MRS Spring 1999 Meeting Features Soft, Magnetic, and Display Materials, Among Other Interdisciplinary Research Topics

Spintronics, limits of scaling, and *soft materials* were among the buzz words heard at the Materials Research Society Spring 1999 Meeting in San Francisco April 5 through April 9. The Meeting comprised 34 symposia held in the San Francisco Marriott and Argent Hotels. Katayun Barmak, co-chair of the Meeting, said, "The cluster of symposia at the Argent Hotel, with its high-quality meeting rooms and cozy break area, provided attendees with a marvelous opportunity for technical discussions on interrelated topics."

Barmak (CMU) with co-chairs Paul D. Calvert (Arizona), James S. Speck (UCSB), and Raymond T. Tung (Lucent/Bell Labs) reported a successful meeting with close to 3,000 attendees, over 630 poster presentations, a continuous flow of business within the equipment exhibit, and ample attendance at the National Science Foundation Seminar and Symposium Tutorial sessions. MRS presented the Outstanding Young Investigator (OYI) award to Chad Mirkin (Northwestern), eight plaques each for the Graduate Student Gold and Silver Awards, and four awards for best poster presentation (see sidebars). Plenary speaker Paolo Gargini (Intel) provided an overview of the impact of new materials on the semiconductor industry (see sidebar).

Technical Sessions

Soft Materials

In keeping with the cross-disciplinary goals of MRS, the interdisciplinary nature of soft materials research has found a niche in MRS programming (Symposia DD–HH). "Soft materials" broadly encompasses biomaterials, organic and polymeric materials, and soft condensed matter. Combining organic and inorganic materials yields versatile and interesting materials properties in multiple length scales, as is evident from the presentations in Symposium DD. Several papers discussed organometallic compounds including silanes, reflecting the origins of this Symposium in the series of previous MRS symposia on "Better Ceramics Through Chemistry." The properties and applications of hybrid materials were discussed in several sessions, which indicates present and potential applications in chemical, biomedical, electronic, optical, and mechanical areas.

Polymers are extensively used as biomaterials and in biotechnology (Symposium EE). In addition, biological production of polymers is now a major field of study. In a presentation on "Self-Assembling Biomaterials for Tissue Repair," S. Stupp (Illinois—Urbana-Champaign) showed several examples of self-assembling biomaterials. This area of research includes formation of self-organized matter containing tissue components and synthetic molecules, self-assembly of lamellar solids, and "nanoimplants." Researchers in this area want to form thermodynamically favorable molecular aggregations for enhanced healthcare capabilities. Also in the field of tissue engineering, J.L. West (Rice) demonstrated the *in situ* polymerization of synthetic hydrogels based on polyethylene glycol to mimic the extracellular matrix. R.A. Stile (North-

Two interactive displays commissioned by the Materials Research Society captured the center of attraction in the registration area of the Materials Research Society Spring 1999 Meeting in San Francisco. One display is an artform called "Polage" (shown here), designed by Austine Wood-Comarow, which uses layers of cellophane to make a collage that plays with polarized light. Ordinarily the Polage appears to be mostly gray with areas of color showing microscopic images of materials. Viewed through a polarizer, the Polage dramatically comes to life showing macroscopic applications of the materials. More information is available at website www.austine.com/art/matters.shtml. The other display (not shown here) is a diffusion machine showing diffusion of interstitial atoms through fcc, bcc, and hcp crystal lattices.

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western) discussed thermo-responsive poly(*N*-isopropylacrylamide) hydrogels for cartilage regeneration.

Biomedical materials represent one of the most exciting areas of current materials research (Symposium FF). Presentations covered new materials and surface modification techniques; several papers discussed the use of combinatorial library analysis for identifying new candidate materials. The field of tissue engineering, including new scaffold materials, was the focus of several presentations. Several papers also introduced various biological techniques for evaluation of tissue responses to materials, which is crucial for biomedical implants. Differences in materials design for organs such as bone, liver, and skin were enunciated by several researchers.

Symposium GG covered a range of presentations on biomembranes. The focus was on molecularly thin assemblies of amphiphiles in or on aqueous solutions. Several groups described work on monolayer or bilayer structures of lipid molecules. A new synthetic approach was used to form thin-shelled vesicles similar to lipid vesicles using "super"-amphiphilic polymers. D.E. Disher and D.A. Hammer (Pennsylvania) and F.S. Bates (Minnesota) demonstrated the ability to encapsulate polymeric solutes within these polymersomes and also proved that these membranes are significantly tougher than their natural counterparts. These results lay the groundwork for a potential new broad class of polymer-based biomembrane mimics.

Soft condensed matter forms a significant part of the core of soft materials. Fundamentals and applications were discussed in Symposium HH covering four major materials classes: colloids, gels, electro-and magneto-rheological fluids, and fiber suspensions. Highlights included a report on space-based experiments on hard sphere crystallization of colloids in microgravity by Z. Cheng (Princeton) wherein an important finding was the absence of a glass transition in the microgravity environment.

Meeting attendees viewed equipment exhibits at the Materials Research Society Spring 1999 Meeting in San Francisco.

Magnetic Materials

Symposia H through L covered different aspects of magnetic materials including hard and soft magnets, patterned magnetic structures, magnetoelectronics, hybrid magnetic materials, semiconductor and superconductor structures, and polycrystalline magnetic thin films. Symposium H, focusing on hard magnets, also included a tutorial on concepts and experimental methods in micromagnetism by G. Hadjipanayis (Delaware) and R. Skomski (Nebraska). The properties of the novel ferromagnetic bulk glassy alloy Nd-Fe-Al were described by K.V. Rao (Royal Institute of Technology—Stockholm, Sweden). These alloys constitute a unique class of materials requiring a modest cooling rate of

ACRONYM KEY

2D: two-dimensional
3D: three-dimensional
AFB: Air Force base
AFM: atomic force microscopy
ANL: Argonne National Laboratory
ARO: Army Research Office
CMOS: complementary metal oxide semiconductor
CMR: colossal magnetoresistance
CMU: Carnegie Mellon University
CSM: Colorado School of Mines
CVD: chemical vapor deposition
DARPA: Defense Advanced Research Projects Agency
DOE: Department of Energy
DRAM: dynamic random-access memory
ER: electrorheology
FED: field-emission display
FeRAM: ferroelectric random-access memory
FET: field-effect transistor
FIB: focused ion beam
GMR: giant magnetoresistance
IR: infrared
LANL: Los Alamos National Laboratory
LC: liquid crystal
LED: light-emitting diode
LLNL: Lawrence Livermore National Laboratory
LSMCD: liquid source misted chemical deposition
MEA: More Electric Aircraft
MBE: molecular-beam epitaxy
MEMS: microelectromechanical system
MFM: magnetic force microscopy
MFSFET: metal-ferroelectric-semiconductor field-effect transistor
MIT: Massachusetts Institute of Technology
MOS: metal oxide semiconductor
MOSFET: metal oxide semiconductor field-effect transistor
MR: magnetorheology
MRAM: magnetic random-access memory
MTJ: magnetic tunnel junctions
NIST: National Institute of Standards and Technology
NMR: nuclear magnetic resonance
NREL: National Renewable Energy Laboratory
OLED: organic light-emitting diode
ONR: Office of Naval Research
ORNL: Oak Ridge National Laboratory
PECVD: plasma-enhanced chemical vapor deposition
PEEM: photo-emission electron microscopy
PNNL: Pacific Northwest National Laboratory
QD: quantum dot
R&D: research and development
RAM: random-access memory
RF: radio frequency
RHEED: reflection high-energy electron diffraction
SCM: scanning capacitance microscopy
SEM: scanning electron microscopy
SOI: silicon-on-insulator
SSRM: scanning spreading resistance microscopy
SNL: Sandia National Laboratories
STM: scanning transmission microscopy
TCAD: technology-computer-aided design
TEM: transmission electron microscopy
TI: Texas Instruments
TPA: two-photon absorption
TXRF: total x-ray reflection fluorescence
UCSB: University of California—Santa Barbara
ULSI: ultralarge-scale integration
VLSI: very large-scale integration

about 1–100 K/s to form an amorphous solid from the melt. These materials also exhibit a large resistance to demagnetization which is not well understood within the framework of conventional amorphous magnetic alloys.

Among the newer topics offered at the meeting were hard and soft magnetic materials. Symposium I on Amorphous and Nanocrystalline Materials for Hard and Soft Magnetic Applications devoted several sessions to ultrasoft nanocrystalline and amorphous materials. M. Hawley (LANL) discussed his work with MFM to image magnetic domains in amorphous and nanocrystalline alloys. R. Waters (DOE) described applications of advanced magnetic materials. In looking for replacements for conventional aircraft secondary power systems as part of the MEA initiative, the Air Force's goal is to invest in four key power technologies: a more electric engine, fault-tolerant distribution systems, integrated power unit, and electric stabilizer actuator. The purpose of this initiative is to eliminate mechanical, hydraulic, and pneumatic parts. Magnetics R&D particularly using unconventional magnetic materials may hold the key to this goal.

Spintronics—spin transport electronics—instead of relying on transport of charge, takes advantage of the spin degree of freedom. Both Symposia J and K covered this topic, including a joint session. S. Wolf (DARPA) kicked off Symposium J by covering research directions and applications in this growing area of Patterned Magnetic Structures and Magnetoelectronics. Spin transport was first used in the form of GMR of very thin multilayers of ferromagnetic metals and metallic spacers in read head sensors for high-density hard disk storage. Enhanced magnetoresistance values of 40% or greater at room temperatures have been achieved. MTJ, which are comprised of sandwiches of ferromagnetic layers separated by thin insulating layers, has applications in nonvolatile magnetic memory cells and MRAMS. Spin-polarized transport has potential to enhance the performance of FETs and other semiconductor devices. An even more exciting development is the unexpected behavior of coherent spin transport. Shining circularly polarized light on essentially any semiconductor or semiconductor quantum dot causes the spin states to coherently align, with the electron spin lifetime lasting for 100s of nanoseconds at room temperature, while the electrons travel more than 100 μm. There is no explanation yet as to why the lifetimes are so long. Coherent spin states could be a route to quantum computing, although for success, coherence times of 1,000 to 10,000 times the clock speed are needed, which would be about 10,000 ns. Wolf said that quantum computing also requires control of the direction of the spin states. Symposium K on Hybrid Magnetic, Semiconductor, and Superconductor Structures presented a range of material combinations with interesting properties. As thicknesses and widths of polycrystalline thin films and magnetic thin films continue to decrease to the 1–100 nm regime, the role of surfaces, interfaces, film stresses, and impurities become more critical, which was the theme of Symposium L. Several joint sessions were held, including one from Symposia K and N on advanced interconnects and contacts wherein the focus was on the microstructure of plated Cu films and film properties leading to resistance transients.


A student mixer was held Sunday evening, April 4, at the Materials Research Society Spring 1999 Meeting in San Francisco, providing students with a forum to mingle, interact, and network with each other, MRS officers, and other materials researchers.

Display Materials

Symposia A–F formed a cluster broadly concentrating on various aspects of display materials and technologies. Symposium A covered amorphous and heterogeneous thin films. This symposium continues the series of MRS spring meeting symposia in the area of amorphous and microcystalline silicon. A 10.5% efficient 920 cm^2 a-Si:H photovoltaic panel using plasma-CVD-deposited amorphous films, with growth parameters just short of the transition to microcystallinity, was reported by J. Yang (United Solar). In the area of MEMS, J. Conde (Instituto Superior Tecnico—Lisbon) showed examples of working MEMS transistors, 20 μm long bridges, and cantilevers fabricated from a-Si:H. K. Pangal (Princeton) reported on techniques to fabricate amorphous and microcrystalline thin-film transistors in a single Si film using reduction in crystallization time caused by local H plasma treatment.

Liquid crystal materials and devices are a critical part of cutting-edge display technologies (Symposium D). One focus was on LC composite technology. A number of talks discussed the application of holography to store information into thin films of these systems. Techniques included the use of spatially periodic light exposure to create switchable permanent gratings by photo-curing, creation of a space charge field by imaging light on a cured film containing dye-filled LC domains allowing for rewritable information, and the use of the trans-cis isomerization mechanism of a LC-based dye for inducing local topographic and refractive index differences. A number of nondisplay applications using ferroelectric LCs were reported, such as for adaptive optics and real-time holography. E.T. Samulski (North Carolina), in an interestingly titled talk, "Javelins, Hockey Sticks, and Boomerangs: The Role of Mesogen Shape in Phase Stability and Phase Type," described the relation between molecular shape and phase symmetry and stability using thiophene analogues of p-quinquephynyl (PPPPP). Moving thiophene from a terminal position (PPPPT) to an asymmetric position (PPPTP) and to a center position (PPTPP) changes the shape of the molecule from that of a "javelin" to a "hockey" shape, and a "boomerang" shape. This shape change also alters LC transition temperatures. Samulski discussed the uses of these materials as potential OLEDs. P. Mach (Minnesota) described structural observa-

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tions of superlattice periodicities associated with antiferro- and ferri-electric phases made using polarized resonant x-ray scattering. In the same session, D. Walba (Colorado) discussed bent-core mesogenic structures and tilted bi-layer smectics, forming a new class of ferro- and antiferroelectric phases. Calling the phases the "banana phase," Walba used two bananas to demonstrate the orientation of the phases and the tilt.

Various issues associated with luminescent materials were discussed within Symposium E. Several novel phosphors were reported for display applications and LED lighting. A number of papers centered around controlling phosphor morphology and surfaces for display applications, and tuning the absorption and emission spectra of materials for LED applications.

Symposium F highlighted various aspects of organic nonlinear optical materials and devices, connecting the areas of photonics with organic materials. S.R. Marder (Caltech) reported a new method for designing molecules with high TPA cross-sections in the area of nonlinear absorbers. J.W. Perry (Arizona) reported examples of applications such as 3D optical storage and 3D microfabrication created by doping these molecules into materials that undergo TPA-initiated photochemistry. A. Dodabalapur (Lucent/Bell Labs) presented an overview on organic and polymer transistors. After reviewing the basic physics, Dodabalapur discussed "smart pixels" with the potential for large displays wherein a transistor resides at each pixel. He showed a fully functional five-transistor smart pixel panel and associated circuitry that could easily be designed for larger arrays. Along with demonstrating the potential for molecular transistors, Dodabalapur showed examples of oscillators and other circuits designed and built using organic transistors. He reported also on organic FETs with gate voltages of 2–3 V.

Silicon Devices

Symposia M–T broadly encompassed aspects of silicon-device-related technologies including engineering and processing, interconnects, and materials reliability. The critical topic of advanced interconnects and contacts was the subject of Symposium N reporting advances in Cu and Al multilevel interconnect architectures and silicides for MOSFET device contacts among others. One of the highlights of the sessions on silicides was a talk by F. Ross (IBM) who showed *in situ* TEM video clips of $TiSi_2$ and $CoSi_2$ growth. In the interconnects sessions, J. Harper (IBM) presented a model to describe room-temperature, self-annealing behavior of several electrodeposited Cu films, and showed that Cu grain growth, resistivity drop, and compressive stress reductions can be explained and calculated on the basis of existing theory.

Symposium O addressed critical issues associated with low-k materials in the semiconductor industry, particularly with the current move to the 0.13 μm technology node. A focus was on the introduction and control of porosity in dielectric materials. J. Brinker (SNL and University of New Mexico) and S. Baskaran (PNNL) presented work on self-assembled surfactant templated ceramic materials. K. Endo (NEC) discussed introduction of large, bulky phenyl groups to a silicate monomer to increase porosity and reduce the dielectric constant in PECVD-deposited films.

Symposium Q was the forum for discussions and recent developments in ultraclean processing of semiconductor structures and devices. The dominant issues were the interactions of process chemistry with silicon surfaces, and various methods of quantifying contaminants on silicon substrates. Detection limits of current techniques and acceptable levels of contamination for future generation CMOS fabrication were discussed in detail. Several papers addressed the use of ozonated water processing—a damage-free and environmentally benign process, in place of sulfuric-acid-based chemistries for photoresist and organic contaminant removal.

Ultrathin SiO_2 and high-k materials for ULSI gate dielectrics was the subject of Symposium R. The topics ranged from atomic scale control of the dielectric/Si interface to high-k alternate gate dielectrics to advances in ultrathin oxides and oxynitrides. Among the highlights was a report by G. Timp (Lucent/Bell Labs) on future silicon technology nodes using SiO_2 as the gate dielectric with thicknesses down to 0.7 nm. Among the alternate (to SiO_2) high-k materials under consideration and study, G. Wilk (TI) presented work on ultrathin amorphous hafnium silicates deposited directly on silicon. R.A. McKee (ORNL) reported on the growth of epitaxial $SrTiO_3$ on (001) Si.

A number of speakers in different symposia addressed the limits of scaling, such as in Symposium S on "Si Front-End Processing—Physics and Technology of Dopant-Defect Interactions." Among the highlights, W. Vandervorst (IMEC—Belgium) discussed nanometer-scale characterization and 2D carrier profiling on submicron devices using new techniques including SSRM, SCM, and nanopotentiometry. The SSRM probes carrier profiles on devices and is useful because it is quantitative, has excellent resistivity, and shows no distortions at junctions. It uses an AFM with a diamond-coated tip or a full diamond tip. These techniques are important in the study of two-dimensional effects in semiconductor devices due to the continual downscaling of the devices. Symposium T covered semiconductor wafer engineering for different semiconductor materials including silicon, gallium arsenide, and silicon carbide. Specific topics covered included large-diameter wafers and value-added wafers including SOI wafers generated by oxygen implantation (SIMOX) or wafer bonding.

Other Highlights

Symposium U addressed issues associated with the synthesis and *in situ* monitoring and modeling of film growth and device-related processes. This is critical for future generations of advanced film-based devices. Within the session on *in situ* emission and optical spectroscopies, areas of discussions included photoelectron emission spectroscopy for *in situ* surface process observation, MEMS-based nondestructive *in situ* diagnostics of crack propagation in structural materials, and *in situ* studies of film stresses during growth.

The field of epitaxial growth was the focus of Symposium V. Transition metal oxides have a history dating back to thousands of years BC. T. Geballe (Stanford), also in a joint session of Symposia V and BB, gave an overview of these materials starting with the mariner's compass up to the current era, dispelling some myths, but introducing new mysteries. Transition metal oxides of current interest are complex and difficult to model, exemplified in high-temperature superconductors and colossal magnetoresistive materials. He focused on the Hg superconductors, which show an increase in the superconducting transition temperature with increasing pressure, much beyond the pressure at which other cuprates begin to experience a decreased transition temperature as they become overdoped. In joint sessions of Symposia V and BB, M.E. Hawley (LANL) gave a talk on MFM to study new nanocrystalline soft magnetic ribbons. The MFM is an AFM that probes the surface twice, first to probe the topography and second to probe the Z-component of the magnetic field by moving the tip about 100 nm above the surface. Her group formed nanocrystalline multicomponent soft magnetic materials by annealing amorphous material, such as $Fe_{44}Co_{44}Zr_7B_4Cu$. Her group then used the MFM to study the effects of residual stress and nanocrystallinity on the structure of the materials.

In a session of Symposium W on Semiconductor Quantum Dots, OYI award recipient Chad Mirkin (Northwestern) described the use of DNA to direct formation of materials at the nanoscopic level (see sidebar on page 60). In the same session on biological and molecular systems, E. Braun (Technion, Israel) discussed his work on self-assembly of nanometer-scale electronics by biotechnology. Braun's group used DNA to connect gold nanoparticles to create a molecular electronic circuit. This work shows the great potential of organizing and self-assembling electronic materials by biological molecules. In another paper in the session, S. Rosenthal (Vanderbilt) described how her group prepared serotonin-labeled nanocrystals which can be used as fluorescent probes for the serotonin transporter protein. The main objective for this research is to use nanocrystal technology to follow the movement of transporters in the neuron synaptic gap. Two Symposium X talks for the nonspecialist on biomimetic materials were also presented (see sidebar on page 64).

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

Amorphous Silicon Bridges Fundamentals to Devices

(See MRS Proceedings Volume 557)

Symposium A, Amorphous and Heterogeneous Silicon: Fundamentals to Devices, featured a special session on medium-range-order. Apparently, ordering correlates with the electronic quality of hydrogenated amorphous Si (a-Si:H) films. M. Gibson (Delaware) reported multi-atom correlations extending to about 1.6 nm in a-Si:H, observed by variable-coherence TEM. Amorphous silicon may resemble paracrystalline structures more than the continuous random networks that have long been used for modeling. J. Yang (United Solar) reported a record 10.5%-efficient, 920-cm^2, a-Si:H photovoltaic panel, which utilizes amorphous films deposited by plasma CVD at growth parameters just short of the threshold for a transition to microcrystallinity. D. Williamson (CSM) described a narrowing of the first x-ray diffraction peak in these amorphous films that also suggests ordering at 10–30 nm length scales.

Important new experimental observations on metastable effects in a-Si:H were reported. S. Nonomara (Gifu) described a metastable volume expansion of about 4 ppm caused by illumination and measured with a sensitive optical-lever bending technique. S. Heck (NREL) showed pulsed-illumination photoconductivity decays that suggest metastable degradation is delayed by about 0.5 ms after illumination begins. Discussions about H configurations in a-Si:H were spirited. R. Borzi (Washington) showed deuteron magnetic resonance spectra suggesting up to 40% of the H in a-Si:H is found as H_2 molecules in interstitial sites, while T. Su (Utah) reported NMR measurement suggesting only about 10%.

Several sessions focused on new devices and processing strategies. K. Pangal (Princeton) showed how he fabricates amorphous and microcrystalline thin-film transistors in a single Si film by exploiting the reduction in crystallization time caused by local H plasma treatment. R. Schropp (Utrecht), in collaboration with a consortium of Dutch universities and Akzo Nobel Chemicals and Coatings, is developing a temporary superstrate technique (where the glass "substrate" is above the a-Si during use) for a-Si:H photovoltaic manufacture. In a particularly entertaining talk, J. Conde (Instituto Superior Tecnico—Lisbon) showed dramatic micrographs of 20-μm long bridges, cantilevers, and even working MEMS transistors fabricated from a-Si:H.

Symposium Support: NREL, Solarex, MVSystems, Voltaix, AKZO, United Solar Systems, Sony, Sanyo Electric, and Fuji Electric.

Polymer-Dispersed, Smectic, and Nontraditional Materials Form Broad Base for Liquid Crystal Technology

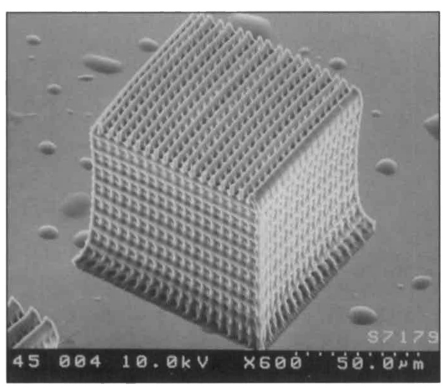
(See MRS Proceedings Volume 559)

Symposium D on Liquid Crystal Materials and Devices covered several large areas of research, including polymer-dispersed liquid crystal technology, twisted smectic materials and applications, and surprisingly, a strong presence from nontraditional LC materials and applications. A large number of the oral and poster presenta-

Nonlinear Absorbers and Organic FETs Show Advances

(See MRS Proceedings Volume 561)

Symposium F on Organic Nonlinear Optical Materials and Devices provided a highly interactive forum for an update in the connected areas of photonics with organic materials. The Symposium was highlighted by several major advances in various fields ranging from nonlinear absorbers and electro-optic polymers, to photorefractive polymers and organic transistors, to electroluminescent materials and devices for displays. In the area of nonlinear absorbers, S.R. Marder (Arizona) presented a strategy to design molecules with high TPA cross sections and demonstrated several molecular designs that led to molecules with TPA cross-sections that outperform previous molecules such as Rhodamine B by an order of magnitude. His colleague J.W. Perry (Arizona) was able to dope these efficient molecules into materials that undergo TPA-initiated photochemistry such as photoinduced polymerization using two-photon processes with an order of magnitude higher sensitivity. Several examples of applications including 3D optical storage and 3D microfabrication were demonstrated (see figure). The new design strategy of molecules with high nonlinear absorption was further supported by the report by C.W. Spangler (Montana State) and co-workers from Wright-Patterson AFB of dithienyl polyene molecules with similar cross-sections. In the photorefractive polymer session, several teams, including W.E. Moerner (UCSD) and B. Kippelen (Arizona), reported materials with a few ms response time.



"Stack of logs" photonic bandgap structure fabricated by two-photon-initiated polymerization. The structure is about 75-µm long on each side. Photo by J.W. Perry, University of Arizona.

Another highlight was the report by A. Dodabalapur (Bell Labs Lucent Technologies) on organic FETs with gate voltages of 2–3 V. This significant reduction in voltage compared with previous organic transistors was made possible by the fabrication of devices with 100 nm channel length. The length of the channel was only a few times the length of the thiophene oligomer chain used as the organic semiconductor, bringing these structures one step closer to real molecular electronics. In that same session, D. Fichou (CNRS Thiais) reported on octathiophene materials with mobilities of $\mu = 0.2$ cm^2/V s.

Symposium Support: ONR, AlliedSignal, Lightwave Microsystems Corp., and Lockheed Martin.

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tions concentrated on various aspects of LC composite technology, the bulk of which were formed by photo-induced polymerization. Of note was the large amount of work concentrating on the use of holography to imprint information into thin films of these systems. Three approaches for employing holography with LC materials were discussed. These included the fabrication of switchable, permanent gratings (holograms) by photocuring using a spatially periodic light exposure. The creation of a space-charge field by imaging light on a cured film containing dye-filled LC domains was also described. This technique allows for rewriteable information to be stored. The third technique used the trans-cis isomerization mechanism of a LC-based dye to induce local topographic and refractive index differences. In the ferroelectric LC area, the intricacies of different chiral smectic-C architecture were described that were obtained by using detailed x-ray structural experiments on freestanding films. In a related discussion, the differences between a molecule and a phase was explored and then followed by a current description of the status of banana-mania in which the shape of individual molecules resembles a banana. A number of nondisplay applications using this class of materials was also presented and included areas such as adaptive optics, real-time holography, and fiber-to-fiber interconnects. Nontraditional materials and applications were featured in a number of talks as well. Several of these centered on glass-forming liquid crystalline films and their ability to polarize photoluminescent emission, their utility in the fabrication of mid-wavelength infrared polarizers, and their utility in the fabrication of bistable electro-optical elements and broadband reflectors. The Symposium was very broad in nature covering small molecule to main- and side-chain polymer physics and chemistry in addition to topical discussions on a wide range of application areas.

Symposium Support: Everlight Chemical Industrial Corp. and Air Force Research Laboratory.

Luminescent Materials Display Their Colors

(See MRS Proceedings Volume 560)

Topics in Symposium E on Luminescent Materials covered synthesis, char-

MRS Presents Graduate Student Awards

The MRS Graduate Student Awards were presented by Vice-President of the Materials Research Society Harry A. Atwater of the California Institute of Technology and a previous recipient of the award himself, on Monday evening, April 5, during the MRS Spring 1999 Meeting in San Francisco.

*The **Gold Award** recipients are* (front row, left to right): ***Hans Boeve**, IMEC, Belgium (**J15.3**: Patterned Electrodeposited Spin-Valve Sensors; **L1.3**: Magnetic Anisotropy in Electrodeposited Co Films and Spin-Valves on GaAs Substrates; **L7.8/I9.8**: Structure and Magnetic Properties of Fe-N Thin Films Grown by ECR Deposition); **Ranee Stile**, Northwestern University (**EE2.3**: Injectable Thermo-Responsive Hydrogels as Scaffolds for Tissue Engineering Applications); **Amy Burkoth**, University of Colorado (**FF1.3**: Photocrosslinked Polyanhydrides as an* In Vivo *Polymerizable Biomaterial); and **Matthew Willard**, Carnegie Mellon University (**I3.3:** Magnetic Properties of HITPERM* $(Fe,Co)_{88}Zr_7B_4Cu_1$ *Nanocrystalline Magnets);* (back row, left to right): ***Erik de Jesus Sánchez**, Portland State University (**AA4.1**: A Novel Scheme for High Resolution Near-Field Microscopy—Two-Photon Fluorescence Imaging with an Illuminated Metal Tip); **Michael McGehee**, University of California—Santa Barbara (**B16.8/F9.8**: Narrow Spectrum Light-Emissive Devices Made from Blends Which Exhibit Energy Transfer from Conjugated Polymers to Rare Earth Complexes); and **Christopher Bowley**, Brown University (**D7.5**: Advances in Reflective Holographic Polymer Dispersed Liquid Crystal Technology). Not shown: **Kiran Pangal**, Princeton University (**A3.2/B5.2**: Integrated Amorphous and Polycrystalline Silicon TFTs with a Single Silicon Layer).*

***Silver Award** recipients are* (front row, left to right): ***Guanuan Yu**, Stanford University (**S8.3**: Two-Dimensional Dopant Diffusion and Activation Study Using Scanning Capacitance Microscopy); **Yuri Nahmad-Molinari**, CINVESTAV-IPN, Mexico (**HH3.9**: Sound Propagation in a Magnetorheological Fluid); **Dawn Takamoto**, University of California—Santa Barbara (**DD8.12**: Atomic Force Microscopy Study of the Reorganization of Langmuir-Blodgett Films); **Atsufumi Lumma**, Massachusetts Institute of Technology (**HH2.8**: X-Ray Photon Correlation Spectroscopy Study of the Microscopic Dynamics of Polystyrene Latex Suspended in Glycerol—Diffusive Dynamics and the Role of Confinement); and **Atsufumi Hiroshata**, University of Cambridge, England (**J8.6**: Magneto-Transport in Submicron Ferromagnetic Wire Structures with a Domain Wall Trapping; **K2.6**: Spin Dependent Electron Transport through the Ferromagnetic/ Semiconductor Interface);* (back row, left to right): ***Balaji Panchapakesan**, University of Maryland (**BB4.1**: Micromachined Array Studies of Tin Oxide Films—Nucleation, Structure and Gas Sensing Characteristics); **Alex Volinsky**, University of Minnesota (**M9.5**: Environmental Effects on the* Cu/SiO_2 *and* $CuTi/SiO_2$ *Thin Film Adhesion; **M9.6**: Acoustic Emission Analysis of Fracture Events in Cu Films with W Overlayer; **M9.10**: Macroscopic Modeling of Fine Lines Adhesion Tests); **Stephane David**, CNRS, France (**H3.4/I6.4**: Coercivity in Lean Rare Earth Nanocomposite Hard Magnetic Materials); and **Jacob Fage-Pedersen**, University of Aarhus, Denmark (**S4.3**: Sb- and Sn-Precipitation Induced Injection of Si-Self Interstitials in Si).*

acterization and optimization of luminescent materials for application in display, LED and FED devices; x-ray phosphors, phosphors for pressure, and temperature sensors; novel luminescent materials such as organic phosphors; luminescence processes in porous silicon, and nanosize phosphors; Er-doped silicon and wide-bandgap materials for electro-optics application; and theoretical and phenomenological investigation of luminescence mechanisms in solids.

These presentations revealed novel phosphors for display applications and LED lighting as an emerging field in luminescence. Papers on controlling the phosphor morphology and surface for display application, and tuning of the absorption and emission spectra of materials for LED application were among the highlights.

Weber Provides Leads for NSF Grants in Materials

Tom Weber, director of the Division of Materials Research (DMR) within the National Science Foundation (NSF), led the NSF Seminar "Materials Research Support at NSF" on Tuesday evening, April 6, now a regular feature at Materials Research Society Meetings. Cy Lapporte from NSF's Chemistry Division and Lance Haworth from DMR helped Weber field questions from the audience. Among the areas of opportunities in materials research, Weber listed education, materials by design, links to biology, complex materials and phenomena, development of new instrumentation ("microscopies"), and international activities. The topics for which NSF is trying to get funding from Congress include Information Technologies, Biocomplexity, and Education for the Future.

DMR is especially looking for international collaborations. NSF has held NAFTA and U.S.-European workshops and most recently Pan-American and U.S.-Asian Pacific workshops in 1998 to explore international collaboration in materials. A U.S.-Africa workshop is under discussion.

Weber also described FastLane, which is an Internet program that carries out electronic proposal submission and review among other NSF interactions. Starting July 1, 1999, all proposals to the Mathematical and Physical Sciences Directorate will be required to be submitted via FastLane.

Principal investigators (PIs) who meet the target date of November 1 for NSF proposals will have the best chance of obtaining a grant. DMR has chosen this date in correlation with the budget cycle. About 70% of the awards have been typically granted six months later in accordance with the Government Performance Results Act. Grant proposals for Instrumentation for Materials Research (IMR) and for Centers have specific deadlines which can be found on the NSF website: www.nsf.gov.

Nano- and Microstructure Important for Hard Magnets

Symposium H on Advanced Hard Magnets—Principles, Materials and Processing provided a forum to assess both the most recent advances and possible future directions in this rapidly growing field. The Symposium commenced with a tutorial on Concepts and Experimental Methods in Micromagnetism, presented by G. Hadjipanayis (Delaware) and R. Skomski (Nebraska). Basic atomic interaction and structural studies of pertinent rare-earth/transition metal compounds were presented from the first-principle electronic structure calculation view (S.S. Jaswal, Nebraska) and the experimental view (W.B. Yelon, Missouri; N.H. Luong, National Univ. of Hanoi). The connections between detailed composition, microstructure, and resultant magnetic properties were emphasized by invited presentations on processing (O. Gutfleisch, Institute of Solid State and Materials Research, Dresden) and microstructural modeling (J. Fidler, Vienna Univ. of Technology; R.W. McCallum, Iowa). Special emphasis was placed on talks detailing exchange-coupled magnetic nanocomposites. These materials, ideally synthesized from intimately mixed nanoscale grains of a magnetically hard phase and a magnetically soft phase, are postulated to constitute the next generation of advanced permanent magnetic materials. To date, exchange-coupled nanocomposite permanent magnet materials have not yet exhibited the outstanding performance predicted by theoretical models of these materials. It is hoped invited presentations by industrial researchers (S. Hirosawa, Sumitomo Special Metals; Q. Chen, Rhodia) and university researchers (S. David, CNRS—Grenoble; S. Majetich, CMU; and D. J. Sellmyer, Nebraska) on this topic will aid in further understanding and optimization of these novel materials.

To round out the Symposium, the wide variety of applications of advanced permanent magnet alloys and factors driving innovation—such as higher temperature capability, improved corrosion resistance, and lower cost—were discussed by industrial suppliers and users (V. Panchanathan, Magnequench International; S. Constantinides, Arnold Engineering; and M. Walmer, Electron Energy).

One of the highlights of the Symposium was an invited presentation on the properties of the novel ferromagnetic bulk glassy alloy Nd-Fe-Al (K.V. Rao, Royal Inst. of Technology, Stockholm). These alloys constitute a unique family of materials that requires only a modest cooling rate, 1–100 K/s, to form an amorphous solid from the melt. Among novel phenomena such as superplasticity, reduced coefficient of friction, and enhanced corrosion resistance, these materials also exhibit a large resistance to demagnetization which is not yet understood within the framework of conventional amorphous magnetic alloys.

Symposium Support: Brookhaven Science Assoc., Magnequence Int'l., Arnold Engineering, Electron Energy Corp., Advanced Materials Corp., and Lake Shore Cryotronics.

Magnetic Nanostructures and Magnetoelectric Transport Take a New Spin

In recent years there has been a great deal of excitement in the scientific and technological communities concerning advanced magnetic thin-film multilayer structures. An area of particular interest has been those materials which show enhanced magnetoresistive effects. It was only 10 years ago that GMR was found, first as a curiosity exhibited at low temperatures in highly perfect single crystalline multilayer films prepared by exotic MBE techniques, and shortly afterwards as a ubiquitous property of a wide range of metallic multilayers prepared using simple sputter deposition techniques. The latter discoveries made possible the technological application of GMR which has become the material of choice for magnetic recording read head sensors just in the past 18 months. Now that GMR is rapidly becoming a mature technology there is increased interest in materials beyond GMR.

Symposium J on Patterned Magnetic Structures and Magnetoelectronics highlighted, in particular, recent developments, both experimental and theoretical, of MTJ. These materials, comprised of sandwiches of ferromagnetic layers separated by thin insulating layers, display enhanced magnetoresistance values at room temperature of more than 40%. While MTJs have been known for more than 20 years, it has only been in the past four years that these materials have received much attention. Notwithstanding their long history, understanding of even the basic properties of MTJs is incomplete. A number of invited papers discussed recent advances in theoretical models of MTJs, both numerical and analytical. An important potential application of MTJs is for nonvolatile magnetic memory cells in MRAMs. Such MRAMs promise very high density and speed and, in particular, nonvolatility of the stored data even when power is removed from the memory. Such devices have been a quest of the military for a number of years but recent advances in MTJs and MRAM architectures suggest the possibility of their widespread application in the near future.

MRAM memory storage cells must be of submicron dimensions if MRAM is to become a reality. Thus the patterning of tiny magnetic devices is of critical importance. A number of talks discussed advanced methods of defining individual and arrays of small magnetic entities. Similarly, advanced methods of examining the detailed magnetic microstructure of such small devices was of great interest. Recent developments, particularly of PEEM, suggest that magnetic imaging on the scale of 10s of nanometers is on the horizon. Until such techniques are developed, micromagnetic modeling of small magnetic devices is even more important. Several talks at the Symposium described the state of the art of micromagnetic simulations, both in the spatial and temporal domains. These models give great insight into the magnetic properties of patterned magnetic nanostructures.

GMR and MTJs are just two examples of magnetic materials and devices whose fundamental properties depend upon spin-polarized transport. There is a consensus that there likely exists a wide variety of other materials and devices based on spin-polarized electrical currents which may be of significant importance.

Symposium Support: Showa Denko K.K., TDK Corp., Hitachi, ALPS Electric, Asahi Komag, NEC, ULVAC Japan, ONR, JEOL, and Toshiba.

Over 630 posters were presented in two evenings in both the Marriott and Argent Hotels in San Francisco during the Materials Research Society Spring 1999 Meeting.

Ferromagnetic, Semiconductor, and Superconductor Materials Take Their Turn

Symposium K on Hybrid Magnetic, Semiconductor, and Superconductor Structures focused on physics and materials science issues related to new materials systems that can enable novel categories of device structures. A dominant theme involved systems that incorporated a ferromagnetic component, and studies of spin-dependent transport. The rapid rise of research related to spin transport in all-metal magnetoresistors and MTJs now extends to semiconductors and superconductors. Ferromagnetic order in III-V semiconductors at relatively high temperature, novel heterostructures composed of semiconductors and ferromagnets, spin lifetimes of extraordinary duration in GaAs, and a variety of experiments relating to local, magnetic fringe field effects on carriers in III-V heterostructures were reported. Novel characteristics of ferromagnet–superconductor structures were related to spin-dependent transport or to proximity effects, and mesoscopic superconductor and semiconductor–superconductor device structures were presented. Included in a joint session with Symposium J were unique, time-resolved studies of the magnetization dynamics of patterned ferromagnetic elements.

Symposium Support: Keithley and ONR.

Copper Films and Magnetic Materials Studied in Polycrystalline Form
(See MRS Proceedings Volume 562)

Symposium L on Polycrystalline Metal and Magnetic Thin Films held a joint session with Symposium N on Advanced Interconnects and Contacts, focusing on the microstructure of plated Cu films. Various film properties leading to resistance transients (where the resistance of plated Cu films decays from 2.5 $\mu\Omega$ cm to around 2.0 $\mu\Omega$ cm at room temperature over the period of 10s of hours to many days) in plated Cu films were presented (Q-T. Jiang, Sematech, Motorola; M.E. Gross, Bell Labs/Lucent Tech; and B. Mikkola, Sematech, Motorola) and the mechanism of abnormal grain growth was used to explain resistance transients in plated Cu films (J. Harper, IBM). Joint sessions were also held with Symposia I and H. A variety of film growth, film deposition, and film characterization talks were presented. Clearly, the role of surfaces, interfaces, defects, film stress, and impurities are becoming more important as demands for tighter performance increase at the same time that the thickness (and often the width) of polycrystalline thin films decrease to the regime between 1 and 100 nm.

Symposium Support: IBM T.J. Watson Research Ctr. and MMC Technology.

Low-Dielectric Constant Materials and Copper Interconnects Integrated
(See MRS Proceedings Volume 564)

Symposium N on Advanced Interconnects and Contacts included state-of-the-art advancements in deep-submicron processes, materials, microcharacterization, and integration for ULSI, including silicides for MOSFET device contacts, and Cu and Al multilevel interconnect architectures. Two joint sessions were held, one with Symposium L on Cu microstructure with electroplated Cu featured, and one with Symposium O on low-k/advanced interconnect integration, with Cu/low-k as the main feature.

In the silicides sessions, work generally concentrated on advanced processes to stabilize the $TiSi_2$ C_{49}-C_{54} transition, for example, by addition of heavy-metal impurities, or characterization work on deep-submicron behavior of $CoSi_2$. One highlight was the display by F. Ross (IBM) of a real-time, *in situ* TEM video clip of the growth of $TiSi_2$ and $CoSi_2$, and the explanation of their respective differences in crystal growth. Another highlight was the novel finding by D. Mangelinck (National Univ. Singapore) that dilute additions of Pt or Ir can raise the stability region of low-resistivity NiSi (against the nucleation of $NiSi_2$) by 150°C to 900°C, and additionally raise the threshold temperature for agglomeration to 800°C. This advent may enable the consideration of NiSi for advanced CMOS.

The interconnect sessions were predominantly targeted at Cu interconnects, refractory damascene barriers, adhesion, and interactions at the Cu/barrier and barrier/SiO_2 interfaces. Significant advancement in the breadth of liner materials and understanding of integration issues was dis-

Semiconductor Industry Requires Increased Basic Research After Long Development Stage

In his plenary presentation, made on Monday evening, April 5, Paolo Gargini, the director of technology strategy at Intel Corporation, conveyed the impact of new materials on the past, present, and future of the semiconductor industry. He outlined the developmental cycle of the industry, as it began with a scientific phase early on, evolved into an engineering phase, and is now approaching a crucial point when it needs to revert to a scientific phase.

Beginning with the invention of the vacuum tube at the turn of the 20th century, Gargini described the industrial evolution pattern. The invention of the first electronic tube in 1905 was followed by fast market growth, during which time the number of tubes shipped each year grew exponentially. In the middle of this industrial revolution, in the late 1920s, nobody noticed when three patents were filed disclosing the concept of making a solid-state electrical device.

"The idea seemed extremely simple," Gargini said. "If you take a semiconductor material and apply a voltage at the two extremities, you will observe a very low flow of current. To increase the flow of current, all you have to do is to place a plate in close proximity to the semiconductor surface. As you apply voltage to this plate, charges of the appropriate polarity will be attracted to the surface of the semiconductor and will form a low-resistance layer. It seems very simple, but nobody could make it work."

Paolo Gargini, Director of Technology Strategy at Intel Corporation, presented the Plenary talk on April 5 at the MRS Spring 1999 Meeting in San Francisco.

From this time until 1947, much research occurred, pulling from various fields including physics and chemistry. Even after John Bardeen, Walter Brattain, and William Shockley invented the point contact and the junction transistor, still more research took place as scientists strove to invent the "right device." However, Gargini added, nobody could yet make the simple surface-effect device function because the dangling bonds left on the cleaved surface of the semiconductor were trapping charges, thus screening the underlying semiconductor from the electric field generated by the upper plate. Experimentation continued until the discovery that positioning an electrolyte between the plate and the semiconductor could overcome the detrimental effect of the dangling bonds. This revelation launched the search for a solid material that could simulate the behavior of electrolytes. Silicon dioxide grown on the surface of the silicon semiconductor was finally demonstrated successfully in 1960 by D. Khang and M.M. Atalla.

Gargini showed further achievements made between 1962 and 1972, when researchers explored the compatibility of silicon/silicon dioxide with aluminum, phosphorus, and boron, along with lithography and silicon gate processing to form a variety of integrated circuits. It was in the late 1960s when the evolution of semiconductors moved from the research stage into the business stage—the winning combination of materials had finally come together.

Large-scale manufacturing of integrated circuits, based on the scaling theory announced in 1974 by R.H. Dennard and others, proved an easy recipe to success. Since that time, engineers have found ways to incorporate a greater number of transistors into a smaller space, thus allowing the integration of complex systems onto one chip. Moore's Law, the underlying guide for the U.S. semiconductor roadmap, projects that the number of transistors per die will quadruple every three years. However, technology has exceeded this industry projection, and progress has been made at a faster rate yet.

Despite this progress in engineering, some of the initial materials are now beginning to reach their limits of applicability. For example, Gargini noted that at the current pace, the industry would reach the limits of what can be accomplished with SiO_2 by the year 2005 or so. As a gate dielectric, the use of a single monolayer of SiO_2 will be dictated by the rules of scaling, and no further reduction in gate oxide thickness can be accomplished. A new material with a higher dielectric constant (high k) is required. In addition, the use of a new conducting material with a resistivity lower than aluminum and a new insulator with a lower dielectric constant (low k) than silicon dioxide are required to reduce signal-propagation delay of interconnect lines. Copper is already being implemented as a replacement for aluminum, and a variety of low-k dielectrics are under evaluation. In light of this projection, Gargini said that the semiconductor industry will need to find viable alternatives to SiO_2 for both low-k and high-k applications. Similar considerations can be made for other materials currently used in other aspects of the fabrication of integrated circuits. With this is mind, material scientists must now refocus on basic research to address challenges in almost every field of the fabrication of integrated circuits, including lithography, interconnects, packaging technology, and so on.

"We need your help!" Gargini concluded.

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played. The joint L/N session concentrated on the phenomenon of room-temperature self-annealing behavior of certain electrodeposited Cu films, which has been studied intently for the past year. The highlight was the model of this phenomenon presented by J. Harper (IBM) where the Cu grain growth, resistivity drop, and compressive stress reduction are explained and calculated based on existing theory (Zener pinning, Ostwald ripening, Mayadas-Schatzkes grain boundary scattering, and Chaudhari grain boundary volume), and found to fall within the range of values observed. Also notable was the work of M.E. Gross, R. Drese et al. (Bell Labs/Lucent Tech) where extensive characterization by FIB, and x-ray pole figure analysis elicited differences in the self-annealing behavior versus process conditions, and differences of Cu texture in damascene trenches versus on blanket films.

The highlight of the low-*k*/advanced interconnect joint session was the invited talk by K. Yu (Motorola) where multilevel dual-damascene Cu/low-*k* integration was demonstrated with inorganic materials (nanoporous glasses), in one case with a material of dielectric constant less than 2.2. Although the net wiring capacitance is increased slightly due to the etch-stop and cap layers (of higher dielectric constant material) required for the integration, the overall capacitance, though not stated, was probably still low. This work showed significant advancement in the ability to yield multilevel integrated Cu damascene interconnects with these very soft materials, with defect densities purported to be approximately as low as Cu/SiO_2 builds. This included the $k < 2.2$ material, whose modulus is below 1 GPa. Leakages, via resistances, and distributions were indicated as being good (again, comparable to SiO_2) for these builds.

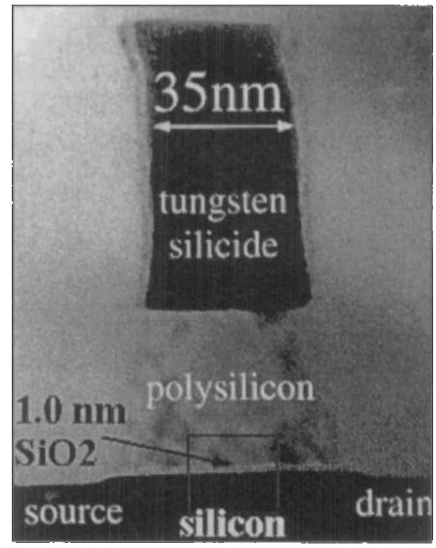
Symposium Support: Advanced Micro Devices, IBM T.J. Watson Research Ctr., and Novellus Systems.

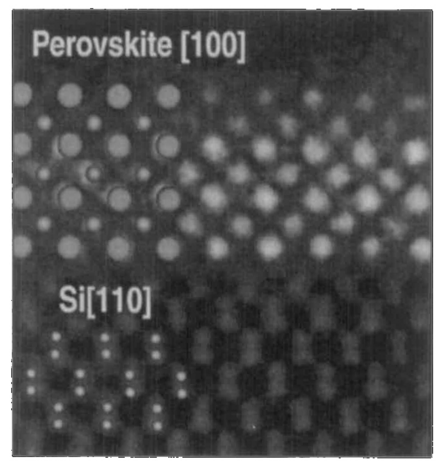
The Future of Gate Dielectrics Considered

(See MRS Proceedings Volume 567)

Symposium R on Ultrathin SiO_2 and High-*k* Materials for ULSI Gate Dielectrics provided an overview of many possible solutions for technologically critical issues associated with present-day and near-future MOS gate dielectrics. Topical sessions were held on a range of subjects including atomic-scale control of the dielectric/Si interface, advances in ultrathin oxides and oxynitrides, high-*k* alternate gate dielectrics, and a joint session with Symposium M on the reliability of ultrathin gate dielectrics.

Among the highlights, G.L. Timp (Lucent/Bell Labs) presented recent research on future generations of silicon technology that use SiO_2 as the gate dielectric with thicknesses down to 0.7 nm. In concluding his talk, Timp observed that he and his co-workers have "probed the end of SiO_2" [for use as a gate dielectric in conventional MOSFETs]. The upper figure is a TEM from Timp's presentation showing an ultrasmall transistor having a 35 nm gate length, and a 1.0 nm thick SiO_2 gate dielectric (which is slightly less than two Si lattice constants).





Many presentations illustrated the strength and weaknesses of various high-*k* materials, such as Si_3N_4, Ta_2O_5, TiO_2, $(Ba_{1-x}Sr_x)TiO_3$, and Al_2O_3, that might be used as replacements for SiO_2. Among the most innovative of these are ultrathin amorphous hafnium silicates deposited directly on silicon presented by G. Wilk (TI) and crystalline oxides presented by R.A. McKee (ORNL). As shown in the Z-contrast image in the lower figure, McKee has succeeded in epitaxially growing $SrTiO_3$ on (001) Si. (The left side of the image is inset with a model of the perovskite/silicon projection.) Capacitors and transistors showing promising electrical properties have been fabricated from these materials, and McKee said that it is an area of "enormous opportunity."

Symposium Support: NEC, Toshiba, Mitsubishi Electric, Hitachi, and TI Tsukuba R&D Ctr.

Creating and Controlling Porosity is Key to Next Generation Dielectrics

(See MRS Proceedings Volume 565)

The papers presented at Symposium O on Low Dielectric Constant Materials and Applications in Microelectronics addressed one of the key challenges for the semiconductor industry, namely, continuing the historic level of performance/price improvement as the industry moves to the 0.13 μm technology node and beyond. This Symposium considered the semiconductor application of low-dielectric constant materials as insulators for chip level wiring. The material set used in the current generation of semiconductor devices consists of silicon dioxide for the insulator, with a dielectric constant of approximately 4, surrounding aluminum wiring. For future devices, materials will be changed industry-wide to copper wiring and lower dielectric constant insulator. The advantages gained from this transformation include faster and lower power devices. The challenges associated with this materials change are enormous, as pointed out in this session and closely related symposia, such as Advanced Interconnects and Contacts (N), Polycrystalline Metal and Magnetic Thin Films (L), and Materials Reliability in Microelectronics (M).

The predominant theme of the materials discussed in this Symposium was the introduction and control of porosity in dielectric materials and methods of characterizing the properties of these films. Adding air-filled porosity can substantially reduce the effective dielectric constant of the material, but this technique also tends to reduce the hardness and thermal conductivity of the insulator. For materials applied by a spin process, several approaches were discussed. S. Baskaran (PNNL) and J. Brinker (SNL) presented work on self-assembled surfactant templated ceramic materials. Using various surfactants in an aqueous TEOS solution, porous films are produced with potentially useful mechanical properties. The pore distribution is random, giving isotropic material properties with pore sizes less than 3 nm. Dielectric constants in the range of 1.8 to 2.2 were measured (by nanoindentation) to have a film modulus of 15 GPa.

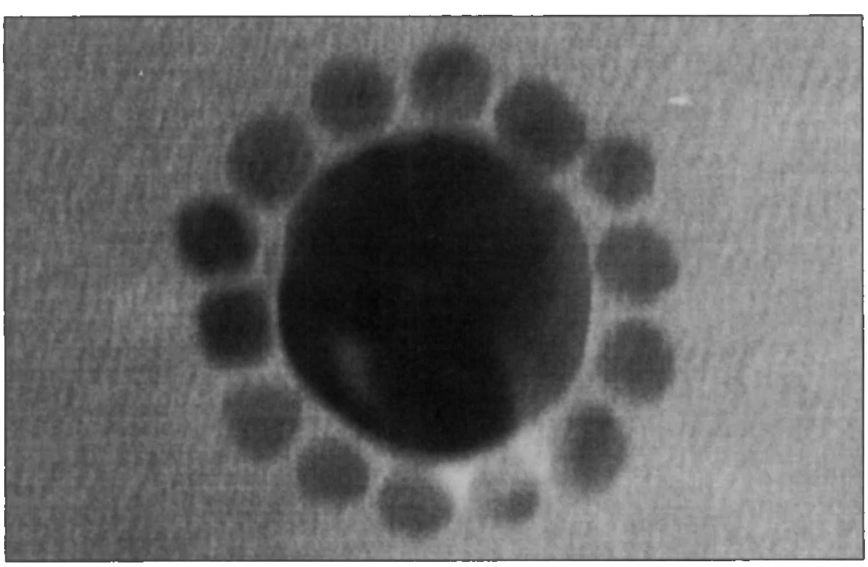
For materials produced using a CVD process, reduction in the dielectric constant was achieved by researchers from NEC Corporation. K. Endo (NEC) reported that the introduction of large, bulky phenyl groups attached to a silicate monomer results in an increase in porosity and resulting lower dielectric constant in films deposited by a PECVD process. The films are thermally stable and have properties similar to those of standard silicate films currently in use. In addition, the CVD process is also compatible with current tooling, making this a potentially attractive material for interconnect applications.

Symposium Support: FSI Int'l, Dow Chemical, AlliedSignal, and Tokyo Electron America.

Mirkin Presents Outstanding Young Investigator Award Talk

Outstanding Young Investigator award recipient **Chad Mirkin**, the Morrison Professor of Chemistry at Northwestern University, presented his award talk, "DNA-Based Methodology for Preparing Nanocluster Circuits and Arrays," as part of Symposium W on Semiconductor Quantum Dots. Mirkin focused on his group's use of DNA to direct formation of materials at the nanoscopic level. DNA has several significant advantages as a linking molecule. DNA was used to interconnect 13-nm diameter gold nanoparticles to form a network, resulting in a material that can be used in an ultraselective colorimetric detection scheme for DNA. For example, Mirkin's group has demonstrated single-base polymorphism selectivity in colorimetric polynucleotide detection. The system has been used to detect anthrax and can be utilized as a type of "litmus paper" for almost any viral, bacterial, or genetic disease. Mirkin also described recent efforts to use an AFM tip under ambient conditions to make molecular patterns with 15 nm resolution. This has applications in soft lithography and high-density information storage.

***Chad Mirkin** (Northwestern), who received the Outstanding Young Investigator Award, presented his talk on "DNA-Based Methodology for Preparing Nanocluster Circuits and Arrays" at the Materials Research Society Spring 1999 Meeting in San Francisco.*



Binary network materials formed from 8 nm and 30 nm gold particles linked with DNA.

Semiconductor Processing Benefits from Clean Start

Symposium Q on Ultraclean Processing of Semiconductor Structures and Devices presented papers related to the cleaning, analysis, and preparation of semiconductor surfaces. Most of the papers dealt with methods applicable to the processing of silicon microelectronics, although some presentations related to compound semiconductors and MEMS. The majority of the papers discussed either the interactions of process chemistry with silicon surfaces or methods of quantifying contaminants on silicon substrates.

Several papers were presented on methods of analysis for determining contamination levels on silicon surfaces. Detection limits of commercially available techniques as well as measurements using research tools (e.g., synchrotron TXRF) were discussed. Such presentations invariably led to dialogue over what levels of contamination are truly acceptable for state-of-the-art and future generation CMOS fabrication and what methods will be used to define these levels.

Several novel cleaning and passivation techniques were presented. Included in these was a method of silicon surface termination with methoxide through iodine activation and nucleophilic attack by methanol. A detailed discussion of surface chemistry relevant to cleaning and passivation was presented. Papers were also given on the use of hydrofluoric acid chemistries for silicon nitride etching. A mechanistic discussion of these chemistries was presented, as well as a discussion of process implementation in a production tool. Preliminary work on a supercritical fluid process for stripping implanted photoresist was presented. Although much work is needed to evaluate the manufacturability of such processes, the benefits of a damage-free, environmentally benign process are compelling. These benefits have driven recent research into the use of ozonated water processes to supplant sulfuric-acid-based chemistries for photoresist and organic contamination removal. Several papers were presented on advancements in the proven methods of ozonated water processing.

Symposium Support: Charles Evans & Assoc. and SNL.

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Ultrashallow Junctions Challenge Si Front-End Processing

(See MRS Proceedings Volume 568)

The aim of Symposium S on Si Front-End Processing—Physics and Technology of Dopant-Defect Interactions was to bring together materials scientists, TCAD researchers, and Si technologists to review recent developments in experiments and modeling and to identify key issues for future research. Two of the participants were Graduate Student Silver Award recipients Guanyuan Yu (Stanford) and Jacob Fage-Pedersen (Aarhus).

P. Packan (Intel) set the theme of the Symposium with a discussion on fundamental issues in scaling dopant profiles for submicron transistor design. The formation of ultrashallow junctions was one of the key issues of the Symposium, and annealing strategies to achieve such junctions were reviewed by A. Agarwal (Eaton Corp.). Transient-enhanced diffusion of B in Si was also a major topic this year. The importance of small clusters of Si self-interstitials in transient diffusion was demonstrated by N. Cowern (Philips Res.) and theoretical diffusion studies were reviewed by T.D. de la Rubia (LLNL). Modeling of {311} defects, which is one of the sources of the transient concentration of self-interstitials was reviewed by G. Hobler (Vienna Univ. of Technology), and results on dopant segregation to {311} defects were presented by K. Taniguchi (Osaka).

In the session on Physics of Dopants and Defects, P. Citrin (Bell Labs/Lucent Tech) presented a controversial model for the observed limit of free carrier densities of *n*-doped Si. Accurate 2D carrier profiling on real device structures is becoming very important and its present status was reviewed by W. Vandervorst (IMEC, Belgium). The present status of impurity diffusion in SiGe alloys was reviewed by A. Willoughby (Southampton), who emphasized the needs of accurate data on Ge.

Symposium Support: Intel, National Electrostatics, ORNL, Applied Materials, Eaton, Lucent Tech/Bell Labs, SEMATECH, and Silvaco Data Systems.

Variety of Compositions and Sizes of Semiconductor Wafers Engineered

A new symposium on Advanced Semiconductor Wafer Engineering (T) concentrated on questions of optimizing either crystal growth or wafer treatment procedures in order to obtain wafers best suited for advanced applications in microelectronics, power electronics, optoelectronics, or combined opto- and microelectronics. The Symposium dealt with all important semiconductors available in wafer form such as silicon, gallium arsenide, or silicon carbide. A special emphasis was put on wafer engineering issues associated with large diameter wafers ("large" having a different meaning for silicon or silicon carbide wafers) and so-called value-added wafers such as SOI wafers either generated by oxygen implantation (SIMOX wafers) or by wafer bonding, SiC-on-Si wafers as well as GaAs-on-Si wafers. The most important techniques to fabricate such value-added wafers were presented in invited and contributed talks from industrial, government, or university laboratories. A lively debate followed the presentations covering the subject of "universal compliant substrates" fabricated by twist wafer bonding. In a very well attended joint session with Symposium S, questions of defects and diffusion in silicon were reviewed and discussed.

Symposium Support: Sula Technologies.

Complementary *In Situ* Process and Modeling Techniques Advance Thin-Film Research

(See MRS Proceedings Volume 569)

A new generation of advanced thin-film-based devices will require the synthesis and *in situ* characterization of thin films and layered heterostructures, and the characterization of thin-film-based device processes. Therefore, Symposium U on *In Situ* Process Diagnostic and Modeling addressed many critical issues related to the synthesis and *in situ* monitoring and modeling of film-growth and device-related processes.

In the session on *in situ* ion and electron beam analysis, the invited presentation discussed a new time-of-flight ion scattering and recoil spectroscopy, which is capable, for the first time, of providing unique *in situ*, real-time insights into the vapor-induced growth processes of films in relatively high background gas pressure. The contributed talks provided information on the use of state-of-the-art conventional ion beam analysis and RHEED methods adapted to *in situ* characterization of film growth processes.

The presentations in Symposium U demonstrated the need for the development and application of a variety of complementary *in situ*, real-time characterization techniques to advance the science and technology of thin films and interfaces, which are critical to the development of a whole new generation of film-based devices.

Symposium Support: ANL.

Surface Passivation Critical for Electronic and Photonic Device Performance

(See MRS Proceedings Volume 573)

The major themes of Symposium Z on Compound Semiconductor Surface Passivation and Novel Device Processing were the use of novel approaches for surface passivation and device processing, and the application to optimization of electronic and photonic device performance. With the continued miniaturization of transistors for wireless communication, lightwave, and satellite applications and of lasers for data transmission, the role of the semiconductor surface has become increasingly critical in determining the device quality. Many of the talks addressed use of novel oxides for compound semiconductor FETs, a breakthrough achieved through the use of careful control of oxide stoichiometry. This now paves the way for development of metal-oxide transistors of the type used in Si technology and removes the need to rely on metal-semiconductor structures which suffer from poor thermal stability and control of the barrier height. In addition, native oxides are being used for efficient surface-emitting laser structures. A continued topic of interest is the use of low energy plasma processes for etching and deposition during device fabrication. These are needed because of the sensitivity of the compound semiconductor surfaces to creation of defects or change in stoichiometry by preferential loss of the group V element. There have been exciting advances in the development of inductively coupled plasma tools for low damage etching and deposition processes. These sources offer excellent control of incident ion energy and uniformity over large wafer areas. The Symposium attracted a diverse audience from academia and industry, which emphasized the strong interplay between basic science and its application to the technology of semiconductor device fabrication.

Symposium Support: Univ. of Florida and Johnsen Ultravac.

Near-Field Characterization Explores Structures Smaller than the Wavelength of Light

Many optically active material systems have spatial structure smaller than the wavelength of light. Thus many groups interested in the optical properties of material are striving to apply near-field spectroscopic and imaging techniques to an increasing variety of materials problems. This was evident in Symposium AA, Near-Field Scanning Optical Microscopy and Spectroscopy, which hosted talks that ranged over the science of semiconductors, metals, ferromagnetics, polymers, and proteins. Techniques were demonstrated to probe the local nature both of the material's linear optical response (scattered and luminescence) and nonlinear response.

Several groups discussed near-field microwave microscopy.

One area of intense scientific interest was on the submicroscopic physics that underlie the optical properties of semiconductors. An especially active focus in the Symposium was the spectroscopy of localized electrons and excitons in semiconductor heterostructures. Presentations in this area ranged from a study of the local character of InGaN heterostructures (D.K Young, UCSB) to a detailed study of the charge fluctuations in the two-dimensional electron gas in semiconductor quantum wells (I. Bar-Joseph, Weizmann Inst., Israel). A number of talks described single quantum dot spectroscopy and imaging. Few particle excitations in individual quantum dots (A. Zrenner, Walter Schottky Inst. Germany) and the local nonlinear response of an individual excitonic state (J. Guest, Michigan) were probed using near-field spectroscopies through fixed apertures. Although no one was able to image the dots themselves (~10 nm), images were presented of more extended states that diffused into the localized luminescing QD states, providing novel perspectives on excitonic diffusion (Q. Wu, Yale; K. Karrai, Ludwig Maximilians Univ., Munich).

The presentations made it clear that near-field microscopy and spectroscopy, although remaining a very demanding technique, is being applied to a quickly growing number of important materials problems.

Symposium Support: ONR and ARO.

Transition-Metal Oxides, Ferroelectrics Contribute to Electronics

(See MRS Proceedings Volume 574)

Symposium BB on Multicomponent Oxide Films for Electronics covered the broad applicability of complex oxides. Presentations ranged from theoretical explanations of the magnetic and electronic properties of transition-metal oxides to integration with silicon technology. Noteworthy is the progress that is being made in the deposition and characterization of these complex materials, as well as in their applicability in ferroelectric memories, MOSFETs, optical devices, and infrared imaging arrays.

T.H. Geballe (Stanford) discussed general features of the magnetic and electrical properties of transition metal oxides, specifically emphasizing the role of negative u-centers and forces between mercury atoms in the Hg-based high-temperature superconductors. He outlined a model in which by allowing the mercury atoms to rearrange in the lattice plane, the pressure dependence of these systems could be explained in terms of Josephson coupling.

Progress in MFSFET-type ferroelectric RAMs were reported by N. Fujimura (Osaka Prefecture Univ., Japan). Fujimura's research group fabricated ferroelectric $YMnO_3$ films on bare as well as Y_2O_3-buffered (111)Si. Although clear ferroelectric polarization could be observed, the unbuffered structures showed strong frequency dependence of the capacitance-voltage response, which was minimized by using the Y_2O_3 interlayer. Another transistor-type structure made use of the field-induced Mott insulator-metal transition at room temperature. A.G. Schrott (IBM) showed results using a modified approach in which the transistor gate is deposited on top of the Mott transition channel material (YBCO [p-type]; and Nd_2CuO_4 [n-type]) $SrTiO_3$ sandwich.

D-K. Choi (Hanyang Univ., Korea) showed the progress that has been made in RF magnetron sputter deposition of metallic oxide electrode materials such as (Ca, Sr)RuO_3 and (Ba, Sr)RuO_3. To achieve high dielectric constant and low leakage current, Choi's research group tuned both the lattice match and chemical match using (Ba,Sr)RuO_3. In addition, the doping effects in the BSR electrode were investigated to minimize the leakage current.

Symposium Support: ANL, LANL, and Digital.

Organic-Inorganic Hybrid Materials Designed from Atomic through Macroscopic Scales

(See MRS Proceedings Volume 576)

Rapidly growing interest worldwide in novel, low-temperature, solution-based synthesis of new functional materials was reflected in Symposium DD, Organic-Inorganic Hybrid Materials. The Symposium offered a comprehensive look at these materials from their synthesis to the broad scope of their useful properties and applications.

A recurring theme was "design of materials." The great versatility of organic-inorganic hybrids lies in the range of properties afforded by the combination of organic and inorganic constituents, and in the multiple length scales—from atomic, through molecular and mesoscopic, to micro- and macroscopic—over which the chemical interactions and structure of the materials may be controlled. This broad theme was subdivided among the individual sessions according to the length scale or property category of interest.

Design of materials on the molecular level was the focus of three sessions on hybrid synthesis. Reflecting the Symposium's origins in the "Better Ceramics Through Chemistry" series of the late 1980s and early 1990s, a significant number

Poster Prizes Awarded at the MRS Spring 1999 Meeting

The Materials Research Society Spring 1999 Meeting Chairs divided themselves between the San Francisco Marriott and the Argent Hotels during the poster sessions in order to choose the best poster presentation from each hotel. Seen in the photo are Meeting Chair Raymond T. Tung (Lucent), award recipient Melissa A. Petruska, and Meeting Chair Katayun Barmak (CMU) at the Marriott. Paul D. Calvert (Arizona) and James S. Speck (UCSB) attended the poster sessions at the Argent.

Poster Award prizes of $500 along with a certificate were presented: **Electrochemical Tailoring and Optical Investigation of Advanced Refractive Index Profiles in Porous Silicon Layers**, S. Zangooie, R. Jansson, and H. Arwin (Linkoping University, Sweden) (A18.3); **The Influence of Processing on the Texture of Electroplated Copper**, R. Drese, M.E. Gross, C. Lingk, W.L. Brown, and K. Evans-Lutterodt (Lucent) (N5.43); **Long Range and Local Structure in Transition Metal (Ti, Cr, Co)-Doped Lithium Manganate Spinels**, B. Ammundsen, D.J. Jones, and J. Roziere (Universitaet Montpellier II, France) and G.R. Burns (Victoria University of Wellington, New Zealand) (CC5.12); and **Metal Phosphonate Langmuir-Blodgett Films Containing Functional Organic Groups**, M.A. Petruska and D.R. Talham (University of Florida) (DD8.10).

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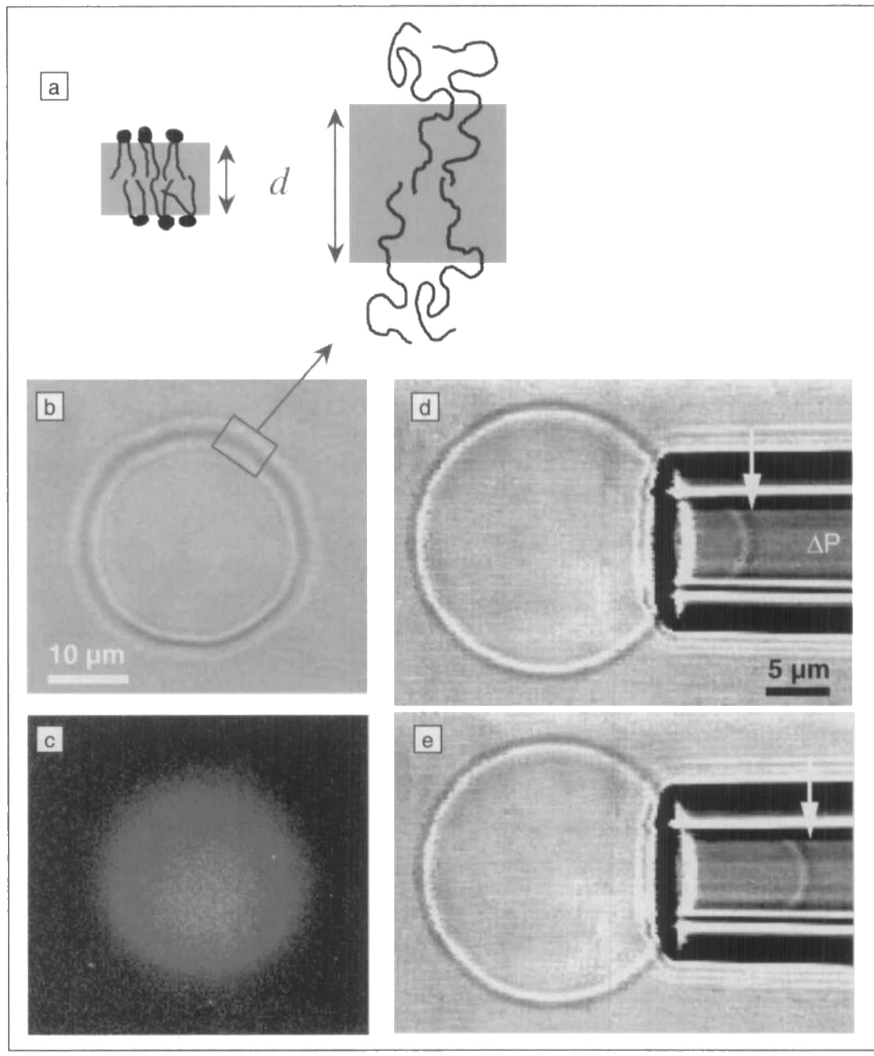
A Materials Bent on Biomembranes

In Symposium GG on Membranes, two sessions focused on biomembranes with a primary focus on molecularly thin assemblies of amphiphiles in or on aqueous solutions. D. Needham's (Duke) gave an overview of the use of the micropipet manipulation technique in establishing the material properties of lipid bilayers—two-molecule thick membranes made from lipids that surrounds every cell on the planet. The presentation included a description of the modes of membrane deformation, elastic expansion and failure, elastic modulus and drug binding and liposome circulation time, water permeability, exchange of surfactants, and intersurface adhesion, and showed how the technique has been instrumental in measuring the composition-structure-property and performance relationships for these ultrathin membranes.

Several groups described recent work on monolayer or bilayer (a, left) structures of lipid molecules—specifically elucidating phenomena arising with polymer or biopolymer interactions. In a new synthetic approach, "super"-amphiphilic polymers were shown capable of forming thin-shelled vesicles that were similar in morphology and properties to lipid vesicles (b). The collaborative work of D.E. Discher and D.A. Hammer at the University of Pennsylvania, and F.S. Bates at the University of Minnesota demonstrated not only the ability to encapsulate polymeric solutes (c) within these "polymersomes," but also proved, through the same methods of micromanipulation (d and e) introduced by Needham, that these synthetic membranes are significantly tougher, or more cohesive, than their natural counterparts. The results appear to lay the groundwork for a broad class of polymer-based, biomembrane mimics.



Symposium Support: Praxair Surface Technologies.

of papers dealt with the chemistry of silanes and other organometallic compounds. Subsequent sessions dealt with the design and synthesis of materials exhibiting order or porosity on the meso-, micro-, and/or macroscopic scales. Organic monolayers on inorganic surfaces were discussed, both as intrinsic hybrids and as agents for exerting control over materials' synthesis and structure.

Five sessions were devoted to properties and applications of hybrid materials: chemical (photochemistry, passivation, and sensing), biomedical, electronic, mechanical, and optical. In several of these areas, hybrid materials are used or are near use in commercial applications; attesting to the technological potential of organic-inorganic hybrid materials, presentations from industrial researchers (IBM, Lucent, Nippon Steel, Samsung, The Aerospace Corp., Affymetrix, NanoPore Inc., Hybrid Plastics, and IVOCLAR AG) constituted a significant portion of the program.

Symposium Support: Eastman Kodak, Chemat Tech., and 3M Advanced Materials Tech. Ctr.

Biopolymers Form Framework for Tissue Reconstruction, Genetic Manipulation, Biosensors

Symposium EE on Polymers in Biotechnology highlighted the excitement in this relatively new field. A number of talks focused on development of new polymers to support cell growth, for example in tissue reconstruction. J.L. West (Rice) demonstrated how poly(ethylene glycol) hydrogels decorated with biomolecules can be polymerized *in situ* to mimic the extracellular matrix. The materials mediate cell adhesion, are degradable, and can regulate cell processes. R.A. Stile (Northwestern) presented work on thermo-responsive poly(*N*-isopropylacrylamide). These materials are injectable at room temperature but undergo a phase transition at 37°C with a decrease in ductility. The gels support cell growth and can thus be considered for potential use in cartilage regeneration. S.I. Stupp (Illinois—Urbana-Champaign) reported on adhering fibroblasts to self-assembled lamellar solids, hinting at potential use in the design of novel therapeutic biomaterials. M. Yamato (Tokyo Women's

Symposium X Presents Technical Talks for the Nonspecialist

Symposium X, traditionally aimed at the nonspecialist, opened with a talk on Monday, April 5, by Wilfried von Ammon (Wacker Siltronic AG—Germany) on recent developments in the growth of silicon single crystals and silicon wafer manufacturing. He said that the major issue in silicon crystal growth is the transition to 300 mm wafers. This development involves high temperature fluctuations, increased corrosion of inner surfaces of the Si crucible, and difficult process control due to longer time constraints. Crystal growth will likely set an upper limit for wafer diameter. Von Ammon also discussed defects in the crystals, and slicing and polishing techniques. The multiwire slicing technique appears to be the only choice for 300 mm wafer slicing. In his discussion of epitaxy, Von Ammon suggested that the erosion of Si wafer prices during the last 12 months, and in the months to come, will cause dramatic changes in the silicon supplier community such as new alliances.

In the second Symposium X talk given on Monday, Tadahiro Ohmi (Tohuku University—Japan) addressed key materials for very high performance next-generation VLSI. With a drive toward a "system on a chip," the major issues involve metal substrate SOI VLSI, high permittivity gate insulator (Ta_2O_5/Si_3N_4) and metal gate electrode (Ta), low-*k* dielectric (PTFE) and copper interconnects with thermal through holes (AlN), ferroelectric films with low dielectric constants for nonvolatile memory, and high-*k* dielectrics for DRAMs.

Ferroelectrics have existed for a long time, but only recently have they reached the commercial market. Now smart cards based on ferroelectric materials are gaining use. In his Symposium X talk, Carlos A. Paz de Araujo (Symetrix and University of Colorado—Colorado Springs) said that device yields have achieved values of over 99%. The next task is how to handle high density configurations, which is being addressed with FeRAM stack cells. "It's duck soup," he said. This technology requires ferroelectric films scaled below 1000 Å. He reported near-zero fatigue degradation, low leakage current, and low dynamic imprint characteristics, which can be achieved through elimination of defects and contamination and proper stoichiometry. Development of conduction and diffusion barriers were also required. Ultrathin films with less than 10 ns switching speeds have been developed using spin-on and LSMCD processes.

Hiroshi Ishiwara (Tokyo Institute of Technology) described the fabrication process and typical behavior of an adaptive-learning neurochip. In the chip, metal-ferroelectric semiconductor FET snare were used as nonvolatile analog memories to store synaptic weight. The devices are fabricated on an SOI structure. The pulse width of each input signal applied to the gate is chosen to be much shorter than the polarization reversal time of the ferroelectric films. Thus the polarization of the film and the resistance between source and drain of the FET are gradually changed by application of a number of pulses, simulating the increased response of a neuron as it is stimulated. Ishiwara described the difficulty of depositing good ferroelectric films on silicon, offering some solutions and describing the fabrication process.

> A "Robofly" sits in two metric tons of mineral oil with bubbles so that the aerodynamics of flight can be studied by observing the movement of the bubbles.

David Wollman (NIST, Boulder, Colorado) offered a comprehensive overview of recent developments in x-ray characterization of materials. Semiconductor energy-dispersive spectrometry (EDS) has been the workhorse for qualitative analysis in electron microscopies. Wavelength dispersive spectrometry (WDS) has been used for trace analysis. The two techniques are complementary. Several detectors have been developed, including the cryogenic microcalorimeters, superconducting tunneling junctions, and near-room-temperature silicon drift detectors. After introducing these techniques, Wollman concentrated on the high-energy-resolution microcalorimeter-based EDS developed at NIST. The fundamental basis of this technology is the transfer of heat by x-rays hitting the detector and electrothermal feedback. The advantages are significantly improved resolution and speed. The microcalorimeter comprises a liquid He cooled compartment within a liquid N cooled container. A sample spectra on AlGaAs showed data that was comparable to EDS results. Several possible applications have been demonstrated, including resolution of peak overlaps in spectra, and pin point analysis of contaminant particles in the semiconductor industry, using very low energies <3 keV at which range the microcalorimeter has excellent resolution, measurement, and analysis of chemical shifts (such as for Al metal and Al_2O_3, Fe, and FeO-OH). Commercialization of the technique is in progress and Wollman suggested that a "well-dressed" SEM in the future would have the cryogenic microcalorimeter as part of the instrument. Several future improvements are also in progress, including multiple array detectors, and applications in x-ray astrophysics, IR astronomy, optical microscopy, and mass spectroscopy.

Two other Symposium X talks focused on biomimetic-related topics. Daniel Morse (University of California—Santa Barbara) addressed silicon biotechnology. Nature appears to have remarkable precision of nanoscale control and synthesis of scale as evidenced by the structure of the diatom. The synthesis process is conducted at low temperatures and ambient pressures. Morse discussed the use of silica spicules (from a marine sponge) for the study of the molecular mechanisms of biosilica synthesis. The proteins occluded within the silica called "silicateins" are homologous to a known family of protease (~50% identical and ~75% homologous). Biological systems appear to have evolved unique mechanisms of catalysis and organization in silicon biotechnology and a full understanding could lead to better material synthesis techniques and routes.

The other talk, by Michael Dickinson (University of California—Berkeley), was on "Flapping for Flight Forces: The Aerodynamics and Neurobiology of Fly Flight." Dickinson and his group study how sensory input alters motor patterns in insects and the resulting kinematic changes that modulate production of aerodynamic forces. Dickinson mentioned that insects were the first to evolve active flying. Insect flight is different from fixed wing aircraft. The quasi-steady-state theory in aerodynamics does not explain the lift generated by the wings of an insect. Dickinson's studies have indicated that lift is generated mainly during downstroke and the latter half of the upstroke. A "Robofly" has been developed in the laboratory that can simulate various aspects of fly flight. The robofly sits in two metric tons of mineral oil with bubbles so that the aerodynamics of flight can be studied by observing the movement of the bubbles. Dickinson showed video clips of different movements of the machine. He concluded the talk by indicating that these studies could conceivably lead to the building of micromechanical robots in the future.

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Medical University) explained the use of thermo-reversible poly(*N*-isopropylacrylamide) as a scaffold to manipulate cells into the architectures of organs.

Genetic manipulation and property characterization of materials produced by living organisms was a theme as S. Williams (Metabolix) described the alteration of the properties of biologically produced polyhydroxyalkanoate polyesters through the control of the monomer pendant groups. A. Chilcoti (Duke) and V.P Conticello (Emory) discussed the genetic manipulation of elastin sequences, fusing segments with temperature-dependent soluble/insoluble phase transitions to target proteins for use in protein purification. Dragline silk and collagen were the subject of reports by Y. Qu (Emory) and H. Bianco-Peled (Minnesota), respectively. M. Grandbois (Ludwig-Maximillians-University, Munich) described studies using STM, with sensitivities greater than 10 pN, to measure forces associated with molecular recognition. He attached polysaccharides to the AFM tip and measured the 50–100 pN attractive forces between them and living cells.

Biosensors were the theme when M. Stone, (Wright-Paterson AFB) described his work on the exquisitely sensitive IR sensing organs in snakes. B. Spangler, (Montana State) described her biosensors based on quartz crystal microbalance technology and Q-H. Hu (Guteborg Univ.) used the same technology to study the interaction of cells with polymer surfaces. P.B. Messersmith (Northwestern) presented novel methods of forming calcium phosphate minerals and polymer hydrogels *in situ* after trapping their reactive precursors in liposomes.

Symposium Support: ARO.

New Materials and Surface Modification Techniques Find a Place in Biomedical Materials

Symposium FF on Biomedical Materials provided numerous examples of how material design can alter the interaction of cells and tissues with biomedical implants. The field of biomedical implants has historically involved a very narrow group of materials. The Symposium emphasized the wide variety of not only new materials which are being considered for implants but the incredible diversity of surface modifications which will enable research and development teams to generate a new class of "smart" materials. These new materials are being analyzed using recent advances in combinatorial library analysis. High throughput biological analysis systems have begun to identify new candidates for the next generation of biomedical implants.

The field of tissue engineering will continue to supply a variety of new artificial organs and tissue substitutes. The construction of these devices will depend immensely on the correct selection of materials in the form of polymer sheets and 3D scaffolds. These new scaffolds will serve as a stable foundation for the attachment and growth of cells leading to the formation of functional tissue substitutes.

The power of modern biological techniques to evaluate material-related tissue responses was actively discussed. With the completion of the human genome project and current understanding of gene-directed body responses to biomedical implants, the development of fully functional biomedical implants is on the horizon. Each tissue implant will undoubtedly require tissue-specific materials. The differences in material design for bone, liver, blood vessels, and skin were discussed with the presentation of examples of tissue specific material design.

Research Flows in Area of Soft Condensed Matter

Complex fluids and soft condensed matter have long been topics of the Fall MRS Meetings in Boston, but this Spring was the first time these topics were represented at the San Francisco Spring Meeting as Symposium HH, Soft Condensed Matter—Fundamentals and Applications. Four material classes were covered: gels, colloids, electro- and magneto-rheological fluids, and fiber suspensions.

H. Winter (Massachusetts) provided an in-depth review of rheological measurements as probes of gelation in both chemically reacting and crystallizing systems. Gelation of polyolefin polymers from the melt occurs at crystallinity values of 1–2%—far lower than previously thought. P. Mather (Wright Patterson AFB) demonstrated the utility of aqueous gels as hosts for nonlinear optical absorbers for laser light damage protection. N. Wagner (Delaware) presented x-ray reflectometery measurements of gelatin adsorption on air/water and solid/water interfaces using Cesium counterions to enhance contrast. S. Khan (North Carolina State) investigated fumed silica dispersions used as fiber optical cable filler materials. The modulus of gel could be correlated with the solubility parameter mismatch of the chemically modified silica surface and the liquid phase.

Highlights of the colloid session included a report of space-based experiments of hard sphere crystallization of colloids in microgravity (Z. Cheng, Princeton). The principal result was the absence of a glass transition in microgravity, whereas on earth the glass transition occurs. Two reports described advances in using x-ray synchrotron sources to study dynamic processes such as reptation in polymer melts (D. Lumma, MIT) and ferrofluids (J. Lal, ANL). M. Carasso (Bell Labs/Lucent Tech) described algorithms for determination of particle size distributions in colloidal suspensions using simple acoustic or optical transmission instruments.

Numerous elegant commercial applications of MR fluids were described by J.D. Carlson (Lord). The use of a sponge to contain the MR fluid greatly reduces the volume of the MR fluid and facilitates inexpensive manufacture of devices of complicated geometry. ER fluids remain commercially nonviable, but D.J. Klingenberg (Wisconsin) has postulated that charge injection from metal electrodes is the source of nonideal behavior.

Flocculation of fibers was a dominant theme. The physical origins were diverse, ranging from charge-induced aggregation (J. Tang, Harvard Medical School) and an entropically driven phase in biopolymers (S. Fraden, Brandeis) and in emulsions (T. Mason, Exxon), to aggregation of fibers in flow. Key factors controlling flocculation of large rods in flow were shown to be the length-to-diameter ratio (*L/D*), interrod friction, and rod flexibility (R.J. Kerekes, Univ. British Columbia; D.J. Klingenberg, Wisconsin). The density of random-packed rods was shown to have two different scaling behaviors, scaling as *L/D* for dry rods (A.P. Philipse, Utrecht) and as the square of (*L/D*) for rods suspended in fluid (R.J. Kerekes, Univ. British Columbia). MRS

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