2001 MRS Fall Meeting Highlights Innovations in Materials Research

The 2001 Materials Research Society Fall Meeting, held November 26–30, 2001, in Boston at the Hynes Convention Center and the Sheraton Boston Hotel, offered technical symposia in a range of areas, categorized into seven clusters: inorganic electronic materials and devices; photonic/optoelectronic materials and devices; thin films and surfaces; materials science, processing, and evaluation; nanoscale materials and processes; organic/biological materials and devices; and materials and society. Meeting Chairs Bruce M. Clemens (Stanford University), Jerrold A. Floro (Sandia National Laboratories), Julia A. Kornfield (California Institute of Technology), and Yuri Suzuki (Cornell University) introduced a new concept of a virtual Symposium AA on self-assembly processes, which consisted of joint sessions with symposia that crosscut a range of disciplines and topics.

In a cluster on inorganic electronic materials and devices, researchers addressed microchemical reactors as potential sources of electrical power for handheld devices, and they described significant steps taken toward high-density nonvolatile ferroelectric memories. Speakers in Symposium E discussed issues ranging from the near-term commercialization of the first-generation BSCCO tapes to the development of the new MgB_2 superconductor.

Highlights of the cluster on photonic/optoelectronic materials and devices included the growth of bulk GaN substrates, the addition of nitrogen in (In,Ga)(As,P) and related materials to reduce the bandgap, and the potential of a double-quantum-well system with possibilities to operate at room temperature for chemical and biological agent detection. In Symposium K on microphotonics, an announcement was made on the fabrication of 3D silicon photonic-bandgap crystals on a Si wafer. The researchers demonstrated how the standard Si-based microfabrication techniques may be applied to make devices out of these structures.

In Symposium O on complex oxide heteroepitaxy, it became apparent that strain alone is incapable of explaining observed enhancement or suppression of the superconducting transition temperature of $(La,Sr)_2CuO_{4+\lambda}$ in epitaxial films. Other highlights of the cluster of symposia on thin films and surfaces revealed, in the area of thin-film growth in electrolytes, that the introduction of one or more molecules that adsorb to the substrate leads to preferential deposition at protuberances, uniform deposition, or enhanced deposition in trenches. The latter process has led to the implementation of electrochemical deposition of copper metallization in the electronics industry, as reported in Symposium M.

A growing interest in organic materials was seen in the cluster of symposia on organic/biological materials and devices. Artificial muscles are materials that combine sensor and actuator functions so that a stimulus causes the "muscle" to contract or expand. G. Spinks (Univ. Wollongong, Australia) used conducting polymers and carbon nanotubes as electromechanical actuators and strain sensors. The aim of his work was to make a glove that can open and close like the human hand. In addition to use for virtual reality, such a glove could be used for rehabilitation after surgery or for arthritis. The glove was made using a polypyrrole conducting coating on stretch fabric, combined with carbon nanotubes. A. Mazzoldi (Univ. Pisa, Italy) also described a process applied in the design of a sensor-motor glove built for the purpose of virtual reality and rehabilitation therapy. Mazzoldi described electroactive polymer-based artificial skin and muscles that relied on conducting electrostrictive and piezoresistive polymers in the form of fibers, threads, and fabrics. Their properties were quantified. Another application of this work is in animatronics. Toward this end, an android face has been constructed, with facial movements governed by biomimetic actuators.

J. Su (NASA Langley Research Center) covered electromechanical properties of some new electroactive polymers. Such materials can exhibit large-electric-field-induced strain or high-strain-energy density. As an example, electrostrictive graft elastomers can produce 4% strain induced by an electric field. These materials consist of a flexible backbone and a plastic graft. Properties can be controlled by choices of the molecular components of the backbone and graft, by the ratio of the components, and through processing. Prototype actuators have been made that can bend in both directions. This work is aimed at enhancing 21st century aerospace vehicles, with embedded nanosensors, self-healing materials, morphing wings, and other innovations.

In Symposium CC on liquid-crystalline materials, H. Coles (Univ. Southampton, UK) described flexoelectric effects in highly twisted nematic bimesogens. Previously, high electric fields were needed to achieve high switching angles, but bimesogenic systems enhance the flexoelectric effect enough to reach large angles at reasonable voltages. Coles' research group has made wide viewing angle birefringence, dye guest host, and molecular mirror devices.

F. Kremer (Univ. Leipzig, Germany) described the use of time-resolved FTIR spectroscopy to study the structure and mobility of ferroelectric liquid-crystalline elastomers (FLCEs). He examined the reorientation response time to a switched electric field of different molecular groups for three sample types: the uncross-linked polymer, the intralayer cross-linked FLCE, and the interlayer cross-linked FLCE. The interlayer cross-linked FLCE showed the slowest response time. He also described AFM of self-supported thin films, comparing the surface topologies of the intra- and interlayer cross-linked samples. Since the intralayer cross-linked samples are primarily 2D cross-linked, the smectic layers can slide, while in the interlayer samples they are fixed. He discussed similar experiments on ferroelectric LC gels.

M. Fisch (Kent State) addressed flexible plastic LC displays. In a description of a flexible reflective cholesteric display made by his research group, Fisch said that the lack of polarizers and alignment layers means that the birefringence of the plastic substrates is not a problem. The researchers segregated the polymer, which

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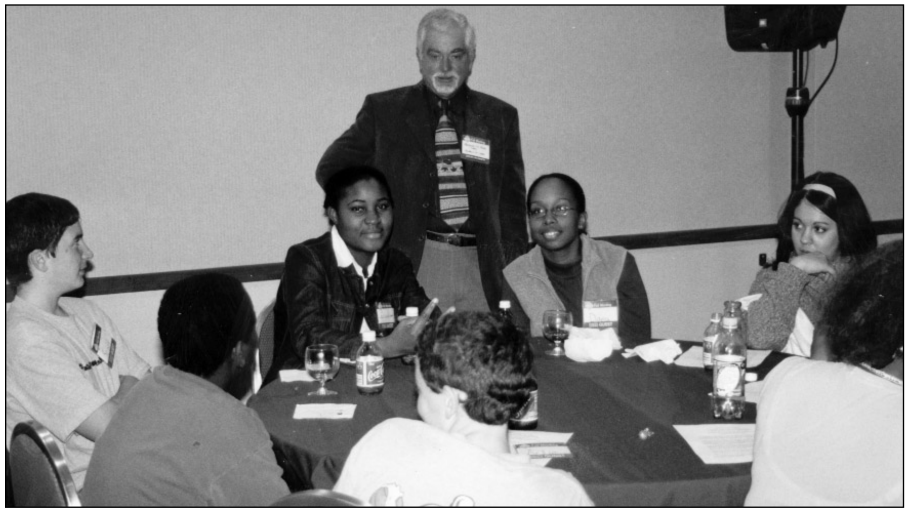
adds mechanical stability to the interpixel regions to increase the contrast. Roll-to-roll processing requires a replacement for photolithography. As a first step, the group used a wax printer to print a wax resist on ITO on a PET substrate. Fisch said that better processing techniques are needed to obtain higher resolution. Another challenge is to optimize the plastic substrates and LC/polymer mixture.

In the cluster on nanoscale materials and processes, invited speaker in Symposium Y, T. Desai (Univ. Illinois—Chicago), described her work on nanoporous membranes. Semipermeable nanoporous membranes are critical for applications such as drug delivery. Desai described the fabrication of nanopore membranes in Si using sacrificial lithography. Initially, conventional lithography was used to create a pattern on the surface. Then a thin coating of oxide was applied followed by a deposition of a structural material. By etching away the sandwiched oxide, very fine channels were formed which became the pores of the membranes. One of the advantages of the technique is that very fine (7–100 nm diameter) and very regular pores can be created. The channels can be tailored by adjusting the oxide thickness and the lithographic pattern. These membranes have been used to perform size-based exclusion and controlled diffusion of model biomolecules including glucose, human serum albumin, and IgG, which have different 3D configurations.



High school students from the Boston area attended an MRS Student Workshop on Materials Science of Sports Equipment, presented by F.H. Froes of the University of Idaho. Topical workshops like this are regularly sponsored, by the MRS Outreach Subcommittee, during the MRS Meetings.

H. McNally (Purdue Univ.) introduced research in biological self-assembly of

ACRONYM KEY

1D: one-dimensional
2D: two-dimensional
3D: three-dimensional
AIST: Advanced Industrial Science and Technology
AFM: atomic force microscopy
AFOSR: U.S. Air Force Office of Scientific Research
AFRL: U.S. Air Force Research Laboratory
ANL: Argonne National Laboratory
ARO: Army Research Office
Caltech: California Institute of Technology
CMU: Carnegie Mellon University
CNRS: Centre National de la Recherche Scientifique
CVD: chemical vapor deposition
CWRU: Case Western Reserve University
DARPA: Defense Advanced Research Projects Agency
DOE: U.S. Department of Energy
ECR: electron cyclotron resonance
EPFL: Ecole Polytechnique Federale de Lausanne
FIB: focused ion beam
FTIR: Fourier transform infrared
Georgia Tech: Georgia Institute of Technology
GM: General Motors
HTS: high-temperature superconductor
IBAD: ion-beam assisted deposition
IC: integrated circuit
IPL: ion projection lithography
IR: infrared
ISD: inclined substrate deposition
ISFET: ion sensitive field-effect transistor
ITO: indium tin oxide
JHU: The Johns Hopkins University
KTH: Kongl Tekniska Högskolan
LANL: Los Alamos National Laboratory
LC: liquid crystal
LED: light-emitting diode
LEEM: low-energy electron microscope
LLNL: Lawrence Livermore National Laboratory
LSI: large-scale integration
MAPLE DW: matrix-assisted pulsed laser evaporation direct write
MBE: molecular beam epitaxy
MEMS: microelectromechanical systems
MESFET: metal-semiconductor field-effect transistor
MIT: Massachusetts Institute of Technology
MOCVD: metalorganic chemical vapor deposition
MOSFET: metal oxide semiconductor field-effect transistor
MPI: Max Planck Institute
MSU: Moscow State University
MWNT: multi-walled carbon nanotube
NASA: National Aeronautics and Space Administration
NC A&T: North Carolina A&T University
NCSU: North Carolina State University
NIST: National Institute of Standards and Technology
NREL: National Renewable Energy Laboratory
NRL: Naval Research Laboratory
NSF: National Science Foundation
NTT: Nippon Telegraph and Telephone Corp.
OLED: organic light-emitting diode
ONR: Office of Naval Research
ORNL: Oak Ridge National Laboratory
PDE: partial differential equation
PECVD: plasma-enhanced chemical vapor deposition
PET: poly(ethylene terephthalate)
PNNL: Pacific Northwest National Laboratory
PSU: The Pennsylvania State University
PZT: lead zirconate titanate
QWIP: quantum-well infrared photodetector
RABiTS: rolling-assisted biaxially textured substrates
rf: radio frequency
RPI: Rensselaer Polytechnic Institute
SAM: self-assembled monolayer
SAXS: small-angle x-ray scattering
SCMRE: Smithsonian Center for Materials Research and Education
SEM: scanning electron microscopy
SNL: Sandia National Laboratories
SOI: silicon-on-insulator
STM: scanning transmission microscopy
SUNY: State University of New York
SWNT: single-walled carbon nanotube
TEM: transmission electron microscopy
TI: Texas Instruments
TPO: thermoplastic olefin
UCLA: University of California—Los Angeles
UCSB: University of California—Santa Barbara
UMIST: University of Manchester Institute of Science and Technology
UNAM: Universidad Nacional Autónoma de México
UV: ultraviolet
VLSI: very large-scale integration

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U.S. Government Agencies Introduce Funding Opportunities

For several Meetings, the Materials Research Society has held seminars on research funding opportunities offered in the United States. At the 2001 Fall Meeting, MRS brought back representatives from the National Science Foundation (NSF) and the Department of Energy (DOE). For the first time, a representative from the National Institutes of Health (NIH) held a session to describe research and funding opportunities related to materials science in biology and medicine.

Richard Swaja, senior science advisor for the National Institute of Biomedical Imaging and Bioengineering (NIBIB) at NIH, described the 24 institutes of the agency, each of which has its own program for funding. The areas involving materials research include biomaterials (such as tissue engineering, devices, prostheses, and implants), imaging techniques, computational applications, and nanotechnology. Among several research needs in biomaterials that NIH has identified are biocompatibility, biomimetics, biodegradability, strength and longevity, electrical and mechanical properties, and organic/organic interfaces. NIH research funding opportunities include grants through individual institutes, mutidisciplinary trans-NIH bioengineering grants, and multi-organizational partnerships. Swaja provided details about the process of applying for a grant from NIH, ways to improve chances of obtaining funding, and ways of getting involved with NIH.

Swaja showed four specific projects that were funded and that have had significant success and impact. The "Abiocor" artificial heart was recently implanted in a few patients and has been in the news. In the area of artificial skin and tissue engineering, Swaja discussed significant improvements in the facial skin of a toddler who had suffered severe burns. A video clip was shown on the use of brain implants for deep brain electrical stimulation in a patient with Parkinson's disease. The fourth example shown was an intelligent prosthetic knee used to replace a conventional prosthesis that allowed for significantly improved mobility; patients experienced better ability to climb stairs more naturally. Swaja said NIBIB is one of the newest institutes, and he pointed to the Web site as the best source of information regarding funding opportunities (www.nibib.nih.gov).

In the 8th seminar in a series of guides to NSF support for materials research and education, Tom Weber, Director of the Division of Materials Research, and Haris Doumanidis, Nanomanufacturing Program Director of the NSF division on Design, Manufacture and Industrial Engineering (DMII), spoke about their respective divisions. Weber said that of the ~$300 million annual support from NSF, about 63% is within the Division of Materials Research (www.nsf.gov/mps/dmr), with additional support in the broader Math and Physical Sciences Directorate and beyond. Weber mentioned the opportunity for funding of focused research groups, with funding of the order of $300 thousand for groups of three or more investigators, filling a funding gap between individual investigators and larger centers. He announced that the average duration of grants is increasing to four years or longer, opposed to the three years more typical in the past, with individual stipends creeping up to about $130 thousand per grant.

Doumanidis followed Weber with an overview of the philosophy and implementation of the new nanomanufacturing program at NSF. This was placed in the context of recent down-scaling processing and miniaturization research developments, as well as the National Nanotechnology Initiative and its connection with nanoscale science, engineering, applications, and societal impacts. The program focuses on up-scaling synthesis of functional structures, devices and systems, integration across dimensional scales and multiple energetic domains, as well as biomimetic approaches. This calls for research programs in nanoscale materials, processes, instrumentation, modeling-control, and design/integration of nanostructured products. Among implementation strategies, Doumanidis said that emphasis is being placed on the role of education and training, interfacing between academic, industrial, government, and professional institutions; outcome dissemination; and impact to society. Doumanidis provided information on currently supported programs and reviewed funding opportunities. The program's Web site can be accessed at www.eng.nsf.gov/dmii.

Iran Thomas, Director of the Division of Materials Science and deputy Associate Director of Basic Energy Sciences for the Department of Energy (DOE), discussed opportunities for funding of fundamental materials research at DOE. He provided sources for information on current and anticipated research areas and for proposal submission and evaluation.

electronics devices that could be applied to further downscaling in the electronics industry. McNally's group used functionalized DNA to attach objects to a substrate, fabricating Si islands with DNA attached. The researchers put a charge on those islands for electrophoretic transport.

A. Chilkoti (Duke Univ.) discussed manufacturing substrates by ultraflat nanosphere lithography. The substrates, which consist of periodically arranged gold or silver particles in an aluminum matrix, are designed for biological applications using self-assembly. Chilkoti also described work on real-time label-free biosensor arrays for surface plasmon resonance. The arrays use functionalized gold nanoparticles to bind biomolecules. Chilkoti presented results on the change in absorbance of fibrinogen and streptavidin as a proof of principle.

Lithography for future microelectronics patterning below 100 nm is not yet clearly set, according to C.L. Henderson (Georgia Tech). Henderson examined some of the less traditional paths lithography could take. One solution is to use top-surface-imaging methods in which exposure in only a thin surface layer is used to create a pattern for a much thicker etch barrier layer. Taking this concept to its limit, Henderson described how the initial image or pattern can be defined in a monolayer. First a pattern is defined by radiation exposure of a reactive monolayer, causing deactivation of selected areas of the monolayer. Then the remaining areas are activated to generate radicals (or other initiator sites) that are used to amplify the initial pattern by growth of an etch-resistant polymer. This method is extremely flexible and shows promise in the fabrication of sensors and biological devices.

In other technical sessions devoted to bioinspired materials, D. Morse (UCSB) described, in Symposium HH, the formation of nacre, a highly organized laminate composite. The structure of an abalone shell, with 400-nm-thick plates separated by thin layers of protein, creates greater fracture toughness than the mineral alone. The orientation of the layers, determined by AFM, is the same from layer to layer even though they are separated by a thin layer of protein. This suggests that there is communication through pores in the organic layer. These pores serve as a molecular stencil to guide the growth from one layer to the next. Other studies on the structure have revealed threads of the protein Lustrin A that act as shock absorbers. The threads have sacrificial bonds that break to let the molecule extend. Morse said it is hoped that examining how biological systems are formed

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will lead to new synthetic routes.

Natural fibers are available worldwide, and have the potential to lead to weight and cost reduction when used in automotive components. In Symposium U, H. Flegel presented research by DaimlerChrysler in Germany to incorporate such fibers into their vehicles. Natural fibers such as flax, hemp, kenaf, and sisal have high transverse and tensile strength. When embedded in plastic, such fibers can achieve strengths comparable to fiberglass-reinforced plastics. Currently more than 30 components made of renewable raw materials are used in the production of Mercedes C-, E- and S-Class automobiles, Flegel said. The engine encapsulations of EvoBus buses like Mercedes Travego and Setra TopClass are made with natural-fiber-reinforced UP-resin, a commercial solution that realizes a cost and weight reduction of 5%. Challenges remain in achieving aesthetically pleasing exterior surfaces. Also, while the fibers come from renewable sources, they cannot be recycled, so the requirement that automobiles be 95% recyclable poses an end-of-life challenge.

R. Weber (Containerless Research) discussed YAG and rare-earth aluminum oxide glass fibers. These fibers are strong, thin, and chemically stable. The large amount (a few percent) of dopant ions they can contain alters their optical properties. The fibers transmit higher wavelength IR than conventional silica fibers. They can be crystallized at ~1200 K into flexible, strong, and creep-resistant polycrystalline fibers.

On the topic of functional materials made with nanotubes, Symposium Z opened with two invited talks in the area of room-temperature hydrogen storage in SWNTs. M. Hirscher (MPI, Stuttgart) showed hydrogen storage capacity below 1 wt% while M. Heben (Parilla National Renewable Energy Lab., Golden, Colo.) announced observation of hydrogen storage of up to 8 wt%. Both research groups used ultrasonic treatments to cut the SWNTs into smaller pieces. There is great debate among researchers over the origin of the discrepancy. Some believe that the metal alloy impurities introduced during ultrasonic cutting are responsible for the hydrogen storage. Some current research focuses on other cutting methods.

Carbon nanotubes are being considered for use in field-emission displays, composite materials, gas storage, and other areas. One goal, then, is to produce these nanotubes in greater quantities and in desirable forms, as discussed by M. Yumura and his colleagues at the Research Center for Advanced Carbon Materials, AIST, Tsukuba, Japan. They have developed a method to produce several tens of grams of MWNTs per day by the continuous arc method, which has higher productivity compared with the arc-discharge method used since 1996. Going further, they have started to develop a production method to produce several kilograms of the MWNTs per day based on catalytic decomposition of hydrocarbons. The method starts with benzene as the raw material and ultrafine metal particles as the catalyst. In another presentation, B.Q. Wei (RPI) described how to mass-produce SWNTs by the vertical-floating-catalytic technique. Starting with hexane and using thiophene and sulfur additives, ferrocene as catalyst, and hydrogen as carrier gas, the research group made weblike deposits of aligned ropes of carbon nanotube strands as long as 20 cm with >85% purity. Currently, the research team makes gram-scale SWNTs per day, noting that the process is continuous and scalable. P. Poulin (CNRS) described how to process carbon nanotubes into long fibers using a simple spinning-like process. The method consists of dispersing the nanotubes in a surfactant solution, re-condensing the nanotubes in the flow of a coagulating polymer solution to form a nanotube mesh, and then collating this mesh to a nanotube fiber. Although far from being fully optimized, he suggested that these fibers are potentially useful as sensors and actuators. In addition, carbon nanotube fibers can be modified to improve their properties through mechanical, chemical, or thermal treatments.

Microelectronic devices need power, and K.E. Swider-Lyons (NRL), in Symposium Q, presented a way of delivering that power by using the matrix-assisted pulsed-laser evaporation process, MAPLE DW, to write power sources directly into microelectronic devices. This puts the energy where it has to go, and the batteries can be made quickly through this direct-write process at low temperatures and ambient pressure. Many types of materials can be deposited this way, including polymers, hydrated oxides, metals, and corrosive liquids. Micromachining then can be used to tailor the battery sizes

Women in MRS Breakfast Hosts Discussion on Mentoring

*At the Women in MRS Breakfast, **Valerie Kuck** (left), formerly of Lucent Technologies, presents a talk about mentoring. **Joanna Mirecki-Millunchick** of the University of Michigan (right) moderates the discussion.*

At the 2001 Materials Research Society Fall Meeting, Women in Materials Science and Engineering hosted a discussion breakfast with guest speaker Valerie Kuck (formerly of Lucent Technologies) on Wednesday, November 28. In her presentation on "The Role of Mentoring," Kuck focused on two main issues: how to choose a mentor and why choose to be a mentor.

When choosing a mentor, Kuck recommended that the following questions should be asked: (1) Does the mentor have time for me? (2) Does the mentor want me to succeed? and (3) Does the mentor respect me? Kuck said that the benefits of being a mentor include the improvement of skills needed for a successful career, such as improved communication and listening skills. Furthermore, Kuck elaborated upon how a successful mentoring partnership is beneficial to people across the board, young and old, male and female, and technical and managerial. In the discussion that followed, it came out that ~50% of the audience had mentors.

Currently, Kuck is an adjunct professor at Seton Hall University in New Jersey. There she is teaming with professors in the Women's Studies Department to continue her studies into the role of mentoring.

The breakfast was co-sponsored by MRS and the American Chemical Society (Colloid and Surface Chemistry Division), arranged by Tina M. Nenoff (SNL) and moderated by Joanna Mirecki-Millunchick (Univ. Michigan) and Bill Hammetter (SNL). Held at several MRS Meetings, the breakfast is organized by the Society's Public Outreach Subcommittee.

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Ancient Technologies Demonstrated in Archaeology Workshop

Meeting participants, including museum scientists and archaeologists, explore the technique of ancient Egyptian faience as demonstrated by Carolyn Riccardelli, now of the Metropolitan Museum of Art in New York.

Breaking away from the formality of symposium presentations, some meeting attendees tried their hand at ancient Egyptian faience, termed as the first high-tech ceramic. The final-day workshop of Symposium II on materials issues in art and archaeology, held in the Department of Materials Science and Engineering at MIT, traced major technological developments in the history of glass: Egyptian faience invented about 4000 B.C., glass core vessel manufacture developed about 1500 B.C., and Roman glass-blowing and molding processes in the 1st century B.C. Important advances in the understanding of these technologies have occurred in recent years, and this workshop provided an opportunity for scientists, conservators, and archaeologists to observe and participate in the manufacture of these materials while employing and evaluating these recent advances. These three developments involved the use of the soda-lime-silicate ingredients of traditional glasses.

Carolyn Riccardelli, a recent graduate from the Art Conservation Program at Buffalo State College, now Assistant Conservator at the Metropolitan Museum of Art in New York, demonstrated manufacturing methods of ancient Egyptian faience, with a particular focus on the invention of inlay techniques. Riccardelli 's recent faience examination and replication research has enabled her to produce the first faience objects that have the clarity of decoration (incised and inlaid) that is observed on ancient Egyptian wares. She provided samples of Egyptian faience paste, which starts as dry ingredients composed of silica, alkali, calcia, and a colorant. Several colors of paste were available: copper carbonate (turquoise), manganese (purple), red iron oxide (light brown), cobalt oxide (blue), and white (no colorant). Participants in the workshop, including museum scientists and archaeologists, slowly added water to the dry mixture until they formed workable paste. Because faience paste contains no clay, it has very little plasticity and is difficult to form. In addition to the lack of plasticity, it is thixotropic, causing the paste to lose shape if any kind of sheer force is applied to it—such as shaking it in the hand. Riccardelli supplied several fired clay molds in which the paste could be formed. Quickly removing their samples from the mold to allow the paste to dry, the participants then shaped details by hand modeling or carving. The soluble salts in the paste were drawn to the surface during drying, forming a white efflorescence on the surface. This crust acted as a flux during firing, resulting in a glazed surface wherever the salts formed.

This demonstration illustrated that to obtain detailed decorative patterns or inlays of very small, but readable, Egyptian hieroglyphic writing, special processing was required that is counter-intuitive to modern ceramic practice. Riccardelli showed that inlays were placed into already-fired substrates with indentations of the correct shape or into dried but unfired substrates. Although these processes involve steps that are uncommon in standard ceramic processing, they were practiced to obtain a particular visual effect in ancient Egypt during the mid-second millennium B.C.

In the pyrotechnology workshop, Peter Houck, technical instructor at the MIT Glass Lab where the workshop was held, worked alongside of glass blowers Andy Magdanz, from Cambridge, Mass., and Fritz Dreisbach, from Seattle, Wash., as they produced vessels through a recreation of the Roman glass-blowing tradition of A.D. 4th–5th centuries. The unique opportunity to watch these craftsmen reproduce ancient objects by their original fabrication methods gave workshop participants many new insights into the skills and technological knowledge possessed by ancient craftspeople. During the course of the workshop, the artists explained and contrasted modern technology with the ancient Roman tradition, demonstrating the production of mold-blown goblets, tumblers, and bottles. Using tools authentic for the time period, a glass, heated to 1160°C, was first rolled on a marver and blown into bronze molds, known as optic molds, to create a surface design on the glass vessel. Once partially shaped, the glass was then transferred from the blowpipe to the punty, allowing it to be worked, shaped, and reheated in a lower-temperature furnace to produce the mouth, base, and other delicate attachments. In Roman times, all of these steps would have been accomplished using one furnace with several flues, utilizing a combination of organic fuel and draft as a temperature-control mechanism during heating and annealing. While maintaining a good working viscosity, the creation of precise shapes and styles demanded the artists' attention for detail and knowledge of the proper balance between time, draft, and temperature. When the design was completed, a temperature differential was introduced at the joint between the glass and the punty, and the vessel was removed by tapping. The final step was to anneal the vessel for several hours in order to equalize heat and eliminate thermal stresses.

Dudley Giberson and Carolyn Rordam of Joppa Glassworks in New Hampshire demonstrated early glassmaking technology as it probably was practiced in the mid-second millennium B.C., 1500 years before the invention of glassblowing. Giberson's methods utilized a vertical updraft furnace—an ancient furnace prototype—that was kept low in temperature (about 815°C). Glass was applied to a sintered ceramic core in a cold state as a crushed glass powder of frit. This coated core was then heated to just above red heat and held at that temperature for about two hours during which time the glass sintered. Additional glass was added by rolling the core in more fritted glass. Decorative colors were trailed on and eventually hooked and feathered to produce the expected traditional patterns. After handles and lip wraps were added, using fancy canes, the object was annealed.

Core-formed vessels prepared using Giberson's methods are the first reproductions of these wares to have the microstructures observed in their ancient Egyptian and Hellenistic counterparts. That only two Egyptian core vessels were made during the day-long workshop and that blown vessels could be produced every few minutes led to a lively discussion of variation in material properties, organization, and methodology of production.

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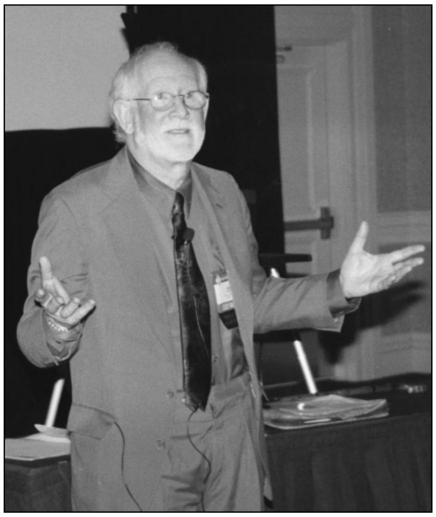

Simon C. Moss *(University of Houston), the 2001 MRS Von Hippel Award recipient, presented an award talk on several aspects of x-ray and neutron scattering studies of defective and disordered materials that he conducted with his collaborators over the past few decades.*

and configurations. Recharging of the batteries can be done by energy harvesting of solar or rf waves. Such conformal application of power sources facilitates space and weight conservation. Swider-Lyons gave examples for planar pseudocapacitors and stacked alkaline batteries.

Ink-jet printing has been shown to be a viable route for fabricating high-resolution, active- and passive-matrix, full-color, light-emitting polymer displays. N. Athanassopoulou (CDT, UK), in Symposium BB, examined what is needed to optimize this ink-jet process. Modifications are needed to the ink-jet printer heads, the substrate, and the polymer solutions, she said. She and her colleagues are optimizing the ink rheology so that the polymer inks are stable, wet the surface, and form isolated drops that stay in place. Likewise, the substrates need to have surface energies that are compatible.

In a cluster on materials and society, P. Vandiver and M. Goodway from the Smithsonian Center for Materials Research and Education and J.L. Mass from the Winterthur Museum, organized Symposium II on materials issues in art and archaeology. The sessions of preservation science and conservation dealt chiefly with two crucial problems in the preservation of cultural heritage: the deterioration of world heritage monuments by salt damage (flaking, cracking, and spalling) and the problematic long-term preservation of oil and acrylic paintings in museums. G.W. Scherer and R.J. Flatt (Princeton) designed a model for the control of salt crystallization in porous building materials by modifying mineral surfaces and consolidant rheology. The mechanical properties, drying, cleaning, and fire damage of oil and acrylic paints were addressed by several researchers.

For the treatment and restoration of fire-damaged paintings, S. Miller (NASA) and co-workers have studied the use of atomic oxygen treatment, based on their experience with effects of atomic oxygen on spacecraft. They used a small chip of paint from Monet's painting *Waterlilies*, which was damaged in a fire in 1958. The surface of the painting was dark with areas of blistering and charring. The chip, about 1 cm in size, was treated with atomic oxygen in a mild 150-mTorr vacuum environment. Diffuse spectral reflectance and contrast were monitored during the treatment. The treatment was found effective in removal of the soot and char without affecting the gross surface features and texture.

K. Trentelman (Detroit Institute of Art) described the restoration and conservation of the aluminum alloys used in Buckminster Fuller's Dymaxion house. The Dymaxion was designed in the 1940s as a mass-produced and inexpensive house. It was determined that primarily two Al alloys, Al clad 2024-T3 and Al clad 2014-T6, were used. The age-hardened characteristics had not changed in 50 years. However, it was observed that there was no cladding layer. It was determined that diffusion of Cu from the core had homogenized the cladding layer, which led to loss of corrosion resistance. Severe corrosion, observed in areas of the Al parts, was removed mechanically and exterior parts were polished for the restoration. The restored exhibit was opened in October 2001 at the Henry Ford museum where the house was donated in 1990. Additional information is available at the museum Web site: www.hfmgv.org/dymaxion/.

For further details about the technical content of the meeting, read the following symposium summaries and see the published proceedings.

MEMS Challenge Addressed with Eye on Commercialization

(See MRS Proceedings Volume 687)

Symposium B on the Materials Science of MEMS covered a large number of the challenges MEMS technologists currently face as well as the enormous commercialization opportunities that lie ahead. In the cases of rf-MEMS, D. Young (CWRU) described the advantages of micromachined devices for rf applications, including low-loss switches, phase-shifters, and wireless communications. Similarly, in the case of microchemical reactors, A. Franz (MIT) elaborated on the potential of these structures as sources of electrical power for hand-held devices. The high-energy densi-

MRS Tutorial Prepares Attendees for Solid-State Lighting Symposium

Michael Shur (RPI) provided a tutorial as part of Symposium J on materials engineering for solid-state lighting, one of the new symposia held at the 2001 Materials Research Society Fall Meeting. Shur began with a historical perspective on various aspects of lighting and illumination, including the history of electric lighting over the past century. He talked about the current design of bulbs and tubes for comparison with light-emitting diodes (LEDs). Subsequently, photometry and calorimetry were discussed, laying the foundation for the field, followed by an introduction to solid-state lighting and LEDs. Shur detailed various aspects of light extraction from LEDs and white LEDs, including technical descriptions and the underlying physics. In the final part of the tutorial, he dealt with current and future applications of solid-state lighting. These included signals (traffic lights, signage), displays, medical applications (phototherapy, phopolymerization), photosynthesis, and optical measurements. Shur showed examples of specific devices under design.

Shur said that several challenges, including technical and economic, need to be met before widespread usage of LED lighting technology becomes a reality. Shur concluded with a quote from N. Holonyak Jr.'s paper "Is the Light-Emitting Diode (LED) an Ultimate Lamp?" in the *American Journal of Physics* **68** (9)(2000) p. 864, "...it is vital to know that the LED is an ultimate form of lamp, in principle and in practice, and that its development indeed can and will continue until all power levels and colors are realized."

A tutorial on microelectromechanical systems (MEMS) was presented in the morning, followed by four other tutorials in the afternoon: ferroelectric thin films, multiscale modeling, organic electronics, and nanofabrication for cellular engineering.

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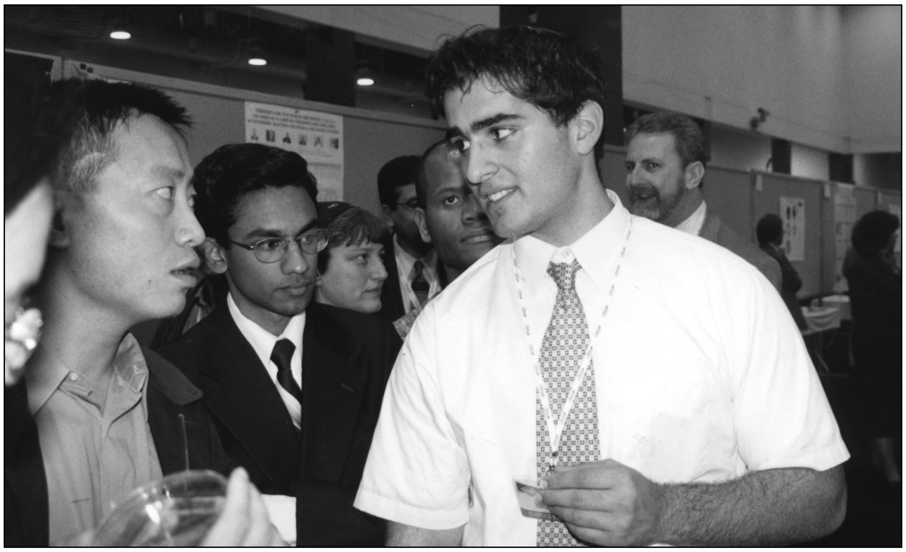

At the poster session, **Mordechai J. Bronner** of Rambam Mesivta High School in New York received an award nomination from Symposium DD for his poster presentation, "The Effect of Carbon Black and Colloidal Silica Fillers on the Fracture Toughness at Polymethylmethacrylate Interfaces." He pursued his research project with high school student **Anshul A. Shah** (not shown) of Ward Melville High School in New York. Their collaborators were **Hyun-Joong Kim** (Seoul Natl. Univ., Korea), **Dennis G. Peiffer** (ExxonMobil Research and Engineering, New Jersey), and **Miriam Rafailovich** and **Jonathan Sokolov** (SUNY—Stony Brook).

ty found in these MEMS structures would be reflected in extended operating times for laptops and cellular phones. Furthermore, D. Wilcox (Motorola) discussed his company's estimates to be able to commercialize miniaturized fuel cells within 2–3 years. Several markets hold high expectations for the success of MEMS devices. The automotive industry already benefits from MEMS technology and a sizable number of devices are currently being employed. However, as reported by G. Flik (Bosch), a great effort is being put into improving the response characteristics of the sensors and enhanced versions are constantly being pursued. This never-ending effort to improve device performance was also discussed by J. Martin (Analog Devices), who emphasized the significance of device performance in conjunction with reliability, timely delivery, cost, and type of application.

The symposium explored the underlying materials issues that ultimately enabled the commercialization of several MEMS structures. O. Kraft (MPI) described the size effects in materials for MEMS due to microstructural and dimensional constraints and the complex relationship between film microstructure and the long-term behavior of MEMS devices. The strong dependence that the characteristics of the films employed in MEMS have on deposition conditions was described for gold films by E. Pruitt (Stanford), and for PECVD silicon nitride films by D. Moore (Cambridge). The knowledge gained by the MEMS community over the years has also allowed the demonstration of ultra-nanocrystalline diamond films, which were described by O. Auciello (ANL). The high strength observed in these microwave PECVD films and their low surface energy make them attractive for a large variety of applications and for tribological reasons.

Norman C. Bartelt (Sandia National Laboratories) presented his MRS Medalist talk on testing fundamental theories of surface dynamics.

The symposium included a view of the issues that need to be addressed by technologists to migrate from the micro- to the nanoworld. This discussion, presented by M. Madou (Nanogen), underlined the necessity of developing new paradigms in terms of processing, device assembly, and the corresponding testing that are needed for this migration.

Symposium Support: ST Systems U.S.A., Tegal Corp., EV Group US, MMR Technologies, Applied MEMS, Tousimis Research Corp., Denton Vacuum LLC, Network Photonics, and TI.

Control of Defects and Domains is Central to Ferroelectric Device Technology

(See MRS Proceedings Volume 688)

Substantial progress in integrated ferroelectric device technology was demonstrated by several groups in Symposium C, along with continuing developments in materials-processing techniques and fundamental understanding of ferroelectricity in thin films. Highlights included the demonstration of low-temperature MOCVD processes for both $Pb(Zr,Ti)O_3$ (~400°C) and $SrBi_2Ta_2O_9$ (~600°C, using an ECR plasma) from H. Funakubo (Tokyo Inst. of Technology). Research on piezoelectric properties has yielded promising results as well: both EPFL, Switzerland, and Penn State groups demonstrated excellent piezoelectric coefficients for PZT films. Several approaches toward developing thick piezoelectric and electrostrictive films were also described by EPFL and by T. Iijima (AIST, Japan). Presentations by both the TI/Agilent collaboration and Ramtron Intl. demonstrated significant steps toward high-density nonvolatile ferroelectric memories. Advances in the fundamental understanding of degradation phenomena and point defects in ferroelectric thin films were reported, including a detailed study of imprint by M. Grossmann (RWTH—Aachen), an investigation of the relationship between fatigue and crystal symmetry by C. Randall (PSU), experiments probing the origins of fatigue through oxygen tracer profiling by P. McIntyre (Stanford), and high-temperature conductivity measurements of polycrystalline and epitaxial thin films by S. Hoffmann-Eifert (Forschungszentrum Jülich).

Several studies of ferroelectric domains in thin films were described. Notable examples included work on polarization domain stability in submicron structures from I. Stolichnov (EPFL), and investigation of domain interactions through depolarization and bound charge by A. Roelofs (RWTH—Aachen) and R. Ramesh (Univ.

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Maryland). Quantitative results on the dependence of T_c on film thickness, and on the equilibrium surface structure of $PbTiO_3$ films, were discussed by B. Stephenson (ANL). D. Bonnell (Univ. Pennsylvania) introduced intriguing device concepts based on controlled adsorption and photochemistry at surface locations defined by specific orientations of the ferroelectric polarization.

Symposium Support: ULVAC Japan, Kojundo Chemical Lab., NEC, and AIXTRON AG.

Progress Seen in High-Current-Density YBCO-Coated Conductors and Novel MgB_2 Superconductors

(See MRS Proceedings Volume 689)

Symposium E provided overviews of the status of HTSs from the near-term commercialization of the first-generation BSCCO tapes to the continuing advancement of the second-generation YBCO-coated conductors and the development of the new MgB_2 material.

A. Otto (American Superconductor) reported that critical currents of 170 A (77 K, self-field) have been achieved in Bi-2223 tapes. This is equivalent to 400 A/cm-width. He also reported on the development of low-resistance splicing technology enabling the fabrication of BSCCO tapes in lengths beyond single piece production lengths.

The development of the second-generation coated conductors continues to show steady improvement toward demonstration of long-length processing capabilities. Several papers on the IBAD, ISD, and RABiTS approach were presented. S. Foltyn (LANL) reported critical currents of 225 A (75 K and self-field) over an 83-cm length of centimeter-wide IBAD-YSZ-based tape. Critical current values I_c over 335 A/cm-width were reported on short samples. In-plane grain alignment of less than 5° was reported to be extremely important in achieving high I_c values in second-generation coated conductors. Researchers from ORNL reported the development of simplified buffer architectures using lanthanum zirconium oxide ($La_2Zr_2O_7$) and lanthanum manganese oxide ($LaMnO_3$). I. Seleznev (MIT) presented improvements in the growth rate of MOD-derived YBCO prepared from metal trifluoroacetates using a reduced pressure process. I. Kim (Applied Thin Films) reported a method for preparing YSZ buffer layers by oxidation of YZN films deposited directly on both textured Ni and Ni-Cr tapes by reactive sputtering in N_2 atmospheres. K.S. Harshavardhan (Neocera) reported a novel pulsed electron-beam deposition process for YBCO film growth.

Numerous presentations were given on the preparation and characterization of the MgB_2 superconductor. C.B. Eom (Univ. Wisconsin) reported the growth of epitaxial MgB_2 films on Al_2O_3 substrates by initial sputter deposition of boron films followed by post annealing in the presence of Mg at 800°C. D. Christen (ORNL) reported the growth of polycrystalline MgB_2 films with current densities of 4 MA/cm^2 at 25 K and self-field. P. Grant (EPRI) reviewed performance of MgB_2 samples prepared around the world and described potential commercial uses for this material.

Symposium Support: ANL, IGC SuperPower LLC, LANL, MicroCoating Technologies, ORNL, and Univ. Wisconsin—Applied Superconductivity Ctr.

Spintronics Turns Up Another Side of Solid-State Physics

(See MRS Proceedings Volume 690)

Symposium F on spintronics focused on novel materials physics important for integrating the spin component into solid-state electronics. Recent discoveries in the field challenged current understandings of solid-state physics. One example is the experimental observation by D. Awschalom (UCSB) of an unexpected nuclear spin participation in the carrier spin diffusion process in GaAs. Another is the prediction by S. Zhang (Univ. Missouri) of a spin-Hall effect that depends in an oscillatory way upon the applied magnetic field.

As magnetic structures shrink into deep submicrons, thermal activation becomes increasingly important, both for magnetic storage (D. Weller, Seagate) and for magnetic random access memory (R. Koch, IBM). Thermal stability is directly related to the amount of write field available, hence a need now exists for alternatives to the use of localized high magnetic fields. One potential candidate is localized spin-current-induced torque. Since the discoveries a few years ago of current-induced magnetic excitation and magnetic switching, rapid progress has been made in the fabrication of sub-100-nm spin-injection

The MRS Fall Meeting Exhibit Offered Education Seminars

Craig Saltiel *(Synergetic Technologies) describes the application of polarized light scattering in a Research Tools Seminar sponsored by Thermo Oriel, offered through the MRS Fall Meeting Exhibit.*

For a second year, the MRS Fall Meeting Exhibit featured educational seminars on advanced techniques for materials research. The Research Tools Seminars aim to provide attendees with the scientific basis and practical application of commercially available tools that are displayed at the Exhibit. James Knope of Engelhard Corp. began the program with a presentation on "*In Situ* Wafer Temperature Measurement." His seminar was not only educational, but also historical, starting with Kirkoff's 1859 theory of blackbody radiation, the first published experimental spectra in 1899, and the seminal measurements of silicon emissivity by Sato in 1967. He reviewed several techniques for wafer temperature measurement and their advantages and pitfalls in a real processing environment.

In the seminar sponsored by Thermo Oriel on "Fine Particle Characterization: Size, Shape, and Structure," Craig Saltiel of Synergetic Technologies described how polarized light scattering can be used as the basis for quantifying characteristics of particles and agglomerates. David Dingley, professor at Bristol University and president of TSL, discussed a transmission electron microscopy technique for measuring and analyzing the nanoscale variations of crystallographic orientation due to crystal deformation, and then graphically displaying the results.

The final seminar was given by Patrick Camus of Thermo NORAN, who described new instrumentation for obtaining comprehensive compound identification in the SEM. He showed how electron beams are used not only for imaging, but also for characterizing surface morphology, chemical composition, and crystallographic identification of microscopic materials features.

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Poster Prizes Awarded at the 2001 MRS Fall Meeting

The 2001 MRS Fall Meeting Chairs Bruce M. Clemens (Stanford University), Jerrold A. Floro (Sandia National Laboratories), Julia A. Kornfield (California Institute of Technology), and Yuri Suzuki (Cornell University) awarded prizes for the best poster presentations. Awards were given based on the posters' technical content, appearance, and graphic excellence. Prize recipients received $500, a certificate, and the honor of having the winning poster displayed for the remainder of the Meeting. Awarded posters and their authors were (C8.5/O6.5) **Orientation-Controlled Epitaxial Growth of $SrBi_2Ta_2O_9$ Thin Films**, Ho Nyung Lee, Dmitri N. Zakharov, Stephan Senz, Alain Pignolet, and Dietrich Hesse (Max-Planck-Institut für Mikrostrukturphysik, Halle-Salle), and Peter Reiche and Reinhard Uecker (Institut für Kristallzüchtung, Berlin); (H9.30) **Strategies for Direct Monolithic Integration of $Al_xGa_{1-x}As/In_xGa_{1-x}As$ LEDs and Lasers on Ge/GeSi/Si Substrates via Relaxed Graded Ge_xSi_{1-x} Buffer Layers**, Michael Groenert, Vicky Yang, Matthew Currie, Christopher Leitz, and Eugene Fitzgerald (Massachusetts Institute of Technology; (I11.40) **Chemical, Electrical, and Structural Properties of Pd/Au Contacts on Chemical Vapor Cleaned *p*-Type GaN Surfaces**, P.J. Hartlieb, A. Roskowski, R.F. Davis, B.J. Rodriguez, and R.J. Nemanich (North Carolina State University); (N3.14) **STM Analysis of Copper Thin Films Using Hyperthermal Copper Ions**, Joshua M. Pomeroy, B.H. Cooper, and Joel D. Brock (Cornell University); (V3.9) **Dynamic Fracture Mechanisms in Nanostructured Silicon Glasses Million-Atom Molecular-dynamics Simulations**, Laurent Van Brutzel, Cindy L. Routree, Rajiv K. Kalia, Aiichiro Nakano, and Priya Vashishta (Louisiana State University); (Z6.27) **A New Class of Carbon Nanocones**, Svetlana Dimovski and Yury Gogotsi (Drexel University), and Joseph Libera (Northwestern University); (DD12.2) **X-Ray Photon Correlation Spectroscopy Study of Block-Copolymer Micelles**, Péter Falus, Matthew A. Borthwick, Adrian Rühm, and Laurence B. Lurio (Massachusetts Institute of Technology), and Simon G.J. Mochrie (Yale University); (FF5.11) **Morphology and Biocompatibility of Hydrogels Constructed via Diblock Polypeptide Self-Assembly**, Lisa Pakstis and Darrin Pochan (University of Delaware), Clifford Robinson (Delaware Biotechnology Institute), and Andrew Nowak and Timothy Deming (University of California—Santa Barbara); and (JJ11.63) **Neptunium Incorporation in Uranium (VI) Compounds Formed during the Aqueous Corrosion of Neptunium-Bearing Uranium Oxides**, Robert J. Finch, Edgar C. Buck, and Stephen F. Wolf (Argonne National Laboratory and Battelle Pacific Northwest National Laboratory).

devices. In this symposium, R. Buhrman (Cornell), V. Cros (CNRS-Thales, France), and M. Tsoi (Grenoble, France, and MSU) presented data that confirmed and quantified the phenomena involved. While the spin-torque mechanism is attractive for future magnetic writing, technological barriers, such as the presently required high-current density of ~10^{7-8} A/cm^2, must still be overcome.

A deeper understanding of spin-transport physics is also emerging. G. Bauer (Delft, The Netherlands) described successful predictions with no adjustable parameters of interface resistances for several metallic interfaces. W. Pratt Jr. (MSU) described measurements of spin-memory loss in metals and at interfaces. B.J. van Wees (Univ. Groningen, The Netherlands) used a mesoscopic structure to measure spin-memory-loss in copper at ambient temperature.

Symposium Support: ONR/DARPA.

Thermoelectric Materials Research Accelerates

(See MRS Proceedings Volume 691)

Thermoelectric materials research continues to be a very active area of materials research and, based on results presented at Symposium G, it is apparent that there is acceleration in the pace of innovation as well as materials and device improvements. T. Tritt (Clemson Univ.) opened the symposium with a review of recent research on bulk materials, providing an overview of the field to date. D. Singh (NRL) presented theoretical insight for improvements in compounds with the skutterudite crystal structure, a material system that continues to grow in interest. He showed how fully filled skutterudites should have higher mobilities due to the reduction of disorder from vacancies and described one compound in particular, $La(Rh,Ru)_4Sb_{12}$, that should result in a higher thermoelectric figure of merit, *ZT*. M. Dresselhaus (MIT) presented band structure and transport properties of $Bi_{(1-x)}Sb_x$ nanowires. By varying the Sb concentration and the wire diameter, *ZT* can be optimized in these nanowires. R. Venkatasubramanian (Research Triangle Inst.) presented his work on thermoelectric superlattices. His work resulted in a $ZT = 2.4$ at room temperature in *p*-type Bi_2Te_3/Sb_2Te_3 superlattice thermoelectrics. This represents a greater than twofold improvement in *ZT* as compared to the best materials presently in use. For *n*-type superlattices, $ZT = 1.2$ at room temperature were achieved. In addition, preliminary results on *p-n* couple devices from these superlattices indicate fast-acting spot cooling in addition to improved performance. P. Hagelstein (MIT) and

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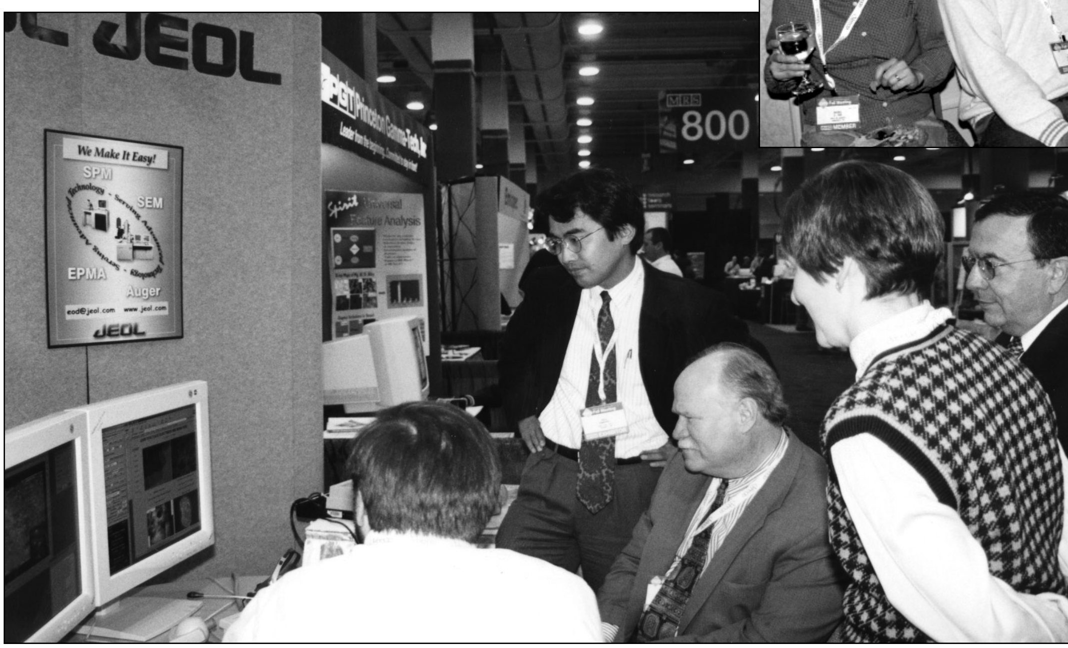

Meeting attendees enjoyed many opportunities to meet other materials researchers at the Poster Sessions, Exhibit Hall, student mixer, and between sessions at the 2001 MRS Fall Meeting.

Y. Kucherov (ENECO) announced the development of an improved device for waste-heat power generation.

Symposium Support: GM, Marlow Industries, Advanced Research Systems, MMR Technologies, and Quantum Design.

Nitrogen Plays Important Role in Semiconductor Materials for Optoelectronic Applications

(See MRS Proceedings Volume 692)

In presentations given in Symposium H, considerable focus was absorbed by nitrogen in (In,Ga)(As,P) and related materials where adding nitrogen can reduce the bandgap. Bandgap calculations were made using a pseudopotential technique with increasing nitrogen composition, and checked with good agreement against experiment (L. Bellaiche, Univ. Arkansas and Y. Zhang, NREL). Others looked at the quality of material, given the difficulty of introducing nitrogen, as grown by MBE and MOCVD (S.R. Kurtz, SNL). Several materials, including dilute III-V nitrides, were investigated for 1-eV bandgap material that should contribute to 40% efficient four-junction solar cells (J.M. Olson, NREL). Quantum dots also generated a lot of interest. Type II (InAs/GaSb) photovoltaic detectors were demonstrated with cutoff wavelengths up to 25 μm at 77 K (M. Razeghi, Northwestern Univ.). Quantum dots are expected to perform well at higher temperature due to longer intersubband relaxation time between the phonon-decoupled ground states and excited states. Initial demonstrations in a double-quantum-well system of narrow band-detectivity tunable from 0.25 THz to 25 THz were made, with the potential to operate at room temperature for chemical and biological agent detection (M. Khodier, Univ. New Mexico). Strong dependences of oscillator strength and band-edge energies, related to laser wavelength shift with injection current, were described for Type

II GaAsSb/GaInAs/GaAs quantum wells (W.W. Chow, SNL). A comparison was made showing GaAs-based QWIPs to be hardened to a variety of nuclear particles, more so than thin-film QW LEDs. But thin-film QW LEDs were, in turn, more radiation-hard than diffused GaAs LEDs (S.M. Khanna, Defence Research Establishment, Ottawa). Radiation effects were also investigated for solar cells.

Symposium Support: AFOSR and ONR.

Dislocations Steer Development of GaN and Related Alloys

(See MRS Proceedings Volume 693)

Symposium I, GaN and Related Alloys, provided an overview of recent progress in Group III nitride device development, including short-wavelength light emitters, electronic devices, and chemical sensors, as well as the latest advances in understanding the fundamental science problems associated with growth and characterization of the nitride materials.

A key driver of research is the need to obtain low dislocation densities. The use of epitaxial lateral overgrowth (ELO) to obtain reduced dislocation densities in GaN grown on masked substrates was central to many presentations. T. Asano (Sony Shiroishi Semiconductor) reported improved laser diode performance that was achieved in part by optimizing the ELO growth process. The growth of bulk GaN substrates is also an active area. S. Park (Samsung) discussed the growth of thick freestanding GaN layers using hydride vapor-phase epitaxy. For GaN films of thickness ~1000 µm, the dislocation density is reduced to the mid-$10^6/cm^2$ range.

The origin of electrical activity of dislocations on the atomic scale was the topic of several experimental and theoretical investigations. D. Cherns (Univ. Bristol) introduced electron holography as a means to determine the line charge of a dislocation, and J. Hsu (Bell Labs/Lucent Tech) presented scanning current–voltage microscopy data demonstrating that screw dislocations give rise to leakage currents in films grown by MBE.

R. Feenstra (CMU) discussed the surfactant effect of metal adlayers on the growth of GaN. The formation of these adlayers is associated with a widely studied transition from rough to smooth surface morphology. Smooth growth was attributed to fast nitrogen diffusion in the presence of the metal adlayers, while rough surface morphology is a consequence of slower diffusion on surfaces without metal adlayers.

Symposium Support: Nichia, Sony, AFOSR, Xerox—PARC, and Fritz-Haber-Institut der Max Planck.

3D Photonic-Bandgap Silicon Crystal on Silicon Shows Complete Reflectance

(See MRS Proceedings Volume 694)

Symposium K on microphotonics, materials, physics, and applications demonstrated that this field, which encompasses varied strategies and materials, is still rapidly developing. The strategies that are used to make 2D and 3D periodic structures with lattice constants comparable to the wavelength include "conventional" lithography, holographic lithography, two-photon polymerization, and various forms of (directed) self-organization. The materials choices range from soft-matter systems, like LCs and colloids, to metallodielectrics and semiconductors.

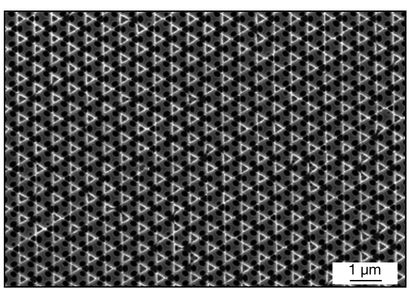

Figure 1.

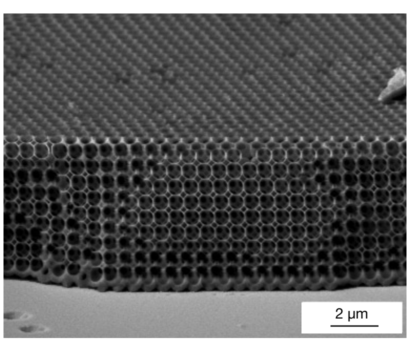

Figure 2.

One of the highlights of the symposium were the results presented by D.J. Norris (NEC) on the fabrication of 3D silicon photonic-bandgap crystals on a silicon wafer. The fcc photonic crystals were made by CVD using a colloidal crystal of silica spheres as a template. The SEM micrographs (Figures 1 and 2, provided by Norris and Y.A. Vlasov, NEC) from this periodic array of "air-filled" spaces in silicon show both (111) and (100) crystal planes. Subsequently, the silica spheres were etched away. The structures made had a region of complete reflectance around a wavelength of 1.3 µm due to the likely presence of a complete photonic bandgap. These photonic crystals had an unprecedented low level of defects due to an improved self-assembly method employed to crystallize the colloids. The researchers showed that standard Si-based microfabrication techniques could be used to make devices out of these structures.

Symposium Support: ARO and FOM Institute AMOLF.

Near- and Far-from-Equilibrium Electrodeposition Leads to Range of Morphologies

Symposium M highlighted advances in electrodeposition of thin films and nanostructures. The development of *in situ* probes with atomic resolution has provided insights into the thermodynamics and kinetics of overlayer growth in solution. In many cases, step and island dynamics lead to the evolution of surface morphologies similar to those seen in vapor-phase growth. Deposition can occur under near-equilibrium conditions or far-from-equilibrium conditions, depending on the applied potential. In electrochemical heteroepitaxial growth, one or two wetting layers can form at potentials where there is no thermodynamic driving force for bulk deposition. This process, known as underpotential deposition, has been used to study surface structures and to mediate subsequent bulk deposition.

The macroscopic features of thin-film growth during electrodeposition have also been of recent interest. By introducing one or more molecules that adsorb to the surface of the substrate, it is possible to obtain preferential deposition at protuberances (subconformal deposition), uniform deposition (conformal deposition), or enhanced deposition in trenches (superconformal deposition). This latter process, also known as superfilling, has led to the implementation of electrochemical deposition of copper metallization in the electronics industry. The role of adsorption in allowing enhanced filling at the bottom of trenches has only recently been elucidated.

Advanced Microscopy, Modeling, Used to Examine Stress Relaxation and Self-Assembly in Heteroepitaxy

(See MRS Proceedings Volume 696)

Symposium N focused on two of the most significant issues in heteroepitaxial growth: stress relaxation and self-assembly.

The talks ranged from the fundamental to the applied with many modeling talks attempting to bridge the gap. Throughout the session, the importance of advanced microscopies in sorting out the interaction between strain, composition, and microstructure was made clear.

The initial sessions in the symposium were devoted to the early stages and fundamental processes of heteroepitaxy. TEM studies of morphology and composition pointed to the importance of composition segregation in initiating the formation of islands. J. Tersoff (IBM) presented a model of growth that takes into account that the crystalline surface and adatom concentration may not be equilibrated, which leads to significantly different kinetics for the evolution of strain-driven instabilities. A joint session was held with virtual Symposium AA on self-assembly processes in materials.

Many interesting approaches to the selective growth of strained islands were presented. Formation of SiGe islands on patterned SOI structures showed that strain relaxation around the patterned features could be used to obtain selective growth of the islands. Real-time STM imaging enabled the formation of highly ordered step structures on Ni surfaces that were used for the growth of Si nanowires. The use of these self-assembled structures in schemes for quantum computing and the formation of semiconductor whisker devices demonstrated the potential application of this work in the near future.

Stress relaxation by dislocation-mediated mechanisms was also an important topic. L.B. Freund (Brown Univ.) presented an analysis showing that the simultaneous formation of a periodic array of dislocations is unstable, indicating that the dislocation spacing will be lower than predicted by the mean field approach. LEEM images of SiGe growth made it possible to directly see the interactions between dislocations in the growing film. Growth of patterned structures was shown to reduce the threading density and make the use of strain relaxed layers in devices feasible.

Symposium Support: Blake Industries.

*At the MRS Awards Ceremony, **Dave Poker** (left) of Oak Ridge National Laboratory and **Steve Moss** (right) of Aerospace Corporation were recognized for their significant contributions in the development of the MRS proceedings. Poker was specifically cited for the development of electronic versions of the past MRS Proceedings Indexes and Moss for his leadership in the production of MRS Proceedings.*

Oxides Tailored for Transition Layers, Superconductors, Ferroelectrics

In Symposium O, R. Droopad (Motorola) presented an approach to device-quality GaAs on Si that involved the introduction of a thin epitaxial $SrTiO_3$ layer between the Si substrate and GaAs overlayer. After the $SrTiO_3$ is nucleated, the oxygen pressure in the MBE is increased to form a compliant SiO_2 layer between the $SrTiO_3$ and Si. The GaAs is then epitaxially grown on the $SrTiO_3$. A/B dislocation-etch studies revealed defect densities in 2-µm-thick GaAs layers as low as 3×10^4 cm^{-2}. Using this method, Droopad and co-workers have made MESFET power amplifiers for cell phones and 12-in. GaAs on Si wafers.

A consistent picture emerged from the invited talks of M. Naito (NTT), X.X. Xi (PSU), and I. Bozovic (Oxxel) of how strain alone is incapable of explaining the observed enhancement/suppression of the superconducting transition temperature (T_c) of $(La,Sr)_2CuO_{4+\delta}$ in epitaxial films. All three speakers showed data illustrating the importance of additional factors, especially oxygen content, on T_c. Bozovic showed that low-temperature anneals could drive T_c from below that observed in bulk $(La,Sr)_2CuO_{4+\delta}$ to above that observed in bulk $(La,Sr)_2CuO_{4+\delta}$, even for epitaxial films grown on $SrTiO_3$(001), that is, under biaxial tensile stress.

Using an advanced oxide MBE system, Bozovic reported trilayer heterostructures with <1% variations in composition, film thickness, and junction area. Extensive film characterization, coupled with a demonstrated means of making over 2000 superconducting contacts in series between two $(La,Sr)_2CuO_4$ layers, has led Bozovic to infer that LSI and even VLSI high-T_c circuitry should be achievable with $(La,Sr)_2CuO_4$-based sandwich junctions.

D. Vanderbilt (Rutgers) described *ab initio* calculations on artificial ferroelectric superlattices in which inversion symmetry is broken. The results suggest a route toward self-poled ferroelectrics with modified properties including enhanced piezoelectric properties. In related experiments, J.N. Eckstein (Univ. Illinois) reported on superlattices built following this scheme and their enhanced nonlinear optical properties, including about a threefold enhancement in second-harmonic generation over analogous superlattices in which inversion symmetry is not broken.

H. Schön (Bell Labs/Lucent Tech) showed the power of field-effect measurements to map out the superconducting T_c versus carrier concentration curve in the infinite-layer compound, $CaCuO_2$—all in a single sample.

Researchers Show How to Judge a Material by Its Surface

(See MRS Proceedings Volume 697)

Symposium P focused on materials issues for the rapidly growing field of surface engineering. Highlights included presentations by S. Suresh (MIT), A. Evans (Princeton), J. Larsen-Basse (NSF), A. Matthews (Univ. Hull), and K. Wahl (NRL). In his presentation, Suresh measured, modeled, and coordinated the effects of surface asperities on dislocation events that occur in nanoindentation measurements of thin films. He applied this knowledge to an examination of nanopatterned structures in MEMS devices. Evans investigated mechanisms for plastic deformation in thin films, specifically dislocations resembling "telephone cord buckles," using FIB techniques. He observed that surface imperfections are always the source of the buckles, and was furthermore able to characterize the stress in the films with the wavelength and height of the buckles. Larsen-Basse described some of the programs that NSF funds in the surface engineering area, and highlighted his desire to coordinate materials research in surface engineering with the nanotechnology initiative. Matthews discussed surface engineering from the tribologists' point of view, and proposed a correlation between the wear of materials and the ratio of the material's hardness and modulus. Wahl discussed the relationship between the mechanical properties and tribological properties of thin films, combining nanoscale and macroscale methods. Of particular interest were video images capturing the mechanism of transfer film formation in MoS_2 thin films.

Symposium Support: Hauzer Techno-Coating Europe B.V., GM, Hysitron, k-Space Assoc., and Balzers AG.

Rapid Prototyping Advances from Electronics to Biological Materials

(See MRS Proceedings Volume 698)

Symposium Q on rapid prototyping was dominated by presentations using different methods and materials approaches to direct-write electronics on the mesoscopic scale, including interconnects, high-κ dielectric capacitors, and simple circuits and subsystems. Significant progress has been made in the area of power sources with designer batteries fabricated to fit specific application needs. The role of porosity was important to the final application in areas from batteries to sensors, and to 3D printing. T. Ellis (K&S, Willow Grove, Penn.) gave an overview of where direct-write techniques could fit into next-generation electronic products. Also, this symposium incorporated work in the area of rapid prototyping biological materials for tissue-based sensors, tissue engineering, microfluidics, and various bioelectronic interfacing and medical applica-

Emerging Applications of Neutron-Scattering in Materials Research Introduced

A special one-day symposium on emerging neutron-scattering applications in materials science and engineering presented the forefront of materials science that is currently taking place at neutron sources from around the world. The symposium considered emerging research directions that will be enabled by the new and upgraded neutron sources.

In his keynote presentation, Thomas Mason, the director of the Spallation Neutron Source project in Oak Ridge, Tennessee, introduced the reflectometers for studying surface phenomena and multilayered structures; the high-pressure diffractometer; and the engineering diffractometer, an instrument designed to study stress/strain as well as real-time dynamics of structural evolution *in situ* (temperature and pressure). Data analysis was identified as one of the challenges. With the higher fluxes, the amount of data available will far exceed what can be done currently. Real opportunities exist for the development of detector technologies and advanced computational techniques, he said.

J. Roberto (ORNL) discussed the role of neutron-scattering in nanoscience and engineering. Neutrons are particularly valuable in the study of soft materials, such as polymers, where understanding of structural evolution over multiple length scales is possible. Other opportunities are in characterization of highly correlated materials such as striped ordering and characterization of functional materials and related phenomena, including magnetic nanostructures.

G. Long (NIST) discussed the value of small-angle neutron-scattering in the characterization of ceramics, including thermal barrier coatings, the evolution of the morphology of porosity, and the emerging area of *in situ* studies of near-surface phenomena during deposition of coatings. She expects that new physics will emerge from *in situ* studies in special environments.

P. Withers (Univ. Manchester) discussed the need to establish standards to enhance the reliability and utility of strain measurements. At the ISIS, one of the new advances is an increase in the length of the time-of-flight paths that will yield higher resolution in strain imaging. The SMARTS spectrometer and the Los Alamos neutron-scattering facility will incorporate a system for experiment design, according to E. Ustundag (Caltech). It also has capabilities for rapid and accurate specimen handling. *In situ* loading studies of composite materials, such as tungsten-fiber reinforced bulk metallic glass, were highlighted.

D. Argyriou (ANL) reviewed neutron-scattering in colossal magnetoresistance studies. In this area, meshing of the neutron-scattering results with theory is very important. The faster times for measurements are significant as well as correlation with results from other techniques such as synchrotron studies. In polymers, according to L. Magid (Univ. Tennessee), more systems will be accessible for real-time neutron studies in the future. Novel sample environments are important, as is the ability to study reptation in a variety of polymer systems. The ability to study smaller samples will make many new materials accessible to neutron studies. H. Mook (ORNL) reviewed the insights that can be gained in studies of superconductivity with neutron-scattering. The high-temperature superconductors provide a fertile research ground for condensed matter physicists as the compounds exhibit a complex phase diagram, from the antiferromagnetically ordered phase to the strip phase to the superconducting phase. Neutron-scattering played a critical role in establishing the phase diagram as well as in elucidating the dynamics underpinning the phase transitions. As yet, there is still no clear understanding of the theory for high-temperature superconductivity.

B. Gaulin (McMaster Univ.) closed the presentations with comments on the application of neutron-scattering to the understanding of magnetism, a phenomena well suited to neutron-scattering studies. New directions include the study of magnetism in materials of reduced dimensionality. Recently, technological drivers have increased with the discovery that some low dimensional magnetic materials are superconducting while others exhibit low-thermal expansion over a finite temperature range.

At the end of the presentations, a discussion commenced on the future of neutron-scattering. Panelists discussed emerging directions in the application of neutron-scattering in materials science from both a funding perspective, with comments from I. Thomas (DOE) and T. Weber (NSF), and from an R&D perspective. Their answers fell primarily into two categories: neutron-scattering for the study of biological materials and increased use of the technique. Thomas summarized current efforts to improve DOE's neutron-scattering facilities. Weber expressed NSF's interest in supporting neutron-scattering research and the development of instruments at the Spallation Neutron Source.

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tions. Dispensing, solid freeform, and laser-based methods were described to fabricate tissue on nearly a cell-by-cell level. Overall, the application of traditionally electronic and structural rapid prototyping techniques was very successful when applied to biological materials. J.A. Lewis' (Univ. Illinois) results for the fabrication of periodic structures on the mesoscopic scale were demonstrated through the research group's method of directed assembly of colloidal silica gels.

Symposium Support: DARPA.

Microstructural Characterization Aided by Electrical Probing

(See MRS Proceedings Volume 699)

Symposium R on electrically based microstructural characterization demonstrated once again that there are many more applications of this methodology than were originally anticipated. The most impressive innovations included the combination of scanning probe imaging with electrical mapping presented by S. Kalinin (Univ. Pennsylvania) and the characterization of ferromagnetic materials presented by R. Valenzuela (UNAM). In a session devoted to metallic materials, encouraging results were presented by V. Silberstein (Jentek Sensors) and R. Gerhardt (Georgia Tech). Continued discussions about the role that grain boundaries play on the electrical response of solid electrolyte materials used in fuel cells were presented by J. Maier (MPI—Stuttgart), S. Haile (Caltech), and others. K.-H. Lee (Pohang Univ. of Science and Technology, South Korea) discussed the possibility of using electrochemical means for determining porosity characteristics in a wide range of materials. The composites session included research on short-fiber and continuous fiber experiments by T. Mason (Northwestern Univ.) and D.D. Chung (SUNY—Buffalo). Semiconductor device research was presented by R.K. Pandey (UA—Tuscaloosa), H. Tuller (MIT), G. Mahan (PSU), Maier, and others. A large number of presentations rounded out the four-day meeting focusing on electrical testing as a means to derive microstructural information from a wide range of materials in a nondestructive way. The knowledge base generated is substantial and several applications are nearing completion. Several groups have demonstrated that electrical testing may be used to monitor quality control in a manufacturing setting; electrical and mechanical degradation in a user setting; and the effect of chemical composition, size, and shape of phases present at length scales ranging from macroscopic to nanoscopic dimensions.

Symposium Support: DOE.

Graduate Students Receive Gold and Silver Awards

During an awards ceremony held on November 28 at the 2001 Materials Research Society Fall Meeting, graduate student finalists received Gold and Silver Awards.

Gold Graduate Student Awards *went to (first row, left to right):* ***Hartmut Rudmann*** *(MIT),* ***Dhaval A. Doshi*** *(Univ. New Mexico),* ***Ruchirej Yongsunthon*** *(Univ. Maryland),* ***Ingrid Shao*** *(JHU),* ***Yi Cui*** *(Harvard),* ***Kenneth B.K. Teo*** *(Cambridge); (second row, left to right):* ***Max Shtein*** *(Princeton),* ***Christopher Leitz*** *(MIT),* ***Derek Stein*** *(Harvard),* ***Sergei V. Kalinin*** *(Univ. Pennsylvania),* ***Kieran Reynolds*** *(Cambridge), and* ***Xiangfeng Duan*** *(Harvard).*

Silver Graduate Student Awards *went to (first row, left to right):* ***Guohan Hu*** *(Cornell),* ***Haiyan Wang*** *(NCSU),* ***Rachel A. Segalman*** *(UCSB); (second row, left to right):* ***Yadong Yin*** *(Univ. Washington),* ***Sergei Kucheyev*** *(Australian Natl. Univ.),* ***Donald Siegel*** *(Univ. Illinois, Urbana-Champaign),* ***Yiying Wu*** *(UC-Berkeley),* ***R. Arief Budiman*** *(Univ. Toronto); (third row, left to right):* ***Brian Mayers*** *(Univ. Washington),* ***Michael J. Escuti*** *(Brown Univ.),* ***Davide Marini*** *(MIT),* ***James F. Hulvat*** *(Northwestern Univ.),* ***Arnaud Videcoq*** *(Université Clermont, France),* ***Christoph Bostedt*** *(LLNL, Univ. of Hamburg), and* ***Robert J. Becker*** *(Stanford). Not shown are* ***Shin Woong Kang*** *(Kent State) and* ***Min Ouyang*** *(Harvard).*

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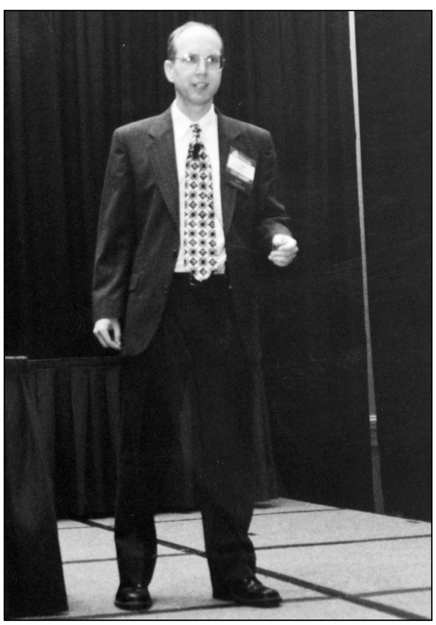
Serendipitous Discovery by Design
(See MRS Proceedings Volume 700)

The field of combinatorial materials research is rapidly expanding and encompasses applications in a wide variety of materials systems, as demonstrated in Symposium S. The diversity in the applications of combinatorial methods was well represented, and major advances in experimental techniques were reported in many fields. Of particular interest were applications in the area of thin-film materials and polymers.

A number of reports on combinatorial pulsed laser deposition techniques were presented by groups at Tokyo Institute of Technology (Y. Matsumoto), University of Maryland (M.A. Aronova and K.-S. Chang), and NIST (D.L. Kaiser). T. Fukumura (Tohoku Univ., Japan) described the discovery of a transparent oxide diluted magnetic semiconductor, a serendipitous discovery brought about by the combinatorial approach. Dilute magnetic semiconductors and wide-gap oxide semiconductors are essential materials for magneto-optical devices. New compositions of transparent $Co_xTi_{1-x}O_2$ that exhibit ferromagnetism at room temperature were discovered. Materials such as these are expected to lead the way for functional spintronics in the future.

In the joint combinatorial session on polymers with Symposium DD, N. Lewis (Caltech) demonstrated the enormous range of sensitivity that arises from monitoring in-parallel responses of polymer arrays to volatile compounds. His "electronic nose" is an impressive application of combinatorial arrays for sensor technology. P. Nealey (Univ. Wisconsin) introduced a method of measuring the effects of confinement on the stability and mechanical properties of lithographic masks using the combinatorial approach. Several scientists from NIST (A. Karim, A.J. Crosby, K.L. Beers, and A. Sehgal) described advances in high-throughput and parallel measurement techniques using the continuous gradient film approach to quantitative measurements of adhesion, polymer crystallization, block copolymer ordering, and UV surface-energy gradients for characterizing interactions in polymer systems. The NIST work in particular demonstrated the application of combinatorial or high-throughput methodology to measurements of properties and effects of processing variables.

Symposium Support: Univ. Maryland, Bruker AXS, MMR Technologies, hte Aktiengesellschaft, Pascal Co., NIST, and AFRL.



In his MRS Medalist talk, ***C. Mathew Mate*** *(IBM Almaden) described early atomic force microscopes and friction force microscopes along the path toward better understanding of atomic/molecular level understanding of friction.*

From Feathers for Filtration to Nanocomposites for Car Body Panels, Natural and Polymer Fibers Find Their Place
(See MRS Proceedings Volume 702)

Symposium U devoted its first two days to lectures from a rapidly emerging scientific and technological discipline that includes advanced biofibers, advanced bioplastics, and hybrid composites from biofibers and synthetic polymers. Three days were devoted to lectures from the established scientific disciplines, which include synthetic fibers, polymers, and composites.

R. Weber (Containerless Research) introduced a process that makes it possible to draw YAG "glass" fibers from levitated, supercooled melts. So far only single-crystal YAG fibers were known. J. McGrath (Virginia Tech.) significantly increased the conductivity, and therefore the value, of polymeric electrolyte membrane nanocomposites used in portable fuel cells, by adding nanosilica and phosphotungstic acid. R. Gregory (Clemson Univ.) quantified the optical and electronic properties of conjugated organic polymers and films and showed that the polymer morphology can be tuned to specific end uses by selectively changing the polymer microstructure during processing.

In the area of biomaterials, W. Risen (Brown Univ.) described the design and synthesis of transparent monolithic silica hybrid aerogels containing transition metals Ru(III), Rh(III), Co(II), Pd(II), silica, and chitosan, a biopolymer. Of special interest were the magnetic properties of new Ru-(III)-containing aerosols. H. Struszczyk (Inst. of Chemical Fibers, Poland) introduced a synthetic wet-spinning method for producing alginate and chitosan fibers from crab or shrimp shells, having superior strength and other specific properties required in demanding medical applications. W. Schmidt (Agricultural Research Service) invented a process for turning animal feathers, a 4-billion pound annual waste product, into microcrystalline keratin fibers, high-quality fiber structures, and commercially useful composites. In one example, keratin fiber structures are being used for water purification and filtration of nanoscale contaminants.

In addition, two commercial technologies were introduced. J. Kurian (DuPont) described a process for producing 1,3-propanediol from cornoil and announced the commercialization of a new polyester polymer and fiber from the natural cornoil derived intermediate. E.G. Joseph (3M) reported the structures and properties of multilayer melt-blown microfiber webs and their commercialization. D.A. Okonski (GM) reviewed a recently commercialized injection molding of polyolefin-based nanocomposite and quantified its advantages over talc-filled TPO. The nanocomposites offer superior properties in car body side panels.

Symposium Support: PPG Industries Foundation.

Bottom-Up Assembly of Nanoscale Materials in Development
(See MRS Proceedings Volume 703)

Presentations in Symposium V addressed synthesis, characterization, and property evaluation and applications of nanophase and nanocomposite materials. P. Alivisatos (UC—Berkeley) discussed methods of controlling the shapes of inorganic nanocrystals such as CdSe and Co and elucidated the possible applications of aligned nanorods in biological detection, photovoltaics, and LEDs. H. Yan and P. Yang (UC—Berkeley) described a simple vapor deposition and transport and condensation process for growing ZnO nanowires and demonstrated room-temperature UV lasing behavior. These nanolasers are potentially useful for high-density information storage. C.M. Lieber (Harvard) reported the synthesis and use of semiconductor nanowires in nanoelectronics and nanosensors. For example, biotin-modified nanowires demonstrate a sensitive detection of streptavidin down to pM concentration. Lieber's group also presented results regarding the potential use of nanowires as building blocks for

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From Candy Wrappers to Metals, Statistical Mechanics Models Show the Way

(See MRS Proceedings Volume 701)

Symposium T, Statistical Mechanical Modeling in Materials Research, first highlighted current modeling strategies for epitaxial film growth and other complex processes at surfaces. Growth on low-index surfaces was described using atomistic lattice-gas models predicting behavior in a specific system; level-set methods incorporating discrete layers but a continuum description of lateral morphology (C. Ratsch, UCLA); and (fully) continuum approaches describing evolution by stochastic PDEs (M. Siegert, Simon Fraser Univ.). Step-wandering and bunching instabilities for growth on vicinal surfaces (A. Pimpinelli and A. Videcoq, LASMEA) and modeling of growth in complex semiconductor systems were also discussed. Other talks addressed optimum catalyst design (A.P.J. Jansen, Eindhoven Univ.) and propagation of reaction fronts (akin to phase waves) in surface reactions (D.-J. Liu, Iowa State Univ.).

In the area of solidification, the symposium highlighted the development of a new phase-field model of electrochemistry, with potentially important application for electroplating (J. Guyer, NIST); molecular-dynamics simulations that characterize the anisotropic capillary and kinetic properties of the solid-liquid interface in pure metals and simple binary alloys (M. Asta, Northwestern Univ. and J. Hoyt, SNL); and the incorporation of fluid flow in 3D phase-field simulations of dendritic growth (J. Dantzig, Univ. Illinois). Also highlighted were phase-field simulations of dendritic evolution in undercooled melts (Figure 1) and during directional solidification, that make use of the atomistically computed interface properties and of new powerful algorithms that extend the phase-field approach into parameter ranges relevant for experiment (C. Beckermann, Univ. Iowa).

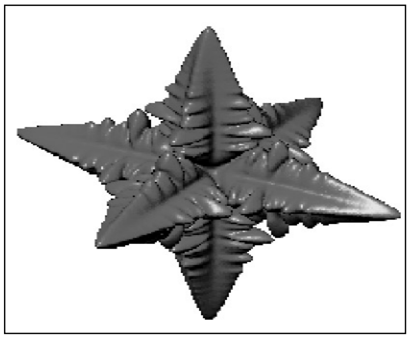

Figure 1. Snapshot of a phase-field simulation showing a three-dimensional dendritic crystal solidifying in an undercooled Ni melt (A. Karma, Northeastern Univ., and M. Plapp, CNRS). The surface tension and kinetic anisotropies for this simulation were computed by molecular-dynamics simulations (M. Asta and J. Hoyt).

The discussion of structures and properties induced by deformation centered on the development of new methods suitable for modeling realistic size systems and plastic strains (V. Bulatov, LLNL). Of particular interest is the emergence of characteristic length scales, as strain localizes in patterns of linear defects, be they networks of "ridges" in crumpled candy paper (E. Kramer, Simon's Rock College), or "loopons" (A. Finel, ONERA) and dislocation boundaries (W. Pantleon, Risoe NL) in deformed metals. Bridging between atomistic and continuum approaches, I. Groma (Eötvös Univ., Budapest), J. Stölken (LLNL), and A. El-Azab (PNNL) introduced stochastic theories for the evolution of materials stresses and dislocation densities during deformation. Other talks showed how fluctuations in these stresses and materials symmetries control the spatial characteristics of propagating fronts (M. Caturla, LLNL, see Figure 2; D. Vandembroucq, CNRS) and branching cracks (L. Sander, Univ. Michigan).

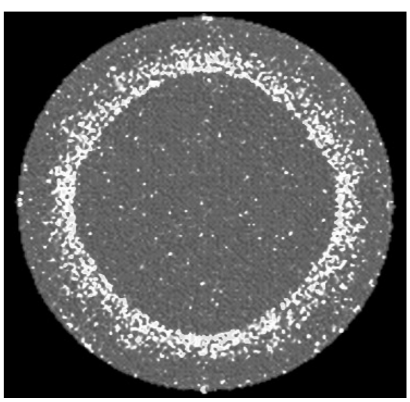

Figure 2. Snapshot of a molecular-dynamics simulation of an initially spherical shock front developing square symmetry in a spherical fcc Cu ball. After bouncing at the center of the ball the front produces a void, as observed in experiment (M. Caturla, LLNL).

Symposium Support: IBM T.J. Watson Research Center, AFOSR, and LLNL.

bottom-up assembly of nanoscale electronics and optoelectronics. H. Katsuki (Saga, Japan) and S. Komarneni (PSU) demonstrated the use of microwaves in liquid state to dramatically increase the kinetics of crystallization of nanophases.

Several papers showed enhanced properties of nanocomposites over their single-phase alternatives. J.G. Winiarz (SUNY—Buffalo) synthesized novel hybrid inorganic–organic systems and suggested their potential use in telecommunications, high-capacity data storage, and biophotonics. R. Tannenbaum (Georgia Tech) showed self-assembly of metal nanoclusters in block copolymers; these nanocomposites are relevant to the optoelectronics area. K. Kuroda (Waseda Univ., Japan) showed that a new class of materials can be created by self-assembly of organoalkoxysilanes and tetraalkoxysilanes with potential applications. J.-H. Choy (Seoul Natl Univ., Korea) synthesized bioinorganic nanohybrids using DNA and anionic clays for potential use in gene therapy.

Symposium Support: ONR and AFRL.

Processing and Characterization of Nanoparticles Addresses How to Control Shape, Distribution, Scale-Up

(See MRS Proceedings Volume 704)

Symposium W focused on the synthesis, characterization, and processing of nanoparticle materials for emerging optical, magnetic, electronics, advanced energy storage, nanodispersions, and biological applications. The key critical processing challenges with nanoparticulate materials that were discussed included (1) novel method for production of controlled size and shape of nanoparticles, (2) ability to process nanoparticles to form uniform dispersions, (3) directed assembly of nanoparticles at specific locations, (4) large-scale production of nanoparticles, and (5) surface control of nanoparticle materials for tailoring of specific properties.

In the area of nanoparticle characterization, talks focused on the use of specialized techniques such as SAXS to monitor the changes in colloidal particles in a solution as well as on magnetic characterization of deposited nanoparticles. In the area of applications, several talks addressed the use of development of magnetic nanoparticles for data storage applications. Other interesting applications included brighter nanophosphors, doped nanoparticles with novel optical properties, metallic nanodispersions for electronic packaging, embedded nanoparticles for nonlinear optical properties, nanotubes for hydrogen-storage applications, and nano-encapsulated coatings for controlled drug delivery systems.

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Nanopattering Options Presented for Ultralarge-Scale Integration to Biotechnology

(See MRS Proceedings Volume 705)

Nanofabrication by lithographic and nonlithographic methods has been applied to fields having a significant economic impact such as microelectronics, magnetic data storage, and integrated optics. The topic highlighted by Symposium Y was nanofabrication for biological applications, which included a tutorial on nanofabrication for cellular engineering where the emphasis was put on the effect of controlled surface topography on cell adhesion, growth, and motility. Key contributions included that of M. Riehle (Univ. Glasgow, UK) on nanometric patterns for tissue engineering, T.A. Desai (Univ. Illinois—Chicago) on nanoporous microfabricated membranes, and B.C. Wheeler (Univ. Illinois—Urbana-Champaign) on designing *in vitro* patterned neuronal networks. In the session on functionalization of 1D and 2D structures, M.-I. Baraton (Univ. Limoges, France) showed that FTIR spectrometry can be applied to characterize the very surface of ceramic nanoparticles grafted with organic molecules for optimum use in gas sensors and ISFETs. This leads to a fundamental understanding of transport mechanisms in those nanostructures and in self-assembled monolayers as well.

Key reviews in the session devoted to nanofabrication with charged particle beams included those of A. Steckl (Univ. Cincinnati) on FIB fabrication of photonic nanostructures and P.E. Russell (NCSU) on nanofabrication and analysis with ion and electron beams. K.E. Gonsalves (Univ. North Carolina—Charlotte) and L. Merhari (CERAMEC, Limoges, France) presented a creative approach for biomaterial patterning by masked ion-beam lithography.

In the session on next-generation and emerging lithographies, besides extreme UV lithography assessed by J. Cobb (Motorola), IPL was extensively addressed. A. Dietzel (IBM, Germany) showed the advantage brought by IPL for resistless patterning of magnetic-storage media where densities higher than 100 Gbit/in.^{2} could be achieved. The performance of such a sub-70-nm resolution lithographic machine intended for IC mass production and exclusively developed by the company Ion Microfabrication Systems (IMS, Vienna, Austria) was assessed by W.H. Bruenger of Fraunhofer Institute for Silicon Technology, Germany. However, whatever the lithographic method that will prevail in future IC fabrication lines, it is recognized that new resists capable of accommodating the requested sub-50-nm resolution must be developed and validated. This bottleneck has been addressed in the sessions devoted to advanced materials and processes for nanolithography. Key contributions from L.E. Ocola (Agere Systems) and J.R. Maldonado (ETEC Systems) dealt with advanced resists for electron-beam lithographies, whereas H. Namatsu (NTT) focused on nanoline formation by using small aggregate resist and supercritical resist drying.

Symposium Support: The Whitaker Foundation; Nanoresist Technologies; CERAMEC R&D, France; NSF; and Motorola France.

Symposium X Features Communication of Materials Science

Science writers who communicate science to the general public as well as the broad science community gave a taste of their work over the lunch hour of the 2001 MRS Fall Meeting. Stephen Sass (Cornell), author of *The Substance of Civilization* (Arcade Publishing, 1998), displayed how shortages of materials have driven innovation. During the Bronze Age, people discovered how to reduce copper ore with charcoal to get copper metal. Originally, they used copper/arsenic alloys, but as that ore ran out, they either found copper-tin ore or added tin. By 1200 B.C., the eastern Mediterranean peoples were facing a tin shortage, which led them to replace tin with iron, beginning the Iron Age. Reducing iron ore required charcoal, which was obtained from wood, and by A.D. 1700, wood was in short supply. In 1709, Abraham Darby developed coke from coal. Coke had a higher concentration of charcoal and was cheaper than wood, so the price of iron plummeted. To get the coal, people needed deep mines, which tended to flood. The steam engine, which led to the Industrial Revolution, was developed to pump out the mines. Thus, said Sass, the Industrial Revolution was driven by a shortage of wood.

Ivan Amato of *Science News* has written the book *Stuff: The Materials the World Is Made Of* (BasicBooks, 1997), also introducing the field of materials to the general public. He is currently working on another book. In his Symposium X talk, Amato discussed “Data as Art.” Phenomena revealed only by scientific instruments produce images that are both scientifically useful and aesthetically pleasing, he said.

He presented a series of slides to illustrate this. In size scale, the images ranged from a 1970s Brookhaven bubble chamber photo to a radio telescope composite of the entire sky. Physical science images included a ferromagnetic garnet film viewed through a polarizing microscope. Amato suggested that, when presenting papers, scientists should linger over aesthetically pleasing images, micrographs, or computer simulations.

Phillip Ball of *Nature*, author of *Made to Measure: New Materials for the 21st Century* (Princeton, 1997), was the first to give a talk at MRS by video teleconferencing. Speaking from London, Ball gave his Symposium X presentation on “The Age of Molecular Engineering” as slides were displayed on a separate screen. Focusing on the current state and future directions of molecular engineering, Ball described a number of recent developments in molecular information technology, molecular motors, transduction and sensing, and energy conversion. He discussed transistors and logic gates made from nanotubes, molecular switching, and DNA computing. His discussion of motors included a description of artificial muscle built from two molecular groups that can reversibly slide through each other to mimic muscle contractions, rotary motors, and directional motion of microtubules in channels. In transduction and sensing, Ball described smart hydrogel valves controlled by the molecular selectivity of antibodies. He also described nanopores, created from peptide self-assembly, that are incorporated into cell bodies and can deliver antibiotics.

Ball concluded with the question of whether it is always best to mimic biology, since molecules do some things well and some things poorly. He described hybrid systems that combine organic molecules and silicon to use the strengths of each and predicted that molecular engineering will become more focused on customized derivatives of molecular biology.

More Than Just Another Form of Carbon, Nanotubes Find Uses from Field Emission to Assembled Nanotube Membranes

(See MRS Proceedings Volume 706)

Regular reports of novel aspects of carbon nanotubes continue to amaze the scientific community. Symposium Z provided a comprehensive view of developments in synthesis and processing and on how to make functional structures with this material. The synthesis of macroscopic strands of organized nanotube structures was presented by researchers at Tsinghua University in China and the development of highly organized patterns on substrates was presented by researchers at Rensselaer

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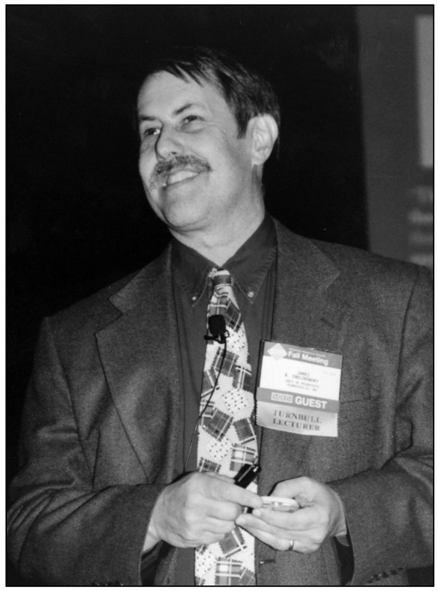
Polytechnic Institute. On the hot topic of field-emission property of nanotubes, companies such as Samsung and DuPont provided glimpses at the prototype displays with nanotubes that will be marketable in the near future. Several invited speakers eluded on the challenges of making high-strength nanotube-filled polymer composites. However, they discussed some unique applications of nanotubes, for example, in OLEDs. One of the most exciting sessions dealt with simulations of nanotube systems, in particular, transport of water through nanotube pores and separation of molecular species across self-assembled nanotube membranes. The latter suggested a possible connection with capillaries in biological systems. It was also suggested that nanotubes with engineered defects could become catalytic and could be interesting electrode material. Hydrogen storage inside nanotubes still remains a controversial topic. However, an improvement in nanotube-based actuators is attributed to improved processing techniques in the fabrication of macroscopic fibers and filaments consisting of nanotubes.

Symposium Support: NEC; Carbon Nanotechnologies; Samsung Advanced Inst. of Technology; MER Corp.; Philip Morris Research; Ise Electronics Corp.; Rigaku Intl; IMRA-EUROPE, S.A.; Hyperion Catalysis Intl; Piezomax Technologies; Versilant Nanotechnologies; and Toyota Motor Co.



*2001 MRS David Turnbull Lecturer **Jim Chelikowsky** (University of Minnesota) spoke about silicon, "in all its forms." Referring to the vast database on silicon—the equivalent of one paper published every 90 minutes—Chelikowsky identified Si as the most useful material for theorists.*

Ink-Jet Printing and Self-Assembly Used for Organic Transistors

(See MRS Proceedings Volume 708)

Within Symposium BB were several talks on the fundamental physics and chemistry of organic transistors and techniques for integrated circuits. H. Sirringhaus (Cambridge) started the session by showing that source and drain electrodes can be patterned by depositing conducting polymer with an ink-jet printer. Since normal ink-jet printing does not enable the printing of submicron features, he used microcontact printing to prepattern the substrate with an organic monolayer. Sirringhaus found that the ink-jet-printed drops would spread to cover the monolayer. This technique enables inexpensive patterning of organic transistors with submicron channel widths. Sirringhaus also showed that solid-state embossing can be used to cut submicron gaps between electrodes.

Z. Bao (Bell Labs/Lucent Tech) showed that field-effect transistors with record-breaking properties can be made by sandwiching a self-assembled monolayer (SAM) of conjugated dithiol molecules between two gold electrodes that are stacked on the side of a vertical silicon gate. These devices have current-voltage curves similar to those of MOSFETs, which is surprising considering that the channel length is only 1–2 nm. Changing the gate voltage by less than 0.5 V modulates the conductivity of molecules in the SAM by more than 5 orders of magnitude. Bao reported that the effects have been observed with more than 10 different conjugated molecules.

Several talks were given on pentacene transistors. M. Shtein (Princeton) and C.D. Dimitrakopoulos (IBM) discussed techniques for vapor depositing high-quality thin films of pentacene that have mobilities of the order of 1 cm^2/V s. The researchers noted that surface treatments of both the substrate and the electrodes are crucial for growing films with large grains.

Symposium Support: MMR Technologies and Universal Display.

Liquid-Crystalline Materials Show Their Colors and Versatility

(See MRS Proceedings Volume 709)

In Symposium CC, talks spanned a diverse set of LC-related topics, ranging from reports on the latest hot research areas, including flexoelectro-optics, V-shaped switching, chiral discotics, and banana phases, to the most recent developments in LC-polymer composite systems and LC gels. The LC-polymer connection has been an active research area for many years, but based upon results presented at this symposium, the field is seeing an impressive acceleration in the pace of innovation. Highlights included descriptions of the control of crystal and polymer morphology achievable using LC templates; interesting LC anchoring behavior observed on polyacrylates grown from LC/monomer mixtures; progress in fabrication of switchable gratings in LC-polymer composites; and demonstration of LC alignment using specially designed polymers dissolved in the LC sample itself, with no surface treatment required. Much of this work has potential applicability ranging from sophisticated photonics and beam-steering to creation of "electronic paper."

Additional highlights included the description of tunable lasers based upon dye-doped cholesteric LC elastomers, where stretching of the elastomer films changes the wavelength of the emitted laser light. This phenomenon takes advantage of the spontaneously formed 1D photonic bandgap present in chiral LCs, which is similar in its optical properties to the famous scarab beetle shells, known for beautiful selective reflection colors. By careful tuning and control of photopolymerization materials and conditions, thin films capable of phenomenal behavior can be created. For example, an easily fabricated thin film capable of reflecting 80% of unpolarized incident white light into a single pure polarization was described. This work is also reminiscent of certain silvery beetles, whose shells can accomplish the same trick, albeit with less efficiency. Perhaps it can be said that researchers have caught up with Scarabs in regards to passive photonic devices.

Polymer Thin Films Benefit from High-Throughput Research, Modeling, and Self-Assembly

(See MRS Proceedings Volume 710)

Seven topical areas defined Symposium DD on polymer interfaces and thin films: (1) theory, simulations, and dynamics; (2) block-copolymer films; (3) combinatorial approach to polymers (including a joint session with Symposium S); (4) adhesion and mechanical properties; (5) self-assembly by polymeric films (including a joint session with the virtual Symposium AA); (6) lithographic, electronic properties; and (7) nanoparticulate-filled films.

The application of combinatorial and high-throughput research methods and tools as being developed at Caltech, the University of Wisconsin, and NIST demonstrated the ability of these emerging methods to investigate problems in

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polymers and materials science. NIST applied these methods in classic areas such as phase separation and important practical areas such as adhesion. The research being conducted at the University of Ulm highlighted the session on self-assembly. This work represents the general emphasis in the use of external fields (topographical, electrical, and thermal) to control structure formation and ordering over macroscopic length scales.

The experimental areas were augmented by a theoretical and modeling effort with talks covering topics such as a microfluidics approach to mixing, mobility and diffusion in polymer blends, and nanoparticles in thin films. The simulations and theories brought insight into nanoscale self-organizational phenomenology and nanomechanical properties that have ramifications for the next-generation lithographic industry.

The synergy of novel experimental methods and fundamental physics on molecular scales showcased the future of the industrial and academic materials science community toward molecular-length-scale phenomena and devices. In all sessions, the invited talks set the direction for the future in each of the established or emerging fields—most impressively into the nanoscale, biomaterials, combinatorial, and nanopatterning arenas.

Symposium Support: NIST and NSF.

At the Publications Desk, ***Robert W. Cahn*** *(Cambridge) signed copies of his book,* The Coming of Materials Science.

Fabric of Carbon Nanotubes Coated with Conducting Polymer Form Smart Glove with Sensing and Actuation Capability

(See MRS Proceedings Volume 698)

Symposium EE on electroactive polymers and their applications as actuators, sensors, and artificial muscles covered topics ranging from fundamental materials understanding and characterization, to new materials development, to novel device concepts and demonstrations. G. Spinks (Univ. Wollongong, Australia) described the employment of conducting polymer and carbon nanotube as actuators for smart gloves in which conducting-polymer-coated stretched fibers were also used as sensors. F. Kremer (Univ. Leipzig, Germany) presented very high electromechanical responses from a side chain liquid-crystalline elastomer. The molecular origin of this "giant" electrostrictive response is based on the electroclinic effect. The work in the electrostrictive P(VDF-TrFE) shows that by the terpolymer approach an electroactive polymer with electrostrictive strain higher than 5% and elastic-energy density more than 1.4 J/cm^3 can be realized. Several presentations demonstrated applications enabled by the high-performance electroactive polymers. Another interesting topic of the symposium is the ferroelectric thin and ultrathin films that are attractive for memory and data-storage devices, IR imaging, and MEMS.

Symposium Support: ONR and Daikin US Corp.

Various Techniques Available to Characterize Biological Materials

(See MRS Proceedings Volume 711)

Symposium FF on physical characterization of biological materials and systems included sessions on specific techniques, such as scanning probe microscopy and electron microscopy, as well as sessions dedicated to specific materials such as mineralized tissues, lipids, proteins, and DNA.

J. Israelachvili (UCSB) described how the properties of diseased myelin can be studied using the surface forces apparatus. When an individual suffers from multiple sclerosis, the myelin demonstrates swelling and vesiculation and the surface forces differ from the weak adhesion observed for healthy myelin. A subsequent talk by R.J. Matyi (NIST) highlighted the use of 3-axis x-ray diffraction to image defects in protein crystals, and D. Pochin (Univ. Delaware) discussed the unusual properties of hydrogels and their potential applications as biomaterials.

In the area of mechanical and rheological properties of biomaterials, J. Kinney (UC—San Francisco) and T. Weihs (JHU) discussed the characterization of dentin and dental enamel, respectively, on the submicron scale. G. Pharr (Univ. Tennessee) described how nanoindentation could be used to study the anisotropic properties of bone, relating these studies to models that have been developed for indentation testing of elastic anisotropy.

A. Donald and D. Stokes (Cambridge) described how environmental SEM could be used at low temperature (<5°C) to study hydrated biomaterials. Donald highlighted the many artifacts that can be seen when using electron microscopy and how careful preparation can help to reduce these. The symposium finished with a session on optical techniques. R. Young (UMIST) and J.S. Stephens (Univ. Delaware) demonstrated the applicability of Raman spectroscopy to the study of chemistry in biomaterials. The use of Raman spectroscopy to study strains in carbon-carbon bonds and polypeptide molecules was also demonstrated.

Symposium Support: The Whitaker Foundation and MTS Systems Corp.

Tissue Engineering Examined on Multilevel Scale

(See MRS Proceedings Volume 711)

Novel polymer synthesis and processing has led to the development of materials for tissue engineering that allow for controlled properties and cellular interactions. Symposium GG highlighted recent advances in this field with a specific emphasis of control at the nano-, micro-, and macroscopic levels. Presenting a wide variety of techniques and novel materials that are at the forefront of materials research, the symposium covered descriptions of various techniques to pattern polymeric biomaterials such as UV irradiation and colloidal assembly and their specific applications in controlling cell function. One session focused primarily on synthesis and degradation of polymeric biomaterials. The degradation of materials being developed for tissue engineering applications including polyesters, polyurethanes, cross-linked poly(vinyl alcohol), and polypyrrole were presented.

Other topics included composite systems; techniques for fabricating porous scaffolds; and novel syntheses of salicylate-based polyanhydrides, substituted polylactides, and amino-acid-based dendrimers. The final session of the symposium presented talks on injectable biomaterials that form directly in the body, and research on the modification of cell-material interfaces through polyelectrolytes, proteins, and adhesive peptides specifically for the engineering of tissues such as cartilage.

Symposium Support: The Whitaker Foundation and ARO.

Materials Advances in Art Conservation, Technology Reconstruction, and Understanding of Ancient Materials Developments Demonstrated

(See MRS Proceedings Volume 712)

Among the several themes that emerged from Symposium II on materials issues in art and archaeology was preservation science and conservation. A. Lins (Philadelphia Museum of Art) discussed the analysis of paint layers from Thomas Eakins' painting "Crucifixion." Originally painted in 1880, the painting was subsequently subjected to various cleaning procedures. Such procedures complicate the interpretation of paintings by obscuring original characteristics. Lins and his co-workers used FIB to prepare TEM specimens to study thin layers of the painting. From a small sample of the painting, TEM analysis revealed a Pb-rich nanocrystalline region on the surface, which was not observed in other samples subjected to milder cleaning techniques. The FIB/TEM analysis thus provides a route to examine alterations of artists' original materials and techniques.

Several talks established evidence for the appearance of a technology earlier than previously documented. For example, the famous Athenian Greek black-on-red and red-on-black sintered-slip ceramic technology had a precursor black-ware produced in Turkey at Gordion as early as 800 B.C. and ceramic technology appeared in the Upper Paleolithic period as far east as Siberia 15,000 years ago.

Museum and archaeological collections, unlike industrial samples, require microscopic amounts of materials be sampled and then often cycled through various analytical techniques. Often the entire sample amounts to only 125 μm^3. Sometimes only nondestructive methods can be employed, especially in the analysis of cultural icons and national treasure objects. Several advances in analysis were reported including the use of Eddy currents to identify various gold-gilding techniques on bronzes, and a combination of techniques to nondestructively differentiate various methods of producing 19th-century photographic negatives and prints. Such differentiation will have an effect on conservation procedures and predictions of longevity.

Often so little of an object is left that a technology must be reconstructed or inferred from corrosion products and/or microscopic amounts of residues or coatings. Occasionally, reconstruction of ancient technologies occurs by analysis of ancient objects and reproduction of that part of the process that is in doubt, followed by comparison of the microstructure and composition of the ancient object or material with the simulation. One such example is a set of analyses and replications that differentiated two techniques to produce gold granulation, a type of decoration on Bronze Age gold jewelry from the Mediterranean.

Rarely studies involve large-sample, multiyear projects that lead to regional or temporal perspectives on ancient materials usages and technologies and that aim to elucidate sociocultural aspects of technology. M. Wypyski (Metropolitan Museum of Art) was able to use enamel compositions to authenticate Renaissance jewelry and differentiate it from 19th-century revivals. In other reported studies, geological sources were sampled, analyzed, and compared to large archaeological corpuses, so that regional technologies, raw material sources, and patterns of production and exchange of goods were established.

Symposium Support: SCMRE.

Past Observations and Future Outlook of Materials Research in Nuclear Waste Presented

(See MRS Proceedings Volume 713)

The 25th Scientific Basis for Nuclear Waste Management, Symposium JJ, opened with a keynote lecture by R.C. Ewing (Univ. Michigan), a member of the Board of Radioactive Waste Management of the National Research Council. Ewing summarized 25 years of materials research in nuclear waste, emphasizing the progress that has been made and the challenges that still confront investigators and technologists in materials science and performance evaluation. The lecture was fol-

Performance Assessments of Nuclear Waste Materials Reported

Safe and effective management of nuclear wastes continues to be of vital international importance and provides a broad range of challenges in materials research. At the 25th Scientific Basis for Nuclear Waste Management , Symposium JJ, a series of invited lectures was given on performance assessment and repository studies that have just been completed around the world. Programs in Belgium, Italy, Japan, Sweden, Switzerland, the United Kingdom, and the United States were represented.

A "performance assessment" attempts to estimate long-term risks by assembling and integrating the best available scientific understanding of the engineered materials designed to contain nuclear waste along with the characteristics of the natural site geology. Because of widely different geologic characteristics of the repositories, each country has developed different packaging materials and waste forms. In the United States and Sweden, spent nuclear fuel is the dominant high-level waste form, but glass is preferred in Japan, Belgium, and Switzerland. Advanced corrosion-resistant alloys are being proposed for the U.S. repository at Yucca Mountain, Nevada, whereas copper containers are being considered in Sweden, and steel containers in Japan, Belgium, and Switzerland.

Each country began its performance assessment with an analysis of features, events, and processes that were to be considered. However, the U.S. approach to performance assessment places strong emphasis on probabilistic analyses instead of more deterministic methods favored by other countries. Despite the considerable differences in approach and methods used, all the performance assessments showed extremely low rates of radionuclide release from the combination of engineered and natural barriers. Projected risks from the disposal of the nuclear wastes were found to be much less than risks encountered by the public in everyday life, such as driving, riding in an airplane, or having a medical x-ray.

lowed by a session on containers materials and engineered barriers where A.A. Sagues (Univ. South Florida), a member of the U.S. President-appointed Nuclear Waste Technical Review Board, discussed the corrosion performance expected for the waste packages to be used in the then-proposed high-level nuclear waste repository at Yucca Mountain, Nevada. Invited talks on performance assessment and repository studies for different national programs were presented by speakers from Belgium, Italy, Japan, Sweden, Switzerland, the United Kingdom, and the United States (see Sidebar). Developments in the United States were discussed in numerous papers on the proposed high-level waste repository at Yucca Mountain; on the Waste Isolation Pilot Plant in Carlsbad, New Mexico, which is now open and accepting transuranic wastes for disposal; and on low-level radioactive waste disposal facilities.

Symposium Support: Southwest Research Institute, Applied Metamix, and PNNL.

***Clayton Christensen** (Harvard Business School) gave the Plenary address at the MRS Meeting in which he described the opportunities and threats of "disruptive innovation." This concept refers to a new product or service brought to market that displaces a high-quality product, even if (and perhaps because) the high-quality product development is managed well. While the new product is not along the metrics-of-performance curve most valued by mainstream customers, it may become good enough to lure customers away from the high-quality standard. For example, personal computers were a disruptive innovation in respect to mainframes and minicomputers.*

Hydration Reactions and Microstructure form Foundation of Concrete Research

Concrete and other cement-based systems have become the world's most widely used construction materials and are also important in waste immobilization. The current enhanced performance of cement-based materials is derived from an improved understanding of the relationships between hydration reactions, microstructure and properties such as mechanical performance and long-term durability, and of the effects of pozzolanic materials and other additives. Symposium KK addressed topics ranging from the fundamental properties of cementitious systems, microstructural development, novel binders, effects of additives on properties and durability, matrix chemistry, system characterization, and nondestructive testing. Additionally, a joint session was held with Symposium JJ on the role of cement and concrete as a structural, chemical, and physical barrier in radioactive waste immobilization.

S. Diamond (Purdue Univ.) traced the origin and evolution of conceptual and experimental work on the micro- and macropore systems in hardened cement paste. He compared the two principal conceptual models that, over the past 50 years, have provoked a great deal of discussion and work to better understand the nature of cement paste in concrete. Presentations on the development of computational materials science in concrete by E. Garboczi (NIST) and molecular-dynamics modeling in cementitious systems by A. Kalinichev (Univ. Illinois—Urbana-Champaign) demonstrated the developments in modeling cement and concrete systems on a macro- to nanoscale level. Concrete is a random, complex composite material that may be modeled on length scales ranging from nanometers to millimeters. Modeling the hydration reactions of ordinary portland cements, and cements with pozzolanic materials, has been the focus of numerous studies. These efforts have matured where problems such as development of strength, viscoelasticity, rheology, transport properties, degradation processes, and new cementitious materials may be investigated. Molecular-dynamics investigations of the pore-solution/solid interface in cementitious systems are similarly exciting developments in computational materials science. The potential through the eventual linking of these efforts has yet to be realized and will certainly be the topic of future meetings. W.J. McCarter (Heriot Watt Univ., Scotland) presented the applications of intrinsic electrical property measurements to characterize early hydration, setting times, and durability of concretes. The role of cement and concrete in radioactive waste immobilization has long been an important area of study. F. Glasser (Univ. Aberdeen, Scotland) examined the role of cementitious systems for immobilization waste products and for providing physical and chemical barriers to waste migration and, given that elevated temperatures often accompany waste storage, he described a long-term study on compositional changes in portland cements following thermal excursions. The database developed as a result of these efforts will be an invaluable resource for those involved in developing models for long-term durability studies for both general construction and for disposal and containment of waste materials.

Symposium Support: Portland Cement Assoc., USG Corp., Clark Schwebel Tech-Fab Co., Construction Chemicals Americas, Lafarge Calcium Aluminate, Knauf Westdeutsche Gipswerke, and Nippon Electric Glass America. MRS

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