

## **NSF-EC Workshop on Nanomaterials and Nanotechnology** **Summary Report**

### I. Workshop Overview

The NSF-EC workshop on nanomaterials and nanotechnology was held in Boston, Massachusetts on December 5-7 2002. Both the US and the EC realize the importance of a globally trained technical workforce. A focused effort to enhance interactions between the U.S. and E.C. in scientific research is one important way to create a culture where international cooperation is the rule rather than the exception. This workshop was developed to provide important feedback to NSF and EC on two issues: I) The most critical and timely issues facing those investigators developing new nanomaterials and technologies related to those materials and II) The best practices for catalyzing cooperative research in the emerging area of nanomaterials. Appendix A provides a list of attendees while Appendix B gives the program and talk titles.

Recommendations for important topics and challenges in nanomaterials research were arrived at by discussions in breakout groups in each of the three topical theme areas of the work. These discussions were preceded by brief talks from each of the participants. The common themes found in this discussion:

- **An increased focus on developing materials which have multifunctional capabilities.** Nanoparticles that can both sense and treat disease for example, devices that leverage both the optical and electronic properties of nanoparticles assemblies, or functional coatings whose biodegradation can be triggered after a certain time.
- **Recognition of the importance that the environmental impact of nanomaterials in developing sustainable nanotechnologies.** Very little is known about how nanomaterials interact with animals and the larger environment. Large collaborative efforts involving nanochemists, biologists, engineers, and toxicologists must be supported to develop a general understanding of the problem.
- **The development of controlled assembly methodologies which allow for the complex arrangement of materials from the nanoscale up to the macroscale.** Here, the integration of nanomaterials into CMOS circuitry and the development of improved nanocomposites for tissue engineering were specific goals.

Participants also were naturally drawn into conversations concerning the best ways to encourage effective interactions between US and EC scientists. The differences between the level of funding and research styles between the two continents were apparent in the workshop; most people felt that programmatic features could be developed to take advantage of these complementary features. Recommendations include:

- A harmonization between the review criteria of the NSF and EC sponsors.
- A two proposal process for collaborative interactions.
- Investment into activities (e.g. more topical workshops) to encourage scientists to overcome the barriers to preparing funding requests.

- An evolution towards a panel review process for proposals with reviewers from both countries participating in the reviews for collaborative US/EC projects.

## I. Introduction

The globalization of the technical workforce is becoming increasingly important as corporations and state economies become more interdependent. A culturally versatile, and globally experienced, scientific community is an important resource for any nation involved in this process. They, and the technology leaders they train, will ensure that emerging technology areas experience faster and more effective integration into the world's economy. Governmental organizations which support research both in the U.S. and in Europe can play an important role here by ensuring that scientists and engineers have ample opportunities to work across national boundaries.

This workshop considered both the content and structure such programs might take in the emerging area of nanotechnology, particularly in the sub-discipline of nanomaterials. This report, developed at a joint NSF/EC workshop held in Boston in December 2002, presents a number of recommendations for creating and nurturing collaborative activities between researchers in the area of nanomaterials. Section II outlines the grand challenges for this area broken roughly into the sub-topics of the workshop: nanomaterials in bioengineering, the chemistry and processing of nanomaterials, and nanomaterials in device structures. In addition to the scientific discussion, workshop participants also discussed 'best practices' for program implementation. Section III outlines these recommendations and comments.

## II. Grand challenges for cooperative research in nanomaterials

Over the past several decades, nanomaterials research has developed new materials, processes and devices which demonstrate the power of controlling matter on the nanoscale. The next several decades will be exciting times as many of these new tools will be brought together to make entirely new types of industries and technologies. The talks in our workshop, and discussions among participants, identified topical areas that are particularly timely and important to the progress of the discipline.

**A. Overarching themes.** Three themes emerged separately from each sub-group's discussion. Their universal importance to such a wide range of scientists and engineers underlines their importance to the area.

- The growing need to characterize and understand the potential environmental impact of nanomaterials.* As it is still unclear which particular class of nanomaterials will be the most prevalent in products, specific nanomaterial toxicology studies are not very useful. Instead, these early efforts should focus on developing a general understanding of the size and surface dependence of nanomaterial interactions with living systems. Research that seeks to address the effect of nanomaterials on biological processes including biochemical processes and cellular function is critically important. Additionally, fundamental characterization of how nanomaterials may be incorporated into organisms, and the distribution and fate of these materials in the body, are required. Teams of

biologists, nanochemists, process engineers and toxicologists are required to make headway into this complex area and will likely require cooperation between funding agencies as well. The information that is gathered should be fed back into nanomanufacturing methodology as well as economic assessment of future nanotechnologies.

- ii) *The need for engineering multifunctionality into nanomaterials.* In biotechnology, nanomaterials must be designed to target disease for example, as well as treat disease. In device architectures nanostructures which are both electronically and optically active create new types of logic devices. Finally, multifunctionality can be used to develop materials which self-heal, or biodegrade after a signal is received.
- iii) *The recognition that nanomaterials assembly, rather than nanomaterials development, is the outstanding problem now.* Methods for assembling quantum dots into micro-scale patterns, for example, or integrating them into CMOS circuitry is essential. In biotechnology, the incorporation of mesoporous structures and drug-delivery schemes into replacement tissues a major goal.

B. Nanomaterials in biology and bioengineering (Rena Bizios, theme leader). The generation of safe, multifunctional and biocompatible materials is an enormous challenge which nanochemistry is well suited to address.

Fundamental science is critically important in this area. While there are diverse needs, a universal issue is the characterization and control over the nano/biomaterial interface. Bioactive materials are useful because they present surface functionalities which can sense or change a biological environment. This requires an understanding of protein-surface interactions, characterization of the molecular chemistry at biomaterial interfaces, and new chemical methods for integrating biological macromolecules with nanoscale materials.

Additionally, nanotechnology has the potential to inform specific biological questions. Engineering principles can and should be applied to the biological realm. The nanotechnology community knows how to engineer on nanoscale and there is great value taking that knowledge and applying it to an understanding of cells, for example. Biological research which uses engineered nanomaterials as a tool to better understand fundamental questions about biological systems is required.

Finally, multifunctional nanomaterials are ideally suited for many problems in bioengineering and medicine. Particle-based technologies that use the unique optical or magnetic features of nanoscale inorganic crystals can find applications to noninvasive sensing of disease, disease treatment, drug delivery, and imaging. For these activities the ability of these particles to target particular organs and cells is essential and should be well established. Monolithic nanocomposites with extraordinary mechanical and chemical behavior should be applied to problems in tissue (hard and soft) engineering. The ultimate aim is for a biodegradable scaffold which guides and directs the body's own healing process. Here, these materials should

possess layers of nanoscopic complexity incorporating particles, for example, to impart strength and mesopores to allow for nutrient transport.

B. Nanomaterial Physics and Devices (Vin Crespi, leader)

The interaction between physics, chemistry, biology, and engineering is desirable and necessary for device advancement. Research which integrates the various disciplines is most likely to lead to major advances in engineering and physics. Quantum computers, self-healing circuitry/systems, inexpensive alternatives to silicon CMOS, biomedical devices, cell biology improved with real time, multi-channel, high bandwidth nanoscale sensors/devices are all possible outcomes if nanomaterials physics and device structures can be controlled.

As nanomaterials grow in complexity the problem of controlled assembly is a major one. On a short term is the development of parallelization in the laborious one line at a time lithographic and probe methods for nanoscale patterning. Methods which exploit competing interactions on different length scales in a cooperative way to generate structures on the 10 nanometer length scale is ideal. While contact interactions through force microscopies are one near-term solution, every effort should be made to look for new approaches. Assembly processes themselves are not the ultimate goal, but rather the tool to access reliability, robustness, improved lifetime, and ultimately self-healing circuits and processes. Ultimately, such processes could be aimed at grand challenges such as the wiring of every element in a molecular electronic circuit.

New devices will require nanometer scale heterogeneity – optical, magnetic, electronic, etc. Multifunctionality is essential for the next generation of nanotechnologies. By controlling all degrees of freedom in a device, new types of behavior can be developed and exploited. The areas of quantum computing and spintronics are two examples where such nanoscale multifunctionality can be utilized.

C. The chemistry and fabrication of nanomaterials (Debra Rolison, leader)

This group concluded that the problems of controlled assembly, characterization of complex materials, and the maturation of nanomaterials synthesis are major outstanding challenges for the global community of nanoscientists and engineers.

For assembly, there is a need to find more rational and complex ways of building nanoscale sub-units into larger structures. The surfaces of such materials are key; highly programmable, encoded particles could be wired to assemble in particular patterns, for example, with appropriate derivatization. This requires the ability to spatially address the surfaces of nanoscale objects with chemical strategies. Such architecture control enables materials that meet many of the needs of the device community; it could extend nanodevices by adding motion, for example.

Nanochemists have been very successful at generating nearly every material in nanoscale form; in many cases, these methods provide adequate material for the research environment. However, for the field to progress it is important that this same community address longer term problems. First is the movement towards the rational design of nanomaterials total synthesis, in

analogy with organic chemistry. Chemists should identify general principles between material classes; it is possible that through course development and textbooks the intellectual groundwork could be developed. Second is the focus on high-yield, environmentally friendly nanomanufacturing. Research which reevaluates standard synthetic methods for nanotubes, quantum dots and other widely studied and applied systems is important. New approaches should focus on reactions which yield material in high yield, with large quantities, using environmentally benign methods.

Finally, everyone concurred that characterization of nanoscale materials is an ongoing challenge, and that tools that are developed to image materials on the nanoscale often can serve dual use as agents to affect chemical change. We need to reduce the size scale of tools to allow us to make and break a single bond on a single molecule routinely. Buried domains and interfaces are becoming increasingly important, and there are no routine tools for characterizing these systems. Finally, because of the dominance of imaging methods for characterization the field has a bias toward assembly of structures with order and periodicity. New characterization methods for materials are needed in order to develop ways to stabilize functional disorder

#### D. Differences between US/EC nanomaterials research.

We considered whether some of these grand challenges were better suited for international collaboration than others, and most of us decided that such distinctions between US and EC science were difficult to identify. Still, some of us felt that the research styles and focus of each continent were different. In particular, EC research in the fifth framework is more applications driven. It might be that joint research, or future workshops, which bring the more molecular work of US researchers together with processing efforts of EC scientists could be fruitful.. Finally, one group noted some general differences in research style between the US/EC. In particular, differing funding cultures force US scientists to publish fast and hunt for new phenomena. In the EC, the focus is also on applications development. It is important to note that these generalizations were not reflective of the group's opinions as a whole, and the ones reported here represent at least the thoughts of a significant minority.

### III. Recommended 'best practices' for E.C./N.S.F. Interactions

Most of the P.I.s present at the workshop were not fully aware of the programs at NSF and the EC that supported international collaborations. An important outcome of this workshop is that interactions between program managers and the P.I.s at the meeting increased everyone's understanding of current program details.

This educational process quite naturally led into a discussion of programmatic features currently in place and whether they were ideal for improving nanomaterials research globally.

Most people agree they do not want either agency to set aside money for collaborative activities – proposals should compete normally with non-collaborative proposals. This maximizes the chance that the best science will emerge from each organization. The problem that arises in open competition is that proposers must spend more time (e.g. writing two proposals) with likely lower funding rates since proposals must pass on both sides of the

Atlantic. This will dampen P.I. enthusiasm for collaborative E.C./U.S. efforts, especially in light of the fact that these barriers do not exist for non-E.C./U.S. collaborations. ***We recommend that NSF/E.C. track the number of proposals/funded projects over time so that the magnitude of this potential problem can be monitored. We also recommend that workshops/meetings be supported to generate possible candidate collaborations and increase awareness in the community about the program.***

Another point of discussion was the two-proposal format versus the one-proposal format; we agreed that as long as proposals must compete with non-cooperative grants it is critical that each organization receive proposals which comply with their format, style and review criteria. Thus, a two proposal format seems the likely mode for E.C./U.S. cooperations. There are several ways that both the NSF and EC can minimize the downside of a two-proposal system. ***We recommend that every effort be made to harmonize the review criteria between agencies and that where possible the same reviewers consider both the EC and US proposals. Additionally, panel reviews of these proposals which have both U.S. and E.C. scientists would allow review criteria to be discussed, as well as providing another point of contact between the international nanomaterials community.***

Finally, we note that the E.C. fifth framework research program is very different from NSF's typical research grants. As the sixth framework comes into development these distinctions may disappear making an ideal environment for NSF/EC cooperation. Still, issues surrounding intellectual property will be important to sort out.

**Appendix A. List of Attendees**  
**NSF-EC Workshop: From Nanomaterials to Nanotechnology**

<b>ATTENDEE</b>	<b>ORGANIZATION</b>
Kevin Ausman	CBEN-Rice University
Vicki Colvin	CBEN-Rice University
D. Todd Philips	CBEN-Rice University
Rebekah Drezek	Rice University
Charles Ahn	Yale University
Joseph A. Akkara	National Science Foundation
Robson Aurélio de Queiroz	University Federal of Pernambuco
James Baker	University of Michigan
Kristin Bennett	Office of Basic Energy Sciences
Rena Bizios	Rennslear Polytechnical Institute
Ian Bruce	Greenwich University
Bob Buhrman	Cornell-NSEC
Harold Craighead	Cornell University
Vin Crespi	Penn State University
Frédéric Cuisinier	University of Strassbourg
Peter Dearnley	University of Leeds
Trevor Douglas	University of Montana
Phillipe Guyot-Sionnest	University of Chicago
Henry Haefke	CSEM
Manus Hayne	KU Leuven
Irving P. Herman	Columbia University
Mark Hersam	Northwestern-NSEC
John Hunt	National Science Foundation
Torbjörn Ingemansson	European Commission
Alan T. Johnson, Jr.	University of Pennsylvania
Roger Legras	Universite Catholique de Louvain
Oonagh Loughran	Institute of Nanotechnology
Chuck Martin	University of Florida
Alain Mathiot	CEA
Giorgio Mattiello	Italian Embassy
Mamoun Muhammed	Royal Institute of Technology
Cathy Murphy	University of South Carolina
Chris Murray	IBM Almaden
David L. Nelson	National Science Foundation
Colin Nuckolls	Columbia-NSEC
Hongkun Park	Harvard University
Fabienne S. Pelle	CNRS
Xiaogang Peng	University of Arkansas
Antonio Porro	Fundaccion Labein
Debra Rolison	Naval Research Laboratory
Siegmar Roth	MPG
Mike Sailor	University of California, San Diego
Daniel Samain	TSAI LUN

## NSF-EC Nanomaterials Workshop 2002

Gunter Schmid	University of Essen
Benjamin J. Schwartz	UCLA
Dick Siegel	RPI-NSEC
José Luis Viviente Sole	European Commission
Martin J. Son	Tufts University
Geoff Strouse	University of Santa Barbara
Michael Stueber	Forschungszentrum Karlsruhe
Carlo Taliani	CNR
Ned Thomas	Massachusetts Institute of Technology
Sarah Tolbert	University of California, Los Angeles
Renzo A.G. Tomellini	European Commission
Thomas Tsakalakos	Rutgers University
Dimitris Tsoukalis	NCSR "Demokritos"
Helko Van Den Brom	Nederlands Meetinstituut
Viola Vogel	University of Washington, Bioengineering
Thomas A. Weber	National Science Foundation
Jan R. Weitzenböck	Det Norske Veritas AS
Robert Westervelt	Harvard-NSEC
Henry White	SUNY Stony Brook
Uli Wiesner	Cornell Bio/Nano participant
Magnus Willander	Chalmers
Kevin D. Wright	National Institutes of Health



Appendix B. Participants and presentations (alphabetical by speaker)

**Nanocomposites for Orthopaedic/Dental Applications**

*Rena Bizios, Rensselaer Polytechnic Institute*

The need for (1) biomaterials with properties similar to those of physiological bone (characterized by surface grain sizes in the nanometer range, and (2) identification of the optimal conditions that maximize the bone-forming potential of osteoblasts for bone tissue engineering applications motivated the study of nanostructured materials (that is, materials with grain sizes less than 100 nm in at least one dimension. Nanoceramics (specifically, alumina, titania, and hydroxylapatite, composites of these nanoceramics with polymers (specifically, poly(L-lactic) acid and poly(methyl methacrylate), as well as composites of poly(L-lactic) acid and carbon nanotubes (current-conducting substrates) promoted osteoblast functions pertinent to new bone formation. Nanophase materials could, therefore, promote osseointegration, a crucial development for the clinical success of orthopaedic/dental implants. In addition to improving the efficacy of orthopaedic/dental implants, these novel biomaterial formulations could be used to explore alternative strategies for bone-related tissue-engineering applications.

**New Approaches for Information Technologies from Nanoscaled Materials and Devices**

*Robert Buhrman, Cornell University*

The research mission of the Center for Nanoscale Systems, an NSF supported Nanoscale Science and Engineering Center, is to understand, enhance and develop nanoscale materials, phenomena and devices that have the potential of being effective solutions for the requirements of future information technology systems. I will briefly summarize some current CNS efforts that are being pursued in the areas of nanoelectronics, nanophotonics and nanomagnetism for possible future applications in computation, communication and information storage systems. These include new approaches for Si electronics at the 10 nm scale, the development of quantum dot systems and other nanoscaled materials systems for application in fiber optical communication systems, and the utilization of spin-polarized currents for the direct reversible switching of nanomagnets for nanoscale non-volatile memory device applications.

**Paramagnetic silica, agarose and mesoporous sieves: new materials and applications in biomolecular separations**

*Ian Bruce, University of Greenwich*

Over the last ten years the Molecular Sciences Research group at the University of Greenwich has been innovating and producing a range of paramagnetic materials including nano-crystalline magnetite, silica coated magnetite, agarose and most recently mesoporous silica (sieves).

These materials range in size from nano- (approx.100nm) to micro- (10 to 25 $\mu$ m) scale and represent both porous and non-porous, homogeneous and inhomogeneous solids demonstrating a range of solvent stabilities. The paramagnetic silica and agarose supports have been extensively characterised physicochemically and used in a variety of biomolecular isolations, separations and enrichments.

These support materials have been activated with a variety of surface chemistries via either silanisation (in the case of nano-crystalline magnetite and silica magnetite) or classical approaches in the case of agarose. Surface functionalisation to -COOH, -NH<sub>2</sub>, MeCOOH, and with a range of ligands possessing ion exchange properties and streptavidin and hydrazide has

been achieved. Most recently new surface activation chemistries involving polymerisation of pyroles and carbazoles are being investigated to improve the performance of the supports.

So far the supports have been successfully applied in immuno-affinity type purifications and diagnostic applications, DNA and RNA isolation, hybrid capture of nucleic acids for diagnostic purposes and as supports for solid phase DNA sequencing.

The paramagnetic agarose has been developed commercially by an industrial partner (Whatman International Ltd) who markets the product under the trade name Magarose®.

Future work of the group relating to these materials involves the development of further applications and improved large scale manufacture. On going work also relates to the use of mesoporous materials in the same way and 'nano-rods' to be developed using a templating strategy based upon the mesoporous solid pore structure.

### **Auto-Assembled Polyelectrolyte Films in Biology: Buildup and Protein Adsorption**

*Frederic Cuisinier, Universite Louis Pasteur, Strasbourg*

The buildup of ordered protein systems constitutes one of the major objectives of bio-related chemistry and biotechnology. Consecutive auto-assembly of positively and negatively charged polyelectrolytes lead to the formation of a nanomaterial which could be a good analogue to extracellular matrix. We investigate the adsorption processes between polyelectrolyte multilayers and a series of positively and negatively charged proteins. The film building up and adsorption experiments were followed by Scanning Angle Reflectometry (SAR) and optical wave light mode spectroscopy (OWLS).

We find that proteins strongly interact with the polyelectrolyte film whatever the sign of the charge of both the multilayer and the protein. When charges of the multilayer and the protein are similar, one usually observes the formation of protein monolayers which can become dense. We also show that when the protein and the multilayer become oppositely charged, the adsorbed amounts are usually larger and the formation of thick protein layers extending up to several times the largest dimension of the protein can be observed. The auto-assembly of proteins onto polyelectrolyte film was also demonstrated. Our results confirm that electrostatic interactions dominate protein/polyelectrolyte multilayer interactions.

### **Theory of nanostructures: Boron-based nanotubes, nanocones, perfect bearings, the strongest nanotubes, and magnetic hurricanes in ordered porous magnets**

*Vincent Crespi, Penn State University*

As time allows, I will discuss several novel nanostructures with interesting electronic and mechanical properties. Boron-based nanotubes with beryllium atoms in the hexagonal faces should exhibit uniformly metallic properties with multiple conduction channels of disparate character. The apical dislocation in a carbon nanocone mixes the low-energy electronic states of a graphene sheet and produces a geometrically-derived effective flux through the apex. A new  $sp^3$ -based nanotube structure promises to be stiffer than a regular carbon nanotube. In contrast, an incommensurate two-walled  $sp^2$ -based tube can form one of the smoothest solid-solid interfaces known. An ensemble of repulsive pointlike objects on a cylindrical structure (e.g. a lightly doped large-diameter semiconducting nanotube) can yield a highly degenerate ground state, possibly with solitonic charge transport. Finally, ordered nanostructured ferromagnets convert the familiar bulk demagnetization factor into an intrinsic material property.

### **Biomimetic Nano-Materials Chemistry**

*Trevor Douglas, Montana State University*

Proteins direct many of the mineralization reactions that occur in biological systems. In particular, the iron storage protein ferritin forms a protein cage, which encapsulates a nanoparticle of ferric oxide. Other protein systems, in particular viruses, form similar self-assembled cage-like architectures. These structures are able to act as “containers” for molecular encapsulation, defining a host-guest relationship between the protein cage and the encapsulated material. This approach to molecular encapsulation has been utilized for the size-constrained formation of minerals in both biological and synthetic (biomimetic) systems.

Some of the encapsulated mineral particles have unique physical semi-conducting, magnetic, and catalytic properties. This presentation will outline some of our work into the study of mineralization reactions induced by well-defined protein assemblies, in both natural and synthetic systems.

### **Potential of Nanotechnology for Molecular-Based Imaging and Therapy**

*Rebekah Drezek, Rice University*

Metal nanoshells are a new class of nanoparticles invented at Rice University. Metal nanoshells are nanoparticles composed of a dielectric core encapsulated by a thin metal shell. The most unique feature of these nanoparticles is that their plasmon resonance (wavelength of optimal optical extinction) can be designed to fall anywhere within the visible, near infrared, or mid infrared regions of the electromagnetic spectrum by changing the particle geometry. Furthermore, the particle design can also dictate whether the nanoshells will principally absorb or scatter light at their plasmon resonance. In this presentation, we will discuss both the fundamental optical properties of nanoshells and work towards development of molecular-specific diagnosis and therapy applications.

Diagnostic Applications of Metal Nanoshells:

Optical technologies promise high resolution, noninvasive functional imaging of tissue at competitive costs. However, in many cases, these technologies are limited by the inherently weak optical signals of endogenous chromophores and the subtle spectral differences of normal and diseased tissue. We plan to develop novel contrast agents using nanoshell technologies that can be optically interrogated using noninvasive approaches and targeted to specific molecular signatures of disease. To fully develop the potential of nanoshell-based contrast agents, we have used computational tools to simulate the interaction of light with tissue containing nanoshells at both microscopic and macroscopic spatial scales using computational electromagnetics and Monte Carlo approaches. Following computational evaluation of the optical signals to identify optimal design parameters for experimental testing, we will study the signals from non-biological and biological tissue phantoms as a function of nanoshell and tissue properties. We will then test the most promising optical contrast agents in vivo using the well-characterized hamster cheek pouch oral carcinogenesis model to determine the enhancements in sensitivity and specificity provided by the nanoshell-based contrast agents.

Therapeutic Applications of Metal Nanoshells:

In parallel to studies to investigate the potential imaging applications of nanoshells, work is also underway to develop molecular-specific nanoshell-based cancer therapies. For the cancer therapy application, near IR absorbing gold nanoshells are conjugated to antibodies against

specific oncoproteins. Upon systemic injection, the nanoshells will accumulate in tumor regions due to the leaky and dense vasculature and the targeting antibody. When near IR light is applied, the nanoshells will generate heat and kill the cancerous cells. Preliminary results from cell and animal model studies will be presented.

### **Synthesis and scaling-up fabrication of functional nanoscale structures for automotive and aerospace applications**

*Henry Haefke, CSEM Swiss Center for Electronics and Microtechnology, Inc.*

Nanotechnology has become a very active and vital area of research, which is rapidly developing in industrial sectors and spreading to almost every field of science and engineering. The fundamental physical, chemical and biological properties of materials are remarkably altered as the size of their constituent grains decreases to a nanometer scale. These novel materials made of nanosized grains or building blocks offer unique and entirely different electrical, optical, mechanical and magnetic properties compared with conventional micro and or millimeter size materials owing to their size, shape, surface chemistry, and topology. Over the past decade, extraordinary progress has been made on nanostructured materials and dramatic increase in research activities in many different fields. Nanostructured materials and their base technologies have opened up exciting new possibilities for future applications in automotive, aerospace, aeronautics, batteries, memory devices, sensors, solar cells, etc. However, in order for this potential of nanotechnology to be realized, novel manufacturing techniques deviating from scaled down versions of currently practiced technologies, are required at the nanoscale.

Current chromium-based coating treatments for magnesium alloys used in automotive, aeronautic and aerospace industrial applications are very hazardous and have to be replaced. Consequently, there is an immediate need to develop new environmentally friendly coatings with enhanced corrosion and abrasion resistance for magnesium-based parts and by using clean and economic processes. Several different methods such as physical vapor deposition (PVD), chemical vapor deposition (CVD) are currently in use for synthesis and commercial production of nanostructured materials. Chemical synthesis of nanostructured materials or nanophases, nanoparticles is a rapidly growing research area with a great potential to make technologically advanced and useful materials. Among them, sol-gel thin films have been widely developed for many industrial protective-coating applications. In the project NANOMAG, nanostructured materials (SiO<sub>x</sub>, CrN) with enhanced mechanical and chemical properties are developed based on plasma polymerization (CVD process), plasma enhanced physical vapor deposition and UV-irradiated sol-gel coating techniques. The production of these new anti-corrosion and wear resistant nanocomposite coatings will create considerable new market opportunities in various industrial sectors, coating centers and Mg alloy producers.

The real future of nanophase materials, and other nanostructured materials as well, will depend on our ability to change significantly for the better, the properties of the materials by structuring them artificially on nanometer scales and on developing economic and environmentally responsible methods for producing these materials commercially viable quantities. The realization of this potential will require multidisciplinary interactions and collaborations between chemists, material scientists, and engineers in order to control and improve the properties of the nanostructured materials.

### **Self-assembled Nanostructured Materials for Electronic and Optoelectronic Applications**

*Manus Hayne, Katholieke Universiteit Leuven*

The Self-assembled quantum dots, wires and rings are formed when a few monolayers of a semiconductor material are deposited on a substrate with a slight lattice mismatch, *e.g.* InAs on GaAs. The deposition of additional substrate material to cover the dots preserves the high quality of these nanostructured materials, allowing their use in lasers and other semiconductor devices. Furthermore, by exploiting the strain fields generated in thin layers of capping material, vertically-aligned stacks of nanostructures can be grown, opening up the possibility for three-dimensional band-structure engineering. The NANOMAT project, which is sponsored by the Growth Programme of the European Commission is dedicated to the investigation of the physics of such self-assembled nanostructured materials with a view to their exploitation in novel (opto-)electronic devices in the medium and long term. A range of state-of-the-art experimental and theoretical techniques, a number of which are unique to the partners in the project, are used to investigate the growth, optical and transport properties of self-assembled semiconductor nanostructured materials such as InAs in GaAs, InAs in InP, InP in GaInP and GaSb in GaAs. In my talk I will briefly review the growth of self-assembled quantum dots (wires and rings), and then introduce the aims and objectives of the NANOMAT project. Some of the investigative techniques available within the partner institutions of the project will then be presented along with a selection of the scientific results obtained within the first year of the project (2001-2002).

### **Nanoscale Biological and Chemical Detection Strategies**

*Mark Hersam, Northwestern University*

The Nanoscale Science and Engineering Center (NSEC) for Integrated Nanopatterning and Detection Technologies was established in September 2001 by NSF Award Number EEC-0118025. A cross-disciplinary effort, the NSEC brings together scientists, engineers, and educators from Northwestern University, University of Illinois at Urbana-Champaign, University of Chicago, Argonne National Laboratory, the Chicago Museum of Science and Industry, Harold Washington College, and twenty-four companies and business groups. The NSEC is working at the nanoscale to develop chemical and biological sensors that will be far more sensitive, selective, and cost-effective than conventional systems. These goals are pursued by an integrated team of three synergistic research groups: nanopatterning, integrated electronic chip, and optical nanoarray sensors. This talk will provide an overview and highlight recent developments in NSEC-supported research.

### **Micro- and Nanofabrication Using Ion-Track Membranes**

*Roger Legras, Catholic University of Louvain*

If a thin polymer film such as polycarbonate is irradiated with energetic ions, holes are burned out and after track etching a membrane is produced. As filters, most membranes rely on several different mechanisms to enhance contaminant removal. Track etched membranes, in contrast, capture particles by simple direct sieving, so particles larger than the pore size cannot pass through. The existing production technology for these membranes has been significantly enhanced to allow the reliable and reproducible manufacture of porous membranes with pore size from several microns and down to around 10 nanometers. They are currently used within the filtration market as molecular filters for biological applications such as water purification.

Now these polymer membranes can be made with a well-controlled pore size and shape in the form of regular periodic arrays. The nanopores can be filled with another organic or inorganic

material such as polymer or metal. If a material like an electrically conductive polymer is deposited in the holes, nanotubules with enhanced conductivity are obtained; filling the nanoholes with a magnetic material such as iron, cobalt, nickel or even with a combination of these metals by electrochemical deposition, produces a membrane with nanoparticles or wires of either one or with multilayers of different metals.

Various combinations of polymers and metals are produced and characterised with the aim of using such membranes to design devices in which the electrical and magnetic properties can be studied, controlled and so optimised. The nanoparticles produced by using these templates take the form of rods or tubes. The metal nanowires embedded in these polymer films are regularly spaced and densely packed. Since the volume and degree of their electrical insulation and magnetism is controllable and can be fine-tuned, they have good potential for use in high density data storage. They also absorb certain wavelengths of electromagnetic radiation similar to those used in microwave ovens and communications. Consequently, potential applications include sophisticated devices such as microwave filters for making shields for microwave ovens and mobile phones. The deposition of conductive polymer nanotubules in the membrane will lead to the preparation of chemical detectors (artificial nose) and biosensors.

### **NanoForum: The New Nanotechnology Network for Europe**

*Oonaugh Loughran, Institute of Nanotechnology*

NanoForum, a new, 2.7million euros pan European nanotechnology 'Network of Networks' was launched in July 2002, with the aim of strengthening Europe's economic competitiveness in the field of nanotechnology.

Why a nanotechnology network of networks? Nanoforum will provide a framework for awareness raising, supporting and encouraging the adoption of new nanotechnologies, and facilitating the development of new industrially oriented nanotechnology research across Europe.

A highly interactive Nanoforum website will be live by January 2003 it will serve as the European gateway to nanotechnology. Nanoforum aims to provide a truly "European" gateway of information aimed at the professional nanotechnology scientific community. The NanoForum goal of strengthening Europe's economic competitiveness will be achieved by the delivery of a variety of events and programmes over the next four years.

Nanoforum is led by the Institute of Nanotechnology, a UK-based organisation established in 1997. Other partners in Nanoforum include VDI -the German Association of Engineers, with over 120,000 members across Germany, CEA/LETI the research arm of the French Atomic Energy Authority, CMP-Cientifica a Spanish group that co-ordinates Phantoms, the European nanoelectronics network, and Nordic Nanotech, based in Denmark.

Nanoforum aims to provide a truly "European" gateway of information aimed at the professional nanotechnology scientific community.

### **The Bio/Nano Interface - Biotech Applications of Template-Synthesized Nanotubes**

*Charles Martin, University of Florida*

We have pioneered a versatile method for preparing nanotubes called template synthesis. With this method, monodisperse nanotubes of nearly any desired length, inside diameter and outside diameter can be obtained. In addition, this method can be used to prepare nanotubes composed of nearly any material; e.g. carbons, metals, polymers, inorganic materials. Applications of

template synthesized nanotubes in bioseparations - in particular enantiomeric drug separations - will be discussed.

### **Nanopowders and Nanoengineered Surfaces at CEA**

*Alain Mathiot, French Atomic Energy Commission*

#### **1 – CEA IN THE FRAME OF FRENCH RESEARCH ON MATERIALS**

French atomic commission is a government research organization which aims to develop nuclear energy applications for electricity, defense and sustainable growth, as well as new technological break through for industrial application. CEA is an applied research organization, even if many among our laboratories are oriented toward basic research.

More than 1200 researchers work on the materials development in CEA and all the technological programs need materials development. So a transverse initiative was launched in order to valorize the expertise in materials, around two multidisciplinary projects :

- Nanostructured materials for technological applications
- Numerical materials, which means influence of modeling and simulation on materials science

#### **2 – WHY NANOMATERIALS AT CEA AND IN FRANCE**

All materials scientists know that interaction of nanosciences and materials is as old as materials science. However the recent progresses in characterization tools, manipulation of single atoms or aggregates with near field microscopy and other such tools, and atomic scale calculations allow to consider more applied and technological evolutions. We have commissioned a market survey (mainly in France) on possible industrial applications of nanomaterials. Two main technological areas appear to be relevant from this point of view:

- Nanopowder synthesis and use in bulk or composite materials
- Development of enhanced or new functionalities for surfaces

From the result of this survey, three sectors of applications come out as important for these developments:

- Weight reduction and strengthening of materials for structural applications
- Surface layers for environment protection, mechanical purposes, or new functions development
- Chemistry and catalysis to enhance reactivity in advanced synthesis processes

#### **3 –NANOMATERIALS PROGRAMS AT CEA**

We made the choice to develop our action in the two above mentioned technical domains, in partnership with other public laboratories, with manufacturers and end users, and with government and European institutions. Our aim is:

- To develop a scientific and technological core of advanced synthesis processes, having the potential capability for mass production
- To valorize this core through high added value applications in the field of environment, health an energy technologies

We promote in France a networking of scientific and technological facilities through transverse programs. A collaborative network on nanomaterials started beginning of 2002, initiated by ECRIN, society for the development of collaboration between research and industry. Several coordinated actions are under progress between Research Department, CNRS and CEA, the aim of which is the creation of “virtual laboratories”. CEA is enhancing the capabilities of two technological platforms:

- One devoted to nanopowders and bulk or composite materials in Saclay
- One devoted to surface engineering in Grenoble

### **Engineering of Nanoparticles for Thermoelectrics Applications**

*Mamoun Muhammed, Royal Institute of Technology*

Dramatic improvement of the materials properties can be achieved through molecular engineering as well as by the material's nanostructuring. Fabrication of next generation nanoparticles, with core-shell structures, allows the fine tuning of the materials properties for advanced applications. Chemistry driven self assembly can be used to obtain 2-D and 3-D hetero-structures with superior properties using these particles as building blocks.

The fabrication of nanostructured thermoelectrics have shown to greatly enhance their TE performance (Figure of merit; ZT). The fabrication of TE materials with high grain-boundary density has shown to dramatically decrease their thermal conductivity due to the selective phonons diffraction. Some recent results on the fabrication and characterization of some Skutterudite TE materials are presented.

### **Synthesis, Assembly and Reactivity of Metallic Nanorods**

*Catherine J. Murphy, University of South Carolina*

Anisotropic metallic nanoparticles are desirable for their electronic, optical, and catalytic properties. We have developed seed-mediated growth procedures in aqueous solution to prepare gold and silver nanorods of controllable aspect ratio. High resolution transmission electron microscopy experiments suggests that gold nanorods grow along a twin defect axis. The nanorods can self-organize into liquid crystalline assemblies upon concentration from solution. Nanorods can also be linked with biological molecules to make designer assemblies. The reactivity of gold nanorods depends on their aspect ratio. Sensor applications using gold nanoparticles will also be discussed.

### **Preparation and Properties of Nanocrystals and Nanocrystal Superlattices: Building with Artificial Atoms**

*Christopher Murray, IBM*

Synthetic chemistry allows the production of nanometer scale structures that are uniform size to +/- one lattice constant while controlling crystal shape, structure, and surface passivation. We combine a high temperature solution phase synthesis with size selective processing techniques to produce organically passivated magnetic nanocrystals with size distributions less than 5%. These nanocrystals then form the basis for a combined structural and magnetic study of the evolution of nanocrystal properties with size. These monodisperse nanocrystals self-organize during controlled evaporation to produce 2D and 3D superlattices (colloidal crystals, opals). The nanocrystals resemble “artificial atoms” sitting on regular close-packed superlattice sites, each separated by a selected organic spacer. The inter-particle spacing can be varied from intimate



contact up to  $\sim 40\text{\AA}$  separation. The superlattices retain and enhance many of the desirable mesoscopic properties of individual nanocrystals and permit the first systematic investigation of new collective phenomena. Our goal is to study the properties of both the dispersed nanocrystals and assemblies as all major structural parameters are varied (composition, size, and spacing). Procedures have been developed for Co, Ni, and FePt magnetic nanocrystals as well as for CdSe and PbSe semiconductor quantum dots. Recent explorations of magnetic recording the transport phenomena in magnetic nanocrystal superlattices will be discussed as well as optical studies of the semiconductor nanostructures. Progress in the development of techniques to pattern nanocrystal superlattices, which will be essential to the fabrication of devices incorporating these molecular-scale building blocks, will also be highlighted.

**The Columbia Nanoscience Center**

*Colin Nuckolls, Columbia University*

This presentation outlines ongoing research in the Columbia University Nanoscience Center investigating new molecular systems and their assembly on metallic surfaces. One of the systems discussed uses hydrogen bonds to enforce stacking between aromatic rings forming one-dimensional nanostructures possessing a dipole moment that sums as the molecules stack. In bulk, these columns further self-assemble into two-dimensional arrays. In films with submonolayer coverage, these self-assembled stacks are isolated from each other and their structure can be probed with atomic force microscopy, electrostatic force microscopy, and scanning tunneling microscopy. Efforts to measure the electrical properties and to direct the self-assembly process are also discussed.

**Transport and scanned probe investigation of chemical nanostructures**

*Hongkun Park, Harvard University*

In this presentation, I will discuss (1) the fabrication and characterization of nanometer-sized transistors that incorporate individual chemical nanostructures, including molecules, single-walled carbon nanotubes, and inorganic nanowires and (2) the synthesis and characterization of transition-metal-oxide nanowires.

**Convert Colloidal Nanocrystals into Standard Chemical and Biochemical Reagents**

*Xiaogang Peng, University of Arkansas*

Colloidal nanocrystals are of broad interest for fundamental studies and technical applications. It would be beneficial for those R&D activities related to nanocrystals if they could be developed as standard chemical and biochemical reagents. This challenge will be addressed in two steps, user friendly and environmentally benign synthesis and universally applicable ligand chemistry.

**Nanotechnology in Construction, From Concepts to Exploitation**

*Antonio Porro, Labein*

It is widely recognised that nanotechnology and its interaction with ICT are leading our Society towards a new industrial revolution.

Nanotechnology is offering huge opportunities to develop new materials/components with new and multiple functionality. On the other hand there is a sector of great economic activity, the construction industry, dealing with coarse components consumed in big amounts seeking for necessary innovations.

The construction sector is of high relevance for several reasons. Its economic significance, the employment generated and induced, and the big number of SMES engaged on it. But there are other significant aspects to be considered. We are spending a considerable part of our life inside buildings that provide us shelter and security.

We are also working in factories, commercial buildings, offices, etc. The infrastructures are absolutely necessary to develop our society activity. That means any improvement achieved on construction can be perceived as close to the general public, that take awareness on the use of the public investment on science and technology.

Another consideration to be done is the nature of the sector. The construction industry is also a great integrator of solutions offered by other industrial sectors. A building integrates water supply, heating, ventilation and communication systems, etc. The materials and components are often supplied by other sectors not included on construction statistics. The construction will take advantage of the developments achieved on those sectors, to be offered to the general public for its benefit.

The conciliation of both, the incredible possibilities offered by the nanotechnology and the enormous need of developments required by the construction is one of the challenges a group of institutes, universities and companies are keen to afford in Europe. A core group integrated by the University of Paisley, The Belgian Building Research Institute, the Centre Scientifique et Technique du Batiment and Labein are leading this action. The full partnership is composed of 30 partners from 15 European countries.

Nanotechnology can provide assistance in achieving the necessary sustainability for the construction sector. It can lead to a minor use on natural resources, not endangering performances. It also can assist to shorten the energy consumption in materials production, and specially on achieving energy efficiency in buildings.

Nanotechnology is then able to provide a revolutionary technological development, but balanced in terms sustainability.

All these aspects are covered in detail on the full presentation.

### **Nanostructured Mesoporous Three-Dimensional Architectures for Catalysis, Energy Storage, and Conversion**

*Debra Rolison, Naval Research Laboratory*

We create advanced electrode and catalytic architectures in which the pore and solid components are controlled on the nanoscale by the use of sol-gel syntheses-including nanogluing guests with necessary functionality into the solid network. The innate solid-pore architecture of aerogels, which are low density, innately nanoscale, highly porous materials, has long been recognized as melding high surface area for heterogeneous reactions with a continuous, porous network for rapid diffusional flux of reactants and products. These advantages, previously explored with aerogel-derived heterogeneous catalysts, are also relevant for active materials in batteries, fuel cells, photovoltaics, and ultracapacitors when electrically conductive paths are created.

We control the pore-solid architecture by removing the pore fluid of wet gels under conditions where the capillary pressures that develop are low (ambigels) or minimal-to-zero (aerogels). The continuity of the mesoporous network is a critical component in establishing the high-rate character of these architectures for sensing, charge-storage, and catalysis. The highly defective nature of the nanoscale mesoporous charge-insertion oxides MnO<sub>2</sub> and V<sub>2</sub>O<sub>5</sub> also contributes to

their electrochemical properties; spectroelectrochemical studies are particularly useful to distinguish whether the charge-transfer reactions at these materials are accompanied by electronic state changes in the manganese or vanadium cation.

We also erect catalytic three-dimensional nanoarchitectures in order to ask: "What does bifunctionality mean when the "support" and the "catalyst" are comparably sized?" Gold-titania composite aerogels are synthesized from oxide sols and alkanethiolate monolayer-protected gold clusters (Au-MPCs) and tested as ambient-temperature oxidation catalysts for carbon monoxide. The monolayer on the gold clusters is tailored such that the Au-MPCs are readily soluble in sol-gel media, allowing high dispersion of the Au throughout the resulting composite nanoarchitecture. Calcination crystallizes the amorphous oxide and removes the alkanethiolate to create catalytically active Au||oxide junctions. The Au-TiO<sub>2</sub> aerogel, with Au particle sizes that are essentially inactive in impregnated Au-TiO<sub>2</sub> catalysts, exhibits catalytic activity toward CO oxidation that equals or betters previously published results because of an increase in the interfacial contact area of the gold with the titania. These nanoscopic materials amplify the nature of the surfaces of technologically relevant conducting oxides and challenge the standard ways in which electrochemically and catalytically active oxides are conceived, studied, and used.

#### **All-Carbon Nanotransistors**

*Siegmar Roth, Max Planck Institut fuer Festkoerperforschung, Stuttgart*

A review is given on the various "generations" of nanotube-based field effect transistors:

- nanotubes over lithographic electrodes and macroscopic back gate, silicon oxide as gate oxide
- lithographic aluminium gate, aluminium oxide
- nanotube also as gate, linker molecules instead of oxide

The presentation will focus on the third of these devices and discuss its performance in terms of electromechanical interactions and shape changes of electrically charged nanostructures (actuator effect). Implications for nanoelectronics and molecular electronics will be alluded to.

#### **Smart Dust: Optically Encoded Porous Silicon Nanostructured Particles for Chemical Sensing and Biological Screening**

*Michael Sailor, University of California, San Diego*

The development of strategies for encoding micron-scale and nanometer-scale particles is of interest for drug discovery, genetics screening, and biological and chemical sensing. A method for encoding silicon particles has been developed based on the thin film optical interference properties of porous Si. Films of microporous silicon are optically encoded by changing the electrochemical conditions during porosification. These materials can be used as smart chemical sensor particles for remote detection of chemical or biological agents, and they can also be used in biological screening applications.

Optical encoding is accomplished by generating multilayer films in porous silicon through controlled etching conditions. Modulation of the current density used in the etch, results in a modulation of the porosity of the films. Light reflected at each layer boundary interferes with light from the other boundaries generating an interference pattern in the reflection spectrum. This pattern can be used as a fingerprint for identification purposes. Methods of encoding that have been demonstrated so far include Bragg Stacks and Rugate Filters and mismatched multilayers films. Bragg stacks generated by alternating layers with matched optical thickness

(refractive index times the metric thickness) produce sharp peaks in the reflection spectrum with FWHM ~15 nm and the wavelength of the feature can be tuned over the entire visible spectrum and out to the near IR by appropriate choice of etch conditions. This new method of encoding based on interference reflection spectroscopy improves upon existing fluorescence encoding methods by dramatically increasing the number of “colors” available. Rugate filters produced by a sinusoidal variation of refractive index also generate narrow peaks (FWHM ~ 10nm) in the reflection spectrum while suppressing sidebands and higher-order reflections. Alternatively, multilayer films with mismatched optical thickness can be designed. The Fourier transform of the resulting interference spectrum appears as a series of peaks corresponding to the optical thicknesses of each layer. Additionally the intensity of the peak can be adjusted by changing the refractive index contrast at each boundary. The position of the peaks is controlled by adjusting the thickness of each layer.

After a code is chemically etched into a wafer, an electropolishing current is applied to the silicon wafer to remove the porous film from the crystalline substrate. Ultrasonic treatment of the film in an aqueous or nonaqueous solvent generates micron-sized encoded particles that maintain the original optical signature.

### **Chromatogenic Chemistry, a new brand of chemistry for molecular grafting nanotechnology**

*Daniel Samain, Centre Interuniversitaire de Calcul de Toulouse*

Nanotechnology involves frequently the modification of surface physico-chemical properties at the nanometer scale. An important application is the hydrophobisation of nano porous hydrophilic materials. The best way to achieve this result is through the covalent molecular grafting of appropriate ligands onto the specific surface of the material. Classical solvent chemistry often gives poor results because of the difficulties for a liquid to wet the entire specific surface of a nano porous material. I would like here to describe chromatogenic chemistry, a new way to “think” chemistry in which the operating parameters are the vapor tension of the reagents and the temperature and flow rate of a gas stream which acts as a solvent. Major attractions of chromatogenic chemistry are its use of industrial reagents, its potential for being performed on web material at high speed and high efficiency and its clean chemistry characteristics.

### **Metal Nanoclusters – Properties, 2D and 1D Organizations**

*Günter Schmid, University of Essen*

Matter changes properties if its dimension falls below a critical size. Metal particles in the nanometer regime no longer behave metallic, but are characterized by a temperature dependent so-called Coulomb blockade. This means that single electrons can be transferred into the particle where they are stored until an increased voltage is applied to move them to a counterelectrode. Therefore, metal nanoclusters, also called “artificial atoms”, can in principle act as single electron switches. To reach that property at room temperature the particles have to be in the size range of only 1 – 1.5 nm, additionally protected by a nonmetallic skin. Those conditions are performed by nanoclusters of the type Au<sub>55</sub>L<sub>12</sub>Cl<sub>6</sub>, where L represents phosphine or thiol ligands. To use those properties, nanoclusters have to be organized two- or one-dimensionally. First results on the generation of ordered monolayers, one-dimensional arrangements and artificial structures of Au<sub>55</sub> clusters will be presented.

### **Multiphoton Nanolithography for the Production of Two- and Three-Dimensional Structures**

*Benjamin Schwartz, University of California, Los Angeles*

Conventional (one-photon) photolithography is based on exposing a photoresist to light through a mask, allowing the creation of 2-D patterns. In this talk, we show that by tightly focusing ultrashort light pulses into a photoresist, the peak intensity is sufficient to expose the resist via multiphoton absorption only in a small volume near the focus. Scanning the focal volume in 3-D followed by development of the resist allows the direct fabrication of 3-D structures. We have applied this technique to commercial photoresists, the photodeposition of Ag nanocrystals inside of sol-gel glasses, and to the 3-D patterning of molecularly imprintable polymers. The resolution can be improved by taking advantage of the field enhancement produced by a metallized AFM tip (apertureless near-field microscopy); with the enhancement, we have been able to write features as small as ~50 nm using 800-nm light.

### **Nanomaterials and Nanotechnology Research at Rensselaer**

*Richard Siegel, Rensselaer Polytechnic Institute*

The past decade has seen explosive growth worldwide in the synthesis and study of a wide range of nanostructured materials, the substance of nanotechnology. An overview of nanoscience and nanotechnology and their relationship to novel materials assembled from nanoscale building blocks will be presented within the framework of the U.S. National Nanotechnology Initiative and our new National Science Foundation Nanoscale Science and Engineering Center for Directed Assembly of Nanostructures at Rensselaer. Several examples from our recent research results will be presented including investigations of functional nanocomposites that could find use in a variety of structural, electrical, and biomedical applications.

### **Doping Nanomaterials**

*Geoffrey Strouse, University of California, Santa Barbara*

The incorporation of transition metal ion defect centers into the core of semiconductor materials have fascinated researchers due to their potential for phosphor, magnetic, spintronic, and electronic applications. In magnetically doped materials, the interaction of lattice, spin, and electronic degrees of freedom between the lattice core and the dopant ions can induce paramagnetic (PM), spin-glass (SG), antiferromagnetic (AFM), or ferromagnetic (FM) behavior depending on the magnitude of d-d (J) and the sp-d (a, b) exchange integrals between the paramagnetic dopant and host lattice. At the nano-scale, size-dependent changes may perturb magnetic ordering and lead to exchange properties that show strong size dependencies. Intentionally incorporating a magnetic defect ion by random ion displacement of the cation site in the core of a CdSe nanoparticle offers a convenient platform to probe the influence of quantum confinement on the interplay of magnetic and electronic degrees of freedom of the guest ion and host lattice. We report on the incorporation of Eu, Mn, and Co ions into CdSe quantum dots. We envision these DMQD may represent the next logical step in quantum computing applications via spintronics.

### **Nanostructured Surfaces for Enhanced Component Durability**

*Michael Stueber and Peter Dearnley, Forschungszentrum Karlsruhe and Leeds University*

Within the European Union there is an increasing need to remain globally competitive through the development of innovative products and processes. In the past few years there has been

increased awareness that nanostructured material surfaces can greatly improve the quality of engineering components. This is being made possible through surface engineering technologies like physical vapour deposition and a variety of established and frontier thermal spray deposition processes. Both nanocrystalline and nanocomposite surface coatings can be produced in this way. Presently there is a cluster of EU projects known as “nanotrib” that have the common aim of improving the tribological function of various engineering surfaces through the concise application of surface engineering. The resulting surface treatments should enable improved performance in a range of sectors that utilise both high and low friction devices. Not least of these is the automotive sector where increased engineering durability is always in demand to achieve vehicle weight reduction and energy savings.

### **Nanotechnology for Organic Semiconductors: The MONA-LISA Project**

*Carlo Taliani, Institute for Nanostructured Materials Studies, CNR*

MONA-LISA is a research project in the EU–GROWTH Programme aiming to explore the behavior of organic transistors upon downscaling of the channel length viz. the lateral size of the active layer. The idea behind MONA LISA is that by matching the characteristic lengthscales of the active layer (domain sizes are in the range 100 – 1000 nm) and the device, charge transport will occur in single molecular domains where order can be controlled. As a consequence, both charge mobility and switching rate of the device can greatly increase. At the moment we made devices based on ultra-thin films of 2-3 monolayers with mobilities larger than 0.04 cm<sup>2</sup>/Vs in the case of sexithiophene, and 0.1 cm<sup>2</sup>/Vs in the case of pentacene, with low hysteresis. Major results concern new methods for nanostructuring the active material, and for device fabrication based on a combination of top-down and bottom up parallel approaches. Channel lengths better than 300 nm by soft – lithography have been demonstrated.

MONA-LISA integrates multidisciplinary competences to address both fundamental and more applied issues, ranging from the understanding of fundamental properties and behaviour of molecules at multiple length scales, to transport in low-dimensional molecular structures, to more technological aspects of fabrication of nanostructures and devices, that are suitable for upscaling.

### **Nanotechnology for the Soldier and Polymer Photonics: Or Why a Scientist Would Ever Want to Direct a Really Big Research Center**

*Edwin Thomas, Massachusetts Institute of Technology*

The Army has recently established a 5 year, \$50M center at MIT for basic research, transitioning, and outreach in nanomaterials and nanotechnology to enable revolutionary advances in soldier protection and survivability. The ISN is the single largest and most visible nanotechnology effort at MIT and a cornerstone for further growth in this important area. The key soldier capabilities that the ISN seeks to investigate are:

- Strong, lightweight structural materials for Soldier Systems and system components
- Adaptive, multifunctional materials for Soldier Systems and system components
- Novel detection and protection schemes for chemical/biological warfare threats and IFF
- Remote and local Soldier performance monitoring systems
- Remote and local, wound and injury triage and emergency treatment systems to enhance Soldier survivability

- Novel, non-combat and combat performance enhancement systems for the Soldier system that would improve Soldier survivability en-route to and in the battlespace.

The first half of the seminar will describe the Institute and its approach of university and industrial partnering.

The second half will cover personal research on polymer-based photonic materials. Self assembling block copolymers provide a route to many interesting periodic structures, and can be designed to contain very specific properties by altering functional groups on the polymer, and/or doping block copolymers with nanoparticle additives. Another approach to fabricating photonic crystals involves using holographic lithography to produce 3D periodic network structures via photopolymerization. A third approach is to infiltrate, polymerize and replicate bio-templates to pattern high index materials. This talk illustrates examples of the 3 types of approaches and addresses the essential challenges in order to achieve desirable photonic properties using polymers. These include obtaining the requisite size of the domains for the wavelengths of interest, attainment of long range order, as well as providing sufficient dielectric contrast between the domains.

### **New Electronic and Magnetic Materials through Inorganic/Organic Self-Organization**

*Sarah Tolbert, University of California, Los Angeles*

In this talk we discuss ways to impart electronic and magnetic functionality into periodic composite materials produced through surfactant or polymer templating. We first show how reactive inorganic precursors such as Zintl clusters can be used to produce porous semiconductors. Using amorphous germanium as an example, electrostatically controlled self-organization is used to produce a periodic, porous material with optical properties that are controlled by the nanoscale dimensions of the germanium framework. We next show how spatial confinement of cobalt nanocrystals can be used to control magnetic coupling between individual superparamagnetic colloids. In these experiments, cobalt nanocrystals are stacked in rows through incorporation into the pores of a hexagonal nanoporous silica. Magnetic susceptibility measurements indicate that the dominant coupling is along the chains of colloids.

### **Nanoparticle Memories**

*Dimitris Tsoukalas, Institute of Microelectronics*

We shall present results on nanoparticle based memories fabricated in our lab during last years. We shall first discuss the fabrication of flash-type silicon memories where the nanoparticles are silicon nanocrystals fabricated in a 2-D configuration within a thin gate oxide using very-low energy implantation and subsequent annealing. This fully compatible CMOS process has the potential to produce either non-volatile memories with long retention times comparable with those of EEPROMs or DRAM like devices (fast write/erase) with long refresh times. Following a different path we also investigated the possibility to obtain memory devices that can be integrated in a 3-D architecture with CMOS logic. This requires the development of different technologies. We shall present here our approach to integrate gold nanoparticles used as charge storage elements and deposited at room temperature with the Langmuir-Blodgett technique on silicon devices. The memory properties of such devices will be discussed.

### **Counting electrons one by one: measurement of very small electrical currents**

*Helko E. van den Brom, NMI – Institute for metrology and technology*

Various national laboratories are performing research on relating electrical units to quantum mechanical phenomena that occur in systems on micro and nanoscale. Two familiar ones are the Josephson voltage standard and the Quantum Hall resistance standard. A quantum standard for current, based on counting individual electrons, is under development in the European COUNT project.

The approach is to exploit techniques based on single electron tunneling (SET) devices: an electron pump and an electron counter. These devices are able to accurately manipulate or detect individual electrons.

Using SET currents one can only deal with currents of typically a few picoamperes. In microelectronics industry these small currents are becoming more and more important with size reduction of electronic circuits, which are used in high performance, hand-held, battery operated, or low power consumer electronics.

### **Mechano-Chemical Sensing**

*Viola Vogel, University of Washington*

Discovering how mechanical force can switch the functions of proteins, and in many cases regulate cell signaling, is of fundamental importance in proteomics and medicine. It will ultimately reveal the molecular basis of many diseases where mechanical forces play critical roles in their onset or progression. Structural insights will be provided illustrating how protein function can be switched by stretching proteins into non-equilibrium states. *E. coli*, for example, binds more tightly to surfaces under shear-flow made possible by a nanoscale switch located at the outer tip of their long fimbriae. This adhesin switches from low to high affinity if mechanically stretched. Other mechanical switches exist in the multimodular adhesion proteins of mammalian cells. We used fluorescence resonance energy transfer (FRET) to probe the conformational states of the adhesion protein fibronectin in cell culture. Displaying protein unfolding events as visible color changes allowed us to prove that cells can apply sufficient tension to fibronectin to induce partial unfolding of its modules. These biological systems also provide new insights how biology addresses the issue of systems integration using nanocomponents. Finally, we assembled a picoNewton force probe meter from molecular building blocks to study receptor-ligand interactions under physiological loading rates.

### **Nanostructured Hybrid Materials for Nanobiotechnology**

*Ulrich Wiesner, Cornell University*

The study of functional organic-inorganic hybrid materials is an exciting emerging research area offering enormous scientific and technological promise. By choice of the appropriate functional organic molecules as well as inorganic precursors unprecedented morphology control on the nanoscale is obtained through cooperative self-assembly. In the present contribution the synthesis and characterization of nanostructured materials will be presented with potential applications ranging from microelectronics to nanobiotechnology. Examples will include the preparation of superparamagnetic mesoporous materials with pore sizes ranging from 5-50 nm for biomacromolecule separation technology and catalysis, the formation of nanostructured ultrathin films (<100nm) with potential biosensor applications as well as the synthesis of fluorescent silica nanoparticles with potential applications in bioimaging and biosensing.



**Sensing and Controlling Single Molecules by Novel Electrical and Optical Methods**

*Magnus Willander, Goteborg University*

We are starting a research project about sensing and controlling single molecules by novel electrical and optical methods. In the project we will study and use the optical field enhancement at specifically designed nanostructures for single molecule spectroscopy. For this reason we need to build up knowledge in spectroscopy-single molecule fluorescence spectroscopy as well as Raman spectroscopy. Nonlinear effects (two-photon excitation) may also be of interest. The molecules will be of biological origin, and the expected results of the project are new tools for single bio-molecule investigation and manipulation. We have research partners in biochemistry, biophysics and spectroscopy scattered around Europe, and a commercial partner specialized in lab-on-the-chip and DNA technology, all closed involved in the project.

