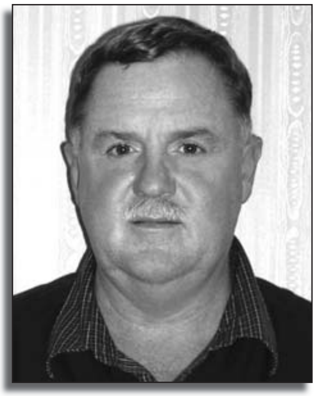
Besser, Fratzl, Spaldin, and Tritt to Chair 2009 MRS Spring Meeting


Paul Besser


Peter Fratzl


Nicola Spaldin


Terry M. Tritt

Meeting Chairs for the 2009 Materials Research Society (MRS) Spring Meeting are Paul Besser (Advanced Micro Devices, Inc., Sunnyvale), Peter Fratzl (Max Planck Institute of Colloids and Interfaces, Potsdam), Nicola Spaldin (University of California, Santa Barbara), and Terry M. Tritt (Clemson University). The meeting will be held in San Francisco on April 13–17, 2009.

Paul Besser is an AMD Fellow in the Technology Research Group at Advanced Micro Devices, Inc. in Sunnyvale, Calif. Besser graduated from North Carolina State University (1988) and earned his doctorate from Stanford University (1993) in materials science and engineering. Since joining the Technology Development Group at AMD in 1993, he has applied his materials and metals knowledge to understand how processing changes can positively influence the technology and product performance, yield, and reliability. He has led numerous cross-organizational metallization and silicide teams for AMD's logic and memory technologies. Besser also researched silicides at IMEC (1997) and researched silicides and contact metallurgy at IBM's T.J. Watson Research Facility (2006). He is currently in the Technology Research Group at AMD, and his research interests are contact metallurgies, novel silicides, metal caps for Cu interconnects, and mechanical properties of in-laid Cu lines. Besser holds more than 150 U.S. patents and has co-authored over 80 research publications on materials issues for the integrated circuit industry. Besser has previously instructed tutorials at the MRS meetings (1995–1997) and organized four MRS symposia (2001–2006).

Peter Fratzl is director at the Max Planck Institute of Colloids and Interfaces in Potsdam, Germany, and honorary professor of physics at Humboldt University, Berlin. He received an engineering degree from the Ecole Polytechnique in Paris, France (1980), and a doctorate in physics from the University of Vienna, Austria (1983). Before moving to Potsdam in 2003, he has been holding professor positions at the Universities of Vienna and Leoben in Austria. Fratzl's laboratory studies the relation between (hierarchical) structure and mechanical behavior of biological materials, such as bones, teeth, or plant cells, as well as bio-inspired composite materials. His bone research includes extensive work on osteoporosis and on bone regeneration. He has previously participated in and organized symposia at the MRS spring meetings. Fratzl is a foreign member of the Austrian Academy of Sciences and he has received several international awards for his work, including the 2008 Max Planck Research Prize together with Robert Langer of the Massachusetts Institute of Technology for pioneering work in the field of "Biological and Biomimetic Materials" and the 2008 Erwin Ühlinger Memorial Lectureship from the German Osteological Society.

Nicola Spaldin is a professor in the Materials Department at the University of California, Santa Barbara. She has a BA (1991) and MA (1995) degree from Cambridge University and a PhD degree (1996) from the University of California, Berkeley. Her research uses first-principles electronic structure methods to design novel materials that combine multiple contra-indicated functionalities; in particular, multiferroics (which are simultaneously ferromagnetic and ferroelectric) and magnetoelectrics (which have electric-field tunable magnetism). She is director of both the UCSB Center for the Chemical Design of Materials (a National Science Foundation Chemical Bonding Center) and the International Center for Materials Research (an NSF International Materials Institute). Spaldin has numerous awards and honors, including the Miller Institute Research Professorhip (2007), the Alfred P. Sloan Foundation Fellowship (2002), and an MRS Graduate Student award (1994). Her recent science outreach activities include an effort to enhance the concert-going public's appreciation of materials chemistry through the commission and premier of a symphony on a chemistry theme, and a trek up the Kangchenjunga Valley in Nepal to install solar-powered refrigerators for medical vaccines.

Terry M. Tritt is a professor of physics at Clemson University, where he received his BA (1980) and PhD (1985) degrees in physics. His current research centers on materials for thermoelectric (TE) refrigeration and power generation applications. His primary research expertise lies in electrical and thermal transport properties and phenomena (especially in measurement and characterization techniques) in new and novel materials. He has recently become involved in the synthesis and characterization of thermoelectric nanomaterials and nanocomposites. He has extensive expertise in measurement science and has built an internationally known laboratory for the measurement and characterization of thermoelectric material's parameters, especially thermal conductivity. Tritt has been involved with MRS for over a decade, serving as a symposium organizer first in 1997. He was recently an author and lead editor of an *MRS Bulletin* (March 2006) theme on "Thermoelectric Materials and Devices." He was also a contributing author to the recent *MRS Bulletin* on "Harnessing Materials for Energy" (April 2008). He has served as a member of the executive board of the International Thermoelectrics Society (ITC) since 1999 and served as chair and host of the 24th ITC-2005 in 2005. Tritt holds two patents, has authored over 150 journal articles, and has edited seven books. He was recently

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elected as an Academy Fellow of the International Thermoelectrics Academy and was the 2008 SC Academy of Sciences Governor's Research Professor of the Year.

For updated information on the 2009 MRS Spring Meeting, access Web site www.mrs.org/meetings/.

MRS Seeks Nominations for 2009 Outstanding Young Investigator Award

www.mrs.org/oyi

The Materials Research Society is accepting nominations for the Outstanding Young Investigator (OYI) Award to be presented at the 2009 MRS Spring Meeting in San Francisco.

The OYI Award recognizes outstanding interdisciplinary scientific work in materials research by a scientist or engineer under the age of 36 (as of January 1, 2009). The award recipient must show exceptional promise as a developing leader in the materials area.

The award consists of a $5,000 prize, a presentation trophy, and a citation certificate. Reasonable travel expenses to attend the MRS Meeting at which the award is presented and the meeting registration fee will be reimbursed.

The deadline for submission of nominations is midnight Eastern time (U.S.) on October 1, 2008. For guidelines and application forms, access the MRS Web site at www.mrs.org/oyi/ or contact Lorri Smiley, Materials Research Society, 506 Keystone Drive, Warrendale, PA 15086-7573, USA; e-mail awardsprogram@mrs.org.

MRS Seeks Nominations for 2009 Materials Research Society Fellows

http://fellows.mrs.org

The Materials Research Society seeks to recognize as "MRS Fellow" outstanding individuals who are notable for their sustained and distinguished contributions to the advancement of materials research. It is intended that, representing excellence in science and engineering, and dedication to the advancement of materials research, the MRS Fellows will collectively exemplify the highest ideals of accomplishment and service embodied in the MRS Mission.

Nomination is open to any MRS member in good standing, whose membership has been continuous for at least five years preceding receipt of the nomination. MRS Fellow is a lifetime appointment.

The deadline for submission of nominations is September 30, 2008. To submit a nomination, go to Web site http://fellows.mrs.org.

Materials Research Society Holds 2008 Elections for Vice President and Directors

www.mrs.org/2008_election

The MRS Board of Directors is the highest governing body of the Materials Research Society, responsible for establishing policy, monitoring progress of the Society toward its long-term goals, and setting the strategic directions for the major activities of the Society, including its meetings, publications, interactions with government agencies, and cooperative efforts with other professional societies throughout the world. The Board is composed of four elected Officers (President, Immediate Past President, Vice President/President-Elect, and Secretary), and up to 18 Board Members, 15 of whom are elected by the membership. A fifth officer (Treasurer) is appointed yearly from the Board. This year, MRS members will elect a Vice President (who will serve as President in 2010), and five Directors, who will serve three-year terms. The elected candidates will serve terms beginning January 1, 2009.

The candidate for Vice President/President-Elect are **David S. Ginley**, *National Renewable Energy Laboratory*, and **Bethany J.H. Stadler**, *University of Minnesota*. The candidates for Director are **Marie Angelopoulos**, *IBM Corporation*; **Eberhard Bodenschatz**, *Max Planck Institute, Goettingen* and *Cornell University*; **Larry R. Dalton**, *University of Washington*; **James J. De Yoreo**, *Lawrence Berkeley National Laboratory*; **Jeffrey C. Gelpey**, *Mattson Technology*; **Paul Muralt**, *EPFL*; **Christine A. Orme**, *Lawrence Livermore National Laboratory*; **Michael F. Rubner**, *Massachusetts Institute of Technology*; and **Takao Someya**, *University of Tokyo*.

The ballot to vote will be online at www.directvote.net/MRS, beginning August 11 through 12:00 noon Eastern Daylight Time on September 25, 2008. Members with a valid e-mail address on file at MRS will receive their unique login information from the election service provider, Survey & Ballot Systems, by email. The e-mail will be from mrsvote@directvote.net. (If necessary, members should modify their SPAM filters to accept this e-mail.) Members without an e-mail address on file, or having a shared address, or who have requested no e-mail messages from MRS will receive their login information by regular mail.

Although the election will be conducted online, members who wish to receive a paper ballot may contact Kathy D'Biagio at dbiagio@mrs.org, or 724-779-3004 ext. 102.

A list of candidates and their biographical information and statements is available on the MRS Web site at www.mrs.org/2008_election, and will be available on the ballot site beginning August 11, 2008.

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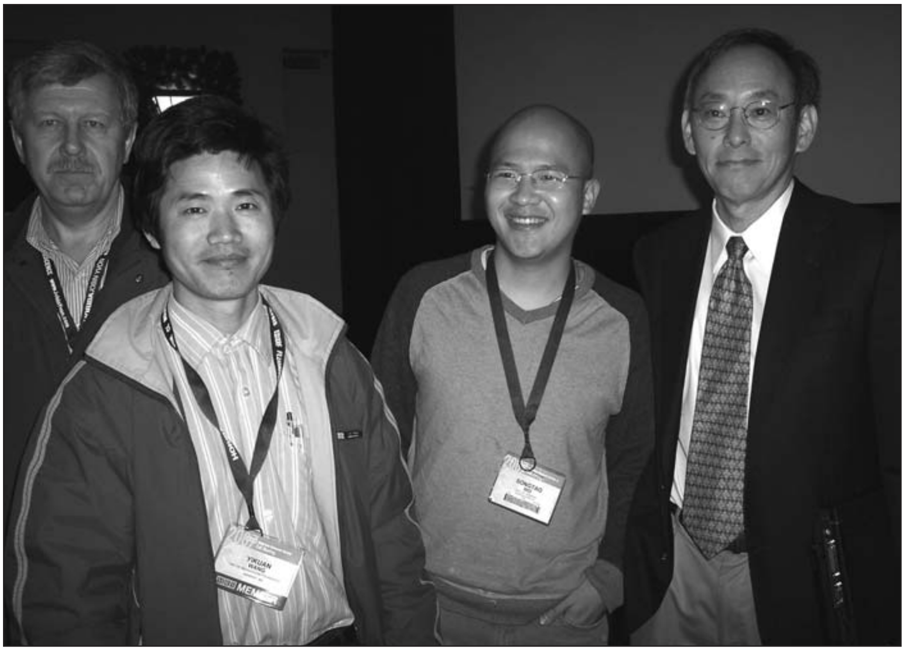
2007 MRS Fall Meeting Explores Themes from Energy to Nanosystems

www.mrs.org

The 2007 Materials Research Society Fall Meeting was held in Boston, Mass., at the Hynes Convention Center and the Sheraton Boston Hotel on November 25–30, 2007. Meeting Chairs **Duane Dimos** (Sandia National Laboratories), **Mary Galvin** (Air Products and Chemicals, Inc.), **David Mooney** (Harvard University), and **Konrad Samwer** (University of Göttingen), in conjunction with the symposium organizers, put together a program of 43 technical symposia as well as a plenary session, an awards ceremony, special events, tutorials, and an equipment exhibit.

One of the dominant themes of the meeting was energy, featuring the plenary address by Nobel laureate Steven Chu, who addressed solutions to the world's energy crisis. "There is no doubt we have an energy crisis on our hands," said Chu, the director of Lawrence Berkeley National Laboratory in California. The potential effects of this crisis could be devastating, including water shortages; population displacements due to rising sea levels; and reduced productivity of farms, forests, and fisheries. Evidence of this problem is seen in the shrinking rate of the Tibetan glacier (by ~1.2 m/year) that serves the water needs of one-third of the world's population.

Although the Intergovernmental Panel on Climate Change (IPCC), which was recently awarded the Nobel Prize, recognized and described the severe global impacts of climate change, the panel did not consider some of the feedback loops that threaten even direr scenarios. For example, vast quantities of trapped methane and carbon dioxide in frozen tundra are being released as a result of the warming of polar regions, resulting in the greatly accelerated melting of the Greenland ice sheet. If the entire ice sheet were to melt, the result would be a 7-m rise in sea levels, which could displace 140 million people from Bangladesh alone as a result of flooding of coastal areas, said Chu.



Stephen Chu, (right), director of Lawrence Berkeley National Laboratory, meets with Meeting attendees following his plenary address, "The World's Energy Problem and What We Can Do About It," at the 2007 Materials Research Society Fall Meeting in Boston on November 26.

Chu discussed the current energy consumption of countries, as well as CO_2 emissions. He suggested a two-pronged strategy to solve the energy problem: maximize energy efficiency and minimize energy use while also developing new sources of clean energy. He said that government regulations would be more efficient in this case than the free market and that, in particular, a worldwide pricing on carbon must be established. He also called for a boost in U.S. R&D funding similar to that seen for the Apollo program. Chu ran through various options for energy sources available now and discussed which are relevant and most promising from a materials development viewpoint. One example is the use of high-voltage dc for long-range electricity transmissions, which would require better solid-state high-power electronics and better insulating materials for cables than are currently available. Chu attempted to predict future energy trends by way of different fuels and methods. He said that he was optimistic about humankind's future and that "…the world can and will prevail over this great energy challenge."

Chu's plenary address on energy was followed throughout the week by presentations on materials research activities and opportunities in various energy sources as well as on environmental concerns, public outreach, and business opportunities regarding energy. In an overview for the nonspecialist in Symposium X, J.S. Nelson of the Energy and Infrastructure Futures Group, Sandia National Laboratories, discussed materials challenges to be solved in order to pursue a more widespread adoption of renewable energy. For example, one option would be to expand the use of unconventional fossil resources. However, this would result in increased environmental degradation effects, he said. Another option would be to expand nuclear power efforts, although this approach entails concerns over waste disposal.

Currently, said Nelson, the world usage of energy is 10 TW of which the United States uses about 3.3 TW. The goal is to achieve at least 10 TW of clean energy generation by 2050, which Nelson said appears to be possible. He said that, in the southwestern United States, for example,

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covering an area of 80 × 80 square miles with solar panels would generate about 7 TW. Wind power in the United States at a modest growth rate of 10% per year would achieve 1 TW capacity by 2050. Nelson concluded by describing a project at Sandia in which solar fuel generation is being used to form synfuel—an activity he referred to as sunlight to petrol. Nelson said that materials researchers can be optimistic about the widespread adoption of renewable energy if the community gets started on solving associated problems immediately and works hard at finding new solutions.

In Symposium T on Materials Innovations for Next-Generation Nuclear Energy, researchers focused on the development of materials for environments with extreme radiation and high temperatures. The temperatures and radiation doses in nuclear reactors require materials resistant to radiation hardening and embrittlement, phase instability, irradiation, creep, volumetric swelling, and high-temperature helium embrittlement. A goal is to widen the temperature operating window. Whereas it took 40 years to achieve a 55°C improvement, "we have to do better than that now," said S.J. Zinkle of Oak Ridge National Laboratory. "Science isn't an enemy of fast," he said; modern materials science now has the tools to develop and optimize materials in a way that was not possible when nuclear reactors were first coming online decades ago, and computer modeling offers the power to accelerate the process, Zinkle said. Use of modeling through molecular dynamics simulations in combination with an understanding of materials structure and properties enables the design of optimal materials in a couple of years rather than decades. For example, two strategies for radiation resistance are starting with amorphous materials or introducing a high density of nanoscale recombination centers. Also, fcc materials can develop large sessile clusters from the radiation displacement cascade, whereas bcc materials generally have smaller, more mobile clusters. Although introduction of nanoscale features can double radiation resistance in some stainless steels, use of a bcc chromium steel does much better, Zinkle said. He gave several examples of how improved steels for fission and fusion reactors can be developed by such techniques.

Among solutions to address overall environmental concerns that result from the energy problem is a method to capture and store methane and carbon dioxide through reticular chemistry and metal–organic frameworks, as discussed by 2007 MRS Medalist Omar Yaghi of the University of California, Los Angeles. Reticular (netlike) chemistry involves the linking of molecular building blocks (e.g., organic molecules, inorganic clusters, dendrimers,

ACRONYM KEY

2D: two-dimensional
3D: three-dimensional
AFM: atomic force microscopy
AIST: National Institute of Advanced Industrial Science and Technology
ANL: Argonne National Laboratory
ARL: U.S. Army Research Laboratory
ARO: U.S. Army Research Office
ASU: Arizona State University
BNL: Brookhaven National Laboratory
CalPoly: California Polytechnic State University
Caltech: California Institute of Technology
CEA: Commissariat à l'énergie atomique
CEMES: Centre d'Elaboration de Matériaux et d'Etudes Structurales
CMU: Carnegie Mellon University
CNRS: Centre National de la Recherche Scientifique
CNT: carbon nanotube
CVD: chemical vapor deposition
CWRU: Case Western Reserve University
DARPA: Defense Advanced Research Projects Agency
DHS: Department of Homeland Security
DoD: Department of Defense
DOE: U.S. Department of Energy
DTRA: Defense Threat Reduction Agency
EELS: electron energy loss spectroscopy
EPFL: École Polytechnique Fédérale de Lausanne
FET: field-effect transistor
FIB: focused ion beam
FSMA: ferromagnetic shape-memory alloy
GEO: geosynchronous earth orbit
Georgia Tech: Georgia Institute of Technology
GM: General Motors
HP: Hewlett Packard
HRTEM: high-resolution transmission electron microscopy
ISU: Iowa State University
JHU: Johns Hopkins University
JPL: Jet Propulsion Laboratory
LANL: Los Alamos National Laboratory
LBNL: Lawrence Berkeley National Laboratory
LCA: life cycle analysis
LED: light-emitting diode
LEO: low earth orbit
LLNL: Lawrence Livermore National Laboratory
MEMS: microelectromechanical systems
MEO: medium earth orbit
MIT: Massachusetts Institute of Technology
MPI: Max Planck Institute
MPCVD: microwave plasma-assisted chemical vapor deposition
MRAM: magnetic random-access memory
MRI: magnetic resonance imaging
MRSEC: Materials Research Science and Engineering Center
NAND: not and, or negated conjunction
NCI: National Cancer Institute
NIH: U.S. National Institutes of Health
NIMS: National Institute for Materials Science
NIST: National Institute of Standards and Technology
NNSA: National Nuclear Security Administration
NRL: Naval Research Laboratory
NSF: U.S. National Science Foundation
ONR: U.S. Office of Naval Research
ORNL: Oak Ridge National Laboratory
PEG-1000: poly(ethylene glycol) with an average molecular weight of 1000 g/mol
PI: principal investigator
PL: photoluminescence
PLA: poly(lactic acid)
PLD: pulsed laser deposition
POSTECH: Pohang University of Science and Technology, South Korea
PSU: Pennsylvania State University
PV: photovoltaic
QD: quantum dot
QM: quantum mechanical
R&D: research and development
rf: radio frequency
RIKEN: Rikagaku Kenkyusho (Institute of Physical and Chemical Research, Japan)
SNARF-1-dextran: carboxyseminaphthorhodafluor-1-dextran
SNL: Sandia National Laboratories
SOI: silicon-on-insulator
SPM: scanning probe microscopy
STEM: scanning transmission electron microscopy
STM: scanning tunneling microscopy
SUNY: State University of New York–Stony Brook
SWNT: single-walled carbon nanotube
T1: longitudinal relaxation time
TEM: transmission electron microscopy
TI: Texas Instruments
TOA: trioctadecylamine
UC: University of California
UCLA: University of California–Los Angeles
UCSB: University of California–Santa Barbara
UCSD: University of California–San Diego
UN: University of Nebraska
UNM: University of New Mexico
USC: University of Southern California
UTS: University of Texas Southwestern
UV: ultraviolet
Virginia Tech: Virginia Institute of Technology
XPEEM: x-ray photoemission electron microscopy
XRD: x-ray diffraction
ZT: dimensionless thermoelectric figure of merit

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peptides, and proteins) into predetermined structures in which such units are repeated and are held together by strong bonds. By using joints and links, the molecular unit building blocks can be used to design nanoparticles, chains, sheets, and networks. Basic default structures can be used to construct larger, more elaborate structures forming metal–organic frameworks (MOFs). Yaghi described the example of a zinc acetate-based structure that was used to form MOF-5. The surface area of this material is 3300 m^2/g; it is 65% open space. Another example is MOF-177, which has a surface area of 4500 m^2/g that can be increased to 5500 m^2/g. This can be compared to the values of 500 m^2/g for zeolites and 1500 m^2/g for porous carbon. BASF is able to manufacture MOFs on a large scale, in batches of up to 250 kg, and has set up a plant dedicated to the production of MOFs, said Yaghi.

The major interest and tremendous potential and opportunity for these materials are in clean-energy applications, Yaghi said. In fact, he said, compaction and storage of methane and carbon dioxide to practical levels has already been achieved. In the area of hydrogen storage, compaction of hydrogen at 77 K to levels expected by the DOE has been achieved and now needs to be demonstrated at room temperature. Calculations demonstrate that doping MOFs with lithium should work, Yaghi said. He then described the use of covalent organic frameworks (COFs) for this purpose. COF-108 is the least dense material currently known. Another aspect of interest is CO_2 separation and storage directly without the use of amines as is done now in power plants. For this purpose, Yaghi discussed zeolite imidazolate frameworks, which are extremely stable and can be used as selective CO_2 reservoirs.

Addressing the global climate crisis is also a particular interest of Bill Joy, who is well-known as a co-founder of Sun Microsystems and the inventor of several computing software technologies. In his search for innovators, Joy travels through universities, laboratories, and conferences such as the MRS meeting, where he was given voice at a special President's Forum. "I am an architect of systems," Joy said. Speaking on behalf of the venture capital firm Kleiner, Perkins, Caufield & Byers (KPCB), Joy said he is looking for innovators who can "make what's possible happen." When talking about innovation, he described the example of glass technology. In this area, innovation is needed to come up with a new materials system in order to make smart windows that are cost-effective and to break into the glass industry, which, he said, is very non-innovative, pointing to double-paned windows as the industry's solution for energy efficiency. With 500 companies in the firm's portfolio, KPCB might be of obvious interest for materials entrepreneurs. Joy said that one-third of the companies they started became public and one-third were acquired by larger companies—and in the way entrepreneurship goes, one-third saw no success. Joy and KPCB, however, move forward, actively investing in Greentech innovation and entrepreneurs.

Ramamoorthy Ramesh of the University of California–Berkeley presents the 2007 MRS David Turnbull Lecture.

Turnbull Lecturer Ramesh Addresses Oxide Electronics

This was a notable meeting for the MRS David Turnbull Lectureship because Turnbull, the namesake of the award, passed away on April 28, 2007. Before the Turnbull lecture delivered by the 2007 recipient Ramamoorthy Ramesh of the University of California–Berkeley, Michael Aziz of Harvard University, one of Turnbull's former graduate students, paid him a tribute. Turnbull rarely missed the MRS Fall Meetings, and his absence at this meeting was felt.

Ramesh, who received the Lectureship in recognition of his work on oxide electronics, began his lecture by acknowledging his past and present collaborators at various institutions. Ramesh said that the field of oxide electronics truly stands on the shoulders of giants, including Arthur von Hippel, Ted Geballe, John Goodenough, and Eric Cross. Ramesh covered the advances in this field chronologically and based on his work from the 1980s until the present. He focused on perovskite-related structures.

The birth of oxide electronics is directly related to the discovery of high-temperature superconductors in the 1980s. Ramesh described his early efforts at Bellcore aimed at eliminating polarization fatigue in perovskite ferroelectrics, which was eventually solved through the use of conducting oxide electrodes. This subsequently led to the discovery of colossal magnetoresistance for which he is best known. In the magnetoresistive La–Ca–Mn–O system, for example, a thousand-fold change in resistivity was observed. This essentially led to a new field of research, which is very active today.

Ramesh detailed multiferroics, another major area of current research for oxides. Specifically, the combination of the ferroelectric and magnetic properties of perovskites yields multiferroics such as $BiFeO_3$. Ramesh described work on heterostructures and nanostructures of multiferroics. There is tremendous current activity aimed at achieving deterministic control of magnetism using an electric field, and there are opportunities for new materials physics as well as a new generation of electrically controlled magnetic devices for storage, logic, and sensing. Ramesh described the growth of complex oxides to form heteroepitaxial structures of $BiFeO_3/SrRuO_3/SrTiO_3$, which can be achieved with precise control. He also mentioned recent efforts at understanding order in $BiFeO_3$, electric control of antiferromagnetism, and creating exchange heterostructures. In the 20 years since high-T_c superconductivity was discovered, significant scientific and technological progress has been made as a result of work on oxide electronics, and tremendous challenges and opportunities remain in the field, Ramesh said.

In closing, Ramesh quoted from Turnbull's autobiography, having been moved by his humanity, "In my view, commitment to humanity arises naturally from a wide ranging and deeply sensitive human consciousness which leads one human to feel sharply within one's self the aspirations or pains of another. I believe it is such consciousness which has led people to imagine or feel that there exists a just and humane basis for ultimate reality."

Energy Day and Public Outreach Activities

On Monday, Nov. 26, at the Fall Meeting, MRS hosted Energy Day, a day-long event for 19 high-school teams from the Boston area. In the morning session, the student teams raced their fuel-cell model cars against each other. The teams started with the same fuel-cell model car kit, but each

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team optimized the performance of its vehicle according to its own design. Norwell High School successfully defended its championship status. In the afternoon session, the teams participated in a Materials Science Fair, which consisted of 10 interactive, table-top activities about materials research that were designed by several MRSECs and the Museum of Science in Boston. During the fair, students created polymers, learned about liquid crystals, made lip gloss, toured the *Strange Matters* Web site, explored hydrophilic and hydrophobic materials, and engaged in several other activities. Energy Day concluded with an informational presentation by Sandra DeVincent Wolf, director of Planning at MRS, about education and careers in materials research and engineering.

"How to make the invisible visible" is a task challenging materials research educators as science and technology has progressed to the realm of the nanoscale. Harold Kroto of Florida State University brought this issue up in his Kavli Lecture, presented at the Fall Meeting, prior to introducing his educational outreach program for children, Global Educational Outreach for Science Engineering and Technology (www.geoset.info). Participants in Symposium W on materials education also addressed this challenge in the session focused on bringing materials science and nanotechnology to the attention of the general public.

With new challenges come new approaches. In order to educate the public about nanoscale science and technology, the National Science Foundation invested in a strategy to put together research institutions with outreach programs to explore how to teach nanoscience to the public. The program is called the Nanoscale Informal Science Education Network. Carol Lynn Alpert of the Museum of Science in Boston discussed her museum's role in this endeavor. Together with the Exploratorium in San Francisco and the Science Museum of Minnesota, researchers and educators are developing exhibits and programs that translate nanomaterials research into something that can be understood by the public audience. Alpert described the need to hire scientists with educational outreach skills to help facilitate this task. Science museums and materials research centers within universities are seeing an increasing role for "translators": materials researchers who are able to describe the abstract outcome of nanomaterials research in concrete images and match the projects taught in workshops with the educational standards that teachers of K–12 students must achieve.

The multidisciplinary nature of nanoscience is also challenging university students, as they need to learn how to communicate across disciplines. Participants in the symposium noted the number of Science Cafes springing up in science museums and other venues, where scientists in various disciplines come together to tell one another and the science-interested public about the exciting innovations in their fields. Between talks, the symposium participants explored the evolution of public outreach. The term "public outreach," they determined, defines a one-way relationship in which scientists educate the general public. However, they realized that, in reality, they are forming educational partnerships, two-way relationships in which researchers and the general public learn ways of thinking about science from each other.

Several speakers described specific outreach projects. Tami Lasseter Clare of the Museum of Art in Philadelphia, Pa., uses her museum as a venue to teach chemistry to high-school students. Clare's workshop consists of a two-hour gallery tour followed by laboratory work involving three activities and a demonstration. One topic, for example, is a silvering experiment and another is modern damascening. Jennifer N. Boice of Simmons College teaches 12 principles of Green Chemistry, where participants experiment with compostable PLA cups in order to determine the greenest method to create a green polymer. The particular project can be adapted to courses or workshops for undergraduate students, research students, and the general public.

Materials Research Society 2007 Vice President/President-Elect Cynthia A. Volkert of the University of Göttingen addressed the Women in Materials Science and Engineering Breakfast. In her talk, "The Role of Professional Societies in Promoting Women—Case Study: MRS," Volkert responded to the National Academies' report on women in science and engineering which issued recommendations on how professional organizations such as MRS can help society to fully utilize the talent of this segment of the population. Volkert reviewed five recommendations from the report and presented data on how MRS is doing within those recommendations. She engaged the attendees in a discussion of how MRS should answer the National Academies' Call to Action. The breakfast, organized by the MRS Public Outreach Committee, was sponsored by Agilent Technologies; EP Laboratories, Inc.; FEI Company; and Sigma-Aldrich Corporation.

Energy and Environment

In the cluster on energy and environment, researchers addressed materials innovations for nuclear energy, hydrogen storage, thermoelectrics, life-cycle analysis, and water purification. Access to adequate supplies of clean water is a growing concern throughout the world, and efficient and cost-effective desalination methods are sought. In Symposium V, E.M. Hoek (UCLA) considered creating advanced water treatment membranes using nanocomposite materials technology. Reverse osmosis is the process of applying a hydraulic pressure to an aqueous solution to force water through a semipermeable membrane, thus separating salt from water. Yet, membrane filtration and desalination processes remain relatively nonselective, energy-intensive, and fouling-prone. Fouling can be reduced by decreasing the sticking efficiency. However, even when pure water passes through some membranes, the pressures can cause mechanical changes, compacting the membranes and squeezing the pores. This further increases the pressure and further compacts the film. Advanced membrane materials are being developed that combine organic and inorganic materials at the nanoscale to attempt to capture the best of both materials classes, such as stability, selectivity, flexibility, and processibility. The challenges include integration of the materials and how much of the nanoparticles can be loaded into the composite. Nanoparticles with diameters of 50–200 nm integrated with zeolite molecular sieve thin films of similar thicknesses

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are being used to create superhydrophilic surfaces that are highly negatively charged. This helps pull the water through the membrane. Hoek described a polyimide membrane with nanoparticles, showing that increasing the nanoparticle component led to more negative, hydrophilic, and even smoother membranes. Some films were even found not only to resist fouling by bacteria, but even to inactivate bacteria.

Arsenic in drinking water has been linked to cancer and is becoming an increasing problem in developed as well as developing countries. However, arsenic is also difficult to remove sufficiently through standard water treatment methods. V. Colvin (Rice Univ.) presented work that focused on point-of-use water purification and the use of magnetic particles, rather than membranes, for purification. Although magnetic materials have been applied to water treatment since the 1970s, water pressures several times that of a fire hose are needed to obtain sufficient throughput. This is not always possible to achieve in developing countries, and the energy costs are increasingly a burden in developed countries as well. Colvin focused on iron oxide, which is a strong and specific absorber of As, although it has to be crystalline to work well. Colvin described the use of nanoparticles of controlled size with large surface areas that are 10 times those of commercial materials. In addition, a high degree of crystallinity (99%) of the nanoparticles can be attained. Iron arsenate forms at high concentrations of arsenic, which reduces the volume of waste to discard. Although this technique does not require a solid support or the high pressures previously mentioned, high magnetic fields of 1.5 T were needed to remove the particles, and smaller particles have even less force per field. However, the strong size dependence of the susceptibility of the particles led to tailoring the size of the particles and the need for just a 0.36-T permanent magnet. Smaller particles have increased susceptibility because of the reduction or elimination of domain walls. Very small particles, however, are superparamagnetic, that is, magnetic only in a field, so an optimal size of a little over 12 nm was found. Colvin also discussed scale up, and the role of surfactants, providing examples of efforts being undertaken in Brownsville, Texas, and in Nicaragua, and discussed how the process can be adapted to use locally available materials.

Characterization Approaches

In the cluster of symposia on characterization approaches, speakers focused on state-of-the-art characterization techniques and modeling. Functional optical lenses are used in various applications such as aspherical glass lenses for high-storage-density optical disks. Such lenses have precise structures such as diffraction gratings, and the molds used to form such glass lenses need to have these structures incorporated. However, it is difficult to create such molds using conventional hard mold materials. A possible replacement material could be amorphous alloys. J. Sakurai (Tokyo Inst. of Technology), in Symposium A, described the use of a combinatorial technique to identify amorphous compositions of alloys for such an application. The technique is termed combinatorial arc plasma deposition wherein three different elements can be deposited using three arc guns as a compositionally graded layer. In the study described, Pt, Ni, and Zr or Hf were deposited, yielding 1089 samples; then the compositions were examined for amorphous characteristics. To evaluate the mechanical properties, larger samples for identified amorphous compositions were obtained separately. Two compositions, $Pt_{51}Zr_{39}Ni_{10}$ and $Pt_{52}Hf_{36}Ni_{12}$, were identified to be amorphous. However, the former did not achieve the target glass transition temperature whereas the latter did but was very brittle. The researchers then replaced some of the Zr with Hf and identified the composition of $Pt_{51}Hf_{20}Zr_{17}Ni_{12}$ as yielding the best properties.

F.J. Giessibl (Univ. of Regensburg, Germany) described the tracing of forces between individual atoms by AFM in his talk in Symposium B. He described how frequency modulation results in a small amplitude of the AFM tip, yielding subatomic resolution, and how quartz is used to develop a stiff cantilever. For example, the qPlus sensor is an implementation of a self-sensing cantilever based on a quartz tuning fork and can be used at room and low temperatures. The tip is clearly very important, and tip preparation is a major challenge in AFM, more so than in the

Materials Research Benefits from Old Lessons

William D. Nix of Stanford University, recipient of the 2007 Von Hippel Award, the Materials Research Society's highest honor, gave an award presentation about exploiting new opportunities in materials research by applying old lessons.

MRS 2007 Von Hippel Award recipient William D. Nix (right) of Stanford University with Craig Barrett of Intel.

Currently, nanoscale pillars of different materials (e.g., single crystals of Ni) can be formed using focused ion beams. However, with decreasing size, the strength increases significantly—uniaxial compressive strength in the case of the nanopillars. This increase in size is observed without strain gradients, microstructural variations, or substrate constraints in crystals not expected to be dislocation-free. However, Nix said, it was shown in the 1950s and 1960s that dislocation multiplication is characterized by a breeding constant δ, defined as the number of new dislocations created per unit length of dislocation motion. J.J. Gilman had suggested in 1969 that there is a length scale for multiplication, the characteristic distance a dislocation must move before it creates another, which is $1/\delta$. P. Haasen had earlier used this concept in 1962 in his treatment of sigmoidal creep of Si. Thus, crystals smaller than $1/\delta$ should harden by dislocation starvation. In small nanopillars, new dislocation sources are not sufficiently activated before mobile dislocations leave the crystal. In fact, the first direct experimental evidence for the dislocation starvation mechanism was recently reported by A.M. Minor and his group at Lawrence Berkeley National Laboratory, said Nix.

Other examples Nix described were N.F. Mott's model of creep controlled by jog drag; A.A. Griffith's work that can be used to understand intrinsic stresses in thin films on substrates; advances made in research on diffusional wedges in polycrystalline thin films using the work of H.M. Westergaard on crack fields and R.L. Coble on diffusive creep; and the lessons of F.C. Frank, J.H. van der Merwe, J.W. Matthews, and A.E. Blakeslee pertaining to Ge–Si nanowire transistors without misfit dislocations.

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STM. Giessibl described a technique for *in situ* tip preparation by inducing cleavage of the tip material.

For molecules adsorbed on substrates such as metals or semiconductors, vibrational excitation is possible using the STM enabling single-molecule vibrational spectroscopy. Inelastic electron tunneling is also used for the manipulation of the molecules. The vibrational spectrum of a single molecule provides useful information not only for the chemical identification of the molecule but also for the investigation of how molecular vibration can couple with the relevant dynamical processes. M. Kawai (RIKEN, Japan) described the example of an isolated acetylene molecule on a surface. Action spectroscopy is the method to clarify vibrational modes of single molecules at surfaces, which can, in turn, be used to identify unknown species on surfaces. Kawai described the process of molecular hopping. When the tip is at the center of the molecule, the hopping direction is random. If the tip is off center, depending on whether the interaction between the tip and the molecule is repulsive or attractive, the hopping direction can be controlled.

Electronics, Optics, and Magnetics

The cluster on electronics, optics, and magnetics focused on new materials, integration issues, device physics, and applications. For example, the question S. Parkin (IBM, Almaden) is trying to answer is whether it is possible to build a solid-state memory device with the storage capacity of current disk drives. His goal is to build a solid-state memory device with no moving parts that has 100 times lower cost than conventional memory devices and moderate to high performance. In Symposium I, he described the current-induced motion of magnetic domain walls confined to nanostructures—in this case, nanowires of permalloy—wherein the domain wall serves as the logic gate or memory element. This novel storage-class memory will use magnetic domains to store information in a structure called a magnetic racetrack. The magnetic racetrack comprises tall columns of magnetic material arranged perpendicular to the surface of a silicon wafer. The domains are shifted up and down the racetrack by nanosecond-long pulses of spin-polarized current using the phenomenon of spin momentum transfer. Parkin described current-induced resonant excitation and motion of domain walls in the nanowires. The injection of spin-polarized current below a threshold value through a domain wall confined to a pinning potential results in its precessional motion within the potential well. By using a short train of current pulses whose length and spacing are tuned to this precession frequency, the domain wall's oscillations can be resonantly amplified. This allows for the motion of domain walls with much reduced spin-polarized currents, more than five times smaller than in the absence of resonant amplification. For the near term, horizontal racetrack memories have been constructed because they are easier to build. Parkin said that these structures are still better than the densest NAND flash devices currently available. His group has thus demonstrated the fundamental concept of a magnetic racetrack memory device.

Magnetic nanowires and nanorods could be used for localized cancer treatments. By localizing these materials near cancer cells and using MRI with ac magnetic fields, it is possible to generate local heating, resulting in the weakening or death of cancerous cells, leaving behind living healthy cells. This is one of the motivations behind the work of J. Morber (Georgia Tech) in developing iron oxide nanowires and nanorods. In Symposium I, she described the use of PLD to form these structures. Single crystals of Fe_3O_4 and α-Fe_2O_3 were formed. In addition, the ε-Fe_2O_3 phase was also observed—a metastable phase of hematite that has not been discussed since the 1950s. This work represents a new reaction pathway for this phase. The ε-Fe_2O_3 phase, Morber said, has very interesting properties and should have useful magnetic properties. However, it was mixed in with other phases and, so, was difficult to isolate. It also might not be water-soluble. Therefore, a wet synthesis technique was used to form ε-Fe_2O_3 nanowires using PEG-1000.

P. John (Heriot Watt Univ., Edinburgh), in Symposium P, presented a comparison of the thermal oxidation kinetics of the low-index planes of CVD diamond in dry oxygen with kinetic simulations based on QM potential energy profiles. The thermal oxidation of diamond was studied for three forms: aligned ⟨100⟩ polycrystalline films, single crystals, and cuboctahedral crystalline films. He said that oxygen aided the bonding of functional groups on the diamond surface; caused *p*-type conductivity on the surface; and can be used in the surface preparation for homoepitaxial growth, such as for anchoring DNA molecules on the surface of diamond. John heated diamond to 550°C in oxygen (with very low levels of water) and studied the surfaces with an *in situ* laser interferometer. The results differed widely for the different crystal planes, with ⟨100⟩ remaining smooth and ⟨110⟩

Omar Yaghi of the University of California–Los Angeles presents his 2007 MRS Medalist talk.

becoming very rough. After 30 h, a beveled edge formed, believed to be on the ⟨113⟩ plane. John also pointed out that the etching of nanoparticles of diamond proceeded rapidly because the reaction is exothermic and the particles heat up.

Also in Symposium P, J.C. Angus (CWRU) talked about transfer doping in diamond surfaces. The direction of electron transfer between diamond and its surroundings depends on the relative positions of the Fermi level of diamond and the chemical potential of electrons in the surrounding medium. Angus said that treating a diamond surface with heptane (or octane) immediately quenches the surface conductivity because it removes the water. Also, organic fumes from glues will quench the electronic transfer. His results confirmed the doping mode of Maier, Restein, and Lay. Angus also showed results on CNTs and GaN.

A. Suzuki (Keio Univ., Japan) described probes made from boron-doped diamond deposited on chemically etched micron-sized tungsten wires by using MPCVD. These 5-μm probes have very good properties such as very low background current, high stability, selective oxidation of dopamine in the presence of ascorbic acid, constant current response, and ability for use in high-resistance media. Measurements were made comparing the boron-doped diamond electrodes with carbon-fiber electrodes and showed superior sensitivity, selectivity, and stability for use in *in vivo* electroanalysis. Suzuki showed, in Symposium P, results that con-

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Scaling Down of Electronics Boosts Their Functionality

The descent of electronics down to the nanoscale presents numerous materials challenges and opportunities. Symposium X speaker Paul Heremans (IMEC) examined both this ultimate scaling and the growth of nanotechnology, literally built on the base of nanoelectronics. Deep scaling, with transistors so small that 50 of them could fit on a virus and with oxide thicknesses of only 1.5 nm, continues to lead to performance improvements, but new materials and architectures are needed to compensate for the slowing performance improvements with further size reductions. Silicon, which has endured decades of scaling, still forms the backbone of electronics, but with thin slivers of it replaced by other materials to boost performance. Germanium and groups III–V semiconductors, nanowires, and graphene are finding homes as high-mobility channel materials, although integrated into just the top few monolayers. Also, high-dielectric-constant materials and metal gates are being introduced. For back-end interconnects, low-dielectric-constant materials are needed. Zeolites have attractive properties in this regime, as they have extremely uniform pore sizes (less than 1 nm) and good mechanical properties. However, the hydrophilic nature of zeolites is a challenge. With air as an ideal dielectric, architectures are being developed with air gaps built into the structures. Now, 30% porosity can be achieved without significant loss of Young's modulus. Moving into a broader regime, nanoelectronics represents a mature platform for nanotechnology, such as nanophotonics, nanomagnetics, and nanofluidics, Heremans said. He described integrating various devices with silicon chips, including high-data-rate transceivers, optical interconnects, and sensors. Cell isolation from blood can be achieved by on-chip magnetic particle manipulation, and even interfaces with neurons can be obtained with integrated circuits.

firmed the effects on dopamine of the drug Nomifensine (a dopamine transport inhibitor) in a mouse brain.

Engineered Materials

The cluster on engineered materials spanned the range from surface phenomena to bulk behavior. Nanoindentation is now a well-known technique for measuring mechanical properties such as hardness and elastic modulus and for exploring details of deformation mechanisms at the nanoscale. There is significant interest now, from both the engineering and basic research perspectives, to extend nanoindentation to higher temperature regimes. In Symposium AA, C. Schuh (MIT) described work in his group on high-temperature nanoindentation measurements. Schuh's group developed a high-temperature indenter based on Hysitron's TriboIndenter™. Using a fused silica sample, they were able to demonstrate nanoindentation up to 405°C, including *in situ* imaging of the indents. They demonstrated that thermal drift could be managed and noise could be controlled. There are certain caveats to keep in mind, Schuh warned, including subtle changes in the indenter tip geometry and shifting of the properties of diamond at higher temperatures. In order to further extend these excellent results, Schuh's group has developed a second version of their high-temperature nanoindenter that includes better heating and cooling and a controlled environment for the samples. They obtained preliminary data at 530°C for fused silica in a vacuum. Schuh listed several activities they can perform with their nanoindenter, including rapid property assessments (an entire deformation mechanism map can be constructed in one day); nanoscale deformation physics studies; and micro- or nano-compression testing, such as the bending of nanoscale pillars.

The space environment is critical for security and defense purposes because of the large number of satellites that are used, and materials have a major impact in this area. In Symposium CC, P.J. Cole (SNL, NNSA) described several materials-related challenges that need to be considered. A primary driver in this community is the reduction of size, weight, power consumption, and cost for satellite payloads. Novel materials approaches and processes are required to enable these reductions. In addition, satellites must function in a variety of harsh environments that can include extreme temperature fluctuations, radiation exposure, particulate collisions, and long lifetime requirements. Cole described some of the materials that might enable large-scale transformations in the satellite community, including novel and lightweight composites and nanocomposites for shielding, thermal management, and 3D electronics packaging, as well as coatings and sensor materials to dramatically enhance detection efficiency in current systems. He discussed the various orbits of interest such as LEO, MEO, GEO, Molniya, and Tundra orbits. Each has its own particular set of issues and requirements. Cole elaborated on particulate-filled high-Z/polymer matrix composites as an example of the types of materials research that are being conducted now and will be necessary in the future.

Nanosystems

Symposia in the cluster on nanosystems addressed synthesis approaches to unique properties. Nanowires, an important class of nanoscale materials, are difficult to control and manipulate in suspension. In her talk in Symposium JJ, D. Fan (JHU) described the use of an electric field to precisely move and manipulate charged nanowires. A combination of dielectrophoretic force and electrophoretic force generated by electric fields from patterned electrodes was used. This represents a combination of a dc field and an ac field. Thus, transport and orientation of the charged nanowires could be independently controlled by the dc and ac fields. Fan demonstrated parallel, perpendicular, and random movements of the nanowires, as well as programmed movement patterns such as a zigzag motion. She also demonstrated selective connection of two specific nanowires that were separated by 185 μm; a high precision of at least 150 nm was achieved. Finally, to reiterate how well nanowires can be controlled with the use of electric fields, Fan demonstrated nanowires dancing to music.

Currently, nanosheets, such as graphenes, are of significant interest from the viewpoints of both fundamental research and potential applications. In Symposium JJ, S. Acharya (Natl. Inst. for Materials Science, Japan) described the use of the Langmuir–Blodgett (LB) technique to form nanosheets of PbS nanowires as a bottom-up approach. In this approach, PbS nanowires

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coated with a surfactant (trioctadecylamine, TOA) were floated on a liquid surface, similar to logs on a river, and then pushed together. The LB technique was used to lift up the sheets and transfer them *en masse*. Multiple layers are also possible. The advantages of this method include scalability and the ability to hierarchically pattern these layers beyond the lithographic limit. A high yield of interconnected devices is possible. These nanosheets offer the opportunity for fabricating 2D devices for testing quantum confinement, for example.

Soft Matter and Bioscience

The cluster on soft matter and bioscience presented a range of research topics from bio-inspired materials to materials for bioapplications. B. Yurke (Bell Labs), in Symposium LL, described the use of DNA as a means to cross-link polyacrylamide hydrogels to obtain novel functionality. It is known that two DNA strands can bind with each other very strongly if their base sequences are complementary, such as A–T and C–G. This property can be used to form DNA-based nanostructures. It is also possible to form motors such as DNA tweezers wherein one part is double-stranded, forming a hinge, and the other parts are single-stranded and sloppy. By appropriately using hybridized single-strand DNA, it is possible to close or open the tweezers, as duplex DNA is stiffer than single-stranded DNA. Also, one member of duplex DNA can be displaced from the second member by a DNA strand that can form more base pairs with the second member. This process is called strand displacement. These properties of DNA can be used to cross-link gels. Yurke described the construction of gels that can be induced to undergo sol–gel transformations or viscosity changes through the application of particular DNA strands. Reversible gels can be formed that allow for swelling and shrinkage, depending on the density of the cross-linkers. Such DNA cross-linked gels exhibit properties that are not easily realized using other materials. They can be isothermally assembled or disassembled. The mechanical properties can be modulated through the application of DNA. Yurke listed several potential applications, including drug delivery, scaffolding and substrates for tissue engineering, and therapeutics or prosthetics.

Also in Symposium LL, C. Viney (UC–Merced) described studies on sweat collected from a hippo at Chaffee Zoo in Fresno, Calif. Hippo sweat, or more accurately sebum, has interesting properties, Viney said. It is a jelly-like material, and one of its properties is its high rejection of UV radiation, similar to sunscreens and sunblocks. It is water-resistant, is an insect repellent, and is an antiseptic. In the laboratory, optical microscopy revealed interesting changes in the optical signature of this material with time, including the formation and growth of various liquid-crystalline phases. Spherulites were found to nucleate other adjacent and internal structures. Clearly, hippo sweat is a more-than-mundane material, indicative of the surprises in nature, leading Viney to proclaim, “I have never looked at a more interesting material than hippo sweat!” His work has caught the attention of the National Geographic Society, who included Viney in a television documentary team that flew to Zambia in August to study hippos living in the wild.

In Symposium OO, A. Folch (Univ. of Washington, Seattle) described the use of microfluidics for modulating the microenvironment of single cells and obtaining cellular data at high throughput for a low cost. Microwells can be formed on substrates and can be used to culture cells for further growth and study. Folch’s focus is neuroscience, for which such microfluidic

Graduate Students Receive Gold and Silver Awards

During the Awards Ceremony held on November 28, 2007, at the 2007 Materials Research Society Fall Meeting, graduate student finalists received Gold and Silver Awards.

Gold Graduate Student Awards went to (left to right): **Mona Zeberjadi** (University of California–Santa Cruz), **Prashant K. Jain** (Georgia Institute of Technology), **Jill E. Millstone** (Northwestern University), **Timothy G. Leong** (Johns Hopkins University), **Marleen Kamperman** (Cornell University), and **Hylke B. Akkerman** (University of Groningen).

Silver Graduate Student Awards went to (front row, left to right): **Weian Zhao** (McMaster University), **Charan Srinivasan** (The Pennsylvania State University), **Deepayan Chakraborti** (North Carolina State University), **Hongbo Zeng** (University of California, Santa Barbara), **Zuankai Wang** (Rensselaer Polytechnic Institute), and **Darshan D. Gandhi** (Rensselaer Polytechnic Institute); (middle row, left to right): **Jinhui Song** (Georgia Institute of Technology), **Guihua Yu** (Harvard University), **Fan Li** (University of Minnesota), **Patrick Görrn** (Technische Universitaet Braunschweig), **Haeshin Lee** (Northwestern University), and **Calvin K. Chan** (Princeton University); and (back row, left to right): **Bo Zhang** (Clemson University), **Christopher E. Carlton** (University of Texas, Austin), **Brendan M. Kayes** (California Institute of Technology), and **Ronny Costi** (The Hebrew University of Jerusalem). Not shown are **Jaeyun Kim** (Seoul National University) and **Ravi Shankar** (North Carolina State University).

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Biomaterials Research Rewires Nature

Instead of using reverse engineering to copy nature, why not rewire it? That was the premise of the Symposium X talk by James J. Collins from the Center for BioDynamics at Boston University. The relatively new field of synthetic biology is opening opportunities to build structures into cells to create new functionality, thus making use of the complex wiring already in place, but adding to it to improve functionality. Many cellular processes are governed by genetic programs that employ protein–DNA interactions in regulating function. Designing and modeling a cellular system using nonlinear dynamics offers a means of understanding the wiring of a cell. Then, synthetic gene regulatory networks can be designed and constructed to control that wiring. Collins described a dynamic toggle switch built from biological material. This is based on a two-gene system in which both genes want to be on, but each one has a cross-inhibitor that binds with a protein that shuts the other off, switching the state of the system. DNA rings based on toggle plasmids can be inserted into *E. coli*. In addition, DNA damage can be sensed with high sensitivity by the formation of a biofilm (e.g., scaffolds that trap bacteria, such as plaque on teeth). Although the toggle switch forms a computing function, switches still take hours. Nevertheless, microbes can be programmed to do interesting things, Collins said, such as sense, regulate, and produce. Among examples of applications, Collins described biosensors to detect pathogens, bioreactors to make proteins of interest (e.g., silk protein), and bacteria with photographic properties to hold an image.

devices are ideally suited. He described the study of neuromuscular synaptogenesis (formation of synapses) on a chip. Myotubes (or immature muscle cells) were formed within channels, and the presence of agrin (a protein involved in the development of neuromuscular junctions) was investigated. Folch also discussed axon growth in embryonic neurons and the study of this phenomenon using microfluidics.

Also in Symposium OO, U. Wegst (Drexel Univ.) described the properties of bamboo that make it such a versatile material. It finds numerous uses, particularly in Asia, ranging from baskets to construction scaffolding. Bamboo is available in different forms and shapes and has an interesting combination of lightness and stiffness. It has been used in ski poles, as well as poles used for pole vaulting. Its properties stem from its hierarchical structure and orthotropic tube form. Diaphragms separate the tube into chambers. Wegst then described the failure modes of such structures to investigate the mechanisms of failure, including ovalization, instabilities, and localized kinking. The studies showed that bamboo has an effective shape that uses its material most efficiently and is an optimized structure. There are lessons to be learned from its shape and structure for creating similar orthotropic tubes, said Wegst.

For further details on the research results reported at the 2007 MRS Fall Meeting, see the following symposium summaries. Proceedings as well as additional meeting highlights are available at the Web site www.mrs.org.

SPM Enables Imaging of Functional Materials at the Nanoscale

(See MRS Proceedings Volume 1025E)

Scanning probe microscopy (SPM) is much more than a toolbox of structural imaging techniques—SPMs can now image the functionality of materials on the nanoscale. That was the headline message from Symposium B on Nanoscale Phenomena in Functional Materials by Scanning Probe Microscopy, which united technical breakthroughs in SPM technology with first applications to important materials. Functionality comes in many forms—mechanical, electrical, optical, and biological, to name a few—and SPM techniques are now refined and diverse enough to combine structural imaging at nanoscale or atomic resolution with corresponding measurements of such properties, and sometimes more than one at a time.

Invidious though it is to select highlights from a symposium littered with excellent presentations, 150 in all, three examples show what is now possible with SPM: thus F.J. Giessibl (Regensburg) demonstrated remarkable subatomic resolution in AFM that enabled direct measurement of the forces involved in single atom manipulation; G.E. Fantner (MIT) and colleagues re-designed all of the components of an AFM to enable spectacularly high-speed image acquisition (28 ms); and E. Tsunemi (Kyoto) and colleagues, one of three symposium poster prize winners, showed how to build an AFM instrument with more than one tip. Indeed, the parallelization of functional SPM is surely one of the grand challenges for the future; if we are excited by two or four tips, how excited will we be by a million?

These highlights are plucked from a four-day symposium that included oral sessions on SPM at the limits of resolution, novel SPM methods, SPM in biology and soft-condensed matter, nano-optics, nanofabrication and manipulation, nanomechanics and tribology, electromechanics, thermal phenomena and transport on the nanoscale, single-molecule studies, and semiconductors—the diverse range of phenomena that can now be addressed with SPM techniques.

Symposium Support: Agilent Technologies; AIST-NT, Inc.; Ambios Technology, Inc.; Asylum Research Corp.; Center for Nanophase Materials Science, ORNL; Minus K Technology, Inc.; Nanofactory Instruments AB; NT-MDT Co.; Omicron Nanotechnology USA; Park Systems; RHK Technologies, Inc.; Nanoscale Research Letters/*Springer; and Veeco Metrology, Inc.*

Research with Electron Microscopy Offers Possibilities of New Instruments and Methods

(See MRS Proceedings Volume 1026E)

The aim of Symposium C, Quantitative Electron Microscopy for Materials Science, was to promote exchanges between the materials science and the electron microscopy communities. Recent years have indeed seen the development of new quantitative techniques and instrumentation in transmission electron microscopy (TEM) for the measurement of the local properties, chemistry, and structure of materials. However, most of the new possibilities in TEM remain in electron microscopy centers. Invited and contributed presentations offered stimulating results both on the possibilities of the new instruments (e.g., Cs-corrected microscope, detectors, and monochromators) and on methods. G. Botton (McMaster Univ.) presented an overview on the possibilities of using EELS to probe the chemistry and bonding of materials with the new instruments. K. Suenaga (AIST, Tsukuba) discussed *in situ* experiments on individual organic molecules, M. Hytch (CEMES, Toulouse) introduced a method for measuring strain at a large scale by electron holography, and P. Midgley described recent developments and results on electron tomography.

In addition, four special guests were invited to present the further grand challenges for electron microscopy. A talk titled "The Perspectives of STEM" was given by J. Silcox (Cornell); D.J. Smith (ASU) presented the "Ultimate Resolution Limits for Electron Microscopy;" and J.C. Spence (ASU) presented the "Automated Electron Nanocrystallography." A. Howie (Cambridge) provided an over-

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view entitled "Options for Pump–Probe Electron Microscopy."

Symposium Support: Carl Zeiss SMT, Inc.; CEOS GmbH; FEI Co.; Fischione Instruments, Inc.; Gatan, Inc.; Hitachi High Technologies America, Inc.; HREM Research, Inc.; JEOL USA, Inc.; and LBNL.

Advances Reported in the Understanding of Materials in Transition from *In Situ* Studies at Synchrotron and Neutron Sources

(See MRS Proceedings Volume 1027E)

Symposium D, Materials in Transition—Insights from Synchrotron and Neutron Sources, highlighted recent progress in using *in situ* techniques for the study of a variety of materials systems, including their processing and synthesis and the elucidation of their dynamic properties.

H. Van Swygenhoven (Paul Scherrer Inst., Switzerland) discussed the capabilities of the two *in situ* mechanical testing facilities at the Swiss Light Source and the results of studies at various length scales of plasticity and deformation. She included as an example the results of white-beam Laue microdiffraction experiments collected during compression of single-crystal gold micron-sized FIB-machined pillars. These demonstrated the important role of preexisting strain gradients as a result of FIB processing in controlling the subsequent geometry of activated slip systems.

In the area of ferroelectric systems, H. Han (POSTECH, South Korea) discussed studies on the domain structure and crystalline quality of ferroelectric films. Nanoislands were studied and quantified by a 2D reciprocal space mapping technique using synchrotron XRD. D. Fong (ANL) presented results of x-ray scattering experiments with precise *in situ* environmental control that demonstrate reversible switching of the polarization in ferroelectric thin films through control of the chemical environment.

Magnetic coupling phenomena and spin-dependent transport processes are sensitively affected by the magnetic nanostructure and atomic arrangement at the interfaces. These have been studied in model systems such as MgO/Fe(001) and NiO/Fe_3O_4(011) by soft x-ray photoemission microscopy and by x-ray magnetic circular and linear magnetodichroic contrast mechanisms. This work and its results were discussed by C. Schneider (Inst. of Solid State Research IFF-9, Jülich, Germany).

The glass transition presented new twists in a presentation by S. Mochrie (Yale). Using multispeckle x-ray photon correlation spectroscopy, his group caught the dynamics of the transitions from the dense liquid state to an attraction-dominated glass and to a repulsion-dominated glass. This work provided experimental evidence of recent predictions that dense liquids in systems with short-ranged attractions can become a glass on cooling and heating.

Several talks highlighted the self-assembly of nanoparticles. J. Fossum (Norwegian Univ. of Science and Technology) presented neutron and synchrotron experiments performed to study the guided self-assembly of clay platelet nanoparticles using electric and magnetic fields and their stability under mechanical stresses. E. DiMasi (BNL) summarized her program using *in situ* x-ray scattering studies to probe various templating mechanisms during the mineralization of organic templates. T. Trainor (Univ. of Alaska–Fairbanks) presented an overview of his work studying chemical processes occurring at the mineral–water interface, focusing on hematite, goethite, and magnetite. These materials are widely distributed iron-bearing minerals whose high surface reactivity and surface area might allow them to be important scavengers of aqueous trace minerals.

In the United States and Europe alone, at least five new synchrotrons and next-generation x-ray sources are scheduled to be constructed in the next decade, and major upgrades are planned for the experimental facilities at existing synchrotrons. At the neutron sources, similar technical advances and new construction are also underway. As evidenced by this symposium, considerable beam time has been devoted to materials research, particularly for studies that elucidate the behavior and properties of materials in transition.

Symposium Support: Blake Industries and Varian, Inc.

Advances Made in Nanoscale Magnetic Materials and Applications

(See MRS Proceedings Volume 1032E)

The aim of Symposium I, Nanoscale Magnetic Materials and Applications, was to bring together materials researchers working on magnetic phenomena at the nanoscale. Magnetic materials and devices have played a major role in science and technology for much of the 20th century. Current magnetic nanotechnologies have their roots in the development of bulk materials, such as permanent magnets where the functionality is derived from a complex two-phase microstructure. R.W. McCallum (ISU) and J. Shields (UN) discussed the state of the art in two-phase permanent magnets. Emerging nanoscience techniques (i.e., lithography and self-assembly) provide dimensional control that goes beyond what can be achieved in bulk materials. As outlined by S. Bader (ANL), the resulting revolution in magnetic materials and devices over the past 20 years is dramatic with many opportunities for materials research.

A number of researchers described new applications arising from the ability to control magnetism at the nanoscale. Recent developments in manipulating domain walls in magnetic wires using fields and currents open the door for new logic and storage devices as described by R. Cowburn (Imperial College) and S.S.P. Parkin (IBM). I.K. Schuller (UCSD) and M. Coey (Univ. Dublin) each described recent advances in the understanding of the effects of temperature on magnetic tunnel junctions that provide the basis for emerging memory and sensor applications. N.M. Dempsey (Inst. Neel) reviewed the progress made in using nanopatterned hard magnetic films to provide unique opportunities for MEMS and magnetic levitations. An emerging field is biomagnetism, where magnetic nanoparticles are used to tag significant biological molecules. J. Gao (UTS) described using functionalized particles for magnetic imaging and drug delivery, and S. Wang (Stanford) outlined approaches for magnetic sifters and microfluidic devices for molecular biology applications.

Symposium Support: AJA International, Inc.; DARPA; J.A. Woollam Co., Inc.; Lake Shore Cryotronics, Inc.; Nanoscale Research Letters/*Springer; ONR; Quantum Design, Inc.; and Rigaku Americas, Inc.*

Researchers Combine Spin and Charge Degrees of Freedom for Future Device Applications

(See MRS Proceedings Volume 1033E)

Spintronics, a possible pathway for future electronics, employs both the elementary charge and the spin of the charge carriers, which adds new functionality for future device applications. There is still a long way to go before working devices can be implemented, and fundamental physical properties and concepts are still under debate. In Symposium J, Spin-Injection and Spin-Transfer Devices, various novel aspects in the field of spintronics were discussed.

Studies on spin-transfer dynamics with particular emphasis on current-induced domain wall motion and spin-torque-driven nano-oscillators and MRAM cells were presented in a series of invited and contributed talks.

For successful combination of the spin and charge degrees of freedom, spin injection into semiconducting materials, spin manipulation in the semiconductor, and subsequent spin detection are necessary

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prerequisites. These topics were discussed in relation to various materials systems. In addition to the established approach of spin injection into GaAs, developments of injection into Si and GaN were reported. Whereas spin injection in GaAs is a mature field and recent advances demonstrate electrical and optical detection, it was only recently demonstrated that spin injection and detection in Si is feasible. In fact, it was demonstrated that transport of spin information across the thickness of an entire wafer is possible, demonstrating that the spin diffusion length is extremely long.

Exciting new results were presented on the subject of spin injection into graphene and other organic semiconductors, underlining the possibility of spin injection into these alternative materials.

$BiFeO_3$ Takes Center Stage in Multiferroics Field

(See MRS Proceedings Volume 1034E)

Symposium K on Ferroelectrics, Multiferroics, and Magnetoelectrics presented a good mix of theory (C. Fennie, ANL; D. Khomskii, Univ. Köln, Germany) and experiments (N.D. Mathur, Cambridge; H. Bea, CNRS, France; A. Barthelemy, CNRS, France). The trendy material continues to be $BiFeO_3$. It is now reported to be a ferroelectric magnet with a metal–insulator transition at room temperature and high pressure (J. Scott, Cambridge), to have new transitions below the Néel temperature (M. Ramirez, PSU; A. Kumar, PSU), and to find application in heterostructures such as exchange bias devices (M. Bibes, Univ. Paris Sud; L.W. Martin, UC–Berkeley), and exhibits electrical control of magnetic order in single crystals (M. Viret, CEA Saclay, France). Very high-quality neutron diffraction data, XPEEM results on electrical control of magnetism, and a leap forward in the understanding of magnetoelectric coupling in these materials were presented.

The presentations in the symposium were complemented by the Turnbull Lecture of R. Ramesh (UC–Berkeley). A special symposium in honor of George Samara was held, with the following invited speakers: E. Salje, Cambridge; D.C. Sinclair, Univ. Sheffield, UK; B. Tuttle, SNL; L.E. Cross, PSU; K.M. Rabe, Rutgers; T. Egami, Univ. Tennessee–Knoxville; and S. Streiffer, ANL.

Overall, this class of materials and structures with coupled magnetic–ferroic order parameters is entering an exciting phase, and the symposium should continue to grow in strength in the coming years.

Symposium Support: DOE.

Zinc Oxide Offers Exciting Prospects for Electronic and Optoelectronics Devices

(See MRS Proceedings Volume 1035E)

In Symposium L on Zinc Oxide and Related Materials, Z.L. Wang (Georgia Tech) gave an invited talk on nanopiezotronics and how semiconducting and piezoelectric properties of ZnO nanowires could be used to create biocompatible energy sources. D. Look (Wright State Univ.) provided an overview of the current status of doping and defect issues in ZnO, which was followed by a presentation by J. Christen (Magdeburg Univ.) on optical properties and kinetics of carrier capture, relaxation, and recombination in ZnO nanostructures using a novel picosecond cathodoluminescence technique. This work estimated the diffusion length of excitons in their ZnO structures to be 140 ps. B. Svensson (Oslo Univ.) discussed hydrogen n^+-doping of ZnO by ion implantation with thermal stability in excess of 600°C. He also presented results of Pd Schottky barriers with a rectification of eight to nine orders of magnitude and found that pretreatment with hydrogen peroxide is crucial to obtain high-quality Schottky barrier diodes on the O face of ZnO. C.H. Park (Pusan Natl. Univ.) discussed defects and hydrogen impurities in the spin–spin interaction in magnetic impurity-doped ZnO. W. Chen (Linkoping Univ.) and D. Gamelin (Univ. Washington) discussed magnetic properties and critical issues for spintronics applications of ZnO. B. Mayer (Giessen Univ.) discussed the growth of ZnO crystals and defects and impurities and related optical emissions, and S.F. Yu (Nanyang Technological Univ.) discussed electrically pumped UV random lasers in ZnO and the physics behind their operation. T. Yao (Tohoku Univ.) discussed the crystal polarity control of ZnO layers during growth and nonlinear properties and devices based on ZnO.

Academics and Industry Experts Address Materials, Integration, and Technology Considerations to Bridge the Gap Between Research and Production of Monolithic Instruments

(See MRS Proceedings Volume 1037E)

The goal of Symposium N on Materials, Integration, and Technology for Monolithic Instruments was to provide a forum for scientists and engineers interested in the materials, electrical and physical design, fabrication, and analysis of monolithic instruments. Monolithic instruments are systems and subsystems that combine conventional integrated circuits with novel solid-state components so that they can interact with their physical environment. Such systems can achieve cost and performance enhancements through integration and miniaturization. As this is an emerging field, one key aspect of this symposium was to bring together the materials and circuit design communities to

U.S. Department of Defense Addresses Funding Opportunities in Materials Research

In a special government agency session, representatives from various divisions in the U.S. Department of Defense discussed funding opportunities that are available in materials research. William V. Lampert of the Materials Sciences Division in the Army Research Office (ARO) emphasized the funding program for basic research for unprecedented materials properties that will help the soldier. The division is particularly motivated to help the soldier of 2032.

Julie A. Christodoulou of the Materials Division in the Office of Naval Research (ONR) described her division's mission as inspiring and guiding innovation that will provide technology-based capability options for the future Navy and Marine Corps through the science and technology program. She distinguished the various types of funding: 6.1 designates basic research; 6.2, applied research; and 6.3, advanced development—the first step toward making a prototype. Both Christodoulou and Lampert said that, although the deadline for proposals is open, the best time to submit proposals is in the beginning of the calendar year so that their divisions know what projects they are funding by October, which is the beginning of the government fiscal year.

Thomas Russell of the Air Force Office of Scientific Research (AFOSR) and Judah Goldwasser of the Defense Advanced Research Projects Agency (DARPA) each showed many examples of the types of research they fund. AFOSR focuses on basic research (6.1 funding), and DARPA focuses on revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use.

The best advice to materials researchers looking for funding is to talk with a program manager and submit a White Paper, which is a working document of their ideas, before turning in a full proposal.

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foster critical discussion about the creation of monolithic instruments. Therefore, the symposium featured a balanced program in which experts from both academia and industry highlighted the wide array of current and future applications and fabrication techniques that are being used to create miniature instruments.

In the first session on optoelectronics and imaging, J. Jacobs (TI) discussed the challenges involved in the integration and scaling of millions of mirrors on a single semiconductor chip to create digital light processing technology. Packaging proved critical in producing this core technology that powers many current projection systems. This topic was also addressed by A. Gosh (eMagin Corp.) in the context of organic LED microdisplays and by L. Spangler (Aspen Technology, Inc.), who dispelled the myth of quasi-hermetic packages.

D.A.B. Miller (Stanford) introduced a type of transform-domain spectrometer, demonstrating how such instruments can be used to make tunable integrated sensors. K. Makinwa (Eindhoven Univ. of Technology) addressed the state of the art in integrated temperature sensors, and M. Brongersma (Stanford) presented the latest updates on plasmonics, an emerging and potentially enabling technology for monolithic instruments. To balance the session on integration and architecture, J. Fragala (NanoInk, Inc.) detailed the implementation of a lithographic technique based on cantilever tip arrays with high-resolution direct-write printing capabilities.

In the session on microfluidics, D. Psaltis (Caltech and EPFL, Switzerland) demonstrated the potential of fluidics for tunable optics and the realization of an optofluidic microscope that is the size of a quarter. R. Fair (Duke Univ.) stressed the importance of reconfigurable microfluidics by means of the electrowetting-on-dielectric technique, and E. Yoon (Univ. of Minnesota) discussed basic microfluidic components that provide the required functions for on-chip single-cell assays.

The symposium concluded with an application-oriented session devoted to chemical sensing in which presentations were given on recent advances in monolithically integrated labchips (M. Böhm, Universität Siegen, Germany), the imaging of electrical dynamics in neurons by multitransistor-array recording (A. Lambacher, MPI of Biochemistry, Martinsried, Germany), and spintronic integrated platforms for point-of-care diagnostics (P. Freitas, Instituto Superior Tecnico, Lisbon, Portugal).

Symposium Support: University of Siegen.

Progress Reported in Growth and Characterization of Radiation Detection Materials

(See MRS Proceedings Volume 1038)

Symposium O, Nuclear Radiation Detection Materials, was held to both promote the study of radiation detection materials using a molecular-based approach and a wide variety of experimental instrumentation and to discuss new materials with significant potential as detection materials. The intent of this focus was to determine details of why radiation detection materials fail with respect to various crystal parameters. These parameters include chemical and lattice defects that can be studied by different techniques, such as synchrotron-radiation-based approaches, x-ray crystallography and microscopy to study lattice and other solid-state phenomena, and surface-related studies to look at interfacial aspects of crystal surfaces of radiation materials. Additionally, several types of materials—both new and improved—were reported. These included polymer composites, diamond materials, rare-earth halides, CsI:Tl, organic semiconductors, and rare-earth perovskites and garnets. Progress was reported in the use of several of the types of instrumentation just mentioned to gain a better knowledge of the materials chemistry of some of the radiation detection materials, including advances in the understanding of precipitates in samples of cadmium zinc telluride.

A. Mycielski (Polish Academy of Sciences) provided details on (Cd, Mn)Te as a new x-ray and γ-ray detector material, and P. Doty (SNL) discussed metal–organic framework-based scintillators. Technical aspects of the phenomena of nonproportionality and energy resolution in scintillation detector materials were presented by M. Moszynski (Soltan Inst. for Nuclear Studies, Poland). N. Cherepy (LLNL) described new scintillators for use as high-energy-resolution γ-ray detectors. M. Duff (Savannah River Natl. Lab.) described the use of synchrotron approaches to study spatial chemical species defects in detector-grade cadmium zinc telluride.

Life Cycle Analysis for Energy Conversion and Storage Explored from Materials to Methodology

(See MRS Proceedings Volume 1041)

Symposium R, Life Cycle Analysis for New Energy Conversion and Storage Systems, included sessions on photovoltaics, nanomaterials, batteries and hybrid cars, hydrogen storage, and LCA methodological issues. Presenters covered novel studies on the land requirements of PV technologies and compared them with the land requirements of the coal fuel cycle. Presentations given on nanomaterial-based technologies for energy storage ranged from overviews of the use of nanostructured materials in hydrogen storage, to environmental issues related to such storage, to descriptions of new nanoscale systems for storing energy. LCA methodologies applicable to energy systems analysis were also discussed, in which presentations detailed ways of quantifying land use and suggested applicable metrics.

Solid-State Hydrogen Storage Sees Global R&D Efforts

(See MRS Proceedings Volume 1042E)

The main goal of Symposium S, Materials and Technology for Hydrogen Storage, was to review the status of hydrogen storage materials and the current progress in this field. The symposium focused on solid-state hydrogen storage materials including traditional metal hydrides and recently developed high-pressure metal hydrides, as well as complex chemical hydrides and cryogenic high-surface-area materials. E. Akiba of the National Institute of Advanced Industrial Science and Technology of Japan reviewed a detailed structure analysis of superlattice alloys. Potential modification of superlattice alloys and optimization of hydrogen sites from composition and geometric viewpoints were discussed. The hydrogen sorption properties of high-pressure Laves phase alloys and improvement of thermal conductivity of the alloys using conductive fillers were explored. In the area of high-temperature metal hydrides, recent progress on the performance of catalyzed nanosize magnesium hydride was reported. A significant improvement in kinetics of hydrogen sorption was observed when nanosize hydride in the presence of nanosize catalysts was used. The key role of particle size engineering for improving kinetics and lowering the temperature of hydrogen sorption was emphasized. Electrochemistry of metal hydride in nonaqueous electrolyte was explored by L. Aymard and colleagues of Amiens, France, in collaboration with the GM Research and Development Center in the United States. The research team reported a new application of metal hydrides as reversible anodes for lithium batteries with significantly improved storage capacity. The chemical nature of lithium storage versus hydrogen storage was discussed in detail. F. Pinkerton reviewed the subject of the destabilization of complex chemical hydrides with an emphasis on phase boundaries and reversibility in the $LiBH_4$–MgH_2 system. J. Reilly (BNL) explored reversible synthesis of AlH3

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adducts with triethyleneamine from activated aluminum and hydrogen.

Various cryogenic, high-surface-area metal–organic framework, and activated carbonaceous materials were explored as hydrogen storage materials. Close to 7 wt% hydrogen sorption at liquid-nitrogen temperature was reported. The electrochromic nature of some of the metal hydrides was also discussed. Overall, Symposium S covered many materials aspects of solid-state hydrogen storage media, demonstrating significant global R&D efforts on the subject.

Materials Needs Explored to Advance Nuclear Energy Technology

(See MRS Proceedings Volume 1043E)

Symposium T, Materials Innovations for Next-Generation Nuclear Energy, considered the current scene for developing new materials that can perform under the extremes of radiation and temperature, as experienced in Generation IV and fusion systems. Clearly, the materials science challenges are daunting, but given recent advances in experimental techniques and the computational tools now available, it is realistic to anticipate that new materials can be developed to perform reliably and safely under these extremes. The first speaker, S.J. Zinkle (ORNL), provided a number of key examples that emphasized this view of nuclear materials. The talks that followed during the first day then expanded the hypothesis to a wide range of systems. In particular, the first session focused on metallic systems and the second session on carbides, both of which find application as structural materials in fission and fusion.

Throughout the symposium, results from modeling and simulation were used to underpin and support experimental studies. As a natural consequence, the second day saw a joint session with Symposium E on theory and modeling. An emerging focus was the development of joined-up modeling across length and time scales specifically for these environmental extremes.

The final day saw a return to structural issues with a particular focus on grain boundary effects. Distinctly new materials with characteristics for nuclear applications are being developed with boundaries that provide enhanced stability against radiation damage. A particular success was the Cu/Nb nanolayer system of A. Misra (LANL) and colleagues in which interfaces act as extremely effective sinks for defects caused during irradiation. This work was also another demonstration of the synergy between modeling and experiment.

Material and Device-Design Innovations Lead to Higher Efficiency in Thermal-to-Electric Energy-Conversion Technologies

(See MRS Proceedings Volume 1044)

The aim of Symposium U, Thermoelectric Power Generation, was to provide a forum for researchers in this field to meet and discuss recent results and possible future directions. Topics included nanocomposites, chalcogenide-based materials, bulk materials, and thin films. The symposium concluded with topics of devices and new and emerging materials. The incorporation of nanoparticles into bulk samples through powder processing techniques was addressed in several presentations and posters. J. He (Clemson) presented a hydrothermal treatment process for coating nanoparticles before hot pressing for Bi_2Te_3 nanoparticles. The use of SiGe nanoparticles in powder-processed samples with $ZT > 1.2$ at 1100 K was reported by M. Dresselhaus (MIT). M. Kanatzidis (Northwestern) presented several bulk chalcogenide-based materials exhibiting self-assembled nanostructuring with ZT values exceeding 1.6 near 700 K. Kanatzidis also reported enhanced power factors for Pb and Sb nanoparticle inclusions in bulk samples. Theoretical studies of chalcogenide materials (S. Mahanti, Michigan State Univ.) and oxide thermoelectric materials (D. Singh, ORNL; W. Koshibae, Sendai Natl. College of Technology; Q. Li, BNL) revealed insights into mechanisms involved in nanostructured materials and strongly correlated electron systems. Additional presentations described phonon-glass electron-crystal compounds such as clathrates (G. Nolas, Univ. of South Florida) and skutterudites (C. Uher, Univ. of Michigan), for which ZT values of 1.3 at 800 K were reported for mixed filling of the voids.

A number of studies on thin-film-based materials (chalcogenides and oxides) and devices including superlattice and embedded nanoparticles were presented. T. Caillat (JPL) described devices for upcoming space missions, S. Yamanaka (Osaka Univ.) presented several new materials with extremely low thermal conductivity, and H. Kleinke (Univ. of Waterloo) discussed high-temperature arsenide and antimonide materials

Symposium Support: GM; Marlow Industries; ONR; Quantum Design, Inc.; Tellurex Corp.; and ULVAC Technologies, Inc.

Novel and Interdisciplinary Approaches Invigorate Materials Science and Engineering Education

(See MRS Proceedings Volume 1046E)

The aim of Symposium W, Forum on Materials Science and Engineering Education for 2020, was to bring together experts from a wide range of disciplines to share their innovative approaches to and initiatives in materials science and engineering education.

Main themes that emerged from the two-day symposium included the importance of partnerships, interdisciplinary and innovative approaches to education, and opportunities for educating students at all levels about the nature of scientific research and engineering problem-solving.

The session "Bringing Materials Science and Nano to the General Public" highlighted the importance of partnerships between informal science education institutions and research institutions. These collaborations ranged in size from single-PI postdoctoral fellowships at an art museum (T.L. Clare, Philadelphia Museum of Art) to large science museums and research universities partnering to train graduate students and improve public science education (E. Sheu, Univ. of Chicago).

Reaching underserved audiences was the emphasis of the session on Increasing the STEM Pipeline. Best practices were shared for establishing research internships for high-school students (D. Reich, JHU; D.E. Nikles and G.B. Thompson, Univ. of Alabama), reaching populations currently underrepresented in STEM fields (T. Sahr and C. Zweil, WGBM Educational Foundation; S.E. Morgan and K.L. Wingo, Univ. of S. Mississippi), and assessing these pipeline programs (R.M. deGroot, Caltech; N. Singhota and K. Dilley, Cornell).

The final two sessions, Incorporating New Research into New Teaching Strategies and Implementing New Course Materials and Strategies, showcased the value of implementing interdisciplinary materials science and engineering education programs (J. Stolk and R. Martello, Olin College; T.S. Harding, CalPoly) and in training and educating students at all levels about the nature of research (T. Moore, Univ. of Minnesota; K. Cadwell, Univ. of Wisconsin–Madison; D. Bahr and K.O. Findley, Washington State).

Symposium Support: Ceramic Materials and NSF.

Insights Gained in the Understanding and Preservation of Artistic and Cultural Heritage

(See MRS Proceedings Volume 1047)

The aim of Symposium Y, Materials Issues in Art and Archaeology VIII, was to present cutting-edge interdisciplinary research used to understand and interpret the materials and technologies of ancient objects and artifacts; to determine processes and rates of deterioration; and to mitigate that damage through use of sensors, nondestructive testing, and remedia-

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tion. J. Mass (Winterthur Museum), using the confocal x-ray fluorescence at Cornell's High Energy Synchrotron Source, investigated the collaboration of David Teniers and Jan Breugel on a single 17th-century panel and was able to show the parts of the canvas that were painted by each artist. T. Katayama (Kyoto Univ.) described the analysis of clothes from the Mongol Empire 500–700 years ago and found traces of gold, copper, iron, and lead by nondestructive synchrotron techniques. G. Scherer (Princeton) presented predictions and test data to correct the heretofore-misunderstood mechanism of the degradation of brownstone, a commonly used building stone in the eastern United States. Scherer presented an exciting new line of evidence for the control of salt crystallization in porous stone, matching calculation and experimentation with molecular modeling. R. Chen and P. Whitmore (Art Conservation Research Center, CMU) demonstrated the use of a silver-nanoparticle sensor to test exhibition and storage conditions in museums that can also serve as an *in situ* materials stability sensor. K. Eremin (Strauss Center for Conservation, Harvard) and J. Giaccai (Walters Art Gallery), in separate talks, presented an overall chronology of pigment use for Thai paintings that documents the introduction of western pigments, including a rare and little-known green copper citrate pigment that has been replicated according to a 17th-century Venetian text. Giaccai also showed results of a study of five objects from a Barye cast-bronze commission that permit understanding of the nature of variability in 19th-century Parisian foundry technology. L.D. Frame (Univ. of Arizona) grouped arsenical and tin bronzes according to a range of variability in production processes by calculating cooling curves for third-millennium metals from Godin Tepe, northeast Iran. M. Walton (Getty Conservation Institute and Getty Villa) presented results of FIB/STEM characterization of fifth-century B.C.E. Greek red and black pigments and differentiated them from the special coral reds about which there has been much speculation; he was also able, from analysis, to reconstruct the technological process of production. I. Favela and P. Vandiver, both from the University of Arizona, compared the early Steuben production of Frederick Carder to Tiffany art glass and found Carder to have employed a narrow range of processes and compositions using less costly materials than the continually experimental Tiffany glass products.

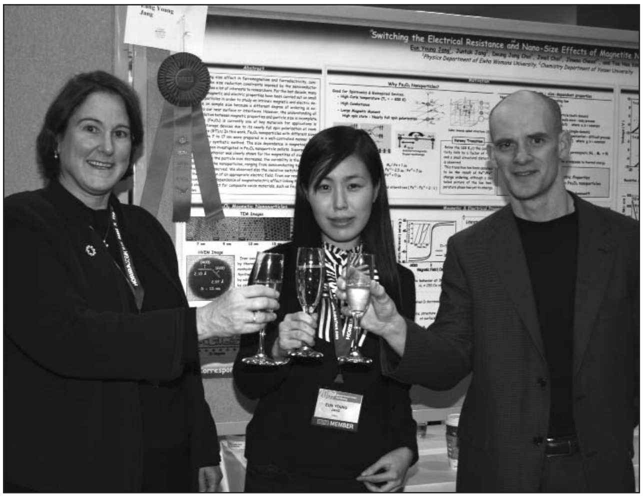
Symposium Support: Bruker AXS, Inc.

Research on Bulk Metallic Glasses Focuses on Flow Defects and Shear Banding

(See MRS Proceedings Volume 1048E)

Bulk metallic glasses are known to have attractive properties and processing opportunities. There has been significant recent development of novel fabrication and processing techniques and new alloy compositions, as well as progress made in the fundamental understanding of the relationship between chemistry, structure, and mechanical properties. As a result, these advanced metastable materials are currently at the frontier of metal research. Symposium Z on Bulk Metallic

Poster Prizes Awarded at 2007 MRS Fall Meeting



The 2007 Fall Meeting Chairs awarded prizes for the following best poster presentations: (A6.14) **Basic Research on Combinatorial Evaluation Method for Coefficient of Thermal Expansion**, Y. Aono, S. Hata, J. Sakurai, R. Yamauchi, H. Tachikawa, and A. Shimokohbe (Tokyo Institute of Technology, Japan); (C5.1) ***In Situ* TEM Study on the Formation Process of Iron Silicide Nanoparticles on Si Substrate**, J. Won, A. Kovacs, M. Ishimaru, and Y. Hirotsu (Osaka University, Japan); (C17.9) **Structural Identification of Nanocrystals Employing HRTEM**. P. Moeck and R. Bjorge (Portland State University); (D6.6) **Analytical Study on Initial Growth Stage of Metal Atomic Layer Deposition by Synchrotron Radiation X-Ray Reflectivity Analysis**, H.-B.-R. Lee, W.-H. Kim, Y.J. Park, S. Baik, and H. Kim (Pohang University of Science and Technology, South Korea; (G6.8) **Nanofabricated Negative Index Optical Elements from InP/InGaAsP and SOI Heterostructures**, R.K. Banyal, B.D.F. Casse, W. Lu, Y. Huang, S. Selvarasah, M. Dokmeci, and S. Sridhar (Northeastern University); (I10.8) **Switching the Electrical Resistance and Finite-Size Effects of Magnetite Nanoparticles**, E.Y. Jang, D.J. Choi, and T.H. Kim (Ewha Womans University, Seoul) and J.-T. Jang, J.-S. Choi, and J. Cheon (Yonsei University, Seoul); (K10.20) **Time-Resolved *In Situ* Diffuse X-Ray Scattering Measurements of the Surface Morphology of Homoepitaxial $SrTiO_3$ Films During Pulsed Laser Deposition**, J.D. Ferguson, G. Arikan, A.R. Woll, D.S. Dale, L.F. Kourkoutis, A. Amassian, D.A. Muller, and J.D. Brock (Cornell University); (Z8.10) **Fabrication of Zr-Based Metallic Glassy Nanowires and Nanospheres**, T. Wada, D. Louzguine-Luzgin, and A. Inoue (Tohoku University); (FF5.22) **Electrochemical Preparation of Bamboo-Like Nanowires and Nanotubes**, M. Guan (Louisiana State University) and E.J. Podlaha-Murphy (Northeastern University); (HH11.72) **Porous High-Temperature Ceramics Structured on Multiple Length Scales**, M. Kamperman, R. Weissgraeber, A. Burns, and U. Wiesner (Cornell University); (II5.8) **Alcohol CVD Synthesis of Flow-Aligned SWCNTs**, L. Huang, Z. Jia, and S. O'Brien (Columbia University); (KK10.19) **Ordered Arrays of Complex Structures Fabricated by Nano Pinhole Lithography**, C. Huang, N. Geyer, B. Fuhrmann, F. Syrowatka, and H.S. Leipner (Martin-Luther-University Halle); (OO9.5) **Engineering Contractility of Myocardial Sheets**, A.W. Feinberg, W.J. Adams, M.A. Bray, S.P. Sheehy, and K.K. Parker (Harvard University); and (PP3.19) **Synthesis of Cu–In–S Fluorescent Nanocrystals**, K. Watanabe (Kyushu University), M. Uehara and H. Nakamura (AIST), and H. Maeda (Kyushu University; AIST; and CREST, Japan).

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Glasses was intended to cover the fundamentals underlying the processing, structure, and properties of amorphous metals and to highlight their performance aspects that are attractive for structural and functional applications.

Many contributions addressed efforts being made to understand plastic deformation in bulk metallic glasses. The issues associated with flow defects and shear banding were clearly the main focus of this symposium. For example, F. Spaepen (Harvard) showed analogies with shear transformation in colloidal systems, and W.L. Johnson (Caltech) reported a cooperative shear model. A.S. Argon (MIT) provided an overview of his earlier contributions. Advances have also been made in modeling the initiation of shear bands.

Relaxation in metallic glasses was the focus of several presentations, and its significant influence on the elastic and plastic properties of metallic glasses is being recognized. Furthermore, it is still clear that understanding the short- and medium-range order and elucidating the nature of the defects in the glasses remain challenging tasks.

Advances have been made in the development of ductile alloys and composites, and innovative processing techniques such as micro- and nanoforming and blow molding were presented. In addition, the area of bulk metallic glasses represents a maturing field but one that is still quite vibrant as these alloys emerge as structural materials in increasing numbers of applications.

Symposium Support: NSF.

Applications Discussed for Nanomechanical Characterization Techniques

(See MRS Proceedings Volume 1049)

In the past several years, the study of the fundamentals of nanoindentation and nanotribology—the topic of Symposium AA—has matured while moving in new directions including application of the techniques developed for bulk and thin-film engineering metals and ceramics to polymers, biological materials, and nanostructures. Emphasis in this year's symposium was on emerging topics and mechanistic research on fundamentals in the field, as opposed to implementation of existing techniques. A highlight on the opening day of the symposium was an invited talk by M. Begley (Univ. of Virginia) considering challenges in applying indentation techniques and instrumentation to free-standing structures, in which compliance at the contact are extremely small. Recent interest in *in situ* indentation, in which the contact events are both observed and quantified in terms of forces and displacements, was reflected in two sessions. Invited talks considered *in situ* indentation in both the scanning electron microscope (B. Moser, Alcan Technology & Management AG, Neuhausen, Switzerland; Empa–Materials Science and Technology, Thun, Switzerland) and the transmission electron microscope (A. Minor, LBNL). A growing topic in the symposium is nanotribology, including both experimental and computational approaches for characterizing small-scale friction and wear. Experiments considering small-scale single-crystal wear in nickel contacts were described in an invited talk by N. Moody (SNL). In another invited talk, I. Szlufarska (Univ. of Wisconsin) highlighted computational nanotribological approaches. Biological applications in both indentation and tribology were considered in a joint session with Symposium OO on Solids at the Biological Interface, including invited talks by A. Mann (Rutgers) and S. Enders (formerly of MPI, Stuttgart, now at Univ. of Nebraska, Lincoln). Overall, the symposium included a wide variety of applications for the nanomechanical characterization techniques developed and expanded in the past decade.

Symposium Support: CNRS Saint Gobain; FEI Electron Optics BV; Hysitron, Inc.; MTS Nano Instruments; and NIST.

Twin-Wall Mobility Emphasized in Magnetic Shape-Memory Alloys

(See MRS Proceedings Volume 1050E)

The technological potential of ferromagnetic shape-memory alloys (FSMAs) in actuator applications was recognized several years ago. Although this topic was still discussed in Symposium BB on Magnetic Shape-Memory Alloys, attention centered on specific topics such as the all-important twin-wall mobility and the general theory of the large deformations created by their motion. Although the fundamental reason for the large twin-wall mobility is not clear, the symposium did show how the near-boundary atomic configurations can be used to control it. Even so, the nature of the critical stress that needs to be applied to initiate twin-boundary motion is as yet unknown, although the interplay of the temperature dependences of the magnetocrystalline anisotropy and the critical stress, and hence the temperature interval in which twin-boundary-motion-controlled actuation is possible, are now well understood. It was also shown that the interactions between twin boundaries, that is, the twin-boundary density, control whether the magnetically induced large deformations are reversible (magnetoelastic) or not (magnetoplastic). Synchrotron radiation and strobed neutron diffraction experiments led to direct insight into the evolution of the texture of FSMA Ni–Mn–Ga taking place during macroscopic deformation.

The large changes in entropy that can be effected in suitably chosen FSMAs have attracted attention, as they could potentially be exploited in solid-state refrigeration. Magnetocaloric effects on the order of tenths of a joule per kilogram-Kelvin were attained for the $Ni_{2(-x)}Mn_{1+x+y}(Ga,In,Sn,Sb)_{1+x-y}$ alloy system that is being investigated widely. In this system, the ferromagnetic and martensitic transition/transformation temperatures can be adjusted in a wide range while maintaining the reversibility of the latter. First-principles calculations permit a solid understanding of the driving forces giving rise to the transitions.

Applications of FSMAs described in the symposium pertained mostly to various actuation schemes. A proposed mirror control stood out although it used the unique properties of FSMAs only tangentially. Polymer-based FSMA composites can be used as high-damping materials. Newly available single crystals using a synthetic slag cover display a much lower critical stress needed to initiate twin-boundary motion and hence will enhance the potential for applications.

Symposium Support: ARO.

Need for Interdisciplinary Developments in Materials and Technologies Emphasized in Programs for Security and Defense

(See MRS Proceedings Volume 1051E)

Presentations in Symposium CC, Materials for New Security and Defense Applications, demonstrated that the strategic environment for defense and security has clearly changed in the last two decades and new materials and technologies are required to defeat terrorists, prevent the spread and use of weapons of mass destruction, and shape defense in the space and cyberspace environments (L. Sloter, DoD; A. Janos, DHS; P.J. Cole, NNSA; and S. McKnight, ARL). It was stressed that close collaboration is required between the military, academia, and industry as the work covers a wide size range, from molecular science to component development and production to hardware and its interrogation. Clear goals for the future include the need for smarter materials and improved processes. Multifunctional materials will also need to be targeted, in order to achieve maximum value for the mass introduced into systems by sensors and detectors. Good

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examples of multidisciplinary projects are plastic optical fibers for intelligent clothing and high-energy-absorption materials for aerospace applications (G. Tomlinson, Kroto Research Inst.).

A particular theme was that lessons and mechanisms can be learned from biosystems and that biomolecules or their derivatives can be used as molecular sensors and as on/off switches for electrical signals. Technologies under investigation use DNA molecules as switches (A. Heeger, UCSB) and to detect biothreat agents (R. Mutharasan, Drexel).

As nanotechnology is an ever-increasing theme in all areas of materials science, this symposium featured presentations on its use in developing nuclear radiation detectors (M. Osinski, UNM), ultrasensitive vapor sensors (T. Swager, MIT), and nanoscale devices (J. Lesco, Virginia Tech; T. Russell, Univ. of Massachussets; J. de Simone, Univ. of North Carolina; M.T. Dugger, SNL).

Symposium Support: SNL.

Materials, Processes, and Devices Explored for Microelectromechanical Systems

(See MRS Proceedings Volume 1052)

Research in microelectromechanical systems (MEMS) technologies currently occurs at the intersection of several major trends: proliferation of device concepts in diverse domains (including physical/biochemical/chemical sensors, actuators of various kinds, portable power generation, rf communications, and optical displays), increasing focus on commercial applications, and a rapid expansion of materials, structures, and processes used in MEMS. In this context, Symposium DD, Microelectromechanical Systems—Materials and Devices, provided a forum for materials researchers and device engineers to explore themes of common interest across broad classes of materials, processes, and devices. This spirit was exemplified by two presentations that conveyed the excitement and challenges in making the transition from academic research to full-fledged commercialization: J.T. Santini (MicroCHIPS) described the development of implantable MEMS reservoir arrays for drug delivery and biosensing applications, and E.R. Deutsch (Polychromix) discussed the evolution of a programmable MEMS diffractive spectral light modulator and provided candid insights into efforts at commercialization for telecommunications and infrared spectroscopy. The symposium featured a number of presentations on micromechanics (e.g., tension testing of free-standing films and methods for materials property extraction at the wafer and chip scales), mechanical behavior (e.g., internal friction, fatigue, brittle fracture, wear, and adhesion), devices (including tactile and biochemical sensors, vibration energy harvesters, micro fuel cells, microchannel resonators, and electrothermal actuators), and materials selection/integration.

Symposium Support: MEMS Industry Group, Nanoscale Research Letters/ *Springer, and Silex Microsystems AB.*

Progress Reported on Phonon Engineering

(See MRS Proceedings Volume 1053E)

Symposium EE, Phonon Engineering—Theory and Applications, addressed the essential concepts in phonon engineering relevant to novel thermal management issues. Progress was reported in growth, processing, and characterization of nanostructures, including diamond films at the nanoscale, GaN nanowires, nanocavities made from GaAs/AlAs layers, and oxide superlattices. Concepts and preliminary reports toward phonon engineering applications included nanowire transistors and graphene devices, nanophononics, terahertz phonon lasers, and thermal management using thin diamond films. Theoretical modeling, ranging from semiclassical to *ab initio* in approach, covered topics such as carrier-induced softening of phonons, dimensionality effects on electron–phonon and phonon–phonon interactions, and phonon transport in nanostructures.

The invited talk by A.A. Balandin (UC–Riverside) discussed the possibility of developing the concept of phonon engineering by fine-tuning phonon dispersion in nanostructures with high-quality interfaces. Balandin suggested that it would be possible to improve carrier mobility in silicon nanowires by proper acoustically hard coatings that suppress electron–acoustic phonon deformation potential scattering. Balandin also presented data on phonon modes in graphene and their temperature dependence that can be applied to help assess the number of graphene layers and their quality.

B. Perrin (PM Curie, Paris) discussed the emerging field of nanophononics to confine, generate, or detect phonons in the gigahertz to terahertz range. He described some experimental results on acoustic Bragg mirrors and acoustic nanocavities made of GaAs/AlAs layers. These structures can also be used as coherent phonon transducers. M.M. deLima (Univ. of Valencia, Spain) described how a coherent and monochromatic beam of acoustic phonons in the form of surface acoustic waves can be used to modulate photons and polaritons in planar semiconductor microcavities. He also discussed novel approaches for using the phase coherence of these phonons to build extremely compact optical devices for in-plane light propagation. D. Hurley (Idaho Natl. Labs.) discussed the generation and detection characteristics of phonons as a function of optical polarization, pitch–catch experiments using two identical absorption gratings, and coherent control of surface acoustic phonons using multiple generation pulses. N. Bonini (MIT) presented numerical results from the *ab initio* pseudopotential method, within the density functional scheme, for the anharmonic lifetimes of the key phonon modes in carbon nanotubes, graphene, and graphite.

Symposium Support: SNL.

Excitons and Plasmon Resonances in Nanostructures Explored

(See MRS Proceedings Volume 1055E)

Symposium GG on Excitons and Plasmon Resonances in Nanostructures covered a wide range of optical phenomena in nanostructures of different types such as self-assembled epitaxial nanostructures, colloidal nanoparticles, and lithographically defined metal structures. The symposium had both fundamental and applied components. Fundamental topics included the problem of production of entangled photons, spin and qubit manipulations using quantum optics means, tunnel and Coulomb coupling between nanostructures, exciton–metal interactions, negative-refractive-index materials, and unusual electromagnetic waves in plasmonic structures. Some of the applied topics concerned sensor applications of bioconjugated nanocrystals, heat generation with optically driven metal nanocrystals, lasers, and solar cells utilizing plasmonic effects.

Symposium Support: Applied Physics A: Materials Science & Processing *special issue:* Plasmonics.

Progress Reported on Synthesis, Processing, and Properties of Nanophases and Nanocomposites

(See MRS Proceedings Volume 1056E)

Symposium HH on Nanophase and Nanocomposite Materials V was led by a number of keynote presentations on the topics of bundled double-walled carbon nanotubes (M. Endo, Shinshu, Japan); the development in microwave processing, including decrystallizations to nanocomposites of magnetic materials (R. Roy, PSU); ultracrystalline diamond (J.A. Carlisle, ADT Inc., Romeoville, Illinois); transition metal oxides (G.R. Patzke, Zurich, Switzerland); design and control in nanocomposites (S. Mather, Universität Würzburg, Germany); and patterned

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assemblies (J. Huskens, Universiteit Twente, the Netherlands). The broad spectrum of science presented ranging from composites of carbon nanotubes through assemblies of compound materials to nanoparticles of metals allowed a variety of interactions to develop among the participants.

Symposium Support: NSF, ONR, and ARO.

Solid-State and Molecular Aspects of CNTs Emphasized

(See MRS Proceedings Volume 1057E)

Symposium II on Nanotubes and Related Nanostructures provided an overview of the current research status of CNTs: non-carbon nanostructures such as boron (R. Pandey, Michigan Tech), boron nitride (R. Arenal, CNRS; C. Zhi, NIMS), and boron–carbon nitride (E. Wang, Inst. Physics) nanotubes. Nanotube synthesis is a starting point for all other investigations. An overview of the state of the art in numerical simulations of the growth mechanism (C. Bichara, CNRS, France) and *in situ* TEM observations of tube growth (S. Hofman, Cambridge) were presented. In addition, progress was reported on scaling-up efforts (D. Futaba, AIST). Optical spectroscopy has been a primary tool for probing the electronic structures of CNTs. Both theoretical (S. Louie, UC–Berkeley) and experimental (T. Heinz, Columbia) studies of the exciton properties in CNTs were reviewed. Device integration and applications of nanotubes have gained popularity. A nanotube radio was demonstrated (A. Zettl, UC–Berkeley). Investigation on *in situ* electron microscopic study (S. Iijima, AIST) attracted great interest. Sorting the nanotubes by diameter and helicity is a key issue for applications exploiting electronic properties, and recent advances in such efforts were reported by M. Hersam (Northwestern Univ.).

Sessions on nanotube/biomolecule interactions and applications were held. The field has moved toward the understanding of fundamental physical/chemical processes that govern carbon nanotube–biomolecule interactions. A. Jagota (Lehigh) reported an in-depth molecular dynamics simulation to study sequence-dependent binding energetics of DNA–SWNT interactions.

B. Weisman (Rice) reported the detection of the intrinsic near-infrared fluorescence from SWNTs in a living fruit fly. M. Strano (MIT) reviewed the use of SWNTs as *in vivo* and *in vitro* optical sensors for the detection of metabolites and toxic substances.

Symposium Support: GDRE; MuSTI, Michigan Technological Univ.; and NIMS.

Challenges Addressed in Nanowire Integration

(See MRS Proceedings Volume 1058E)

The aim of Symposium JJ, Nanowires—Novel Assembly Concepts and Device Integration, was to bring together experimental and theoretical researchers in the area of nanowire integration. Nanowires, because of their small size, anisotropic properties, high purity, and single crystallinity, are novel building blocks for electronic, photonic, and biomedical devices. Current challenges include growth of multicomponent nanowires and their integration into functional devices. Although there are several strategies for fabricating these wires from a wide range of materials, techniques for assembling them into functional integrated devices are still limited.

K. Likharev (SUNY) and A. DeHon (PSU) discussed possible architectures for high-density nanowire integration and for bridging the macroscale–nanoscale gap. The predominant theoretical paradigm that emerged was a crossbar architecture with multiplexer-based addressing of nodes, essentially a field-programmable gate array type of computational architecture. Representatives of several experimental groups described strategies for fabricating nanowire heterostructures (C.M. Lieber, Harvard; S.-T. Lee, City Univ. of Hong Kong) and assembling them into integrated arrays. Novel FET architectures were also discussed with an emphasis on vertically aligned FETs (L. Samuelson, Lund; U. Gosele, MPI Halle). Progress on direct assembly of nanowires on metal pads by dielectrophoresis and hollow nanowires was discussed (T. Mayer, PSU; P. Searson, JHU). Novel memory devices based on reversible phase changes in $Ge_2Sb_2Te_5$ nanowires (R. Agarwal, PSU) and filament formation in amorphous Si nanowires (Y. Dong, Harvard) showed great potential for realization of next-generation data-storage devices. In addition, attempts toward the assembly of thin films of conducting large-bandgap nanowires and nanotubes for applications in transparent electrodes (F. Ishikawa, USC; W. Lu, Univ. of Michigan) were discussed. Novel integration methods of directed growth of nanowires (T. Kamins, HP) and DNA-based assembly (T. LaBean, Duke) demonstrated challenges and progress in assembly techniques.

Nanoscale Pattern Formation Achieved by Combination of Self-Assembly with Templating

(See MRS Proceedings Volume 1059E)

The emergent theme in Symposium KK on Nanoscale Pattern Formation was the use of preimposed patterns to modify and direct intrinsic, nanoscale, self-assembly processes. The ubiquitous nature of intrinsic pattern formation in surfaces, films, and aggregates was demonstrated by the extensive discussions of pattern-forming mechanisms during ion and laser irradiation, homo- and hetero-epitaxy, dewetting, electrochemical dealloying, phase separation, spinodal decomposition, and colloidal nanoparticle deposition. The templates being used to direct subsequent self-assembly often are themselves self-assembled, for example, regular nanovoid arrays in anodic alumina, molecular templates such as block copolymers, and nanosphere lithographs. Alternatively, templates can be imposed top-down through the use of various lithographies including electron-beam, nanoimprint, inkjet, dip-pen, and even crystal-lattice projection.

Lithographic patterning was used to guide subsequent ion-induced pattern formation, increasing both short- and long-range coherence and enabling assembly of geometrically complex patterns (B. Ziberi, Leibnitz Inst. for Surface Modification). Picoscale ripple formation was created by glancing incidence bombardment and redeposition with a focused ion beam (W. MoberlyChan, LLNL). The theoretical connection between ion-induced ripple formation and Aeolian ripples in sand was shown to provide further insight into nonlinear effects on pattern evolution (R. Cuerno, Universidad Carlos III de Madrid). The vanishing of spontaneous ion-induced pattern amplitudes with a length scale that remained finite as control parameters were varied was presented as proof that nonlocal effects are critical in pattern formation—even at the linear stability level—in silicon, thereby refuting the classical theory (B. Davidovitch, Univ. of Massachusettes, Amherst). Classic spiral growth theory was related to the effects of Ehrlich–Schwoebel barriers to better understand pattern formation during homoepitaxy, not only in inorganic systems, but in organic crystal growth as well (J. Krug, Univ. of Cologne). Pattern formation in Ge/Si quantum dot arrays formed through strained heteroepitaxy is being directed over macroscopic length scales and with arbitrary complexity using focused ion beam prepatterning of the substrate (R. Hull, Univ. of Virginia). Electrochemical dealloying of ternary alloys produced nanoporous material with pore sizes below 4 nm—the smallest size known for this method (J. Erlebacher, JHU). A novel mechanism for dewetting of Cr on W involving cooperative long-range step motion was identified using real-time low-energy electron microscopy (K. McCarty, SNL). N. Geyer (Martin

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Luther Univ., Germany), who received a Best Poster award, showed that pinholes as small as 50 nm in diameter, created by annealing nanosphere arrays, act as pinhole cameras for atomic beams generated from a shaped source. An unusual advance in battery technology employed soft lithographic patterning combined with self-assembly to order the M13 virus, which was then biomineralized to form CoO nanowires. These were utilized to form the anode of a Li-ion microbattery (P. Hammond, MIT). The precise placement of "DNA origami," custom self-assembled DNA-based nanocomponents, was obtained using electron-beam lithographic patterning to control local surface chemistry (R. Kershner, IBM–Almaden).

Role of Polyelectrolytes Featured in Bioinspired Polymer Gels and Networks

(See MRS Proceedings Volume 1060E)

One of the enduring themes of Symposium LL on Bioinspired Polymer Gels and Networks was the role of polyelectrolytes in both synthetic and natural gels. The opening lecture set the scene with an exposition of the theoretical state of the art, and a number of invited and contributed lectures addressed the many experimental and theoretical aspects. Presenters in this symposium consistently placed the research subject in its societal context.

Responsive gels, with driving fields including temperature, solvent quality, ion concentration, and pH, were considered in regard to a number of potential applications. Self-oscillating systems attracted both experimental and theoretical attention. One of the highlights was the deconstruction of gels through the incorporation of specific degradable groups, and the disassembling of gels could well be an interesting theme in the future.

Therapeutic gels for tissue engineering and drug delivery turned out to be the overwhelming technology push in this area. A number of presentations concerned the design, synthesis, and characterization of protein and polypeptide hydrogels. The understanding of these materials systems benefited from the combination of experiment with thermodynamic considerations and modeling. Gels and cells linked together a wide range of subject matter, ranging from the materials science of cartilage to fundamental studies of how cells interact with the culture gels upon which they are grown. A wide range of gel-based therapeutic methodologies were discussed, including spinal cord regeneration, fibrin networks for wound repair, and injectable materials that form solid scaffolds *in situ*.

Integration of Bioassembly and Synthetic Processes Leads to New Materials and Interfaces

(See MRS Proceedings Volume 1061E)

Symposium MM, Biomolecular and Biologically Inspired Interfaces and Assemblies, featured biology in the starring role, providing starting materials for biomaterials and the inspiration for new synthetic materials. On the biomaterials side, researchers B. Dragnea (Indiana Univ.) and T. Douglas (Montana State Univ.) used capsule structures derived from viruses and proteins to create new materials for optics and catalysis. DNA played multiple roles, from therapeutic applications (D. Lynn, Univ. of Wisconsin) to its use as a building block for complex nanostructures (C. Mao, Purdue; H. Yan, ASU; N. Seeman, New York Univ.).

Biomolecular motifs also figured prominently in assembly strategies for synthetic materials. J. Davis (Univ. of Maryland) used self-assembled DNA-based materials for ion channels, and J. Nowick (UC–Irvine) and J. Hartgerink (Rice) presented peptide-based materials that provided unique hybrid structures that mimic protein motifs. Moving closer toward the biological realm, L. Pasquato (Univ. Trieste) described an elegant integration of synthetic and biomolecular systems through the creation of enzyme-like catalysts using peptide-functionalized nanoparticles.

The interfacing of biosystems with synthetic materials provided a third topic for the symposium. A. Wei (Purdue) reported dithiocarbamate ligands for particularly stable monolayers on gold, whereas T.A. Taton (Univ. of Minnesota) demonstrated the use of diblock copolymers to provide stable nanomaterials. H. Matoussi (NRL) showed how appropriate functionalization of nanomaterials can be used to provide highly sensitive and versatile biosensors.

Symposium Support: ARO.

Advances Made in Protein and Peptide Engineering for Therapeutic and Functional Materials

(See MRS Proceedings Volume 1062E)

The objectives of Symposium NN, Protein and Peptide Engineering for Therapeutic and Functional Materials, were (1) to provide a forum for scientists and engineers who use proteins and peptides as a critical component in current and emerging technologies ranging from drug delivery and tissue engineering to molecular electronics and nanotechnology and (2) to facilitate collaborative interactions between two disciplines, namely, the protein/peptide engineering discipline that focuses on new synthetic and discovery tools and the biomolecular materials discipline that applies principles of protein folding and function to the development of technologically useful materials. In the symposium's opening talk, D. Tirrell (Caltech) discussed the design and incorporation of unnatural amino acids into the biosynthetic machinery of bacteria. By engineering enzymes that participate in bacterial protein synthesis, Tirrell was able to produce proteins that contain reactive functional groups such as halogens, double and triple bonds, azides, and others that can be used further to produce useful biomaterials. J. Schneider and D. Pochan, both of the University of Delaware, and J. Collier of the University of Chicago presented hydrogel systems composed of self-assembled β-sheet fibrils that seem to show great promise as tissue engineering scaffolds. R. Raines (Univ. of Wisconsin) presented the basic principles of collagen triple helix folding, and A. Wang (JHU) presented the interactions between collagen mimetic peptides and collagen and the application of such interactions for biomedical applications. A. Belcher (MIT) and S. Lee (UC–Berkeley) were able to extend the phage-display technique to the discovery of metal-binding peptides for engineering novel biomaterials and energy storage systems.

Symposium Support: CEM Corp., JHU Inst. for NanoBiotechnology, NSF, Samsung Advanced Inst. of Technology, SNL, and SynBioSci Corp.

Recent Developments Reported for Nanostructured Probes and Their Applications in Biotechnology

(See MRS Proceedings Volume 1064E)

Symposium PP, Quantum-Dot and Nanoparticle Bioconjugates—Tools for Sensing and Biomedical Imaging, focused on issues ranging from the design, synthesis, and surface functionalization of metallic, semiconducting, and magnetic nanoparticles to their being interfaced with biological receptors. The symposium also provided a venue for various groups to showcase relevant biological demonstrations and applications that have been realized using these bioinorganic hybrids. M.G. Bawendi (MIT) kicked off the first session with a presentation that touched on several aspects of QDs used in biology. For instance, he described the engineering of water-soluble luminescent QDs with very small hydrodynamic diameters and showed that these particles promote rapid renal clearance from the blood veins in mouse models. He was followed by W. Parak (Technical Univ. of Munich), who discussed the design of polyelectrolyte microcapsules loaded with a pH-sensitive SNARF-1-dextran conjugate as a means to sense pH changes during the transition from the alkaline cell medium to the acidic endosomal/lysosomal compartments. F. Raymo (Univ. of Miami) and I.L. Medintz (NRL) addressed the use of electroactive compounds (including photochromic and redox-active complexes) to control the fluorescence emission of hydrophilic QDs, as well as the use of this means of interactions to design sensing assemblies that can detect specific targets. These included the sensing of pH variations in buffers and the detection of enzymatic activity. A. Patri (NIH/NCI) gave an overview of the national Nanotechnology Characterization Laboratory and the services it offers to the community in terms of conducting testing studies for potential preclinical trials.

F. Winnik (Univ. of Montreal) and E. Jares-Erijman (Univ. Buenos Aires, Argentina) led the sessions on the use of QDs for labeling live cells and probing specific intracellular processes. Particular attention was paid to defining and understanding the potential cytotoxic effects of core-only and core–shell QDs capped with various surface ligands. The study in particular demonstrated that the cytotoxicity of QDs can be reduced and even eliminated in the presence of CdSe overcoated with a layer of ZnS, regardless of how stable and strong the capping ligands are. A.P. Alivisatos (UC–Berkeley) presented work by his group on the development of plasmonic rulers. By using two or more gold nanoparticles coupled through oligonucleotides, or any potential amino acid sequence, Alivisatos showed that, because of strong proximity plasmon coupling between the nanoparticles (which affect the scattering intensity of the assembly), small changes in the separation distance due to interactions with target molecules could be easily and accurately detected. K. Hamad-Shifferli (MIT) described the synthesis and characterization of fluorescent Au_8–dendrimer nanoparticles. In particular, she detailed the conditions for the controllable synthesis of such discrete size clusters, their structural characterization, and their fluorescent emission. U. Wiesner (Cornell) discussed work on developing silica-encapsulated organic fluorophores, called Cornell Dots. Wiesner described how the encapsulation process and shielding of the dye within the silica core improves the PL emission of the dye and translates into a marked enhancement of the brightness of these nanofluorophores. He further showed the use of these nanoparticles for live cell labeling.

V. Rotello (Univ. of Massachusetts) described the progress made in developing nose sensors using Au nanoparticles conjugated to selective receptor proteins. He also described the use of a fluorescent polymer matrix containing Au nanoparticles to develop quenching assays specific for the detection of target proteins. C. Mirkin (Northwestern Univ.) described the design and preparation of nanodisk barcodes and their use in studying molecular bridges between nanoscale electrode gaps. He also described the use of these barcodes as a sensing tool for detecting hybridization. A. Wei (Purdue) described the use of two-photon fluorescence from gold nanorods to image a specific cellular compartment with reduced background. He further explored the ability of metallic nanorods to generate heat as a means of locally treating affected tissue and cells. T. Hyeon (Seoul Natl. Univ.) described efforts on designing and making a gram amount of high-quality magnetic nanoparticles. He also described recent efforts geared toward the design of T1 contrast magnetic nanoparticles for use in MRI. J. Ying (Singapore Univ.) described the design of water-soluble luminescent QDs and magnetic nanoparticles using ligand design and/or silica encapsulation. She showed that the capping of core–shell QDs with glutathione followed by cross-linking provides compact nanoparticles that can allow selective uptake by live cells. The symposium also hosted a joint tutorial with symposium MM, where several aspects of interfacing nanoparticles (namely, semiconductor QDs, metallic, and magnetic nanoparticles) with biology were covered. The tutorial was presented by Rotello, H. Mattoussi (NRL), and J. Cheon (Yonsei Univ.).

Symposium Support: DTRA Basic Research and Evident Technologies.

Bioapplications Explored in Tissue Engineering, Sensors, Actuators, and Controlled Drug Delivery

(See MRS Proceedings Volume 1065E)

Symposium QQ, Electroactive and Conductive Polymers and Carbon Nanotubes for Biomedical Applications, gathered scientists studying the interface of carbon-based conductors with biological cells and living tissues. The symposium focused on four bioapplications: tissue engineering, sensors, actuators, and controlled drug delivery.

Several research groups presented work that demonstrated the utility of intrinsically conducting polymers to mediate, improve, and stabilize the interface between cells and medical devices including hearing aids (S.E. Moulton, Univ. of Wollongong, Australia), prosthetic devices (S.M. Richardson-Burns, Biotectix), brain electrodes (X.T. Cui, Univ. of Pittsburgh; M.R. Abidian, Univ. of Michigan), and heart auscultation devices such as stethoscopes (D.J. Griffiths, Virginia Tech). Because of their high charge injection capacities and their wide electrochemical windows, electrically conducting polymers were found to be useful when applying electrical stimulation to neuronal tissues (M. Asplund, Linkoping Univ., Sweden; S.F. Cogan, EIC Laboratories), as well as mechanical stimulation to cells (A. Stemmer, ETH Zurich, Switzerland).

Conducting copolymers and gels are also being evaluated as smart responsive materials for the *in vivo* detection of glucose and lactate (A. Giuseppi-Elie, Clemens), as microactuators (E. Smela, Univ. of Maryland), and as biofuel cells (T. Palmore, Brown). They are also being used to promote the regeneration of peripheral nerve injuries (C.E. Schmidt, Univ. of Texas at Austin; S.D. Luebben, TDA Research). J. Kim's group at the University of Michigan reported the investigation of various conjugated polymers to amplify the signal in biosensors and to be used for *in vitro* cell imaging. F. Bruno of Natick and S. Nagarajan of the University of Massachusetts–Lowell presented a greener way of making conductive polymers using enzymes and a new catechol-based conjugated polymer with antitumor activity. Several researchers presented biomedical applications of CNTs, from sensing ions, small molecules, viral proteins, and DNAs to neural electrode tissue interfaces and brain tumor therapy. A. Kleinhammes of the University of North Carolina presented a work in progress aimed at making a cathode that is able to produce a small focused x-ray beam by using an array of carbon nanotubes.

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