Materials Researchers Strut Their Stuff at the 2005 MRS Fall Meeting

Hynes Convention Center and Sheraton Boston Hotel ~ Boston, Mass.
November 28–December 2 ~ www.mrs.org

Just when materials researchers thought they looked sharp at the 2005 Materials Research Society Fall Meeting, the "Wearables Runway" models showed them up. Students from the MRS University Chapters at Carnegie Mellon, Boston University, the Massachusetts Institute of Technology, and other universities strutted their stuff in advanced fabrics engineered for fashionable and/or practical purposes.

Among the fashionable were the glowing models in lightning jackets, made by ITP, which are half tank tops sewn with optical fibers that carry light from light-emitting diodes throughout the entire jacket. Other chic models danced in Rosner jackets, which appear to be normal ski jackets. However, these parkas are embedded with an MP3 player, cell phone capabilities, wireless headphones in the hood, and a controller in the sleeve.

A lot of clothing with shape-changing, temperature-calibrating, color-transforming, music-composing, and other wild capabilities were modeled. But what is perhaps most impressive about the "Wearables Runway" exhibit is that it is not actually futuristic—it is current technology made possible through materials research.

While fashion was demonstrated in the exhibit hall, with the science behind it explained by presenters in Symposium X, high school students raced to the finish line with their hydrogen-powered cars in the MRS Hydrogen Fuel Cell Model Car Challenge. While these activities energized the hallways, the technical meeting buzzed in the conference rooms, covering energy and the environment, bio-organic–inorganic composites, nano- and microstructured materials, smart materials and devices, mechanical behavior, electronics and photonics, actinides, solid–solid interfaces, characterization, and combinatorial methods and informatics. The technical sessions were complemented with plenary and award presentations; special forums on materials education and entrepreneurship; a special outreach event with the Women in Materials Science and Engineering Breakfast; Research Tools Seminars, tutorials, and poster sessions; and government seminars, an exhibit, and a career center. The 2005 MRS Fall Meeting was held in Boston, Mass., at the Hynes Convention Center and Sheraton Boston Hotel, November 28–December 2, 2005. It was chaired by **Yang-Tse Cheng** of General Motors R&D Center, **David S. Ginley** of the National Renewable Energy Laboratory, **Kathryn E. Uhrich** of Rutgers University, and **Ralf B. Wehrspohn** of Paderborn University.

Energy and Environment

Plenary speaker Alan Taub (General Motors) presented the automotive-industry angle on energy conservation and environmental concerns, both of which require a materials focus for solving technological problems. Fuel economy requirements, emissions regulations, and the push for energy independence are key factors driving the auto industry to increase vehicle efficiency, said Taub, who is the executive director of Research & Development at GM. The main avenues for efficiency improvement are powertrain enhancements and mass reduction. GM is using lightweight materials such as aluminum and magnesium alloys, high-strength steels, and composites to reduce vehicle weight. The company is also employing

"Wearables Runway" was held at the 2005 MRS Fall Meeting in Boston. The fashion show modeling advanced fabrics was supported by the University of Paderborn.

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novel materials in the development of advanced vehicle and powertrain systems to achieve additional efficiencies. Taub described smart materials that enable new features and functions through mechamatronic solutions, that is, the integration of smart materials with mechanical systems and electronics. He is looking forward to breakthroughs in fuel cell and hydrogen storage technologies.

Migration to a hydrogen economy requires that a myriad of technological requirements be met, which was the focus of Symposium A, The Hydrogen Cycle—Generation, Storage, and Fuel. One specific need for high-performance hydrogen fuel cells is a proton-exchange membrane that is able to function at high temperatures with high proton mobilities. R.J. Berry (AFRL) showed how molecular dynamics simulations might in the future predict molecular structures for improved proton-exchange membranes. Currently, however, Berry is content to provide explanations on a molecular level for experimental observations of sulfonated polythioethersulfone (SPTES). For example, the dependence of the glass-transition temperature on the degree of SPTES sulfonation is consistent with experiments; water molecules strongly bound to sulfonate ions restrict chain mobility. Berry also investigated strategies for proton hopping, which is an important contribution to net proton diffusion.

K. Ross (Univ. Witwatersrand, South Africa) delivered the opening talk in Symposium A, addressing the implications of fossil fuel combustion for climate change. The concern is not that the climate is changing, she said, for the global climate has never been static. Rather, the issue for concern is the rate of climate change and the role of anthropogenic activities in precipitating such change. Greenhouse gases raise the temperature of the planet by about 33°C above what it would be in the absence of an atmosphere, and ice core records show that variations in greenhouse gas levels are tightly linked to temperature. However, while carbon dioxide levels have typically varied between 180 ppm and 280 ppm over the past 420,000 years, the global average carbon dioxide level has now reached 365 ppm. According to the Intergovernmental Panel on Climate Change, general circulation models predict that by the year 2100 temperatures will rise by between 1.5°C and 6°C, depending on the rate of fossil fuel consumption. Other consequences include changes in rainfall patterns and sea levels. Anthropogenic activities have disrupted the energy balance of the earth, Ross said; it is only natural that the earth will find a new equilibrium with a changed climate.

In Symposium D, J. Kido (Yamagata Univ., Japan) presented work on OLEDs for solid-state lighting. He presented small molecule-based devices, fabricated using vacuum deposition, with white-light efficiencies of 36 lm/W and lifetimes of >30,000 h at high brightness. Large-area devices with dimensions of 30 cm × 30 cm

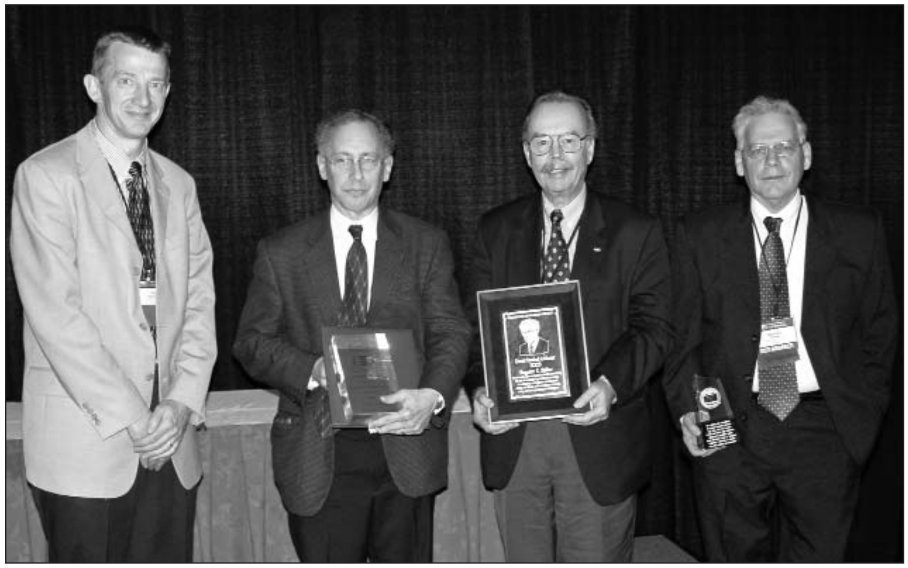
ACRONYM KEY

1D: one-dimensional
2D: two-dimensional
3D: three-dimensional
AFOSR: Air Force Office of Scientific Research
AFRL: Air Force Research Laboratory
AIST: Agency of Industrial Science and Technology
AMR: anisotropic magnetoresistance
ASU: Arizona State University
BNL: Brookhaven National Laboratory
CL: cathodoluminescence
CMOS: complementary metal oxide semiconductor
CNT: carbon nanotube
CRT: cathode-ray tube
CUNY: City University of New York
cw: continuous wave
CWRU: Case Western Reserve University
DARPA: Defense Advanced Research Projects Agency
DFT: density functional theory
DOE: U.S. Department of Energy
EC: electrochemical
FET: field-effect transistor
FRET: Förster resonance energy transfer
GE: General Electric
Georgia Tech: Georgia Institute of Technology
GM: General Motors
GMR: giant magnetoresistance
HEMT: high-electron-mobility transistor
HP: Hewlett-Packard
HRTEM: high-resolution transmission electron microscopy
IC: integrated circuit
IR: infrared
ITO: indium tin oxide
IZO: indium zinc oxide
JHU: The Johns Hopkins University
JPL: Jet Propulsion Laboratory
LANL: Los Alamos National Laboratory
LBNL: Lawrence Berkeley National Laboratory
LCD: liquid-crystal display
LED: light-emitting diode
LLNL: Lawrence Livermore National Laboratory
MBE: molecular-beam epitaxy
MEMS: microelectromechanical systems
MIT: Massachusetts Institute of Technology
MPI: Max Planck Institute
MRL: Materials Research Laboratory
MSE: materials, science, and engineering
MTJ: magnetic tunnel junction
MURI: Multidisciplinary University Research Initiative
NCSU: North Carolina State University
NEMS: nanoelectromechanical systems
NIDCR: National Institute of Dental and Craniofacial Research
NIEHS: National Institute of Environmental Health Sciences
NIH: National Institutes of Health
NIMS: National Institute for Materials Science
NIST: National Institute of Standards and Technology
NMR: nuclear magnetic resonance
NREL: National Renewable Energy Laboratory
NRL: Naval Research Laboratory
NSF: National Science Foundation
OLED: organic light-emitting diode
ONR: Office of Naval Research
OSU: Ohio State University
OTFT: organic thin-film transistor
PARC: Palo Alto Research Center
PDMS: poly(dimethylsiloxane)
PEDOT: poly(3,4-ethylenedioxythiophene)
PNNL: Pacific Northwest National Laboratory
PPE: photon photoemission
PSI: Paul Scherrer Institute
PSU: The Pennsylvania State University
PV: photovoltaic
PVDF: poly(vinylidene fluoride)
PZT: lead zirconium titanate
QD: quantum dot
R&D: research and development
REU: Research Experience for Undergraduates
rf: radio frequency
RFID: radio-frequency identification
RPI: Rensselaer Polytechnic Institute
SAM: self-assembled monolayer
SAW: surface acoustic waves
SEM: scanning electron microscopy
SERS: surface-enhanced Raman spectroscopy
SMA: shape-memory alloy
SNL: Sandia National Laboratories
STM: scanning tunneling microscopy
SWNT: single-walled carbon nanotube
TEM: transmission electron microscopy
TFT: thin-film transistor
UCLA: University of California–Los Angeles
UCSB: University of California–Santa Barbara
UHV: ultrahigh vacuum
UIUC: University of Illinois at Urbana-Champaign
UPS: ultraviolet photoemission spectroscopy
UV: ultraviolet
VCSEL: vertical-cavity surface-emitting laser
VCU: Virginia Commonwealth University
WPAFB: Wright-Patterson Air Force Base
XPS: x-ray photoemisson spectroscopy

have been fabricated in a prototype facility that uses linear sources for vacuum deposition over large areas. Kido estimated that commercial lighting products based on this technology will be sold by his industrial partners in Japan starting in 2007.

Bio-Organic–Inorganic Composites

In the 1970s, when many of Robert Langer's colleagues were applying their chemical engineering capabilities in oil companies, Langer found himself turning to the medical field as he sought to understand how materials can be used to address medical and biological problems. In his Von Hippel Award presentation, Langer (MIT) discussed early research on developing systems for the controlled release of large molecules (molecular weight >1000), such as polypeptide hormones, in the developing field of drug delivery systems. Against conventional wisdom, Langer's group discovered that microspheres made of hydrophobic polymers could release many different macromolecules in bioactive form for more than 100 days *in vitro* and *in vivo*. By using these techniques, a variety of systems for releasing polypeptides such as insulin, have been designed. More recently, in order to provide increased release rates on demand, controlled release microchips have been designed.



MRS Awards Ceremony (left to right): David J. Eaglesham, 2005 MRS President; Robert Langer, Von Hippel Award recipient; Eugene Haller, David Turnbull Lecturer, and Reshef Tenne, MRS Medalist. Courtesy of Marianne Haller.

Langer talked about the attempt to rationally design new materials for specific medical applications. Bioerodable polymers—in particular, polyanhydrides—have been synthesized as vehicles to release both large and small molecules. These polymers are unique in that they show surface erosion and lead to near-constant release rates of incorporated drugs. By altering the hydrophobicity of the polymer backbone, release times from one week to six years can be achieved. The polymers have been approved by the FDA in a novel drug delivery system for treating brain cancer. Langer said that the principle developed herein—local chemotherapy—is now being applied to a number of medical problems.

Approaches involving the synthesis and application of bioerodable polymers as implantable tissue scaffolds for mammalian cells are also being studied. Langer discussed the use of materials coupled with human embryonic stem cells or other cells, and the applications of these approaches to the creation of new tissues. This approach has been used to create a variety of tissues such as liver, skin, nerves, blood vessels, cartilage, and heart muscle in animals and humans.

In Symposium L on Mechanical Behavior of Biological and Biomimetic Materials, M. Sacks (Univ. of Pittsburgh) described the use of electrospun poly(ester urethane) urea (PEUU) as a possible material that could be used as a scaffold for tissue engineering of human body parts such as the heart valve leaflet (i.e., the soft tissue "flaps" that form the valve). Tissue-engineered parts should closely resemble the *in vivo* mechanical and structural properties of the tissues which they are intended to replace, he said. PEUUs are elastomeric and allow for the control of fiber diameter, porosity, and degradation rate through a variety of fabrication methods. Electrospun PEUU scaffolds can be fabricated to have a well-aligned fiber network, which is important for applications involving mechanically anisotropic soft tissues. Sacks described the development of a range of variable-speed electrospun PEUUs in an effort to quantify the effect of fiber orientation on the mechanical properties of the scaffold. In particular, PEUU scaffolds displayed increasingly higher orientation with increasing mandrel speed; the mandrel is part of the process equipment. The work demonstrated the tailoring of PEUU scaffolds for specific soft-tissue applications.

Increasingly, medical devices are being implanted in humans. Some of these devices are large, and to implant them would require major surgery and a large incision. This is where shape-memory polymers can help. Similar to shape-memory alloys, such polymers can be compressed into a smaller volume by thermomechanical deformation. When subjected to a stimulus, such as heat, they regain their original shape. K. Gall (Georgia Tech) discussed the properties and structures of shape-memory polymer networks used for such applications. One example is the cardiovascular stent, which is inserted into a blood vessel in a compact form and then expands to its pre-designed shape by body heat, thereby allowing easy flow of blood. However, other applications such as for orthopedics also require actuation. Gall described work by his group on using copolymerizing *tert*-butyl acrylate (tBA) and poly(ethylene glycol) dimethacrylate (PEGDMA) under UV irradiation to create shape-memory polymers. These networks have tailorable transition temperatures, biocompatibility, potential biodegradability, photocurability, and versatility. The shape-memory properties of the tBA-*co*-PEGDMA networks were shown to depend strongly on the cross-linking density and molecular weight of the cross-linking chain.

Neural probes, implanted in the brain, are used to deliver electrical signals or drugs to specific areas. Serious problems associated with such probes include rejection by the body and device bio-fouling. D. Martin (Univ. of Michigan) described the use of nanostructured polymer coatings for such probes to reduce or eliminate these problems. The polymer coatings used for these biosensors must be able to accommodate the exchange in charge transport from electrons on the device to ions in the tissue. The polymer used by Martin's group is PEDOT, which is grown electrochemically on the probes. In addition, chemical and biological dopants can be incorporated within the coating. A large surface area is important, and Martin described the formation of nanostructured microfibrils of the coating. The polymer coatings can be used for other applications as well, including retinal implants and cochlear electronics. More recently, Martin's group has explored *in vivo* growth of the polymer into the surrounding brain tissue. This technique benefits from much better carrier transport between the probe and brain cells.

Nano- and Microstructured Materials

Reshef Tenne (Weizmann Institute, Israel) proposed in 1992 that nanoparticles of layered compounds will be unstable against folding and close into fullerene-like structures and nanotubes (*IF*). Initially, this hypothesis was realized in WS_2, MoS_2, and their respective diselenides. Subsequently, nanotubes and fullerene-like structures were prepared from numerous compounds with layered and, recently, non-layered structures by various groups. Much progress has been achieved in the synthesis of inorganic nanotubes and fullerene-like nanoparticles of WS_2 and MoS_2 and many other metal dichalcogenides over the last few years, as Tenne discussed in his 2005 MRS Medalist presentation. He described synthetic methods for the production of multi-walled WS_2 nanotubes by sulfidizing WO_3 nanoparticles. His group has established a fluidized bed reactor for the synthesis of up to 100 g/day of fullerene-like WS_2 nanoparticles, and the scaling-up of the synthesis to 100 kg/day and beyond is under way. He detailed the mechanisms for the synthesis of fullerene-like WS_2 and MoS_2 nanoparticles and nanotubes of these compounds.

Tenne said that substantial progress has been accomplished in the use of such nanoparticles for tribological applications and lately, for example, impact-resilient materials for self-protection. Numerous testing programs have been undertaken jointly with different laboratories and major industrial partners and have clearly indicated the usefulness of the fullerene-like WS_2 and MoS_2 as solid lubricants in various products. These tests demonstrated that *IF*-MoS_2 and *IF*-WS_2 are heading for large-scale applications in the automotive, machining, aerospace, electronics, medical, and other industries. This technology was licensed to ApNano Materials Inc., which is currently involved in many collaborative development programs. Tenne presented novel applications of inorganic nanotubes and fullerene-like nanoparticles in the fields of catalysis, microelectronics, Li rechargeable batteries, optoelectronics, and medicine.

Nanoparticles can be fabricated in a wide variety of shapes, including wires, bells, peapods, core–shells, and nanotips. Functionalization of these nanoparticles is a first step toward device fabrication. In Symposium R, L.-C. Chen (Natl. Taiwan Univ.) described a technique for silicon and copper nanotip fabrication called self-masked dry etching that works on a variety of substrates. Chen showed that the nanotips, which are very sharp, can be functionalized with platinum or gold coatings. Arrays of these functionalized nanotips were shown to be promising for applications such as antireflective coatings, biosensors, field-emission, and surface-enhanced Raman spectroscopy.

Applications for nanofabricated devices, such as sub-wavelength optics and plasmonics, require the extension of the resolution of soft lithography to dimensions below 1 μm. G. Whitesides (Harvard) provided experimental evidence that the resolution of replica molding is two orders of magnitude lower than printing (0.4 nm versus 75 nm). Whitesides presented a new technique for nanodevice fabrication he calls nanoskiving. First, the surface of a polymer substrate is patterned with gold using nanolithography techniques. The surface is then covered with polymer. Next, a microtome is used to slice the structure at right angles to the gold layer, thereby forming gold nanowires or nanorings, depending on the original gold nanopattern. Whitesides said that he and his group are now working on extending this method to fabricate 3D nanostructures.

Being able to controllably place molecules on surfaces would be a tremendous advance for nanotechnology. P. Beton (Univ. of Nottingham, UK) discussed approaches for rationally constructing molecular templates using non-covalent interactions. Melamine–cyanuric acid interactions involving three hydrogen bonds are commonly used to construct 3D networks in the solid state. Beton and his colleagues have used similar interactions to fabricate honeycomb-like hexagonal networks on Ag-passivated silicon surfaces. These monolayers are grown over large areas and essentially segregate the surface into tiny pores. These pores can then be used as receptacles for a wide variety of molecules and nanostructures. As an example, Beton showed STM images indicating the formation of C_{60} heptamers in the receptacles. Nanoscale confinement in the pores leads to the formation of novel structures such as molecular clusters. Beton said that concepts of supramolecular chemistry can be used to rationally design complex nanoscale templates with controlled dimensions, and stressed the advantages of working with multimolecular networks.

Traditional optical "rulers" that measure conformations and interactions of small organic molecules are limited to distances of about 4 nm and are therefore insufficient when applied to large biomolecules. G. Strousse (Univ. of Florida) showed that his gold nanoparticles can be used to increase the measurement range of optical rulers to about 20 nm. Explaining that established techniques, like FRET, are limited due to the $1/r^6$ distance-dependence of dipole strength, Strousse based his technique on literature (circa 1980) that derived a $1/r^4$ distance-dependence of nanoabsorbers like gold. Strousse and coresearchers synthesized a series of DNA molecules to which a 1.5-nm gold particle and fluorescein dye were attached so that the intervening distance varied. Strousse demonstrated that the quantum efficiency of the dye displayed a $1/r^4$ dependence. He further demonstrated the utility of his technique by observing the formation of a hammerhead ribozyme from two strands of RNA—one labeled with fluorescein, and a gold nanoparticle bound to the other. The formation mechanism confirmed observations by crystallographers, but this new technique is much faster. Strousse plans a "molecular beacon" approach to bioassays in which a restriction cuts DNA at a point between the dye and gold nanoparticle.

For a long time, gold was considered to be completely non-reactive. However, in the nanoparticulate form, gold is surprisingly reactive, showing remarkable catalytic activity in redox reactions. In Symposium O, G.J. Hutchings (Cardiff Univ., UK) provided numerous examples of commercially significant reactions that can be catalyzed by gold nanoparticles. Carbon monoxide produced in fuel cells needs to be selectively oxidized to carbon dioxide at 80°C while avoiding the oxidation of hydrogen to water. Hutchings and his group have engineered an iron-oxide–supported gold catalyst which is able to meet the stringent requirements for fuel cells. Since metallic and cationic gold can be very catalytically active, developing the catalyst required the careful fine-tuning of calcination conditions. Hutchings also discussed a novel gold–palladium catalyst that catalyzes the reaction between hydrogen and oxygen to give hydrogen peroxide with very high selectivity, without the need for any promoters or stabilizers. Hutchings and his group made another catalyst of gold–carbon particles, ~25 nm in size, that can be used for the selective oxidation of glycerol to glycerate.

On the subject of nanostructures and sensors in Symposium O, R.J. Hamers (Univ. of Wisconsin, Madison) presented a novel digital approach to biosensing. Existing FET-based analog sensors are susceptible to drift and require ohmic contacts at the electrodes. Hamers and his colleagues have designed sensors that essentially work as switches. Gold nanowires equipped with biological-recognition properties by surface functionalization can be dielectrophoretically trapped between micropatterned electrodes that are functionalized with a complementary biomolecule. The trapping event can be detected in real time by a significant change in the current across the junction, corresponding to the "on" stage of a switch. The opening and closing of this nanoscale switch can thus be used to detect biological molecules without any

Seminars and Workshops Provide Tips for Obtaining U.S. Government Funding
http://Grants.gov • Materials Voice: www.mrs.org/materialsvoice

Materials researchers spend a good amount of time "chasing money" to fund their research. With help from the MRS Government Affairs Committee, the Fall Meeting hosted a number of seminars on the landscape of funding available for materials research, along with a workshop on communicating with the U.S. government in support of science policy.

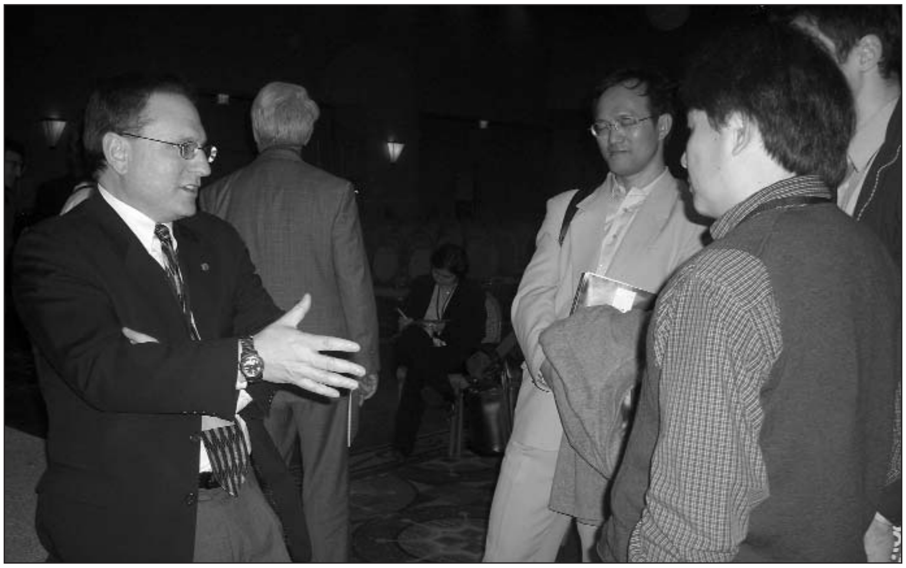
The first step in obtaining funding for research is to convince the government to make funding available. Michael Holland, professional staff member at the House Science Committee; Eric Werwa, senior legislative assistant in the office of Rep. Mike Honda (D-Calif.); and Michael Lubell, director of Public Affairs at the American Physical Society, told the attendees that congressional representatives and their "staffers" are extremely busy; the best way, the workshop attendees were told, to get their message across—if they get an appointment with a staffer—is to be direct and concise, and to put their request in the context of science initiatives that the politicians are already working toward. Attendees at the workshop received a reading list, a tip sheet on letter-writing, and an opportunity to send a letter to Congress through the MRS Web-based letter-writing program called Materials Voice, which is also located on the MRS Web site (**www.mrs.org/MaterialsVoice**).

Representatives from the National Science Foundation (NSF) and the National Institutes of Health (NIH) presented a separate workshop on how to write grant proposals. For NSF, proposals must provide a strong educational component along with the materials research idea. The Division of Materials Research within NSF now posts samples on its Web site of education highlights from past grant recipients: **www.nsf.gov/mps/dmr/highlights.jsp**. A particular challenge in preparing a proposal for the NIH resides in making the connection between materials research and medicine. To assist researchers in understanding the grant review process, the Center for Scientific Review within NIH has posted a video of a mock review session on its Web site: **www.csr.nih.gov/video/video.asp**. The most important piece of advice from both the NSF and the NIH is to research their respective Web sites for grant proposal guidelines and discuss research ideas with a program director or manager before preparing and submitting the proposal. In this way, scientists can determine the best program within the institution or agency where their research may get funded. The speakers at the workshop were Lance Haworth, executive officer of the Division of Materials Research at NSF; John Bowers, chief of biological chemistry and macromolecular biophysics at NIH; and Phillip B. Messersmith, associate professor at Northwestern University, who described his personal experience in writing successful funding proposals. The workshop was moderated by Eleni Kousvelari, director of the Center for Biotechnology and Innovation in the National Institute of Dental and Craniofacial Research at NIH.

In a separate funding seminar held by NSF, Tom Weber, director of the Division of Materials Research, listed the agency's "hot areas" as nanoscale science, cyberscience/cyber infrastructure, learning from biology, and global activities. From the U.S. Department of Energy, in response to the energy crisis, Harriet Kung, director of the Materials Science and Engineering Division, emphasized two types of materials solutions being sought: those to serve basic research needs for a hydrogen economy and for solar energy utilization.

Representatives from three branches of the U.S. Department of Defense spoke about the department's funding opportunities in both basic and applied research. John Prater from the Army Research Office based in North Carolina said that subsequent to Desert Storm in the early 1990s, the army decided to focus on the mobility and speed of its soldiers. Materials play an important role for this objective. Joan Fuller, a program officer at the Air Force Office of Scientific Research (AFOSR), described opportunities such as the summer faculty fellowship program, the resident research associateships program, and the undergraduate research program (ASSURE) along with research grant opportunities that reside primarily in basic research. In contrast to the AFOSR, funding from the Office of Naval Research (ONR) is strongly focused on the needs of the Navy and the Marine Corps and on developing real products for the fleet. Technical director and chief scientist of ONR, Starnes Walker, said that funding is intensely managed by a small cadre of professional program managers.

The U.S. government is moving toward an all-electronic process for grant applications. See Web site **http://grants.gov** for more information.



Following his Plenary address, Alan Taub (left) of GM meets with attendees.

need for ohmic contacts. Hamers and his colleagues are also able to trap bacterial cells between microelectrodes. This "catch and release" method enables bacterial cells to be dielectrophoretically trapped, measured, and released. Hamers said that the combination of microelectronics, biomolecular recognition, and electrical measurements provides rich and interesting opportunities for developing selective and sensitive biosensors.

Presentations in Symposium P covered the subject of quantum-confined semiconductor nanostructures. The extremely large extinction coefficients and remarkable photostability of CdSe/ZnS quantum dots enable single quantum dots to be easily imaged. M. Dahan (Ecole Normale Supérieure, France) discussed his work on using single quantum dots to probe optical and biological environments. Dahan and his colleagues were able to measure the radiative decay rates of single quantum dots, and found that the individual quantum dots have quantum yields that are close to 1. Dahan said that this is somewhat surprising, since ensembles of quantum dots (as measured in solution) typically show quantum yields of about 0.5, likely due to contributions from quantum dots that do not fluoresce and from some dots that blink. Dahan and his colleagues are also able to tag glycine receptors in live neurons with quantum dots by functionalizing the surface of the dots. This enables individual receptors to be tracked with a resolution of ~10 nm. In another experiment, Dahan and his colleagues tagged kinesin molecules, which are linear molecular motors for intracellular transport and cell division, with quantum dots, and were able to track the motion of these motors in the cytoplasm of living cells. Dahan said that the stage is now set for these quantum dot probes to be used to track cellular processes in complex biological environments such as tissues.

To generate and store power in space, batteries and photovoltaic cells need to be able to withstand harsh conditions such as high-energy radiation. In Symposium Q, R.P. Raffaelle (Rochester Inst. of Technology) discussed the use of nanostructured materials to increase the radiation tolerance of these devices. While radioisotopes can store orders of magnitude more energy than regular materials used in batteries, they cause severe radiation damage to the converters, thereby rendering them unusable even before the nuclear material is completely used. In the approach taken by Raffaelle and his colleagues, the high-energy radiation from the radioisotopes is used to excite quantum dots, and the converted photons are used to generate electricity. This has led to the development of a battery based on nanostructured rare-earth phosphors and InGaP devices, showing less than 1% degradation under exposure to a year's worth of α-particle radiation. Raffaelle mentioned long-lived radioisotope microbatteries as an example of a promising application resulting from the high radiation tolerance of nanostructured materials. Raffaelle and his colleagues have also explored radiation damage in CNTs and InAs quantum dots. CNT networks show little decrease in electrical conductivity upon exposure to α-particle irradiation, while InAs quantum dots show a much improved radiation tolerance as compared with the bulk. Raffaelle accounts for the enhanced stability of nanostructured materials by citing the fact that electrons in quantum dots do not interrogate defects caused by radiation in the same way they do in the bulk. In other words, he said, an electron in a quantum dot is not as affected by defects in a neighboring quantum dot.

While nanomaterials have many beneficial aspects, researchers need to exercise caution to ensure safe production and implementation of these materials, said Erik Rushton (Univ. of Rochester), delivering an invited talk in a combined session of Symposia G and S. Rushton said that while nanoparticles are increasingly being used for applications such as biological imaging and tumor therapy, there is little that has been done in terms of a life-cycle analysis for these materials. Rushton said that virology may be a good starting point for understanding the toxicity of nanomaterials, since viruses have dimensions similar to nanoparticles. Some of the pathways and mechanisms through which viruses access the body may also be common to nanoparticles. A significant problem for nanomaterial toxicology is the great variability in the methods used to obtain toxicological profiles of nanomaterials, which makes it difficult to compare the relative toxicities of different materials. There is still no consensus on the correct dosimetric parameters for nanoparticles, or whether they should be quantified according to the number of particles, mass, or surface area, said Rushton. In general, it seems likely that nanoparticles, due to their large surface area, are able to generate reactive oxygen species, which can have adverse effects on biological molecules. Rushton and his colleagues have carried out comparative studies of the toxicity of MnO and TiO_2 nanoparticles. The MnO particles are seen to be much more toxic than the TiO_2 particles. Rushton said that not only size but also crystal structure and composition play key roles in determining the toxicity of a nanomaterial.

Smart Materials and Devices

Multicomponent polymer systems exhibit properties that are greater than the sum of their parts. Delivering an invited talk in Symposium W, M.D. Dadmun (Univ. of Tennessee) said that the nonlinear enhancement of properties in polymer blends and nanocomposites critically depends on the dispersion of the minor phase in the matrix and on the interfacial adhesion between phases, which facilitates interactions between the two components. To achieve improved dispersion of rod-like liquid-crystalline polymers and CNTs in polymer matrices, Dadmun and his colleagues make use of intermolecular hydrogen-bonding interactions between the components. By separating hydroxyl groups along the chain of the polymer, intermolecular hydrogen bonding between the polymer matrix and the fillers is optimized. Furthermore, Dadmun explained that separating the hydroxyl groups along the polymer chain imparts dynamic freedom to the functional groups, which enables optimized hydrogen-bonding with the filler. Dadmun and his colleagues have found that in CNT–polymer composites, the most favorable enhancements in mechanical and electrical properties are seen when hydrogen-bonding between the nanotubes and the polymer matrix is optimized.

Symposium V, on Materials and Devices for Smart Systems, reached a number of significant conclusions. In order to realize true smart technology, highly efficient actuator/sensor element materials research and development are required in areas such as the optimal control of the high-performance polymers based on a self-organization mechanism, the nanodomain morphology, CNT composite, and submicron crystalline structure and its interface. Technological fusion in new functional materials by nanotechnology processing and NEMS/MEMS fabrication system is becoming indispensable to active and smart device development, and the development of the field of sensors with NEMS technology is making its appearance. Significant advancements are expected in the technical possibilities of active vibration control; active, non-contact, nondestructive evaluation; and structural health monitoring with wireless sensing technology such as SAW sensing. The development of *in vitro* and *in vivo* biosensor research is becoming more important, where very light and small devices are able to be used on or in the body through the combination of thin-film, MEMS, and smart actuator and sensor technologies.

Mechanical Behavior

There has been limited work on hardness measurements of bcc nanocrystals until now. In Symposium Z, T.G. Nieh's group from the University of Tennessee reported results of nanoindentation hardness measurements on bcc Ta nanocrystals. For a 76-nm average grain size, a hardness of 11.6 GPa was obtained, which is 10 times higher than the hardness of commercial coarse Ta. This compares very well with other nanocrystals, for example, bcc Mo with a 26-nm average grain size yielding a hardness of 11.8 GPa. In additional preliminary work, Nieh's group reported that for a Ta nanocrystal coating on Si with a 35-nm grain size, a hardness of 16 GPa was obtained, which is close to the theoretical strength of the material. While it is not clear whether this is solely due to grain-size strengthening—for example, impurity strengthening and tetragonal β-phase effects cannot be ruled out—the results are very intriguing, the speaker said.

In Symposium AA, sessions on tribology exposed the role of small scales and chemistry. K.S. Kim (Brown) introduced a method for calibrating the lateral deflection forces on the cantilever in an atomic force microscope, enabling the accurate measurement of friction forces at the nanoscale. He then showed that the friction of nanotube composite surfaces could be modified by controlling the length of the nanotubes protruding from the nominal surface of the material. He also obtained quantitative friction data in the mesoscale regime that demonstrates the size scaling of the transition between high friction at the atomic scale and low friction at the macroscopic scale, consistent with recent theoretical models.

The final session in Symposium BB commenced with a review, by Y. Gogotsi (Drexel), of the effect of temperature on the indentation response of semiconductors. This presentation reminded the audience that mechanical properties of very small volumes are of interest over a wide temperature regime and that the almost exclusive focus on room-temperature property characterization is severely limiting. The emerging availability of nanoindenting instruments to reliably measure such properties will increasingly be in demand by those involved in such mechanical characterization techniques.

Electronics and Photonics

The 2005 David Turnbull Lecturer, Eugene E. Haller of the University of California, Berkeley, presented his talk on "Isotopically Controlled Semiconductors." Isotopes of a given chemical element differ in the number of neutrons making up their nuclei. For example, each silicon nucleus has 14 protons but can have 14, 15, or 16 neutrons forming the stable isotopes $^{28}_{14}$Si, $^{29}_{14}$Si, and $^{30}_{14}$Si, respectively. In crystalline semiconductors, the resulting differences in nuclear mass affect certain properties in subtle ways and others in pronounced ways. These properties include thermal conductivity, lattice vibrations, lattice constants, density, and bandgaps. Isotopic composition influences localized vibrational mode spectra as well as far-infrared, Raman, and photoluminescence spectra. Artificial isotope multilayer structures and isotope superlattices exhibit new phonon dispersion relationships and have been used to study self- and dopant-diffusion in novel ways. Besides the different masses of isotopes of a given element, differences are found in nuclear spin and in the absorption cross section for thermal neutrons. These isotope-specific properties may lead to applications in doping and quantum computation, Haller said.

In nature, about 80% of all the elements consist of more than one stable isotope. The remaining 20% are monoisotopic and include, among others, the elements aluminum, phosphorus, arsenic, and gold. The semiconductor elements silicon and germanium have three and five stable isotopes, respectively ($^{28}_{14}$S, 92.2%; $^{29}_{14}$Si, 4.7%; $^{30}_{14}$Si, 3.1%; $^{70}_{32}$Ge, 20.5%; $^{72}_{32}$Ge, 27.4%; $^{73}_{32}$Ge, 7.8%; $^{74}_{32}$Ge, 36.5%; and $^{75}_{32}$Ge, 7.8%). Separation of an element into its isotopes requires highly sophisticated equipment that was developed during the Second World War, Haller said. At prices of a few dollars per milligram to tens of dollars per milligram, access to sizable quantities of enriched elemental semiconductor isotopes or isotopes of elements forming compound semiconductors (e.g., GaAs, GaN, and ZnS) remained very limited. This situation changed dramatically after the end of the Cold War, when scientists and engineers were able to form collaborations with Russian and Ukrainian researchers who had access to large reserves of highly enriched isotopes of a broad range of elements. Haller said that this conversion from the use of isotopes for nuclear weapons to civilian use is a case of "swords into plowshares."

In the opening talk of a joint session of Symposia EE and FF addressing semiconductor materials, J. Dong (SVT Assoc.) presented recent results on ZnCdO alloys and *n*-ZnO/*p*-AlGaN–based heterostructures. The advantages of ZnO-based optoelectronics include high-temperature device operation, the availability of low-dislocation-density substrates, and the lower cost of raw materials as compared with competing materials systems (e.g., zinc costs a tenth of the price of gallium and a fifth of the price of indium). ZnO-based structures will produce emission spanning a wide wavelength range. Alloys of ZnO (3.2-eV bandgap) with MgO (7.9-eV bandgap) will produce devices operating far into the UV and alloys of ZnO with CdO (2.3-eV bandgap) will provide emission throughout the visible spectrum due to the strong bandgap bowing for the ZnCdO alloy. Dong reported recent results on RF plasma-assisted MBE growth of ZnCdO. Films were homogeneous and produced bright CL emission. With regard to LED production, the challenge of obtaining *p*-type ZnO remains. Heterostructures incorporating *n*-ZnO and *p*-AlGaN may provide a solution, with the added advantage that a hole accumulation layer should form at the interface; calculations estimate a hole sheet density of up to 1.8×10^{13} cm^{-2}. Dong concluded with a report of a UV LED based on a *p*–*n* junction MgZnO/ZnO/AlGaN/GaN semiconductor triple heterostructure, which operates up to 650 K.

Progress continues in the development of deep-UV LEDs with emission below 300 nm. In the first talk of Symposium FF, A. Khan summarized recent research results from a research team at the University of South Carolina. The researchers have devices that produce 2.5 mW at 280 nm, 0.6 mW at 265 nm, and 0.35 mW at 255 nm, all at pump currents of only 20 mA. Such LEDs have applications ranging from the detection of biochemicals such as anthrax, to air and water purification, to the excitation of phosphors in light sources, to the curing of polymers in dentistry. Significant improvements in device performance have been realized from the implementation of growth techniques such as pulsed lateral epitaxial overgrowth, which provides improved lateral growth rates, and in the production of interconnected micropixel LEDs. Micropixel 280-nm LEDs now exhibit lifetimes of up to 1000 h. The small pixel size leads to the elimination of current crowding and the reduction of device self-heating.

In another session of Symposium FF, A. Kim demonstrated the Lumileds Lighting pocket projector. It is based on a red, a green, and a blue LED and is literally small enough to fit in the palm of the hand. As well as the advantage in size, such projectors have the advantage of long life (no bulbs to burn out), low-voltage operation, and high color saturation, and they may be switched on and off instantly—no need to worry about blowing the projector bulb. Kim summarized the features that allow Lumileds to produce LEDs that are sufficiently bright to be used in a projector system. For example, clever packaging with integrated optics and flip-chip design allow efficient heat extraction and enable devices to operate at high power. Kim also emphasized that there is still plenty of scope for further improvements in LED operation. Optimal performance will be realized through obtaining an understanding of the underlying fundamental physics. Kim asked the questions of why the efficiency of InGaN-based LEDs reduces with increasing indium composition, and why there is a 45% enhancement in the growth rate of InGaN quantum wells when compared with that of a thick GaN template. He then presented the results of growth studies aimed at addressing these issues, showing phenomena such as the loss of step flow growth for InGaN on GaN and islanding on terraces.

G. Gruner (UCLA) predicted that 2D networks of CNTs will very soon outperform indium tin oxide (ITO) and conducting polymers for transparent and flexible electronics applications. Gruner and his colleagues have developed a low-cost, room-temperature process for fabricating films of CNTs on appropriate substrates. By reducing the bundle size and purifying the tubes, good conducting paths can be established through these nanotube networks while still retaining transparency, Gruner said in an invited talk in Symposium DD. The sheet resistance for films with 80% transparency is as low as 100–150 ohm per sq, comparable or better than certain ITO films on plastic and conducting polymer films, with a further increase of performance expected upon network optimization. An additional advantage for CNT networks is that the optical transmittance does not show significant wavelength dependence in the visible range, thus providing neutral-colored films, rather than the bluish and yellow coloring seen for polymer and ITO films, respectively. Gruner and his colleagues are exploring applications of these networks in smart windows, conducting fabrics, OLEDs, solar cells, and also as artificial eyes for the direct conversion of light to electronic signals.

U. Wiesner of Cornell University, in his Symposium CC talk, discussed a new class of materials called "Cornell dots," consisting of dye molecules encapsulated in a silica shell. These novel core–shell materials show a significantly enhanced quantum yield and high brightness per particle, as compared with the dye molecules or just the dye core. The silica shell engenders many applications of these materials by imparting water solubility and compatibility with various surface-functionalization protocols. A number of different dyes can be sequestered in these silica shells, and the size of the particles can be tuned between 20 nm and 1 μm. Wiesner and his colleagues have developed methods to make many variations of these particles to specifically engineer the photonic properties by changing the size of the cores and even by adding two different dye layers to the same particle. Preliminary results presented by Wiesner demonstrate that these particles may be useful for constructing photonic crystals as well as for

Teenagers Race Hydrogen Fuel Cell Model Cars at 2005 MRS Fall Meeting

Drivers, start your…fuel cells? That's what students from 25 New England high schools did at the 2005 MRS Fall Meeting during the MRS Hydrogen Fuel Cell Model Car Challenge. The event challenged teams of high school students to design and fabricate a small vehicle powered by hydrogen to be raced in a double-elimination tournament. In preparation, the teams were provided in advance with information about how hydrogen fuel cells work and with some basic tips for automotive design. Beginning at 9:00 a.m. on Monday, Nov. 28, participants began to assemble their vehicles, aided by volunteer mentors from the MRS University Chapter of the Massachusetts Institute of Technology. Teams were allowed to build their chassis ahead of time, but the remainder of the vehicles had to be built on site. Although all the entries were based on the same reversible membrane fuel cell (provided by Fuel Cell Store; www.fuelcellstore.com), a wide variety of vehicles demonstrated the creativity of the designers. A fun-filled hour of racing provided meeting attendees and racers alike with a chance to cheer on their favorite car, be it a speed racer, a steady roller, or, unfortunately, dead in the water. In the end, students from Cumberland High School in Rhode Island proved to have the winning design, taking the six-foot-tall first-place trophy for their school.

The event was sponsored by MRS, General Motors, National Renewable Energy Laboratory, and Energy Conversion Devices.

making micro-oscillators for lasing applications. Furthermore, these particles can be surface-functionalized to specifically bind to cell surfaces. A significant example of the potential applications of these nanoparticles in biology involves a core–shell particle with two dyes. An inner rhodamine core in the particle provides a reference signal while an outer fluorescein sensor dye imparts pH sensitivity. These multifunctional particles have been used to map the pH in different areas within a cell. Wiesner reported that studies on mice indicate no adverse effects for these new materials.

C.J. Murphy and her colleagues at the University of South Carolina reported the growth of gold nanorods from small spherical gold nanoparticle seeds by the addition of a surfactant, cetyltrimethylammonium bromide (CTAB). The reactions were performed in water, in air, and at room temperature, Murphy reported in Symposium CC. The CTAB molecules formed a bilayer on the gold nanorods, enabling spatially directed chemical reactions to be carried out at the surfaces of the rods. Since the CTAB surfactants impart a positive charge to the nanorods, a short, negatively charged adipic acid linker can be used to assemble the nanorods, side by side, through electrostatic interactions. Electrostatic interactions can also be used to form layer-by-layer assemblies of these nanorods using polyelectrolytes. Furthermore, while the CTAB bilayer protects the sides, the ends of the nanorods can be biotinylated through sulfide chemistry, and the rods can be stitched together in end-to-end arrangements using biotin–streptavidin interactions. Murphy and her colleagues also polymerized styrene in the tiny hydrophobic domains within the bilayer, leading to plastic-coated nanorods. Murphy said that the rich diversity of functionalized nanorods that are accessible through chemical reactions at the CTAB bilayer will be useful for developing sensing and imaging applications for these materials.

For further details on the research results reported at the 2005 MRS Fall Meeting, see the following symposium summaries. Proceedings as well as additional meeting highlights are available online at www.mrs.org.

Basic Research Endeavors Required to Enable Transition to Vehicular Hydrogen-Based Society *(See MRS Proceedings Volume 885E)*

Approximately 95% of hydrogen produced is generated by reforming natural gas, a catalytic thermochemical process. However, in order to utilize hydrogen in a virtually pollution-free cycle, it is necessary that renewable resources be explored for hydrogen production. The hydrogen production session in Symposium A on Hydrogen Cycle—Production, Storage, and Fuel Cells largely revolved around developing more durable and less expensive materials than currently available to employ solar or wind power in the electrolysis of water. The development of methods for the conversion of biomass to hydrogen in an economical fashion was also discussed. On-board hydrogen storage has been deemed the cornerstone technology for implementing hydrogen as a fuel in the transportation sector, as none of the current technologies meet the DOE's 2015 technical targets. The storage sessions consisted of both theoretical predictions and experimental efforts geared toward the development of a safe and practical storage medium. Topics of discussion largely included chemical hydrides, complex metal hydrides, and the development of carbon-based adsorption systems. Although proton electrolyte membrane fuel cells are already operative, numerous talks on the ongoing research to bring down their cost and increase their durability were presented. In addition, there was a technical session devoted to solid-oxide fuel cells as a promising possible alternative.

Symposium Support: GM R&D Ctr.

New Battery and Supercapacitor Designs Demonstrated

Presentations in Symposium B focused on new battery and supercapacitor designs, along with advances in synthesis, characterization, and modeling. In his opening talk, B. Dunn (UCLA) described novel approaches for preparing electrode arrays. In one example, silicon molds were fabricated through silicon micromachining; vanadium oxide nanorolls were then used to fill the molds. In a second system, Ni was electrodeposited and then subsequently oxidized to $Ni(OH)_2$.

In the area of novel, non-oxide-based electrode materials, G.G. Amatucci (Rutgers) described the use of fluoride nanoparticles (e.g., BiF_3, CuF_2, and FeF_3) as cathode materials. Of particular note was the high volumetric capacity (8000 Wh/1) obtained in the conversion reaction of Li and BiF_3 nanoparticles, which occurs at 3.1 V (vs. Li), and the reversible reaction of bismuth oxyfluoride nanoparticles with lithium. M.R. Palacin (ICMB, Barcelona) showed how the stability of lithium manganese nitrides could be improved through the formation of oxynitrides. S.J. Visco (Poly-Plus Battery Co.) described the design and construction of lithium metal anodes that can operate in aqueous electrolytes. The Li anodes electrodes were stable in seawater—a concept illustrated by constructing an operating battery in a seawater aquarium containing live fish. The fish appeared unaffected by the experiment. J. Gaubicher's (IMS–Nantes) work on lithium vanadates highlighted the importance of understanding and controlling structure and particle size and morphology if optimum battery electrode performances are to be realized. B. Bowden (Duracell, Proctor and Gamble) showed how an improved understanding of the local and long-range structures of manganese oxides (from TEM, electrochemistry, and NMR) has led to the development of improved materials for lithium cells.

NMR studies of both local and long-range ionic motion were described by G. Goward (McMaster) and S. Greenbaum (Hunter). Theories were given on how DFT methods could be used to understand and predict optimal ionic conductivity of Li^+ in layered materials (K. Kang, MIT) and phosphates (D. Morgan, Univ. of Wisconsin). Both DFT (Y. Hinuma, MIT; A. van der Ven, Univ. of Michigan) and experimental methods such as magnetic susceptibility measurements (N.A. Chernova, SUNY Binghamton) and TEM/diffraction results (Y. Shao-Horn and Y. Shirley Meng, MIT; L. Croguennec, ICMCB-CRNS) were used to investigate cation ordering in lithium nickel manganese oxide and lithium nickel manganese cobalt oxides and how this varies with temperature, synthesis conditions, and cycling.

Link Forming between Materials Research and New Building Technologies

Symposium C on Material Innovations for High-Performance Building Systems brought together the architecture and materials science communities to discuss the potential for and impact of new materials in the design and construction of buildings, from individual homes to high-rises. Presentations ranged from the modular UP!house, an upscale hi-tech house out of the Parsons School of Design at Columbia University, to a tag-team presentation by architect Billi Faircloth from the School of Architecture at the University of Texas at Austin and scientist Ben Dietsch from the Cornerstone Research Group showing how shape-memory polymers can change the way buildings are designed. Other topics included next-generation windows, improved concrete, and the impact of new materials on building performance.

Advances Made in Organic and Nanostructured Composite PVs and Solid-State Lighting

J. Kido (Yamagata Univ.) announced in Symposium D that a white-light OLED with an efficiency of 36 lm/W has been fabricated, and estimated that a product based on this technology would come out of a Japanese consortium in 2007. Several research groups discussed recent developments with polymer-fullerene, bulk heterojunctions, PV cells that now have a power conversion efficiency above 4%. Researchers at Konarka Technologies have made a new polymer with an optical bandgap of 1.4 eV and a field-effect hole mobility of 10^{-3} cm^2/V s. Theoretically, the polymer should enable the fabrication of bulk heterojunctions with fullerenes that have a 7% efficiency. So far, the highest obtained efficiency is 3.5 %. P. Blom's research group (Univ. of Groningen) has made a polymer tandem cell with low- and medium-bandgap polymers absorbing light in different regions of the solar spectrum. B. Rand (Princeton) reported that tris(acetylacetonato) ruthenium (III) serves as a better exciton blocking layer than previously used materials because it does not need to be damaged by the electrode deposition to function properly and can therefore be thick enough to optimize optical interference at the exciton splitting junction. M. Summers (Stanford) showed that energy transfer can occur from conjugated molecules to fullerenes and that resonance energy transfer can be used to more than double the distance over which excitons can be harvested in polymer–titania solar cells. I. Gur (UC–Berkeley) showed that pastes of CdTe and CdSe nanocrystals can be cast and then fused together to make very stable solar cells with an efficiency greater than 2%. CIGS cells with an efficiency of 6% can be made by printing nanocrystals.

Symposium Support: Air Products and Chemicals, GE, NREL, PARC, and Xcel Energy.

Organic Materials Help Electrochromic Systems Show Their Colors

A rising interest in the field of organic electrochromics, with an emphasis on the use of polymers in displays, was demonstrated in Symposium E. J. Reynolds (Univ. of Florida) summarized a vast array of colors and combinations achievable with electroactive polymer films. G. Sonmez (Sabanci Univ., Istanbul) reported the development of green EC polymers to complete the set of additive primary colors. N. Robinson (Linköping Univ.) used electrochromism to elucidate the mechanism and potential distribution in thin-film organic transistors designed for use in displays.

In the field of oxide electrochromics, D. Pender (Saint-Gobain Sekurit) unveiled the EC sunroof now available in ultraluxury automobiles, soon destined for the mid-range market. The WO_3-based, all-solid-state units achieve a blue-to-clear contrast ratio of 20:1. C. Granqvist (Uppsala Univ.) introduced lightweight, flexible EC face shields and sunglasses, the former going into production in 2006. Tunable IR emissivity coatings containing tungsten or cobalt oxides were described by M. Morcrette (Laboratory of Reactivity and Chemistry of Solids, Amiens, France).

Presentations covered four types of switchable mirrors. R. Griessen (Vrije Univ., Amsterdam) has developed a highly absorbing/highly reflecting coating for solar collectors utilizing hydrogen-absorbing Mg-Ti films. K. Yoshimura (AIST, Nagoya) presented a solid-state Mg-Ni mirror with a WO_3 counterelectrode that switched from 0% to 50% in transmittance. T. Richardson (UC, Berkeley) described a similar mirror using a transparent gas reservoir counterelectrode. M. Tench (Rockwell) detailed extensive refinement of the silver–silver EC mirror and introduced a new version using a soluble EC chromophore that reduces the window's reflectivity as seen from the inside. B. Farangis (Giessen) showed a Mg-Ni hydrogen sensor that responds both optically and electronically to low levels of hydrogen.

Advances in Thermoelectrics and Thermionics Emphasized in Direct Thermal-to-Electric Energy Conversion *(See MRS Proceedings Volume 886)*

M. Dresselhaus (MIT) opened Symposium F with an overview of nanoscale thermoelectric materials research. Theoretical and experimental work on bulk nanocomposites identify promising future research directions for nanocomposites produced both by nanofabrication processes and by chemical methods. J. Fairbanks (DOE) discussed the near-term to far-term potential for high-efficiency thermoelectric applications in transportation. F. Stabler (GM) highlighted the path and the challenges of thermoelectric technology development. A growing trend in research into nanoscale enhancement in materials and devices is evident, with talks on J. Heremans' (OSU) work on PbTe with nanostructures, M. Kanatzidis' (Michigan State Univ.) talk on nanostructured $AgPb_mSbTe_{2+m}$, H. Linke's (Univ. of Oregon) presentation on energy-specific equilibrium in heterostructured nanowires for high-efficiency thermoelectric energy conversion, T. Harman's (MIT) quantum-dot-superlattice thermoelectric materials, and H. Ohta's (Nagoya Univ.) study on the giant Seebeck effect originating from two-dimensional electron gases. A number of theoretical studies provided a fundamental understanding of the physics underlying materials and phenomena, for example, thermoelastic refrigerators (J. Maynard, Penn State) and the filling fraction limit for skutterudites (W. Zhang, Shanghai Inst. of Ceramics).

Symposium Support: GM, Keithley Instr., Marlow Industries, MMR Technologies, ONR, Quantum Design, Thermal Technology, and ULVAC Technologies.

Life-Cycle Analysis of Environmental Profiles of Products and Processes Presented *(See MRS Proceedings Volume 895)*

A cradle-to-grave approach using life-cycle analysis (LCA) tools was the main focus in Symposium G for addressing the complex and multidisciplinary environmental issues of products and processes. Life-cycle assessments have become widely used for the evaluation of the environmental impact associated with the extraction of raw materials and the manufacturing, use, and end of life of materials. The main goal of such an analysis is to identify the sources that contribute the most to adverse environmental pollution and to provide design and manufacturing engineers the information that will allow them to choose among alternative materials and processes.

A wide variety of applications were presented, ranging from the production of alternative fuels using various feedstocks (N. Brinkman, GM; H. MacLean, Univ. of Toronto), hydrogen storage (A.C. Dillon, NREL), the environmental impact associated with PV production (E. Alsema, Utrecht Univ.; M. De Wild-Scholten, Energy Research Center, the Netherlands) recycling of products, and nanomaterials (E. Rushton, Univ. of Rochester; D. Rolison, NRL). Two joint sessions with Symposium S provided a forum for exchanging valuable knowledge on the impact of nanotechnology on the environment, with the potential of expanding the use of LCA techniques into the area of nanomaterials research (S.I. Olsen, Technical Univ. of Denmark).

Case studies focusing on the LCA of automotive systems (S. Papasavva, GM; M. Binder, PE-Gabi), the engineering/economic barriers associated with the development of a hydrogen infrastructure that supports hydrogen as a fuel for future transportation (J. Ogden, UC, Davis), the design of alternative materials to enhance sustainability (G. Keoleian, Univ. of Michigan), and the impact of carbon sequestration on the cost and greenhouse gas emissions of alternative energy options (P. Kobos, SNL) were emphasized.

Symposium Support: GM.

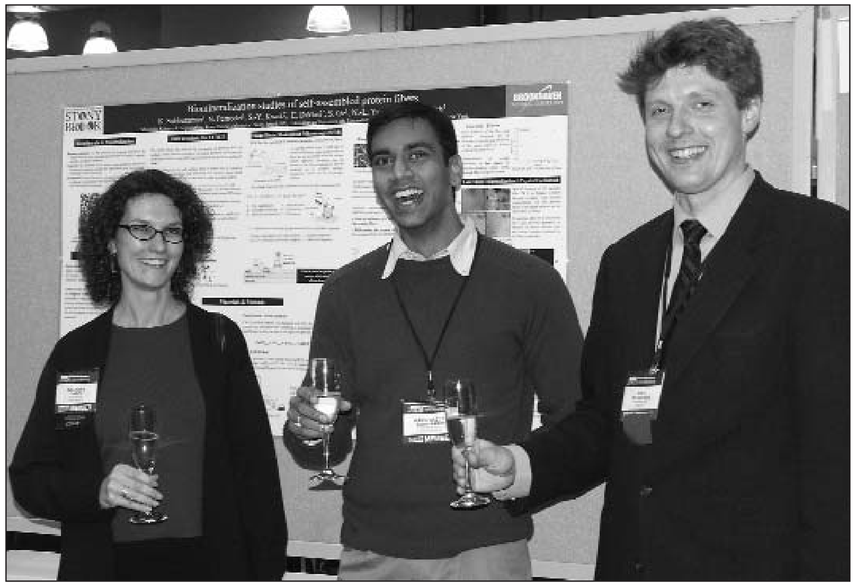
Multifunctional Energetic Materials Continue to Evolve
(See MRS Proceedings Volume 896)

Symposium H on Multifunctional Energetic Materials covered basic materials property evaluations for reactive materials, new techniques for the synthesis of energetic materials, including thermites; high-explosive structures; self-assembled systems; nanometric aluminum and related metals and intermetallics; and polymer-coated particles. Particularly impressive were the innovative and creative applications of energetic materials. For example, T. Weihs (JHU) talked about the use of reactive multilayer foils for structural energetic applications. The use of mechanical milling for creating nanocomposite reactive materials, with their unique characteristics, was demonstrated by various members of the group at the New Jersey Institute of Technology, as well as the Nanyang Technological University in Singapore. J. Cochran (Georgia Tech) described the novel application of linear cellular alloys as exoskeletons for energetic materials for possible control of their initiation characteristics. Tailoring the properties of particulate energetic materials, for example, through polymer coatings, was described by P. Brousseau (DRDC Valcartier, Quebec). Characterization of the very early stages of reaction initiation is the goal of the recently started MURI program led by the University of Illinois, as presented by D. Dlott, who described the new facilities aimed at capturing the ultrafast dynamics of nanoenergetic materials. Along the same lines, S. Son described the theoretical and experimental nanoscale energetic materials research being performed at the Los Alamos National Laboratory.

Not forgotten among the otherwise beneficial attributes of nanoscale energetic materials was the issue of the toxicity of nanoparticles. K. Powers (Particulate Research Center) talked about *in vitro* toxicity screening of Al nanoparticles. M. Zachariah (Univ. of Maryland) talked about advances in chemical kinetics that provide the understanding that can enable tuning of the reactivity of nanoenergetic materials. B. Baschung described the work being performed at the Institute Saint-Louis in France on the influence of the addition of inorganic nanoparticles to solid propellants, in which case the burning rate is observed to increase by nearly two orders of magnitude. Perhaps the truly "energetic" response of multifunctional energetic materials was best revealed in the presentation by R. Ames (Naval Surface Warfare Center, Virginia), who showed examples of the energy-release characteristics of these materials upon impact.

The effect of nanoscale structure on the reaction mechanism and ignition of energetic materials continues to be a subject of much study. Much work is now also

Poster Prizes Awarded at the 2005 MRS Fall Meeting



The 2005 Fall Meeting Chairs awarded prizes for the best poster presentations. Prize recipients received $400, a certificate, and the honor of having their posters on display for the remainder of the meeting. Posters and authors awarded prizes were (D6.7) **Tandem Organic Solar Cells**, A. Hadipour, B. de Boer, and P. Blom (Moleculare Electronics, the Netherlands); (K3.5) **Nanoscale Mapping of Electrostatic and van der Waals Interactions on Silicon-Substituted Hydroxyapatite**, J. Vandiver, D. Dean, and C. Ortiz (MIT); N. Pate, S. Best, and W. Bonfield (Univ. of Cambridge, UK); and C. Botelho and M.A. Lopes (Instituto de Engenharia Biomedica and Faculdade de Engenharia da Universidade do Porto, Porto, Portugal); (L5.12) **Biomineralization Studies on Self-Assembled Protein Fibers**, K. Subburaman, N. Pernodet, S. Ge, and M. Rafailovich (Stony Brook Univ.); S.-Y. Kwak and E. DiMasi (BNL); and N.-L. Yang (CUNY, Staten Island); (O9.33) **Template-Based Electrochemical Method for Multi-Segmented Metallic Nanotubes**, W. Lee, R. Scholz, K. Nielsch, and U. Goesele (MPI, Microstructure Physics, Germany); (P13.8) **Optical Signature of Aharonov-Bohm Phase in Multilayer Structures with Type-II Quantum Dots**, I.L. Kuskovsky and W. MacDonald (Queens College of CUNY, Flushing); M.C. Tamargo (City College of CUNY, New York); A.O. Govorov (Ohio Univ.); and X. Wei (National High Magnetic Field Laboratory, Tallahassee); (Ra22.27/Rb22.27) **"Smart" Defects in Colloidal Photonic Crystals**, F. Fleischhaker (Univ. of Toronto, Canada and Univ. of Mainz, Germany); A.C. Arsenault, N. Tetreault, Z. Wang, V. Kitaev, F.C. Peiris, G. von Freymann, I. Manners, and G.A. Ozin (Univ. of Toronto, Canada); R. Zentel (Univ. of Mainz, Germany); and A. Mihi and H. Miguez (Universidad Politecnica de Valencia, Spain); (T3.39) **Growth Mechanism of *c*-Axis-Oriented Epitaxial Bismuth Layer-Structured Dielectric Films**, K. Takahashi, M. Suzuki, and M. Yoshimoto (Tokyo Inst. of Technology, Japan); and H. Funakubo (Tokyo Inst. of Technology and Japan Science and Technology Agency, Japan); (AA7.36) **Dislocation Core Radii in Carbon Nanotubes: Continuum and Atomistic Analysis**, E. Ertekin and D.C. Chrzan (UC, Berkeley and LBNL); and (MM9.1) ***In Situ* TEM Observation of Solid-Gas Reactions at High Temperatures**, K. Kishita (Toyota Motor Corp., Japan); T. Mima, H. Saka, K. Kuroda, and S. Arai (Nagoya Univ., Japan); and T. Kamino (Hitachi High-Technologies, Japan).

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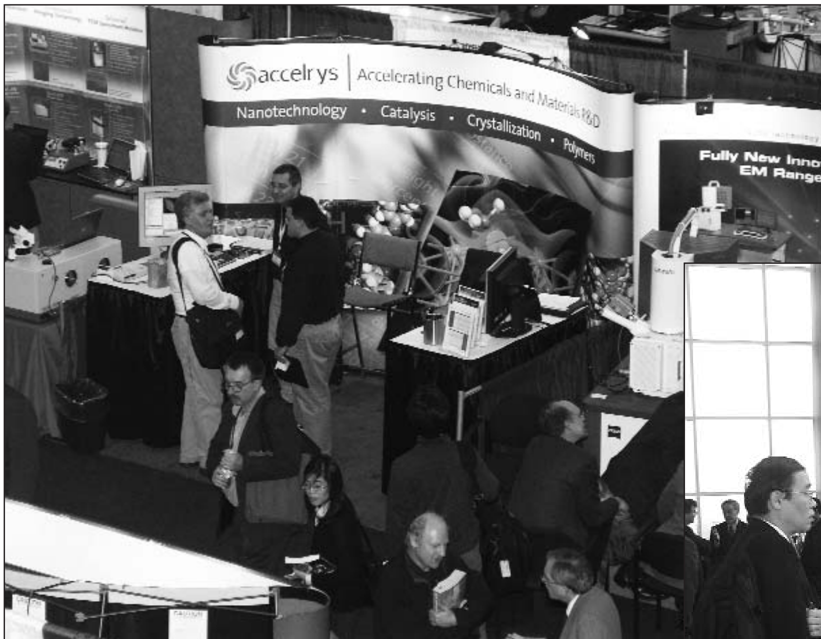

2005 Materials Research Society Fall Meeting.

being focused on theoretical modeling of reaction initiation studies in energetic materials.

Creation of biomedical skeletal structures, shell casings, metal foam structures, environmentally attractive igniters or cartridge primers, and missile components are providing a new dimension for the many touted applications of energetic materials.

Symposium Support: LLNL, Nanotechnologies, and ONR.

Deciphering Interfaces in Organic and Molecular Electronics: New Materials Need Good Old Surface Science

Symposium I focused on the so-called contact problem of organic and molecular electronics. Optical and electron spectroscopies came to the fore in much of the work presented, providing insight into orbital alignments, chemical bonding, and interface dipoles at these organic–inorganic interfaces. As in the decades-long study of semiconductor interfaces, sample purity and fabrication cleanliness emerged repeatedly as a critical factor. Many reports recognized that every non-UHV-fabricated sample included a few monolayers of oxides and surface adsorbates that often dominated subsequent physical and chemical properties. *In situ*, high-sensitivity optical, electron, and ion spectroscopies are proving to be the best methods to address this critical interface characterization. Several groups are therefore applying UHV techniques including UPS and 2PPE to deduce band alignments for electrode/organic interfaces in OLED and OTFT structures. Some of the mystery was taken out of "clean" and "dirty" electrode surfaces when they were carefully distinguished by their XPS and UPS spectra. Ion spectroscopy also helped decipher top-contact metallizations, which show a rich set of behaviors. Real device structures always bury these critical interfaces in a complex stack of materials—innovative IR spectroscopy and UHV-stripping techniques were demonstrated to measure such buried interfaces. Electron-transfer dynamics are being probed most successfully in ultrafast optical measurements on molecule/nanoparticle complexes.

The symposium brought together electrical transport, surface spectroscopies, and theory of organic–inorganic interfaces. The complexity of the physical and chemical structure was shown repeatedly. It was interpreted successfully only by combining multiple surface spectroscopies, and, in several cases, correlated with technologically relevant organic electronic devices. Future device progress will focus on correlating multiple spectroscopies at every sample fabrication step with subsequent electrical performance.

Symposium Support: DARPA, HP, NSF, and Universal Display.

Biomimetic Polymers and Gels Designed for Biological and Medical Applications
(See MRS Proceedings Volume 897E)

Symposium J focused on the design of biomimetic polymer and gel materials for applications in biology and medicine, covering, more specifically, gels and self-assembly in biopolymer systems; biomimetic polymers; drug and gene delivery; functional biomimetic systems; design, synthesis, and characterization of biomaterials; and scaffolds for cell and tissue engineering. Novel materials concepts and the availability of an ever-widening range of building blocks, both biological and synthetic, have opened new areas of research in the development of biomimetic materials. This has led to applications in diverse areas including controlled drug delivery, tissue engineering, synthetic replacements for biological tissues, implants, and medical devices. Highlights of the symposium included presentations on theory and modeling of functional biomaterials; design of matrices for promoting cell function, tissue regeneration, and wound healing; nanomechanical properties of biopolymer assemblies; novel medical and pharmaceutical applications of biomimetic gels; high-throughput combinatorial methods to assess structure–property relationships; and biological responses in biomaterials/biomedical devices.

Biointerfaces Engineered by Cell-Interactive Materials

Symposium K focused on the use of materials for controlled structural, biochemical, and biomolecular interactions with living cellular systems. P. Campagnola (Univ. of Connecticut Health Center) described the use of multiphoton excitation to fabricate cell-interactive protein patterning, while T. Petrie (Georgia Tech.) summarized micropatterning efforts to exploit specific integrin-mediated adhesion. N. Lockwood (Univ. of Wisconsin, Madison) probed the possible use of liquid crystals as cell-interactive substrates. A. Garcia (Georgia Tech.) highlighted advances in the chemical modification of materials to guide integrin-specific cell adhesion. E. Kokkoli (Univ. of Minnesota) described the design approach toward engineered amphiphiles to direct cell adhesion, while J. Harden (JHU) extended the design to biologically engineered hydrogel materials. A. Chilkoti (Duke Univ.) presented a talk on designing substrates to passivate cell-adhesive substrates providing a complementary perspective. C. Mohrdieck (Univ. of Stuttgart) presented her modeling efforts on coordinated cell responses to nanoconfigured substrates. C. Roth (Rutgers) highlighted the opportunities and challenges related to design of molecules and materials for complexed deliveries of genes to cells. R. Kane (RPI) described advances in the interfacial recognition and transport of biomolecules enabled by biomimetic design. D. Martin (Univ. of Michigan) shared the promise of drug coatings on microfabricated neural prosthesis.

Mechanical Behavior of Biological and Biomimetic Materials Explored
(See MRS Proceedings Volume 898E)

Presenters in Symposium L examined the intersection between materials science and biomechanics, focusing on naturally existing biological materials and on biomimicry. A joint session was held on the applications of scanning probe techniques to the analysis of biological and biomimetic materials. Work presented in these sessions covered a wide range of materials at multiple length scales, including small-scale modeling and mechanical testing of individual proteins and cells, and characterization of bulk materials or tissues on the millimeter scale and larger. An invited talk on mineralized tissues was given by the anatomist Alan Boyde (Queen Mary, Univ. of London), who provided an overview of the biology that underpins structure–function relationships for mechanically important biological hard materials.

In accordance with one of the goals of Symposium L, to reach out to clinicians in fields related to materials research, one session (held jointly with Symposium BB) featured an invited talk by Erin Mahoney (Univ. of British Columbia) and a contributed talk by Alison Fallgatter (Univ. of Minnesota). Both Mahoney and Fallgatter, who are practicing dental clinicians, presented research bridging the gap between materials and dentistry, as did Ching-Chang Ko (Univ. of Minnesota), who is a practicing dental clinician as well as a recognized materials researcher. Fallgatter reported work in which the supra-surface area of enamel slabs with fluoride treatment demonstrated decreased crush-absorbing energy compared to those without fluoride. Fluoride may not impart protection over long periods of demineralization. Mahoney reported that the mechanical properties of dentine from carious primary incisors and enamel from permanent molar teeth affected with enamel hypoplasia are severely compromised. Ko reported that the gelatin concentration can modify crystal formation and arrangement of bone-like apatite nanocomposites as demonstrated in nanoindentation response.

Symposium Support: Biocompatibles UK; Bose, EnduraTEC Systems Group; Hysitron; Instron; MTS Systems, Nano Instr. Innovation Ctr.; and NSF.

Much Progress Seen in Flexible and Printed Electronics, Photonics, and Biomaterials

Progress was reported in Symposium M in the area of high-throughput and low-cost fabrication of organic electronics and photonic devices and circuits, especially in the direction of roll-to-roll manufacturing, as well as novel micro- and nanostructure fabrication and applications in various areas such as biotechnology. H. Kopola (VTT, Finland) described roll-to-roll printing and its potential in photonics and electronics. G.E. Jabbour (ASU) described new approaches to using a desktop printer in the fabrication of novel photonic and electronic devices, both on hard and soft substrates (including textile and paper). Researchers at BASF in Germany demonstrated fully mass-printed ring oscillators; optimization of the process could enable the manufacturing of RFID tags and flexible backplanes for displays.

J. Rogers and R. Nuzzo (UIUC) have collaborated to produce single-crystal–based high-performance electronic components on flexible substrates by using a transfer-printing technique with the assistance of a PDMS stamp. M.-G. Kang and colleagues from the University of Michigan introduced a new scheme of using nanopatterned metal electrodes to replace the traditional ITO anode in organic OLEDs and provide better compatibility with flexible substrates, which also promises a new top-emitting OLED configuration.

S. Chou (Princeton) spoke about the latest development in the area of nanoimprint lithography (NIL). H. Lee (Seoul Natl. Univ.) introduced simple and useful "rigiflex" molds that will make NIL more convenient to use. C. Sotomayor Torres (Univ. College Cork, Ireland) further advanced the reverse nanoimprint technique to create 3D nanostructures. Y. Hirai (Osaka Prefecture Univ., Japan) developed a nanocasting method and created impressive high-aspect-ratio nanostructures in polymer materials. Collaboration between J. Guo (Univ. of Michigan) and P.-F. Fu (Dow Corning Corp.) led to several new polymer resists better suited for large-area nanoimprint applications with simple instrumentation. Researchers from Molecular Imprints Inc. introduced a dielectric material for Si integrated circuits that can be directly patterned by using step-and-flash imprint lithography.

In the emerging technologies session, A. Hunt (Univ. of Michigan) discussed a technique for using ultrashort laser pulses to pattern structures in solid objects and in cell membranes well beyond the light diffraction limit due to a special nonlinear interaction. Y. Chen (UCLA) introduced a nanoelectric lithography technique. S.K. Smoukov (Northwestern Univ.) and colleagues developed a direct subtractive technique based on hydrogel stamping and etching. H. Jacobs (Univ. of Minnesota) described a technique to use Coulomb force to direct assembly and transfer of nanomaterials. J. Lewis (UIUC) gave an update on her group's progress on the direct-write approach to build 3D periodic Si microstructures. P.E. Sheehan (NRL) and colleagues from Georgia Tech demonstrated direct nanoscale deposition of molecular electronic materials with thermal dip-pen nanolithography technique.

In the bio application session, G. Whitesides (Harvard) reported a study on controlling the direction of cell migration by "patterning" the cell into different

Symposium X Delivers Presentations for the Nonspecialist

Do you sometimes wish you could remember the name of the colleague speaking to you, but her badge is conveniently hidden behind her lapel? The answer might be right before your eyes, said Alex Pentland of MIT, with a pair of glasses similar to a prototype developed in MIT's Media Lab. A quick electronic flash of the name appears on a display built into the eyeglasses, giving a subliminal reminder. Clothing is beginning to come alive, able to sense what you are doing and proactively help you in the classic manner of a good butler, said Pentland, who came dressed "smartly" to Symposium X to give the audience a glimpse of how electronics are working their way into clothing, literally. From military garb that senses the environment to an MP3 player built into a sleeve, there is no end to high-tech fashion statements. Pentland and his associates are connecting with fashion designers from Tokyo to Paris, trying to transform clunky, nerdy fun into "fashion with function." And while shape-changing polymer hair treatments changing a hairdo in the heat of the moment may not sound like a lasting venture, perhaps health monitoring through jewelry or piezoelectric motion assistance is worth a look.

In yet another look at smart textiles, Symposium X speaker Jan Beringer, head of the Competence Center, Smart Textiles, at the Hohenstein Institutes, described the role of nanotechnology in textile finishing. Ceramic nanocoatings applied to wound dressings using sol-gel processes can reduce adhesion to healing skin. Nanoparticles worked into fibers can provide a textile with antimicrobial functionality or increased UV protection. Micro- or nanocapsule systems applied to a finished textile are suitable for wellness monitoring and other medical applications. And then there is the swimsuit for top athletes modeled on shark skin, with extremely low flow resistance.

While applications abound, so too does the hype. To separate nano from nil, the Hohenstein Institutes test and certify personal protective equipment and are developing labeling for textiles incorporating nanotechnology. Testing modules and labeling would address soil repellency, skin compatibility, abrasion resistance, and durability.

"For a flexible display, everything must be flexible," said Ghassan Jabbour (ASU, Flexible Display Center) in his Symposium X talk. Jabbour asserted that current displays—both CRTs and flat panels—are still very fragile, bulky, and heavy, with fixed shapes. Flexible displays, on the other hand, are indeed "flexible" in terms of conformability and applications. After describing the various components of a display, Jabbour then detailed the various technical options currently available. These include the substrate and the backplane electronics as well as encapsulation methods. Jabbour described various possibilities for OLEDs, including polymer OLEDs.

Sensors are important for a number of applications and are widely used today. However, one of the best sensors currently known is a dog's nose! Is there a way to replicate the sensitivity and functionality of a dog's nose? asked Tim Swager of MIT. His answer was affirmative, as he gave an overview of the use of polymer electronics as chemical sensors that exploit and harness the transport properties of conducting polymers for sensing specific chemicals. The ultimate example is a molecular-wire sensor, wherein an excitation could migrate along the backbone

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shapes. L. Montelius (Univ. of Lund) applied this technology to biomaterial surfaces and structures for the study of protein interactions. A. Chilkoti (Duke) described his group's work on *in situ* fabrication of nanoscale macromolecular structures of soft hydrated synthetic polymer brushes, and stimulus-responsive polypeptides and polynucleotides, with the goal of developing an ensemble of easy-to-use tools for bionanofabrication. J. Lee (OSU) described patterning of single DNA molecules on a polymer surface for medical and electronic applications. F. Cerrina (Univ. of Wisconsin) discussed progress in light-directed digital synthesis of DNA strands in an effort to produce synthetic genes.

Symposium Support: Univ. of Michigan, Macromolecular Science & Engineering Dept.

Structure and Dynamics under Geometric Restrictions Examined from Various Angles
(See MRS Proceedings Volume 899E)

In Symposium N on Dynamics in Small Confining Systems, participants from various disciplines shared different points of view on the fundamental questions of how spatial restrictions modify a system to behave significantly different than in the bulk, how this difference relates to the molecular properties, and how it can be probed. Concepts of ultralow energy dissipation at sliding interfaces, such as superlubricity, were discussed by several groups. The group of E. Meyer (Univ. of Basel) showed that energy dissipation occurring in a frictional process can be significantly suppressed with alternate current induced disturbances at appropriate frequencies. Using a revolutionary and principally simple microfluidic extrusion process, drop-in-drop microemulsions were manufactured and "sorted" by the group of D.A. Weitz (Harvard).

Of special interest was a session on dynamics in biological systems. Participants addressed spectral distributions in single-molecule dynamics and transport of DNA, proteins, and peptides. Magneto-photonic nanorotors were introduced by R. Kopelman (Univ. of Michigan) as nanophysical probes to study rheological properties in submicrometer-confined geometries such as living cells. This session demonstrated that interdisciplinary interaction between researchers working on biological systems and on the properties of confined systems can be very fruitful.

Other sessions dealt with various ways to probe the nature of liquids at interfaces. In particular, the mobility of nanoconfined water has been addressed from multiple perspectives. Glass-forming fluids have proved interesting in investigations of the role of confinement in ordering and phase transitions.

Progress Seen in Nanostructures in Sensors and Catalysis Applications
(See MRS Proceedings Volume 900E)

Several exciting areas of current research in nano-related catalysis were discussed in Symposium O. G. Somorjai (UC–Berkeley) described 2D and 3D metal nanoparticle catalyst systems to obtain high reaction selectivity and the catalytic nanodiode for energy conversion. Recent developments and insights in the study of nano gold catalysts were discussed by G. Hutchings (Cardiff Univ.), highlighting selective oxidation using supported nanocrystalline gold, and by M. Haruta (Tokyo Metropolitan Univ.), highlighting supported gold nanoparticles for the oxidation and sensing of CO and hydrogen. M. El-Sayed (Georgia Tech) discussed shape-dependent nanocatalysis and the effect of catalysis on the nanoparticle shape and size in colloidal solution. Other materials issues discussed include the enhanced charge transport in oxide nanoarchitectures by bonded electrical pathways (D. Rolison, NRL) and materials advances for fuel cell applications (H. Abruna, Cornell).

until it hits a quenching agent as a side group. Different quenching agents could be used to detect different chemicals on a molecular level. Swager described the development of sensors that can detect explosives, using conducting polymer films. This technology is commercially available through a company called Nomadics, and was described by Swager as "fluorescence impersonating dog olfaction." The basis of this technology can also be used to detect "taggants" and even biological agents. Swager concluded by describing laser sensors using organic polymers. His group has discovered record-low lasing thresholds for organic polymers and significant sensitivity gains, which bode well for sensor applications.

"Size Matters! Smaller is Stronger," proclaimed the title of the talk given by William Nix (Stanford), who focused on strength and plasticity at the nanoscale. There is a decades-long trend to build useful engineering devices and structures on a smaller and smaller scale. The creation of such structures and devices calls for an understanding of the mechanical properties of materials at these small length scales. Nix first reviewed recent advances in nanoindentation, which is a robust and well-established technique for studying nanomechanical properties of materials. He then examined some of the effects that arise when crystalline materials are mechanically deformed in small volumes.

Size effects in plasticity are now well known, he said. Plastic deformation in small volumes requires higher stresses than are needed for plastic flow of bulk materials. Nix described the various effects that appear to be responsible for this. The size-dependence of the hardness of metals is described in terms of the geometrically necessary dislocations created in small indentations. But such accounts break down when the size of the deformation volume begins to approach the spacing of individual dislocations.

Nanoindentation of epitaxial films reveals irregular load-displacement curves. In the nano domain, the nucleation of dislocations appears to be more important than strain gradients. In an effort to shed additional light on these topics, uniaxial compression experiments on single-crystal pillars made by focused ion-beam machining were conducted. These experiments involve small deformation volumes and minimal strain gradients, yet strong size effects are still observed. These size effects suggest that plasticity is dislocation source-controlled, wherein smaller volumes are stronger because fewer sources of dislocations are available. The central idea is that, for very small crystals, dislocations leave the crystal more frequently than they multiply, forcing other, harder sources of dislocations to be activated. Understanding and controlling the mechanical properties of materials on this scale are expected to lead to new and more robust nanomechanical structures and devices.

The structure of bone and of a gecko's feet can be used as inspirations to develop flaw-tolerant, hierarchically scaled materials for structural and adhesion applications. In a typical material, crack growth leads to unstable, catastrophic failure. Flaw-tolerance indicates optimizing strength in the presence of crack-like flaws. However, a bottom-up hierarchical design from the nanoscale upward yields materials that resist cracks at all scales. Huajian Gao (MPI for Metals Research, Stuttgart) described a model (fractal bone) developed by his group using fracture mechanics principles. From the model, it was found

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A number of recent advances in nano-related sensors were also addressed. V. Rotello (Univ. of Massachusetts) described the "bricks and mortar" assembly of nanoparticles using polymers and proteins. J. Lahann (Univ. of Michigan) discussed biphasic polymer nanocolloids. J. Grate (PNNL) described monolayer-protected nanoparticles as sorptive phases for sensing and separations. R. Penner (UC–Irvine) described chemical sensing using metal nanowires prepared by electrochemical step edge decoration. M. Porter (Iowa State) discussed nanostructure-based strategies for the design and readout of ultrahigh-density immunodiagnostic platforms. C. Murphy (Univ. of South Carolina) described metal nanoparticles for optical sensing and metal oxide nanoparticles for catalysis. R. Hamers (Univ. of Wisconsin, Madison) discussed the fabrication and characterization of nanowire bridges for bioelectronic switches. Other interesting topics included single-walled CNT networks for sensor applications (R. Haddon, Univ. of California, Riverside), plasmonic nanostructures for SERS sensing (N. Halas, Rice), and dendrimer-encapsulated metal nanoparticles (R. Crooks, Texas A&M Univ.).

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Fabrication, Characterization, and Applications Addressed in Field of Semiconductor Nanostructures

Symposium P on quantum-confined semiconductor nanostructures covered the design, growth, characterization (including optical and electronic properties), and potential application of semiconductor nanostructures. The first symposium session was led by S. Erwin (NRL), who discussed recent theoretical and experimental results on doping colloidal QDs with manganese impurities and demonstrated that the crystal structure plays a major role in whether doping can or cannot be successfully carried out. The session featured presentations by Al. Efros (NRL) on the optical properties of CdSe nanorods and A. Zunger (NREL) on the optical spectra of PbSe quantum dots. Zunger and G. Allan (IEMN) also presented new estimates of muticarrier generation rate in quantum dots.

In subsequent sessions, U. Banin (Hebrew Univ. of Jerusalem) described the preparation of semiconductor colloidal nanorods terminated with metallic nanoparticles. J. Cheon (Yonsei Univ.) and S. Weiss (UCLA) led a session on the use of magnetic and fluorescent nanoparticles as tools for live-cell imaging and scaffolds to implement target-specific biosensors. Groups have demonstrated the use of QD–protein and peptide conjugates to sense raft formation on live cells and enzymatic activity. On the topic of transport properties in devices using colloidal QDs, D. Talapin (IBM) showed that manipulating the capping molecules on the surface of QDs can have far-reaching effects on the device function and properties of *n*- and *p*-channel FETs. A. Zrenner (Univ. of Paderborn, Germany) showed that resonant interaction with cw or pulsed-laser excitation on a single-surface-grown quantum dot can be studied in detail using photocurrent spectroscopy. He showed that excitations with picosecond laser pulses result in multiple qbit rotations, which can be evidenced in a quantitative way with as many as 5 Rabi oscillations reported in photocurrent experiments. The properties of QDs in photonic structures (U. Woggon, Univ. Dortmund); B. Gayral, CEA Grenoble), size-dependence of the kinetics of exciton decay in photonic crystals (D. Vanmaekelberg, Univ. of Utrecht), and aspects of the growth of covalent self-assembled QDs were also addressed.

Presentations were given on slightly different aspects of both self-assembled and colloidal nanocrystals. These included the

that strength drops by approximately a factor of two with each added level of hierarchy. It was shown that the soft material and the interface need to be increasingly weaker at higher hierarchical levels. In the second part of his talk, Gao focused on modeling a hierarchical structure for an adhesive pad using hair-like structures mimicking the structure of a gecko's feet. In addition to strong adhesion arising from van der Waals forces, a gecko is also able to detach its feet quickly and easily. Gao incorporated this aspect into his model as well.

Samuel Stupp (Northwestern Univ.) addressed self-assembly codes for soft materials in his Symposium X presentation. Biology creates sophisticated functions using soft materials in which the basic units are nanostructures with defined shapes and internal order. The vision behind Stupp's work in this area is to use self-assembly to multiplex attributes of soft materials with complex functions. Possible applications of the approach include photovoltaic cells for solar energy and scaffolds for regenerating human body parts. An example Stupp gave is the formation of helices with controlled pitch and handedness with molecules. Helices are present everywhere in biology, for example, supercoiling observed in DNA. He gave the example of a helical nanofiber with a bulky end unit. By modifying the bulky unit, the pitch of the helix can be modified. Such a molecule can self-assemble to form a specific nanostructure, such as bioactive nanofibers with peptide amphiphiles that self-assemble into cylindrical structures. In a study, a mouse with a spinal cord injury was paralyzed in both hind legs. After injection with a liquid that self-assembled into nanofibers (nanocords), the mouse showed activity in its hind legs within a few weeks. Stupp said that it is tremendously exciting to consider similar possibilities for treating spinal cord paralysis in humans, and that clinical trials may begin in the next couple of years using this approach. Stupp also gave the example of growing blood vessels on demand, wherein blood vessels were grown in a cornea by self-assembly triggered by a polymer, creating artificial anchors for heparin, which is a crucial component for blood vessel growth. A similar scenario can be envisaged for growing blood vessels in a diseased human heart.

Loet Leydesdorff (Amsterdam School of Communications Research, the Netherlands) gave a talk on "The Self-Organizing Dynamics of a Knowledge-Based Economy," in which he posed three key questions: First, what is the knowledge base of an economy? Leydesdorff described how a knowledge base is constructed within social systems and the conditions under which it is stabilized and also globalized. The self-organization was specified and described as an interaction among three dynamics, the so-called triple helix of university–industry–government. Second, how can the knowledge base be measured? The production of negative entropy within the system was used as an indicator. Using the triple helix model, the mutual information in three dimensions was introduced as serving this function. Third, can the knowledge base be modeled or simulated? Leydesdorff described anticipatory systems, which are knowledge-based systems-process models of themselves. He discussed strong anticipation versus weak anticipation. He described how psychological systems are only weakly anticipatory (that is, they entertain models of themselves), while social systems can become strongly anticipatory (under historically specifiable conditions). Strongly anticipatory systems construct their own next stage.

Symposium X received symposium support from GM R&D Center, NREL, and the University of Paderborn.

use of resonant Rayleigh scattering at photon frequency near resonance with the ground-state exciton in single InAs/GaAs QDs to obtain the real and imaginary part of the exciton resonant scattering cross section independently (K. Karrai, Ludwig Maximilians Univ.). R. Shaller (LANL) presented the effect of carrier multiplication in PbSe and CdSe QDs, where multiple carrier (exciton) generation can increase the efficiencies for electrons/photons as large as 700%. P.M. Fauchet (Univ. of Rochester) led a session on silicon nanocrystals; issues such as lasing in such materials, designing and implementing LEDs, and energy and charge transfer were presented. An evening session was led by T. Itoh (Osaka Univ.), who presented a study exploring two-photon resonant excitation of confined biexcitons in CuCl QDs grown in NaCl matrices. He showed that ultrafast radiative decay in these systems could allow observation of stimulated emission. M. Barnes (Univ. of Massachusetts) presented work on single-molecule fluorescence of polymer "nantennae," where he showed that good control over the polarization of single molecules could be achieved using conducting polymers.

Symposium Support: DARPA, Evident Technologies, and ONR.

Degradation Processes Face Scrutiny under Nanoscale Confinement
(See MRS Proceedings Volume 887)

Symposium Q aimed for a better understanding of degradation processes in materials confined at the nanometer scale, with an emphasis on nanostructured materials. Several sessions were dedicated to degradation processes in carbon nanostructures (mostly CNTs) and composites based on CNTs. The effect of ionizing radiation and oxygen on CNTs and composites obtained by dispersing CNTs in polymeric matrices was dissected by several speakers. The effect of the space environment on such materials was also analyzed. Polymer–CNT composites are appealing for space applications due to their lightweight and multifunctional capabilities. The combined effect of ionizing radiation, atomic oxygen, and extreme temperatures will enable researchers to simulate the space environment and to predict more accurately the lifetime of such materials in space.

Several talks focused on degradation processes of polymers, including the time evolution of self-assembled polymeric materials such as block copolymers. The effect on nanofillers (including CNTs) on the mechanical and electrical properties, phase transitions, and thermal stability of polymeric matrices was under intense scrutiny. The role of adhesion, nanofiller surfaces, and interfaces on the physical properties of polymer–nanoparticle composites was discussed. An in-depth analysis of various approaches to the simulation of the mechanical properties of polymer–nanoparticle composites was addressed. The limits of the theoretical models used to simulate the mechanical properties of nanotubes were critically reviewed.

Degradation in magnetic materials was addressed by several participants. The physical properties of magnetic films that exhibit exchange-biased features, perovskite–superconductor systems, and nanocomposites obtained by dispersing magnetic nanoparticles within polymeric matrices were briefly analyzed. The potential biological and medical applications of magnetic nanocomposites were also discussed.

Exciting contributions on the effect of ion beams on materials, including nanopatterning and nanodosimetry, were also presented.

Assembly and Patterning Strategies Demonstrated for Creating Functional Materials from the Nanoscale
(See MRS Proceedings Volume 901E)

The challenge of assembling nanoscale building blocks into functional materials was the theme of Symposium R. A variety of assembly and patterning strategies were discussed, including molecular self-assembly, manipulation via electrical fields, template-directed patterning, soft lithography, and biomimetic approaches. Work toward using these engineered nanoscale structures for molecular/organic electronics, photonics, sensing, and biological applications was also presented. One of the themes emerging from several of the presentations was the use of molecular self-assembly and approaches borrowed from the field of supramolecular chemistry to form functional molecular assemblies on surfaces. D. Fichou (CEA Saclay) and S. DeFeyter (Katholieke Universiteit Leuven) described *in situ* scanned probe studies of self-assembling molecular structures—of interest for molecular-scale electronics—at the liquid–solid interface. J. Barth (Univ. of British Columbia) and P. Beton (Univ. of Nottingham) described the assembly of hydrogen-bonded supramolecular assemblies, demonstrating their use for the selective adsorption of host molecules such as C_{60}. A number of presentations focused on the controlled formation of potentially functional structures based on nanoparticles, nanowires, and CNTs. B. Lennox (McGill) introduced a method to control the formation of gold nanoparticles using electron-beam irradiation. J. Hone (Columbia) reported the use of a mechanical transfer method (used in conjunction with optical scattering and structural studies) to position single CNTs of known diameter and chirality between electrodes for electrical transport studies. S.T. Picraux (LANL) described the formation of superhydrophobic surfaces based on chemically modified silicon nanowires. Attachment of photoswitchable molecules (spiropyrans) to the nanowires was used to demonstrate light-induced control of the wetting properties of these assemblies.

Symposium Support: JEOL USA, Molecular Imaging, NanoInk, Nanonics Imaging, Omicron NanoTechnology USA, Seki Technotron USA, and SPECS Scientific Instr.

Environmental Concerns of Nanomaterials Explored

The aim of Symposium S on Nanomaterials and the Environment was to bring together experts working in a variety of fields, including environmental engineering, chemistry, physics, and toxicology, as well as social science, to expound on the possibilities and concerns of relating nanotechnology to the environment. Life-cycle assessment tools are being developed and are available for the integration of nanotechnology in engineering processes. Nanotechnology offers new paradigms, not only for the architecture but also for the interior design of structures for energy production and power generation. The feasibility of low-cost array-based sensors is becoming evident, and the application of novel platforms such as tuning forks, thin films, and nanojunctions is expected to lead to nanostructured arrays that can be combined with pattern-recognition analysis. Beyond those objectives, a combination of green chemistry principles and nanotechnology was shown to lead not only to functional materials, but to those that are more economical in terms of process and product costs. Nanomaterials offer unique solutions for environmental treatment and remediation, with the enhanced capabilities of greater surface area, light-activated semiconductor photocatalysis, and superparamagnetism.

While concern about risk exists, progress is being made. Specifically, CNTs were characterized using a quartz sensor platform and gas-phase electrophoresis. In addition, current reviews of the toxicological profiles, and the ecotoxicology studies being conducted around the world were offered. The progress of this technology will depend on risk assessment and risk perception. To that end, communication and regulation need a consistent approach for industry to flourish, while maintaining public safety and trust.

Symposium Support: NIH, NIDCR and NIEHS; and Wilmer Cutler Pickering Hale and Door LLP.

Naturally Occurring and Composite Multiferroic Materials Explored

Symposium U on multiferroic materials featured ferroelastic–ferromagnetic (FEL/FM; e.g., FePd), ferroelastic–ferroelectric (FEL/FE; e.g., PMN-PT), and ferroelectric–ferromagnetic (FE/FM; e.g., Y_2MnO_5) materials. Only naturally occurring materials of the first two categories were discussed, whereas both naturally occurring and composite FE/FM materials were covered. Most presentations on FEL/FM materials dealt with NiMnGa alloys that are under consideration as novel actuator and sensor materials, and, in modified form, as the active material in magnetocaloric cooling devices. Experimentally, the balance of the critical twinning stress σ_c and anisotropy energy K_c densities commanded much attention. It is desirable that $K_c >> \sigma_c$, which is not always fulfilled in the currently available alloys. Theoretically, it is becoming clear that the core frustration giving rise to the phase transformations in NiMnGa is associated with the unnatural bcc coordination of nickel. The talks on FE/FM materials started with a group theoretical classification of the symmetries enabling FE/FM interactions. It was pointed out that coupling terms third-order in the polarization and magnetization are crucial. Physically, the frustration of the spins forced into a trigonal symmetry provides the FE/FM interactions. All currently known FE/FM materials are characterized by very low critical temperatures. The quest for high-temperature FE/FM materials is driving many research groups. Bi(ferrous metal)-manganites appear promising. FE and FM solids can be coupled by their stress fields. Nano- and macroscopic FE/FM composites featuring very high magnetoelectric coupling constants were also featured in the symposium. Self-assembled composite perovskite/spinel FE/FM nanostructures were found to be particularly interesting.

Symposium Support: Swiss National Centre of Competence in Research, Materials with Novel Electronic Properties-MaNEP.

Materials and Devices for Smart Systems Illustrated
(See MRS Proceedings Volume 888)

Symposium V addressed materials and devices for smart systems. In the development of high-performance solid-state actuator materials having crystalline phase transformations, the size of a microdomain and optimal control of the interface become essential. The domain engineering of single-crystal or thin-film PZT were presented by S. Wada (Tokyo Inst. of Technology), T. Iijima (AIST), and colleagues. Piezo-response of lead-free ceramics is under development (A. Soukhojack, Lehigh Univ.), and the high potential of PZT for wide engineering applications was introduced by T.P. Daue (Smart Mater. Corp.). A unique metal-core–type PZT fiber actuator/sensor was presented by H. Sato (AIST). In SMA, thin-film actuator development, a trial research review of a micropump application using a TiNi alloy system was reported by S. Miyazaki (Tsukuba Univ.). A new Fe-Ga magnetostrictive alloy system (Galfenol) has been recently studied by A. Flatau (Univ. of Maryland) and T. Okazaki (Hirosaki Univ., Japan) because Galfenol has better workability and higher stiffness and is cheaper than the conventional rare-earth–based Terfenol-D. In active polymers, nanophase and CNT-reinforced composites were introduced by Q. Zhang (PSU) and G. Spinks (Univ. of Wollongong, Australia). Transient rheology and structure evolution in electro- and magnetorheological fluid suspensions were overviewed by D. Klingenberg (Univ. of Wisconsin). From the part of novel devices combined with nanotechnology processing, several unique and impressive research proposals were presented, for instance, electrochemical storage compounds with high displacement and high authority actuation by Y.M. Chiang (MIT); a novel fabrication technique for composite materials processing (metal insulator semiconductor fiber components) by M. Bayindir (MIT); and reversible transitions on electrically tunable nanostructured superhydrophobic surfaces and their various applicability for electrical switching devices and surface morphology control. Multifunctional reflection-type SAW sensors for health monitoring (T. Nomura, Shibaura Univ., Japan) and SAW signal excitation by coincident resonance (J. Petrie, Cornell) were presented. The application of ferromagnetic materials coated with an environmentally active film in highly sensitive biosensors was presented by Z-Y. Cheng (Auburn Univ.).

Symposium Support: Hirosaki Univ.

Electroresponsive Polymers See Commercial Success and Continued Basic Research
(See MRS Proceedings Volume 889)

Symposium W was devoted to the development and application of electroresponsive polymers. A highlight of the symposium was the substantial industry involvement in the field. 3M (V. Bharti) is implementing piezoelectric-materials in stethoscopes, and Measurement Specialties Inc. (M. Thompson) showed an enormous range of moderate- to large-volume products employing PVDF sensors. H. Raisanen and S. Bauer from EMFIT Ltd. each presented a relatively new class of materials dubbed ferroelectrets, in which microporous polymers show a piezoelectric coefficient of ~300 pN/C.

Ferroelectric polymers were a major focus of the symposium, ranging from fundamental characterization (Z.-Y. Cheng, Auburn Univ.) to application to energy storage, harvesting (Q. Zhang, PSU), and piezopolymer biosensors (Z.-Y. Cheng). R. Vaia (AFRL) reported on the addition of small amounts of CNTs to polyurethane shape-memory polymers and PVDF actuators, improving performance.

Conducting polymers and CNTs were also heavily featured. Presentations by Swager and his co-researchers from MIT introduced synthetic polymers that undergo conformational changes to produce large strains, while X. Lin (MIT) said that polypyrrole could also undergo large light-driven strains. On the force side, G. Spinks (Univ. of Wollongong, Australia) reported actuation of nanotube-reinforced polyaniline fibers under a record 100-MPa load. Similar loads were also reported in CNT yarn actuators by M. Kozlov (Univ. of Texas at Dallas), who also presented 10% strain in polypyrrole grown into low-density CNT sheets. G. Malliaras (Cornell) showed that electrochemical transistors are promising as chemical sensors and demonstrated their use to detect glucose.

Dielectric properties of polymers were a

Research Tools Seminars Provide “How-To” Explanations of Equipment for Materials Research

Focusing on the scientific basis and practical application of commercially available, state-of-the-art tools for materials research, representatives from various companies presented Research Tools Seminars at the 2005 MRS Fall Meeting.

R. Bruce Weisman from Applied NanoFluorescence, based in Houston, Texas, described the company’s NanoSpectralyzer. Recent research breakthroughs allow SWCTs to be identified by structure on the basis of their near-infrared fluorescence spectra. The NanoSpectralyzer, a new turnkey laboratory instrument, uses these findings to perform rapid, detailed, and automated analyses of bulk samples for nanotube producers, industrial consumers, and researchers.

Other presenters were Expert System Solutions, Italy; Masscal Corp., Chatham, Mass.; Molecular Imaging, Tempe, Ariz.; and Nanonics Imaging Ltd., Israel.

major theme. H. Katz (JHU) introduced organic transistor devices based on the combination of charge electrets and organic semiconductors, creating memory devices, inverters, and logic circuits. T. Marks (Northwestern) introduced ultrathin gate dielectrics for organic transistors, allowing for transistor operation at a few volts. G. Chen (Southampton) reviewed techniques for the nondestructive measurement of charge distributions in polymers for high-voltage applications and provided details on charge distributions in polyethylene obtained from the pulsed electroacoustic technique. Further contributions were devoted to the theory of flash memories, charge storage, and dipolar polarization effects in organic FETs, as well as on polythiophene FETs.

Symposium Support: 3M, Boston Scientific, and the Pennsylvania State Univ., Materials Research Inst.

Surface Interactions and Engineering See Growth in Manufacturing Applications
(See MRS Proceedings Volume 890)

The span of the sessions in Symposium Y demonstrates the widening importance of surface interactions and surface engineering in modern manufacturing processes. In the field of tribological coatings, the increasing sophistication of coating processes was shown in providing control over properties such as adhesion, reaction to stresses, thermal-barrier behavior, and wear resistance. Presentations from companies including SKF, Sumitomo, Sandvik, Timken, and Pilkington provided insight into the state of the art of coatings used to enhance the performance of rolled steel, cutting tools, inserts, bearings, and architectural glass. The influence of nanostructured coatings, either in the form of superlattices or nanocomposites, was discussed in terms of developing superhard and wear-resistant materials. The critical influence of low levels of impurities on the hardness properties of coatings typifies the increasingly stringent specifications of deposition processes. The influence of low levels of impurities on the hardness properties of coatings was discussed.

A session on nano- and micromanufacturing addressed recent developments in MEMS research, including discussions on measuring nanoscale adhesion and friction, shape-memory alloys for actuators, and micromolded metal parts from bulk and surface engineered mold inserts. This theme was continued in a session focused on laser-, photo-, and plasma-based manufacturing processes. Advances in direct laser writing of embedded microelectronic components demonstrate the prospect of rapid prototyping of components such as microbatteries and miniature components for wireless networks. The growing applications of femtosecond lasers to both materials characterization and nanomaterials processing were highlighted.

A joint session with Symposium NN on scanning probe microscopy in materials research focused on the understanding of mechanical and tribological processes on the nanoscale. The range of analytical microscopy approaches has increased significantly in recent years, and research highlighting *in situ* Raman tribometry and near-edge x-ray absorption fine structure was reported. Understanding of the interaction between chemical and physical factors in terms of adhesion and wear at the nanoscale are the subjects of increasing research.

Symposium Support: Epichem Group UK and Timken Research.

Developments and Opportunities Highlighted for Amorphous and Nanocrystalline Metals
(See MRS Proceedings Volume 903E)

The aim of Symposium Z, Amorphous and Nanocrystalline Metals for Structural Applications, was to bring together researchers working on both amorphous and nanocrystalline metals to compare and discuss the behavior of these two categories of nonequilibrium metallic materials in terms of their mechanical responses and common features. Molecular dynamics simulations carried out by H. van Swygenhoven and colleagues at PSI, Switzerland, predicted the thermally activated emission and propagation of dislocations in nanocrystalline grains. Attempts to model the deformation behavior of nanocrystalline ensembles across the entire atomistic to continuum spectrum were reported by J.-F. Molinari (JHU) and F. Sansoz (Univ. of Vermont). For amorphous metals, plastic deformation by shear banding was also modeled both on atomistic (M. Falk, Univ. Michigan; M. Li, Georgia Tech) and continuum basis (L. Anand, MIT). On the experimental side, both the deformation and fracture aspects were discussed, for metallic glasses (e.g., R. Schwarz, LANL; J. Leodowanski, CWRU) and for nanocrystalline metals (e.g., F. Ebrahimi, Univ. of Florida; J. Weissmuller, INT-FZK, Karlsruhe, Germany). A number of participants, including invited speaker D. Wolf (ANL), discussed stress-induced grain growth in nanocrystalline metals during deformation, whereas deformation-induced *in situ* nanocrystallization and grain coarsening was reported for metallic glasses (A.R. Yavari, INP Grenoble, France). C. Volkert (INT-FZK, Karlsruhe, Germany) described microcompression tests of both nanocrystalline and amorphous metals.

J. Xu (IMR-CAS, Shenyang, China) demonstrated inch-diameter bulk metallic glass based on ordinary metals. D. Dunand (Northwestern) described metallic glass forms and their superior properties. It was mentioned at the symposium that glassy metals containing nanocrystals can be deformed to plastic strains as large as 50% in compression tests. C.C. Koch (NCSU) reported that flaw-free nanocrystalline Cu exhibits a tensile strength as high as 1 GPa and simultaneously a tensile ductility well over 10%.

It is clear from the presentations made that the mechanisms and deformation modes of amorphous and nanocrystalline metals are very different from the familiar plasticity behavior of conventional polycrystalline metals and that much can be learned by keeping abreast of recent progress in processing, structure, and properties of the other group of materials. This field offers ample research opportunities, and new discoveries are emerging at a rapid pace.

Large-Scale Structural Material Performance Depends on Nanoscale Phenomena

Presentations at Symposium AA on Micro- and Nanomechanics of Structural Materials spanned the range from quantum studies of dislocations and tribological surfaces to the processing of steels for heavy machinery. At the quantum scale, independent theoretical works by E. Kaxiras (Harvard) and L.G. Hector Jr. (GM) computed the first-principles structure of dislocation cores in Al. D. Trinkle (WPAFB) demonstrated that first-principles calculations of dislocation interactions with alloy additions could explain the unusual temperature-dependence of plastic flow in molybdenum. Y. Qi (GM) demonstrated that hydrogen-saturated diamond surfaces would not stick to aluminum metal, pointing toward diamond coatings for environmentally friendly drilling of holes in Al components. These efforts contribute to the growing evidence that basic studies at the quantum scale can provide fundamental insights into the macroscopic mechanical properties of structural metals.

At the nanoscale, Y.-H. Zhao (LANL) elucidated the effect of classical precipitation strengthening in ultrafine-grained metals. B.G. Gore's (UIUC) *in situ* TEM results showed that dislocations interact with such precipitate particles in ways not previously envisioned, suggesting new strengthening mechanisms at this scale. In pure materials, J.R. Greer (Stanford) demonstrated that single-crystal gold pillars could have the strength of steel. Y. Xiang (Harvard) showed that nanoscale films also exhibited high strengths. Mesoscale dislocation modeling by A. Needleman (Brown) and V.S. Deshpande (Univ. of Cambridge) showed quantitative agreement with Xiang's data and qualitatively explained Greer's data, pointing to the influence of both dislocation/surface interactions and dislocation "starvation" phenomena in strengthening nanoscale materials, depending on the precise conditions of the experiments.

Symposium Support: Alcoa, DARPA, Northrop Grumman, and Pratt & Whitney Aircraft Engines.

Graduate Students Receive Gold and Silver Awards

During the Awards Ceremony held on November 30 at the 2005 Materials Research Society Fall Meeting, graduate student finalists received Gold and Silver Awards.

***Gold Graduate Student Awards** went to (left to right): **John P. Mills** (Massachusetts Institute of Technology); **Kisuk Kang** (Massachusetts Institute of Technology); **Blythe G. Clark** (University of Illinois, Urbana-Champaign); **Chiara Daraio** (University of California, San Diego); **Yukio Sato** (University of Tokyo); and **Chad R. Barry** (University of Minnesota).*

***Silver Graduate Student Awards** went to (front row, left to right): **Xiaoyu Zhang** (Northwestern University), **Julie S. Biteen** (California Institute of Technology), **Alicia M. Jackson** (Massachusetts Institute of Technology), **Kimberly A. Dick** (Lund University), **Krista L. Niece** (Northwestern University), and **Shin G. Chou** (Massachusetts Institute of Technology); (center row, left to right): **Youngiong Kang** (University of Minnesota), **Myung-Han Yoon** (Northwestern University), **Husnu E. Unalan** (Rutgers), **Ludovico Cademartiri** (University of Toronto), and **Frank W. DelRio** (Sandia National Laboratories); and (back row, left to right): **Wai Lun Chan** (Brown University), **Craig J. Fennie** (Rutgers), **Jason D. Slinker** (Cornell University), **Hezy Cohen** (Hebrew University of Jerusalem), and **Zayd C. Leseman** (University of Illinois, Urbana-Champaign).*

Indentation-Derived Micromechanical Property Characterization Emphasized in Brittle Materials Deformation *(See MRS Proceedings Volume 904E)*

Symposium BB on Mechanisms of Mechanical Deformation in Brittle Materials focused on indentation-derived micromechanical property characterization of brittle materials. It commenced with a joint session with Symposium L on the mechanical behavior of biological and biomimetic materials at which E. Mahoney (Univ. of British Columbia) gave a presentation on the use of nanoindentation to quantify various diseased states in teeth. This session also addressed the fracture mechanical properties of teeth (D. Ruse, Univ. of British Columbia) and specific clinical issues of nanoindentation, namely, the crushing of incipient carious lesions (i.e., cavities) and the consequence of bleaching agents on the mechanical integrity of tooth enamel.

R. Cook, who has recently been appointed to lead the nanomechanics group at NIST, provided an overview of toughness and damage in brittle materials. Cook's talk was followed by a series of presentations on the mechanical characterization of extremely porous aerogel materials, where not only density but also particulate microstructure resulting from precursor chemical preparation plays key roles. Subsequent sessions covered characterization based on molecular dynamics modeling of the behavior of small volumes of materials under localized contact conditions as well as at crack tips and under shock loading. There is an increasing use of such modeling to assist with the interpretation of a range of mechanical and microstructural behavior seen in materials.

B. Lawn (NIST) discussed the role of thin films on the mechanical properties of silicon. Lawn's talk was followed by a series of presentations on the nature of deformation and damage in silicon as well as by a presentation by S. Ruffell (Australian Natl. Univ.) on the characterization of the electrical properties of silicon during nanoindentation. G. Pharr (Univ. of Tennessee; ORNL) presented a review of deformation and cracking in silicon and germanium using indenters with different acuity. Pharr considered not only the role of stress-induced phase transformations but also the nature of the cracking and plastic deformation induced during loading.

E. Stach (Purdue) discussed the *in situ* characterization of nanoindentation of silicon in TEM. Other participants dealt with a range of topics, from twinning in TiAl alloys, to high-strain-rate shock-loaded copper, to different glass systems varying from low dielectric, to observations of water at crack tips, and to contact-induced fatigue cracking.

Symposium Support: Hysitron and LLNL.

Materials Developments Demonstrated for Transparent Electronics
(See MRS Proceedings Volume 905E)

Presentations in Symposium DD on transparent electronics covered novel materials and devices and explored the technological challenges and the fundamental materials science issues associated with the implementation of transparent electronics. Growing interest in alternative transparent conducting materials suitable for use in, for example, high mobility channel materials for transparent thin-film transistors, was reflected by work that included In_2O_3-based systems doped with Zn or Mo, doped ZnO, CNTs, and diamond thin films. New analytical approaches to the characterization of the thermophysical properties of these new materials were discussed and included, for example, the presentation (Y. Shigesato, Aoyama Gakuin Univ.) of a novel technique for the characterization of the thin film thermal diffusivity of ITO and IZO thin films using nanosecond-pulsed laser pump and probe methods. The advantages of room-temperature deposition of amorphous oxides for the control of thermal budget for heat-sensitive substrates was the focus of several talks motivated by the promise of using flexible polymeric substrates such as polycarbonate and polyethyleneteraphthalate (PET).

The realization of high-performance thin-film transistors was reported in several talks, which showed that the field-effect mobility of TFTs fabricated using amorphous oxide semiconductor films compares favorably to conventional a-Si:H and organics for active-matrix LCD applications. The performance of amorphous, multicomponent, heavy metal cation oxide films used in the critical channel region of TFT devices were discussed (J. Wager, Oregon State Univ.) and the performance of oxide TFTs on polymer substrates was discussed in terms of field-effect mobility and ring oscillator frequency. High switching performance and device mobility was presented for field-effect transistors on PET, containing an amorphous oxide channel of In_2O_3-Ga_2O_3-ZnO, demonstrating current on/off ratios of 10^6, a field-effect mobility of 10 cm^2/V s, and a threshold voltage of 1.3 V (K. Nomura, Japan Science and Tech. Agency). Amorphous-IZO thin-film transistors were reported (B. Yaglioglu, Brown Univ.), in which the same IZO material was used both for the source/drain metallization (degenerately doped) and the channel region (low carrier concentration). These *n*-channel, depletion-mode devices were reported to have an on/off current ratio of 10^8 and a field-effect mobility of 20 cm^2/V s.

Among the alternative materials being considered for transparent devices, CNT-based films were shown to compare well against ITO (G. Grüner, UCLA). Films were formed from random 2D percolation networks of CNTs, in which a critical density can give rise to films with high electronic mobility and electrical conductivity, with density- and frequency-determined metallic or semiconducting attributes. The CNTs allow high transparency of visible light due to their nano-size diameter. The difficulty in characterizing the electrical mobility of stand-alone films mandated fabricating a TFT and quantifying the film performance from the measured device performance. Other developments included the demonstration of high-electronic-mobility, *p*-type ZnO films epitaxially grown by repeated temperature modulation laser MBE (A. Tsukazaki, Tohoku Univ.). To achieve *p*-type doping, alternating layers of nitrogen-doped and undoped ZnO were deposited in a superlattice-type structure. The high crystallinity of the film and abruptness of the heterointerfaces were demonstrated by the first reported observation of the quantum Hall effect for a 2D electron gas in an oxide semiconductor, while blue luminescence from a *p-i-n* diode was attributed to the higher than bulk single-crystal mobility and longer than bulk single-crystal exciton emission lifetime.

Recent Advances in Semiconductor Materials Lead to Novel Lasers and Other Devices
(See MRS Proceedings Volume 891)

For Symposium EE on Progress in Semiconductor Materials—Novel Materials and Electronic and Optoelectronic Applications, Patrick McCann from the University of Oklahoma gave an invited talk on the uses of IV–VI infrared lasers to detect exhaled NO and CO_2. This technique is being developed to aid in the diagnosis of a variety of diseases such as asthma and cancer. Speakers in the session addressing infrared issues discussed a variety of advanced laser and detector applications, including mid-IR quantum cascade lasers (R.Q. Yang, JPL) and high-power, room-temperature 2–3-μm lasers (J.G. Kim, Sarnoff Corp.).

Advances in the development and understanding of quantum dot growth and device design have resulted in significantly improved device performance. J.-P. Leburton (UIUC) and L.R. Ram-Mohan (Worcester Polytechnic) discussed recent improvements in theoretical approaches that have enabled increased understanding of quantum dot behavior. On the experimental side, N. Holonyak's group (UIUC) has made progress in developing quantum-well-coupled quantum dot lasers, and D. Deppe's group (Univ. of Texas at Austin) is working on quantum dot microcavities including VCSELs and photonic lattice structures. L. Wilson's group (Univ. of Sheffield) is pushing quantum cascade lasers to shorter wavelengths in the 3–5-μm range.

J. Allen (UCSB) is working on developing what he calls "super-superlattices" to develop terahertz oscillators for use in lasers and other devices. A. Tredicucci (NEST-INFM, Italy) discussed his recent progress in quantum cascade lasers at terahertz frequencies and briefly reviewed other work that has demonstrated lasing in this regime. A. Gossard (UCSB) discussed his novel work on generating terahertz sources based on "photomixing" in metal semiconductor composites grown by MBE.

R. Dupuis (Georgia Tech) discussed the growth of III-nitrides for devices. Nitrides are being used for LEDs and lasers over a broad range of wavelengths from UV to green as well as in a variety of electronic devices such as field-effect and bipolar transistors and rectifiers. D. Look (Wright State Univ.) summarized the current understanding of the properties of defects in ZnO. A. Osinsky (SVT Assoc.) summarized the developments of ZnO-based heterostructures for visible and UV emitters. S. Francoeur (NREL) presented results of the spectroscopy of isolated nitrogen pairs in GaAs that sheds light on the properties of the dilute nitrides. J. Harris's group from Stanford presented results on the performance of InGaAsSbN lasers at 1.3–1.5 μm, which are of great interest for enhanced optical communications. Some results on the novel semiconductor GaNAsBi were presented by M. Yoshimoto (Kyoto Inst.). This material is being explored as a possible temperature-insensitive material for lasers.

Symposium Support: AIXTRON, Epichem, and Veeco TurboDisc Operations.

Progress Highlighted in GaN, AlN, InN, and Related Materials
(See MRS Proceedings Volume 892)

Symposium FF on GaN, AlN, InN, and Related Materials focused on the latest advancements in the research and development of nitride materials and devices. Several presentations demonstrated the development of deep-UV LEDs where

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impressive strides have been made to improve the efficiency of high-Al-content AlGaN and AlInGaN devices. UV LEDs with 100-mW output power and a peak wavelength of 280 nm were reported (M.A. Khan, Univ. of South Carolina), but challenges remain to improve the emission efficiency of devices in the spectral region under 250 nm. In the area of visible LEDs, techniques to enhance light-extraction efficiency were discussed, along with efforts to develop nonpolar or semipolar nitride materials. A.Y. Kim (Lumileds) summarized the latest developments in InGaN growth and demonstrated a compact, high-power LED projector. Several sessions focused on issues relevant to nitride-based electronics. T. Kazior (Raytheon) reviewed the current status of GaN HEMTs for solid-state phased arrays, highlighting advances in the field and the potential for further improvement in device performance through substrate and device structure development. A. Saxler (CREE) reported on progress in the epitaxial growth of uniform AlGaN/GaN heterostructures on 4-in.-diameter SiC substrates. Additional sessions were organized around the topics of InN, bulk growth of AlN and GaN, characterization, and nanoscale structures. In the area of InN, evidence of *p*-type conductivity was reported (W. Walukiewicz, LBNL), along with the growth of InN quantum dots (O. Briot, Univ. of Montpellier).

Symposium Support: AIXTRON, Cree, Nichia Semiconductor Research Laboratory, Renishaw, Sony, SVT Assoc., Toshiba, and Veeco Compound Semiconductor.

Metallic Nanostructures Becoming New Frontier in Optical Nanotechnology

Symposium GG on Plasmonics—Nanoscale Optics and Photonics Based on Metals brought together researchers from physics, materials science, and engineering working toward the common vision of creating nanoscale photonic devices for future highly integrated optical circuits. Unified in a new photonic research area called plasmonics, these researchers use the intriguing optical properties of metallic nanostructures—particles, wires, and holes in a metal film—to confine, guide, and steer electromagnetic waves on the wavelength and subwavelength scale. Talks by S. Bozhevolnyi (Aalborg Univ.) and P. Berini (Univ. of Ottawa) described the state of the art of plasmon waveguides, which can guide energy using 2D modes at metal surfaces over distances ranging from micrometers to centimeters, with varying degrees of confinement, from the deep subwavelength to wavelengths, respectively. A debate ensued surrounding the origins of another phenomenon occurring in metal optics, the efficient transmission of light through arrays of subwavelength holes in a metal film. Talks by H. Lezec (Caltech), J. Garcia de Abajo (Spanish Council for Scientific Research and Donostia Intl. Physics Center, Spain), and F. Garcia-Vidal (Universidad Autonoma de Madrid) summarized new results on current theories about this phenomenon. A large number of talks also centered on new approaches for the excitation and imaging of plasmons, for example, the use of cathodoluminescence, which A. Polman (FOM Inst.) presented.

Challenges Discussed for Magnetic Sensor Systems *(See MRS Proceedings Volume 906E)*

In Symposium HH on Magnetic Sensors and Sensing Systems, W. Egelhoff (NIST) reported the latest progress in developing ultrasoft magnetic materials for MTJ sensors, which may be seen as one of the most important achievements toward picotesla sensitivity. P. Freitas (INESC, Portugal) showed promising results in fabricating magnetic sensors and sensing systems for bio applications. M. Tondra (NVE Corp.) presented his recent work on magnetic sorters and selectors with embedded magnetic sensing arrays for bio applications. D. Wang (NVE) reviewed fundamental requirements and challenges in magnetic materials and devices for AMR and GMR, and MTJ sensors in general. He also reported his work on magnetic sensors with superparamagnetic-type free layers. X. Gang (Brown) presented his work on prototyping a magnetic detection system for IC wafers using nanoscale MTJs as sensors. M. Siegler (Seagate) reported a new type of Hall sensor for future magnetic-recording disk drives. D.P. Pappas (NIST) talked about his team's progress on shape-controlled AMR sensors and fundamental magnetization switching studies. A. Edelstein (ARL) reported the invention of combining magnetic sensors with MEMS to overcome the intrinsic 1/f noise limit for any magnetic sensor. He showed that he could detect any moving motor vehicle within 100 m using his new type of magnetic sensor.

Novel Characterization Methods and Synthesis Techniques Discussed for Magnetic Nanostructures

Symposium II emphasized novel characterization techniques for magnetic nanostructures; synthesis of magnetic nanoparticles, nanowires, and nanotubes; spintronics; magnetoelectronic applications; and recent developments in the field of magnetic semiconductors. Techniques for magnetic characterization of nanostructures by electron microscopy were presented (A. Petford-Long, ANL; J. Chapman, Univ. of Glasgow; R. Dunin-Borkowski, Univ. of Cambridge; and M. McCartney, ASU). D. Dahlberg (Univ. of Minnesota) discussed novel aspects of magnetic force microscopy, and S. Bader (ANL) gave a broad overview of the area of patterned magnetic thin films. K.M. Krishnan's (Univ. of Washington) presentation on high-T_c ferromagnetic-doped semiconductors was followed by several presentations on ferromagnetic semiconductors based on Ge, Si, TiO_2, ZnO, GaAs, and ZnTe, showing the dynamic developments in this research field. Subsequently, J.-P. Wang (Univ. of Minnesota) addressed current-induced switching in MTJs. C. Murray (IBM) discussed the development of novel, highly defined magnetic composite nanostructures based on the 3D self-assembly of colloid nanoparticles. D. Grundler (Technical Univ. of Munich) discussed characterization of spin wave excitation in magnetic nanorings.

Symposium Support: JEOL USA.

Solid-State Theory and Experiments of Actinide Metals and Chemistry Discussed *(See MRS Proceedings Volume 893)*

In Symposium JJ on Actinides—Basic Science, Applications, and Technology, J.E. Klepeis (LLNL) set the stage for electronic structure theory by presenting a comprehensive overview of techniques being applied to the actinides. P.A. Soderlind (LLNL) and M.H. Penicaud (DAM, CEA) continued the theme of electronic structure with recent advances aimed at elucidating the underlying fundamental physics on actinide solids. J.M. Wills (LANL) discussed his latest advances in successfully applying the mixed-level method. E.D. Bauer (LANL) and J.-C. Griveau (ITU-JRC) presented new results on ambient and high-pressure properties of the $PuMGa_5$ superconductors.

Recent advances in electronic structure and solid-state experiments were described (J. Joyce, LANL; J.G. Tobin and S. McCall, LLNL). K.T. Moore (LLNL) described the importance of including a measure of the 5*f* electron anisotropy in the classification of the crystal structure. The high-pressure physics of the actinides was highlighted (S. Li, VCU; R. Ahuja, Uppsala Univ.; B. Johansson, Uppsala Univ., Sweden). P. Faure (CEA) introduced experimental results that show that the transformation of δ-stabilized Pu under pressure goes through the transformation sequence δ—γ´—α´.

R.C. Ewing (Univ. of Michigan) dis-

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cussed the significant amounts of actinide materials worldwide, the effect of radiation on storage materials, and the design of nuclear waste forms. T. Murakami (Univ. of Tokyo) presented results on the naturally occurring Koongarra uranium ore deposit. The symposium concluded with several invited talks on novel spectroscopies by C. den Auwer and colleagues (CEA) and L. Soderholm (ANL), as well as synthetic strategies to elucidate aspects of actinide coordination chemistry (P. Burns, Notre Dame, who spoke on behalf of S. Krivovichev, St. Petersburg State Univ.).

Symposium Support: LANL and LLNL.

Entrepreneurs Explain the ABCs of Commercialization

There's a reason that materials science conferences are not swarming with venture capitalists. It takes a long time to see a return on materials inventions, and venture capitalists typically like to see a significant return on their investments within 10 years, according to Greg Blonder of Morgenthaler Ventures in New Jersey. However, recent successes have been reported, as discussed in Symposium QQ, which was aimed at materials scientists who are interested in understanding the key issues in taking an inventive concept, creating intellectual property, and developing the concept into a feasible project for commercialization. Yoel Fink, associate professor of materials science at MIT and co-founder of the startup company OmniGuide Inc., discussed his work on photonic-bandgap fibers. Joining Fink and Blonder were patent agent Tani Chen of Wolf, Greenfield & Sacks (Boston); Stephen Brown of the MIT Technology Licensing Office; and Mert Flemings, the Toyota Professor of Materials Processing emeritus and director of the Lemelson-MIT Program in invention and innovation at MIT. A few key points made at the symposium, titled "IP, TT, VC, IPO, and U," for "intellectual property, technology transfer, venture capital, initial public offering, (and You!)" were that scientists who want to move their inventions into commercialization through the MIT Technology Licensing Office will need to remain directly involved in the process. In order to obtain a patent, it is a good idea to document every step of the research development in a notebook. The notebook should contain experimental data, for example, and the entries should be signed and dated by the inventor and by a non-inventor colleague who understands the work. This notebook serves as both a scientific and a legal document. The session ended with a panel discussion in which the speakers received questions from the audience.

Solid–Solid Interfaces Observed and Modeled

The aim of Symposium KK was to give an overview of recent progress in the study of grain and interphase boundaries made possible by rapidly evolving experimental techniques and ever-increasing computational power. In addition to the possibility of atomic imaging of near-interface regions HRTEM now allows quantitative determination of interface-related lattice strains. In particular, E.A. Marquis, D.L. Medlin, and colleagues at Sandia National Laboratories identified the interfacial disconnections at the edges of grain-boundary facets and determined their role in the accommodation of grain-boundary coherency strain. HRTEM combined with density functional theory and molecular dynamics simulations allowed Y. Sato, J.P. Buban, and colleagues at the University of Tokyo to identify the segregation sites at grain boundaries in carefully prepared and controllably doped bicrystals of ZnO and alumina. The researchers showed a clear relationship between grain-boundary segregation and electrical and mechanical properties of the boundaries. D.N. Seidman, C.K. Sudbrack, and co-workers at Northwestern University used the increased power of the 3D atomic probe to reliably identify solute clusters and their chemistry in a multicomponent Ni-based superalloy. A statistically reliable cluster size distribution was measured and combined with predictions of coarsening theory for multicomponent alloys, allowing the measurement of the interfacial energies. Also using a 3D atomic probe, R. Kirchheim and co-workers at the University of Göttingen observed an unusual, elongated morphology of Co precipitates in Cu-Co alloys, which suggests the use of this morphology to produce materials with new magnetic properties. Major progress was also reported in computer simulations of interfacial phenomena. H.-S. Nam and D.J. Srolovitz of Princeton University outlined a systematic approach to molecular dynamics simulations of the challenging and poorly understood phenomenon of liquid-metal embrittlement. It was shown that tensile stress applied normal to the boundary plane significantly accelerates the penetration of atoms of the liquid phase into the boundary. Y. Mishin (George Mason Univ.) and J.W. Cahn (NIST) explained the use of geometrical models and computer simulations to determine how shear stress applied parallel to the grain boundary translates into boundary migration.

Combinatorial Methods and Informatics Speed Throughput and Understanding *(See MRS Proceedings Volume 894)*

In the opening keynote address of Symposium LL, X.-D. Xiang (Intematix) summarized his work of the past 10 years and demonstrated that the combinatorial approach to materials science represents not only high-throughput engineering but also is applicable in understanding science. Xiang related the transition of high-quality phosphors from laboratory to industrial applications. E. Amis (NIST) reported on the combinatorial study of polymers. K.J. Van Vliet (MIT) presented the nanomechanical screening of polymers using nanoindentation, a major step forward in characterizing the mechanical properties of polymer libraries. J. Goschnick (Forschungszentrum Karlsruhe) presented the applications of a gradient nanostructured electronic nose microsystem to everyday life and how the combinatorial approach accelerated materials research in sensors. A. Demkov (Univ. of Texas) described computer modeling in relation to modern CMOS technology, discussing how thin and how small devices can be made. J.W. Liebeschuetz (Cambridge Crystallographic Data Centre) discussed the Cambridge chemical structure database for materials science.

Symposium Support: Dutch Polymer Institute, GE Global Research Ctr., HP, NIMS, and NREL.

In Situ Electron Microscopy of Materials Put into Action *(See MRS Proceedings Volume 907E)*

Many novel and significant results were presented in Symposium MM involving the use of *in situ* TEM and *in situ* SEM equipped with straining stages, heating stages up to 2000ºC, and nanoindentation stages in vacuum or gas environments. *In situ* observations revealed grain growth in nanocrystalline materials when the samples were subjected to deformation, a nanomechanical effect on the deformation behavior of silicon when subjected to nanoindentation, the ability of measuring local strains in Al interconnect lines by *in situ* convergent beam electron diffraction, and the ability to quantitatively measure *in situ* magnetization of magnetic domains. Other highlights included phase transformation in individual nanoparticles, the encapsulation of solid particles by a liquid film, the formation of stacking-fault tetrahedra during

Women in MS&E Breakfast Address the "Leaky Pipeline" Worldwide

At the Women in MS&E Breakfast, over 100 MRS members gathered to participate in a panel discussion on "The 'Leaky Pipeline' of Women in Science: Does It Leak More in Your Country than in Others?" featuring eminent women in materials research, with work experience on three continents. The panelists included Debra Rolison of the Naval Research Laboratory, Hifang Lang of Aldrich Chemical Company, and Suzi Jarvis of Trinity College, Ireland. After perspective views from the United States, Ireland, and Asia were presented, the attendees engaged in discussion of their personal views and experiences and considered the potential reasons why women are not better represented in the fields of science and engineering, particularly in faculty and upper management positions. Major concerns of many in attendance included the difficulty in identifying female mentors (due to a lack of females in senior positions), and challenges associated with balancing family and work, particularly in tenure track university settings. While it was noted by the moderator, Sandy Yulke of Yale University, that significant progress has been made in the past 20–30 years, efforts are still needed to ensure that the science and engineering communities are not excluding or missing significant percentages of their talented (female) individuals.

The breakfast was sponsored by FEI Company and Sigma-Aldrich, and organized by the MRS Outreach Subcommittee.

abnormal grain growth in nanocrystalline Ni, and the wall-by-wall breakdown occurring in multiwalled nanotubes as a result of electrical transport.

Symposium Support: Carl Zeiss SMT AG, Fischione Instr., Gatan, JEOL USA, Kammrath & Weiss GmbH, and NANONET-Styria.

Development and Application of Scanning Probe Microscopy Range from Nanomechanical Data Storage to Polymers and Biological Systems

A number of breakthroughs were reported in Symposium NN on scanning probe microscopy, including the application of frequency-modulation methods to carry out atomic-resolution imaging of alloy surfaces under liquids (H. Yamada, Univ. of Kyoto). J.C. Davis (Cornell) presented an STM, operated at temperatures in the mK range, which exhibited extraordinary mechanical stability and the best possible vibration isolation. Atomically resolved STM spectroscopy of hole-doped cuprates was investigated, where the local hole density could be related to the appearance of a superconductive bandgap. The detection of ultrasmall forces (below 2 attonewtons, or 10^{-18} N) were described by R. Budakian (Univ. of Illinois and IBM Almaden Research Center), who performed magnetic resonance with ultrasoft cantilevers and succeeded in detecting a single electron spin. The manipulation of single atoms by dynamic force microscopy was shown by S. Morita (Osaka Univ.).

In situ tribological applications using both scanning-probe-based nanomechanical measurements and Raman spectroscopy were described by K.J. Wahl and R. Chromik (both of the Naval Research Laboratory). This approach yields information that allows the correlation of measured tribological values with physical processes occurring in real, macroscopic contacts. A.D. Corwin (SNL) reported rate–state effects relating to adhesion in fluorinated SAM-coated silicon contacts. The influence of time on stiction behavior in such systems has profound consequences for MEMS reliability.

C. Marliere (Université Montpellier) and S. Wiederhorn (NIST) gave back-to-back talks with competing interpretations of nanoscale observations of fracture. Marliere interprets his observation of nanoscale pits on a surface in advance of a crack as emblematic of nanoscale plastic deformation, but Wiederhorn reported that this should be accompanied by pits on the faces of the fracture surfaces themselves, which were not observed in his study. This motivates future work elucidating nanoscale deformation processes in fracture.

Symposium Support: Ambios Technology/Quesant Instr., Asylum Research, Nanoworld AG, nPoint Inc., NT-MDT, and RHK Technology.

Growth, Modification, and Analysis Done by Ion Beams at the Nanoscale *(See MRS Proceedings Volume 908E)*

Ion-beam techniques are well established in many traditional technological and analytical areas. But are they also useful for the growth, modification, and analysis of nanostructures and nanostructured materials? This was the question posed by Symposium OO within the group of general interest topics at the 2005 MRS Fall Meeting. A large number of contributions as well as lively discussions throughout this symposium demonstrated that ion beams are increasingly being used in many areas of nanoscience and technology.

The presentation topics included: swift heavy and light ions, focused ion beams, broad keV and MeV ion beams, structural modifications, metallic nanoparticles, semiconductor nanoparticles, nanotube/wires, magnetic nanoparticles, nanopatterning, ion-beam analysis, and computer simulations. The symposium highlighted the range of new topics that has emerged over the past two years. These include the use of ion beams to tailor the shape of nanoparticles and nanomasks for future photonic materials, to form nanocavities suitable for collecting impurities in nanoparticles, to engineer the strain of near-surface electronic device regions, and to connect CNTs to semiconductor surfaces. The formation of narrow open channels along ion tracks, suitable as a filter for biomolecules or as a mold to form nanowires, was presented, as well as the use of fullerene ions to gently kick off large molecules like benzene (and possibly more complicated biomolecules) from surfaces for analytical purposes. Many ion-beam approaches to synthesize nanostructures/materials currently involve self-organization/assembly, where irradiation of a surface with the ion beam is used to achieve an instable or metastable state which upon relaxation against thermodynamic equilibrium leaves behind a nanostructured state, such as nanoscale ripples on surfaces. There is progress in the direct writing of nanostructures using low-energy focused ion beams. High-energy focused ion-beam systems are in development, with the potential for 50-nm beams for nanoscale modifications and analysis. These are not yet in operation, however. Further significant progress is expected once low-energy focused ion-beam systems become available with more flexibility concerning the range of available ion species.

Symposium Support: PNNL and SNL.

Forum on Materials Science Education
(See MRS Proceedings Volume 909E)

There are many important issues associated with the education of the next generation of materials scientists and materials engineers. Rosemary Haggett of the National Science Foundation said one of the biggest challenges is attracting students into the field. With the number of U.S. engineers and scientists declining, it is essential to broaden the participation of underrepresented groups and to build and strengthen links with community colleges and other two-year institutions, Haggett said. The importance of research experiences, such as REU, as means for attracting and retaining students in MSE was stressed, as was the need to demonstrate the societal role played by materials. Introducing innovative curricula can make a significant impact on enrollment. P. Davies (Univ. of Pennsylvania) showed dramatic increases in undergraduate enrollment following the introduction of a nanoscale MSE curriculum. Many of the participants discussed how to most effectively incorporate "nano."

Many academics are developing outstanding educational resources for MSE. This forum and others like it represent one way to exchange ideas and techniques related to materials education. L. Bartolo (Kent State) described the Materials Digital Library. This online resource was started in 2005 and is a multi-institution initiative funded by NSF.

On the topic of accreditation, S. Cargill (Lehigh) discussed "design" within MSE. One approach to address the ABET design requirement may be for students to assemble a portfolio that includes results of their REU experiences, internship positions, and the outcomes from research they do at the home institution. R. Gibala, Dean of Engineering at the University of Michigan, described his experiences with the accreditation process and concluded that the process is important and can lead to improvements in program quality. Summarizing, he said that, overall, the good aspects of ABET exceed the sum of the bad and ugly. The final session described some of the outstanding work being done in REU programs.

Symposium Support: NSF and Springer. MRS