and the thickness of bilayers are also given.

Wade LA, Shapiro I, Ma Z, Quake SR, Collier CP. Single-molecule fluorescence and force microscopy employing carbon nanotubes. 2003 Nanotechnology Conference and Trade Show - Nanotech 2003. 2003 Nanotechnology Conference and Trade Show - Nanotech 2003; San Francisco, CA, USA. Computational Publications, Cambridge, MA 02139, United States, 2003 : 317-20.
Keywords: Atomic force microscopy/ Fluorescence/ Sensors/ Microscopes/ Nanotechnology/ DNA/ Semiconductor quantum dots/ Scanning electron microscopy/ Carbon nanotubes
Abstract: We are developing generalized high-throughput techniques for the growth and attachment of single-wall nanotubes (SWNTs) as robust and well-characterized tools for AFM imaging, to serve as the foundation of an effort to develop single-molecule sensors on nanotube AFM tips for a hybrid atomic force microscope that also has single-molecule

fluorescence imaging capability. We have been most successful in attaching SWNTs to AFM tips by growing individual SWNTs on flat surfaces, and using the silicon probe tip to pick up vertically oriented tubes during imaging of these substrates in tapping mode. Once a nanotube has been picked up and shortened, the probe can be transferred to a sample for high-resolution imaging, biomolecular manipulations or force spectroscopy. SWNT AFM images can be used to determine the equivalent resolution to be typically less than or equal 4 nm for 3 nm diameter SWNTs (noise floor width - tube diameter). This is a factor of two better than is normally achieved with the best conventional silicon tips.

Walter EC, Favier F, Penner RM. Palladium mesowire arrays for fast hydrogen sensors and hydrogen-actuated switches. Anal Chem 2002;74(7):1546-53.
Keywords: Nanowires/ Hydrogen sensors/ Palladium, electrotechnical uses
Abstract: Arrays of mesoscopic palladium wires prepared by electrodeposition form the basis for hydrogen sensors and hydrogen-actuated switches that exhibit a response time ranging from 20 ms to 5 s, depending on the hydrogen concentration. These devices were constructed by electrodepositing palladium mesowires on a highly oriented pyrolytic graphite surface and then transferring these mesowires to a cyanoacrylate film supported on a glass slide. The application of silver contacts to the ends of 10–100 mesowires, arrayed electrically in parallel, produced sensors and switches that exhibited a high conductivity state in the presence of hydrogen and a low conductivity state in the absence of hydrogen. After an initial exposure to hydrogen, 15–50 nanoscopic gaps are formed in each mesowire. These nanoscopic gaps or "break junctions" close in the presence of hydrogen gas and reopen in its absence as hydrogen is reversibly occluded by the palladium grains in each wire, and the palladium lattice expands and contracts by several percent. The change in resistance for sensors and switches was related to the hydrogen concentration over a range from 1 to 10%.

Wan Q, Li QH, Chen YJ, et al. Fabrication and ethanol sensing characteristics of ZnO nanowire gas sensors. Appl Phys Lett 2004;84(18):3654-6.
Keywords: Gas detectors, manufacture/ Mechatronics/ Alcohols
Abstract: The authors fabricated ZnO nanowire gas sensors using microelectromechanical system technology and investigated their ethanol-sensing characteristics. The sensors displayed high sensitivity and fast response to ethanol gas at a working temperature of 300 C. The potential application of ZnO nanowires for fabricating highly sensitive gas sensors is thereby demonstrated.

Wang J, Wan H, Lin Q. Properties of a nanocrystalline barium titanate on silicon humidity sensor. Meas Sci Technol 2003;14:172-5.
Keywords: Barium titanate films/ Nanostructured materials/ Moisture detectors, testing
Abstract: A nanometric barium titanate film is fabricated on a silicon substrate by the spin-coating technique to make a resistive-type humidity sensor. The humidity sensing properties of the sensor were measured, including sensitivity, hysteresis, and response. The level of the applied voltage did not change the sensing properties of the sensor. The best linearity of the curve of impedance versus relative humidity (RH) manifests at the frequency of 100 Hz. The capacitance of the sensor increases as RH increases, particularly for low measurement frequency. The highs of the dielectric loss of the humidity sensor move in the higher frequency direction as RH increases.

Wang SX, White RL, G.-X. Li, Joshi V, Sun S, Robinson DB, et al. Design and fabrication of biomagnetic sensors and magnetic nanobead labels for DNA detection and identification. Intermag 2003: Int Magnetics Conf. Digests of the Intermag Conference; Boston, MA, USA. Institute of Electrical and Electronics Engineers Inc., 2003: 01.

Keywords: Magnetooptical devices/ Nanotechnology/ Arrays/ DNA/ Photolithography/ Electron beam lithography/ Sensors

Abstract: The fabrication and design of biomagnetic sensors and magnetic nanobead labels were studied for DNA detection and identification. The basic methodology of biomagnetic sensing system and the challenges in developing a magnetic DNA microarray were reported. The durability of the spin valve sensors in the DNA hybridization solutions was also studied.

Wei Q, Luo WD, Liao B. Giant capacitance effect and physical model of nanocrystalline CuO-$BaTiO_3$ semiconductor as a CO_2 gas sensor. J Appl Phys 2000;88(8):4818-24.

Keywords: Capacitive sensors/ Nanostructured materials, electric properties/ Carbon dioxide detectors

Abstract: The authors designed a carbon dioxide sensor made of nanocrystalline CuO-$BaTiO_3$ semiconductor based on the principle of the physical effect in the nanocluster. The sensor has a giant capacitance effect. A correlation was found between the quantum size effect and giant capacitance effect. A gas detector was used to study the characteristic physical quantities relating to the giant capacitance effect of the sensor. A model is proposed for describing the giant capacitance effect of the sensor.

Wohltjen H, Snow AW. Colloidal metal-insulator-metal ensemble chemiresistor sensor. Anal Chem 1998;70(14):2856-9.

Keywords: Electrochemical analysis/ Thin films/ Gold clusters

Abstract: A colloidal metal-insulator-metal ensemble chemiresistor sensor based on a monolayer stabilized metal nano-cluster transducer film is described. In the example presented, the thin transducer film is composed of 2 nm gold clusters encapsulated by octanethiol monolayers and is deposited on an interdigital microelectrode. Responses to organic vapor exposures are large (resistance changes up to 2-fold or more), fast (90% response in less than 1 s), reversible, and selective. Chemiresistor sorption isotherms for toluene, tetrachloroethylene, 1-propanol, and water vapors are nonlinear and illustrate the high sensitivity and selectivity (ppm detection for toluene and tetrachloroethylene; negligible response for 1-propanol and water). Copyright 1998, American Chemical Society.

Wu AT, Seto M, Brett MJ. Capacitive SiO humidity sensors with novel microstructures. Sensors and Materials 1999;11:493-505.

Xu H, Aylott JW, Kopelman R, et al. A real-time ratiometric method for the determination of molecular oxygen inside living cells using sol-gel-based spherical optical nanosensors with applications to rat C6 glioma. Anal Chem 2001;73(17):4124-33.

Keywords: Oxygen in the body/ Fiber optic sensors/ Fluorescence

Abstract: The first sol-gel-based, ratiometric, optical nanosensors, or sol-gel probes encapsulated by biologically localized embedding (PEBBLEs), are made and demonstrated here to enable reliable, real-time measurements of subcellular molecular oxygen. Sensors were made using a modified Stober method, with poly(ethylene glycol) as a steric stabilizer. The radii of these spherical PEBBLE sensors range from about 50 to 300 nm. These sensors incorporate an oxygen-sensitive fluorescent indicator, Ru(II)-tris(4,7-diphenyl-1,10-phenanthroline) chloride ($[Ru\text{-}(dpp)_3]^{2+}$), and an oxygen-insensitive fluorescent dye, Oregon Green 488-dextran, as a reference for the purpose of ratiometric intensity measurements. The PEBBLE sensors have excellent reversibility, dynamic range, and stability to leaching and photobleaching. The small size and inert matrix of these sensors allow them to be inserted into living cells with minimal physical and chemical perturbations to their biological functions. Applications of sol-gel PEBBLEs inserted in rat C6 glioma cells for real-time intracellular oxygen analysis are demonstrated. Compared to using free dyes for intracellular measurements, the PEBBLE matrix protects the fluorescent dyes from interference by proteins in cells, enabling reliable in vivo chemical analysis. Conversely, the matrix also significantly reduces the toxicity of the indicator and reference dyes to the cells, so that a wide variety of dyes can be used in optimal fashion.

Zhang D, Li C, Liu X, et al. Doping dependent NH_3 sensing of indium oxide nanowires. Appl Phys Lett 2003;83(9):1845-7.
Keywords: Indium oxides/ Nanowires/ Ammonia
Abstract: The authors investigate the NH_3 gas sensing properties of In_2O_3 nanowires. Different nanowire structures exhibit a change of conductance in opposite directions. This differential response is thought to be due to different doping concentrations in the semiconducting In_2O_3 nanowires. A gate-screening effect is also observed in the sensors at high NH_3 concentrations, which is induced by adsorbed NH_3 molecules acting as charge traps.

Zhang H-R, Zhang H, Yang Q, Zhang N-S, Yang D-R. Investigations of room temperature nanoporous alumina humidity sensor. Zhejiang Daxue Xuebao (Gongxue Ban)/Journal of Zhejiang University (Engineering Science) 2004;38(4):420-4.
Keywords: Nanotechnology/ Alumina/ Porous materials/ Etching/ Capacitance measurement/ Electric impedance measurement/ Equivalent circuits/ Electrons/ Ions/ Sensors
Abstract: A humidity sensor based on porous alumina was investigated. The porous alumina was fabricated using electronic chemical etching. An LCR instrument was used to measure the capacitance and impedance characteristics related with relative humidity (RH). The results indicated that the capacitance and impedance characteristics had excellent linearity. The complex impedance characteristic was analyzed by means of an equivalent circuit model. It is concluded that the sensor is equivalent to an R/C parallel circuit and conducts mainly through electrons at low RH, while two R/C parallel circuits in series and conducts through ions at high RH.

Zheng H, Luo H, Zhang T, Zhang R. Study on the synthesis of highly stable $\gamma\text{-}Fe_2O_3$ and on its gas sensing characteristics. Gongneng Cailiao/J Functional Mater 1995;26(4):305-8.
Keywords: Nanostructured materials/ Nanotechnology/ Doping (additives)/ Sensors
Abstract: The $\gamma\text{-}Fe_2O_3$ crystallites of nanometer size were synthesized here through using the air oxidation in the $Fe(CO_3)_X(OH)_{Z(1-X)}$ suspension liquid system by both controlling the pH value and adding proper amount of Y element into the reaction system. The analysis from DTA-TG and XRD shows that the $\gamma\text{-}Fe_2O_3$ obtained from the process of dehydration of gamma-FeOOH has good thermal stability, and its γ–α phase transfer temperature can reach as high as 725 C. Its high gas-sensitivity and gas-selectivity are due to its particle size which are

of nanometer grade. The gas sensitivity of element sintered at 600 C is greater than 70 for liquefied petroleum gas (LPG), and the sintered element at 700 C has its gas sensitivity greater than 40 for C_2H_2. Besides, their selectivity for measured gases such as CO, H_2, petrol, C_2H_2, LPG are also good.

Zhou Y, Yu B, Shiu E. Potentiometric sensing of chemical warfare agents: Surface imprinted polymer integrated with an indium tin oxide electrode. Anal Chem 2004;76(10):2689-93.
Keywords: Indium tin oxide films/ Chemical weapons detection
Abstract: Rapid and specific recognition of methylphosphonic acid (MPA), the degradation product of nerve agents sarin, soman, VX, etc., was achieved with potentiometric measurements using a chemical sensor fabricated by a surface imprinting technique coupled with a nanoscale transducer, indium tin oxide (ITO). An octadecylsiloxane thin layer was covalently bound to the ITO-coated glass surface in the presence of MPA. After extraction of MPA, potentiometric measurements showed selective detection of MPA. The selectivity of the sensor has been tested on other alkylphosphonic acids, such as ethylphosphonic acid and propylphosphonic acid, as well as *tert*-butylphosphonic acid. The viability of the sensor in the presence of other chemical analogues, such as organophosphorus pesticides and herbicides, was investigated.

Zhu Y, Shi J, Zhang Z. Development of a gas sensor utilizing chemiluminescence on nanosized titanium dioxide. Anal Chem 2002;74(1):120-4.
Keywords: Titanium oxide powders/ Chemiluminescence / Gas detectors
Abstract: A gas-sensing mode based on chemiluminescence generated on the surface of nanosized materials is proposed in the present work. Seven nanosized materials were tested, and chemiluminescence was detected from six of them during the catalytic oxidation of organic vapors in air. The luminescence characteristics of ethanol and acetone vapors passing through the surface of TiO_2 chosen were studied with a chemiluminescence-based detection system. The linear range of chemiluminescence intensity versus concentration of organic compounds is 40–400 mg/mL for ethanol and 20–200 mg/mL for acetone dissolved in water, respectively. X-ray powder diffraction and Raman spectrometry were used to investigate the changes in catalytic activity of TiO_2 after a 60 h reaction at 380 C. The results showed that the carbon deposited on the surface of TiO_2, decreasing the catalytic activity, but can be removed in air by controlling the temperature at 500 C for 3 h. Regenerability and no consumption of sensor substrate signify the long lifetime of the gas sensor.

Appendix D. Selected Web Links

[In the Microsoft Word file, the URL references in this section are linked to the actual websites. For users of recent versions of Microsoft Word, simultaneously press the "Ctrl" key and click on the desired web address below to access the website directly.]

Nanotechnology and the Environment: Reviews, News and Workshops

Encyclopedia of Nanoscience and Nanotechnology (10 volumes), 2004. Published by the Journal of Nanoscience and Nanotechnology: www.aspbs.com/enn

Kamat PV, Meisel D. Nanoscience opportunities in environmental remediation. Comptes Rendus Chimie 2003;6(8-10):999-1007. [Review]. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6X18-4B0BX5J-10&_coverDate=08%2F31%2F2003&_alid=197903285&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=7236&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=f0ed78f85f40fb20d9e3820c87cd9aa9

Masciangioli T, Zhang WX. Environmental technologies at the nanoscale. [Review] Environmental Science and Technology 2003;37(5):102A-8A. www.nano.gov/html/res/GC_ENV_PaperZhang_03-0304.pdf

Rodriguez-Mozaz S, Lopez de Alda MJ, Marco M-P, Barcelo D. Biosensors for environmental monitoring: A global perspective. Talanta 2005;65(2):291-7. [Review]. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THP-4D20070-9&_user=10&_handle=B-WA-A-W-VD-MsSAYWA-UUW-AAAUVBVBEZ-AAUYUACAEZ-EUZVZCVEB-VD-U&_fmt=summary&_coverDate=01%2F30%2F2005&_rdoc=1&_orig=browse&_srch=%23toc%235288%232005%23999349997%23528350!&_cdi=5288&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=0fbd1cbb2553cbe61352134f5534bfa3

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Small Times Environmental Newsgroup [Updates on the latest in environmental nanotechnology]. www.smalltimes.com/section_display.cfm?section_id=21

The Canadian Nanobusiness Alliance [News and resources]. www.nanobusiness.ca

Nanotechnology: Reviews

The Royal Society, The Royal Academy of Engineering. Nanoscience and Nanotechnologies: Opportunities and Uncertainties. www.nanotec.org.uk/finalReport.htm
ETC Group. The Big Down: Atomtech - Technologies Converging at the Nano-scale. www.etcgroup.org/documents/TheBigDown.pdf
ETC Group. The Little Big Down: A Small Introduction to Nano-scale Technologies. www.etcgroup.org/documents/littlebigdown.pdf

Nanotechnology: News, Information and Lists of Web Links

National Institute for Nanotechnology (Canada): www.nint.ca
The Canadian Nanobusiness Alliance (Canada): www.nanobusiness.ca
National Nanotechnology Initiative (USA): www.nano.gov
Nano Science and Technology Institute (USA): www.nsti.org
NanoBusiness Alliance (USA): www.nanobusiness.org
Small Times (USA): www.smalltimes.com
The Institute of Nanotechnology (UK): www.nano.org.uk
Asia Pacific Nanotechnology Forum: www.apnf.org
International Frequency Sensor Association nanosensors page: www.sensorsportal.com/HTML/SENSORS/Nanosensors.htm
USA list of nanotechnology web links: www.nano.gov/html/res/links.html
UK list of nanotechnology web links: www.nanotec.org.uk/Weblinks.htm

Nanotechnology: Products, Vendors and Human Resources

Small Times Directory. This is a large business directory from Small Times Media, "the first media company devoted entirely to MEMS [microelectromechanical systems], microsystems, and nanotechnologies." www.SmallTechDirectory.com

Unofficial EPA List of Nanotechnology Products. This document, generated by the Environmental Protection Agency (USA), is an unofficial list of products based on nanotechnologies. It was distributed at a May 18, 2004 dialogue on nanotechnology at the Woodrow Wilson International Center for Scholars in Washington, DC. www.etcgroup.org/documents/nanoproducts_EPA.pdf

Micralyne Inc. This is a MEMS manufacturing company located in Edmonton, AB, that has an international reputation for its work with market leaders and well-established start-ups. It is a world leader in the design and fabrication of MEMS silicon, glass, and thin film components. The Micralyne website contains nanotechnology news and information relevant to Alberta industry. www.micralyne.com

Canadian Nanotechnology Job Centre. The Canadian NanoBusiness Alliance website for Canadian job seekers and employers in the fields of nanotechnology, MEMS, and related disciplines. http://cnba.tinytechjobs.com

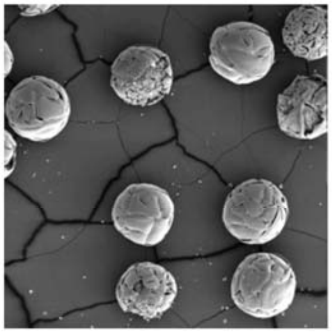
Appendix E. Workshop Program

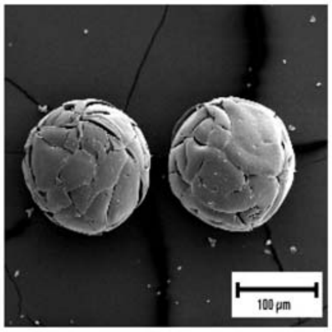
This section contains a reproduction (reduced in page size) of the program provided to the participants of the “Nanotechnology Solutions and Opportunities for the Environmental Industry” workshops in Calgary and Edmonton on December 8 and 9, 2004.

Environmental Services Association of Alberta

ESAA

Nanotechnology Solutions and Opportunities for the Environment Industry





Wednesday, December 8, 2004
McNight West
Sheraton Cavalier Hotel
2620 - 32nd Avenue NE
Calgary, Alberta

Thursday, December 9, 2004
Meeting Room #7
Fantasyland Hotel
West Edmonton Mall
Edmonton, Alberta

Nanotechnology is a new and expanding field. New nanomaterials will be of great benefit to the environmental industry, especially in the areas of soil remediation, water filtration and desalination, and high sensitivity chemical sensors for use in field applications.

Two identical half-day workshops in Edmonton and Calgary will highlight advances in nanotechnology for the environmental industry and will introduce a number of solutions and potential opportunities.

DK3 Scientific
www.dk3.ca

SynchroComm Inc.
Wordsmiths for Science, Medicine and Engineering
www.synchrocomm.ca

CHI 3 Consulting Inc.
www.chi3.ca

Workshop Supporters

Alberta Economic Development
www.alberta-canada.com/aed

Alberta Environment
www3.gov.ab.ca/env

Alberta Innovation and Science
www.innovation.gov.ab.ca

Environmental Services Association
of Alberta
www.esaa.org

Industry Canada
www.ic.gc.ca

NRC National Institute for Nanotechnology
www.nint.ca

Western Economic Diversification Canada
www.wd.gc.ca

The photos on the cover of this program are of sub-millimetre sized but nanostructured oxide beads. These are made by loading metal precursors onto ion exchange resin beads and then oxidizing the beads at low temperatures. The oxide beads are composed of oxide nanoparticles with excellent absorbent properties, but the approximate overall form of the original resin beads is retained. This makes the products large enough for practical industrial applications. Photos are courtesy Dr. Allen Apblett (Department of Chemistry, Oklahoma State University).

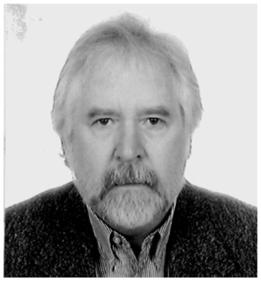
Schedule

9:30 AM	**Registration and Coffee** Continental breakfast will be available.
9:45 AM	**Dr. Ken Schmidt** (President, DK^3 Scientific Ltd.) *Opening Remarks*
10:00 AM	**Dr. Terry McIntyre** (Environment Canada) *An Overview of Nanotechnology*
11:00 AM	**Dr. Ken Schmidt** (DK^3 Scientific Ltd.) *Environmental Nanotechnology Literature Review*
11:30 AM	**Coffee and Networking**
11:50 AM	**Dr. Steve Dew** (University of Alberta) *Nanotechnology and Sensors for the Environment*
12:20 PM	**Dr. Allen Apblett** (Oklahoma State University) *Water and Soil Remediation Using Nanoparticulate Metal Oxides*
12:50 PM	**Round Table Discussion and Questions**
1:15 PM	**Lunch and Networking**
2:00 PM	*[Please return completed surveys]*

About the Nano-Environmental Cross-Sector Initiative

New technologies are needed by Alberta industry to help remediate existing environmental contamination and to reduce or prevent future pollution problems. Nanotechnology will likely be of great benefit to the environmental industry, especially in the areas of water filtration, desalination, and high-sensitivity chemical sensors for field applications. In addition, solid nanomaterials have excellent potential as absorbents for the removal of contaminants. The development and adoption of such new approaches by industry will be accelerated if the nanotechnology researchers are informed of the opportunities for applications that still exist and the environmental industry is familiarized with the solutions that nanotechnology can offer them. The Nano-Environmental Cross-Sector Initiative was established to facilitate these tasks in Alberta. A literature review of relevant nanotechnologies, two major workshops, an industry survey, and a final report (due February 15, 2005) form the basis of this project. The partners in this Initiative are Alberta Economic Development, Alberta Innovation and Science, Alberta Environment, Industry Canada, the National Institute for Nanotechnology (NINT), and Western Economic Diversification. The project is being coordinated by the Environmental Services Association of Alberta. The firms DK^3 Scientific Ltd., SynchroComm Inc., and CHI 3 Consulting Inc. have been retained to deliver the majority of the project objectives.

An Overview of Nanotechnology



Terry McIntyre, PhD, PAg
Chief, Environmental Biotechnology
Applications Division
Technology and Industry Branch
Environment Canada

Nanoscale science, engineering, and technology—collectively referred to as nanotechnology—give the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization. Nanotechnology is a crosscutting area involving disciplines such as chemistry, physics, biology, and engineering. It has truly revolutionary transformation potential for an entire host of products and processes, including enhancing the environmental performance of pollution detection, monitoring, and surveillance devices; removing some of the more recalcitrant contaminants from contaminated sites and waste streams; and reducing the ecological footprint of a variety of industrial and manufacturing activities. However, the proliferation of nanotechnology could also lead to new environmental problems such as novel classes of toxic materials or related environmental hazards. This presentation will provide a global overview of nanoscale-related R & D activities on three fronts: applied environmental technologies, selected industrial and manufacturing operations with anticipated environmental co-benefits, and risk assessment and management issues. It is intended that this will stimulate discussions on identifying future research niches for the Alberta environmental services sector.

Terry McIntyre is the Chief of the Environmental Biotechnology Applications Division, Technology and Industry Branch, Environment Canada. For the past 25 years, he has held a number of senior research positions within Environment Canada and has explored the potential of a variety of microbial-based products and processes in such areas as renewable energy and energy efficiency, industrial ecology, genomics and proteomics, regulatory acceptability, and plant-based remediation and restoration systems. Terry has also worked extensively internationally on environmental biotechnology projects across North and South America, Asia, Eastern Europe, India, and Africa. He holds undergraduate degrees in economics (BA, University of Western Ontario) as well as physics and chemistry (BESc, University of Waterloo), an MSc in soil science (University of Guelph), and a PhD in environmental science (University of Waterloo). He is a Professional Agrologist and is the author of seven book chapters and over 250 scientific and technical papers and presentations.

E-mail: Terry.McIntyre@ec.gc.ca

Abstracts and Biographies

Environmental Nanotechnology Literature Review

Ken Schmidt, **PhD, PChem**
President
DK^3 Scientific Ltd.

This talk will provide an overview of the scientific literature since 1995 on the development of nanotechnologies related to several areas in the environmental sector: soil and water remediation, water desalination, and field-based analytical sensors. Trends in the applications of nanotechnology relevant to these areas will be presented, and examples from each area will be described to demonstrate some of the innovative solutions currently being developed.

Ken Schmidt is President of DK^3 Scientific Ltd. Most recently he was the Project Leader for the Industrial Science Project of the Alberta Synchrotron Institute, and continues to be heavily involved in bringing to industry innovative synchrotron analysis techniques and knowledge about the new Canadian Light Source synchrotron facility. Ken previously spent eight years in industry working on high-tech ceramics production, CVD coatings, sulphur chemistry, and industrial analytical development and implementation. He holds a PhD in Inorganic Chemistry from the University of Calgary, and a Combined Honours BSc in Chemistry/Biochemistry from McMaster University. He is a Professional Chemist and serves on the boards of both the Association of the Chemical Profession of Alberta and the Edmonton Section of the Chemical Institute of Canada. On the latter, he currently holds the position of Chair. He is the author of over 50 publications and presentations. DK^3 Scientific Ltd. is a privately owned Alberta-based chemical consulting company that specializes in technical marketing, scientific project management, and analytical and process development.

Telephone: 780-998-0113
Fax: 780-998-5327
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URL: http://www.dk3.ca

Nanotechnology and Sensors for the Environment

Steven Dew, PhD, PEng
Associate Dean (Research and Planning),
Faculty of Engineering
Professor, Department of Electrical
and Computer Engineering
University of Alberta

Nanotechnology represents a tremendous opportunity for the development of new kinds of sensors for low cost, highly sensitive and exquisitely selective sensors. Scaling to very small sizes improves speed and makes possible single molecule detection. Designing the sensor at the atomic scale provides the opportunity to customize the response for a very specific molecule or collection of molecules. The prospect of massively parallel assembly or even self-assembly promises the creation of complex sensors at such low costs that they will be ubiquitous and disposable. However, challenges exist in creating and powering these sensors as well as interfacing them with the macroscopic world. This talk will address the scaling, principles and construction of a variety of nano-sensors, with particular focus on those that will be of interest to the environmental industry.

Steve Dew is currently Associate Dean (Research and Planning) of the Faculty of Engineering and Professor of Electrical and Computer Engineering at the University of Alberta. He received his BASc and MASc degrees in Engineering Physics from the University of British Colombia in 1987 and 1989, respectively. He completed his PhD degree in Electrical Engineering at the University of Alberta in 1992. His research areas are in micro- and nanofabrication and in thin film technology; he has published over 70 journal papers. He has been awarded the distinctions of Killam Professor (2002) and McCalla Research Professor (1998) and has received the Douglas R. Colton Medal for Research Excellence from the Canadian Microelectronics Corp. (1994). He is the Chair of the Microsystems Technology Research Institute (MSTRI) and the project leader of the Centre of Excellence in Integrated Nanotools (CEIN) at the University of Alberta.

Telephone: 780-492-7370
E-mail: Steve.Dew@ualberta.ca
URL: http://www.ece.ualberta.ca/~sdew/

Water and Soil Remediation Using Nanoparticulate Metal Oxides

Allen Apblett, PhD
Associate Professor
Department of Chemistry
Oklahoma State University

Major impacts of nanotechnology research in the environmental area will be in the development of nanoscale materials and processes for (i) the remediation of polluted environments and (ii) the end-of-pipe treatment of waste streams. Target pollutants include heavy metals, arsenic, dioxins, polynuclear aromatic hydrocarbons, organic solvents, pesticides, herbicides, and pathogens. Because of their small size, nanoparticles have very high surface areas compared with their bulk equivalents, thus tremendously accelerating their reactions with contaminants and promoting more complete reactions as well. Nanoparticles can also exhibit higher chemical reactivity due to unusual crystal shapes, lattice order, and surface chemistry. They can therefore be extraordinarily useful for detoxifying or mineralizing organic pollutants via catalytic reactions and can serve as excellent absorbents for toxic species. Another area of application is in the photocatalytic oxidation of organic pollutants, a process that takes advantage of both the high surface area and the unusual electronic properties of nanoparticles. A further property that can be exploited for environmental applications is the superparamagnetism of magnetic nanoparticles, which permits the development of efficient magnetic separation processes using "magnetic extractants." All of these technologies will be reviewed along with specific examples of their applications.

Allen Apblett is an Associate Professor of Chemistry at Oklahoma State University. He received a BSc (Honours) degree from the University of New Brunswick in 1984. He completed graduate school at the University of Calgary under the supervision of Dr. Tristam Chivers, receiving his Ph.D. in March of 1989. He was awarded a Natural Sciences and Engineering Research Council Postdoctoral Fellowship that he took to Harvard University to work in Dr. Andrew Barron's research group. In 1991 he became an assistant professor at Tulane University, and then moved to Oklahoma State University in 1997. In addition to academic positions, Professor Apblett has also worked as an analytical chemist for the Canadian Department of Fisheries and Oceans and as a member of the drug-testing team for the International Olympic Committee in the 1988 Winter Olympics. He has published over 67 scientific papers or book chapters, made over 100 presentations in the past seven years, and graduated three PhD and seven MSc students. Among the awards that Dr. Apblett has received are the ACS Environmental Division Certificate of Merit, nomination as a member of Project Kaleidoscope's Faculty for the 21st Century, a Mortar Board Award for Excellence in Teaching, the Governor General of Canada Medal, and a Lilly Endowment Teaching Fellowship. He recently received the College of Arts and Science Junior Faculty Excellence in Research Award at Oklahoma State University.

URL: http://www.chem.okstate.edu/FacultyPage/facultymain.html

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Masciangioli, T. and Zhang, W.-X. *Environmental Technologies at the Nanoscale*
www.nano.gov/html/res/GC_ENV_PaperZhang_03-0304.pdf

Environmental Applications and Impacts of Nanotechnology
www.nanotec.org.uk/environmentForWeb.pdf

General Reviews and Web Links Pages on Nanotechnology

Nanoscience and Nanotechnologies: Opportunities and Uncertainties
www.nanotec.org.uk/finalReport.htm

Reviews from a "green" point of view:
The Big Down: Atomtech - Technologies Converging at the Nano-scale
www.etcgroup.org/documents/TheBigDown.pdf
The Little Big Down: A Small Introduction to Nano-scale Technologies
www.etcgroup.org/documents/littlebigdown.pdf

USA list of nanotechnology web links:
www.nano.gov/html/res/links.html

UK list of nanotechnology web links:
www.nanotec.org.uk/Weblinks.htm

Nanotechnology News and Information Websites

National Institute for Nanotechnology (Canada):	www.nint.ca
National Nanotechnology Initiative (USA):	www.nano.gov
NanoBusiness Alliance (USA):	www.nanobusiness.org
Small Times (USA):	www.smalltimes.com
The Institute of Nanotechnology (UK):	www.nano.org.uk
Asia Pacific Nanotechnology Forum:	www.apnf.org

International Frequency Sensor Association nanosensors page:
www.sensorsportal.com/HTML/SENSORS/Nanosensors.htm

Nanotechnology Products and Vendors

Small Times Directory. This is a large business directory from Small Times Media, "the first media company devoted entirely to the fast-growing industry that includes MEMS [microelectrical mechanical systems], microsystems, and nanotechnologies."
www.SmallTechDirectory.com

Unofficial EPA List of Nanotechnology Products. This document, generated by the Environmental Protection Agency (USA), is an unofficial list of products based on nanotechnologies. It was distributed at a May 18, 2004 dialogue on nanotechnology at the Woodrow Wilson International Center for Scholars in Washington, DC.
www.etcgroup.org/documents/nanoproducts_EPA.pdf

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DK^3 Scientific Ltd. has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report, but makes no guarantees or warranties as to the accuracy or completeness of this information. The information contained in this report is based upon, and limited by, the circumstances and conditions acknowledged herein, and upon information available at the time of its preparation. The information provided by others is believed to be accurate but cannot be guaranteed. DK^3 Scientific Ltd. does not accept any responsibility for the use of this report for any purpose other than that stated in Section 1.2, and does not accept responsibility to any third party for the use in whole or in part of the contents of this report. Any alternative use, including that by a third party, or any reliance on, or decisions based on this document, are the responsibility of the alternative user or third party.

Any questions concerning the information or its interpretation should be directed to

Dr. Ken Schmidt
President and Senior Consultant
DK^3 Scientific Ltd.
www.dk3.ca

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[In the Microsoft Word file, the URL references in this section are linked to the actual websites. For users of recent versions of Microsoft Word, simultaneously press the "Ctrl" key and click on the desired web address below to access the website directly.]

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