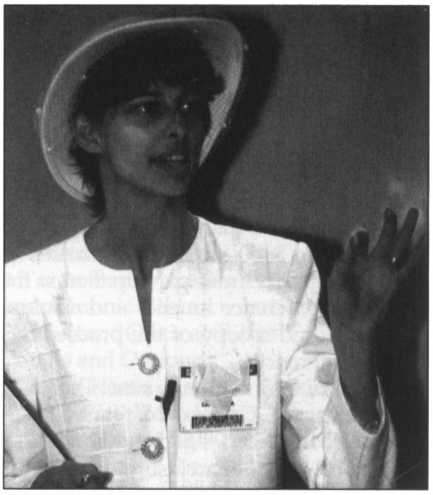
# MRS 1998 Spring Meeting Encompasses Broad Spectrum of Materials Research

The 1998 MRS Spring Meeting was held in San Francisco at the downtown Marriott Hotel April 13–17, 1998. Comprising a record 32 technical symposia and with about 3,000 attendees, the meeting included several joint sessions between symposia, three major poster sessions, with nearly 500 posters, and several tutorials as well as the exhibit. The Meeting was chaired by John A. Emerson (SNL), Ronald Gibala (Univ. of Michigan), Caroline A. Ross (MIT), and Leo J. Schowalter (RPI).

Parallel with symposia sessions and presentations, several events took place during the meeting. An NSF Seminar on Materials Research Support was held Tuesday evening to describe various materials-related programs. Senior NSF staff discussed ways for researchers to improve their chances for obtaining NSF funding. In addition to programs in specific sectors of materials science such as ceramics, metallurgy, polymers, solid-state chemistry, and condensed matter, the Office of Multidisciplinary Activities offers special assistance for noncore proposals. Attendees were encouraged to contact program officers for information on programs. In addition, an informal drop-in session was held for attendees to directly discuss NSF funding-related issues with personnel. See also *MRS Bulletin*, March 1998, page 67 for a report on the NSF presence at the 1997 MRS Fall Meeting in Boston.

*The plenary speaker at the 1998 MRS Spring Meeting in San Francisco, **John P. Lockwood**, president and chair of Geohazards Consultants International, Inc., described his work with volcanoes, the source of chemical elements found on the surface of the earth.*



***Anne M. Mayes**, a professor in the Department of Materials Science and Engineering at the Massachusetts Institute of Technology, received the MRS Outstanding Young Investigator Award. She presented her award talk, "Tailoring Polymer Surfaces for Controlled Cell Behavior," in Symposium CC at the 1998 MRS Spring Meeting in San Francisco.*

### Special Sessions and Awards

The plenary session held on Monday also included award presentations. The plenary speaker, **John P. Lockwood**, president and chair of Geohazards Consultants International, Inc., described his work with volcanoes. He said that volcanoes are the source of chemical elements found on the surface of the earth. He showed several photographs of erupting volcanoes and described two classes: red volcanoes that spew out lava, and the grey volcanoes, typically conical ones, that do not actually expel lava but rather emit high-temperature incandescent rocks and ash. Lockwood also described current worldwide efforts to control lava flow following an eruption. One of his recent projects was as consultant to *Dante's Peak*, a movie about a volcanic eruption. While showing two video clips from the movie, he talked about the issues involved in the production. He mentioned that overall the movie was realistic and faithfully represented volcanic science.

The Outstanding Young Investigator (OYI) award was presented to **Anne M. Mayes**, a professor in the Department of Materials Science and Engineering at MIT. In Symposium CC, Mayes presented her award talk "Tailoring Polymer Surfaces for Controlled Cell Behavior" to an overflowing room. Polymer scaffolds are currently under development, for example to direct cell adhesion to regenerate organs. The polymer surface needs to have the ability to prevent proteins from infiltrating the surface causing deleterious cell interactions, while tethered end-chains need to attract appropriate signaling molecules. Taking a materials science viewpoint, Mayes described how linear and star polymers affect surface coverage and cell adhesion. She reported several of her students' findings including those using star-shaped polymers that have many arms and gain in end functionality but can create traps for proteins. Looking both at self-consistent field calculations and experimental results, the best approach is described as a self-assembling blend of linear and star polymers to further control the surface behavior. Additional modifications can further improve protein resistance.

During the plenary session, Alan Hurd (SNL), Treasurer of MRS, presented six Graduate Student Awards selected from 15 finalists, and the Meeting Chairs presented eight poster awards during the course of the Meeting (see respective sidebars).

### Technical Sessions

Symposia D and H presented topics on defects and impurities. In Symposium D, Y.H. Lo (Cornell Univ.) presented an example of lattice defect engineering for semiconductor heteroepitaxy featuring intentionally misaligned bonding of an ultrathin semiconductor layer to a bulk crystal wherein the twist boundary underneath makes the thin layer atomically springlike or compliant for overgrowth. The substrate can absorb high levels of lattice strain and grow dislocation-free thick epitaxial layers. Other innovative ideas reported included deuterium sintering to improve Si MOS hot carrier reliability, the "smart-cut" process incorporating SOI using controlled fracture of a buried hydrogenated layer, and a novel non-



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volatile MOS memory device using proton trapping in the gate dielectric. H.J. Queisser (MPI—Stuttgart) eloquently described the emergence of quantum theory and the opposition it faced even into the 1930s. While the quantum theory and the-ory of transistors was soundly based, it was not until defects in materials could be controlled that the simplicity and usefulness of FETs could be realized. Queisser said that the invention of the first transistor in 1947 proved that semiconductors can be understood quantitatively and can be controlled, thus making semiconductors a respectable part of physics. At that time single-crystal semiconductors seemed like a dream, but the need for control of defects literally drove the growth of semiconductor crystals, now moving toward 300-mm-diameter single-crystal wafers.

Symposium H covered Hydrogen in Semiconductors and Metals. Hydrogenated silicon forms trihydrides on the surface and within the bulk. Hydrogen storage in carbon nanotubes with 5–10 wt% storage was reported which is 3–5 times better than metal hydrides for H storage. Rare-earth hydrides such as Gd-Mg-H exhibit remarkable optical properties with H storage. The materials are metallic in the absence of H, but become transparent and colorless insulators when loaded with H.

Various symposia addressed diffusion and epitaxial growth. Diffusion in crystalline materials, covered under Symposium Z, is important from a fundamental and practical point of view. Several recent advances in experimental techniques were reported such as nuclear scattering of synchrotron radiation, positron lifetime measurements, and perturbed angular correlations of gamma rays. One of the more significant topics of the Symposium was diffusion mechanism in intermetallic compounds. C. Herzig (Univ. of Münster) reported on simultaneous measurements of grain boundary diffusion and segregation characteristics by using carrier-free radiotracer isotopes and advanced detection techniques.

Materials scientists and applied mathematicians working on modeling and simulation of microstructural evolution in bulk and thin film materials met in Symposium BB on computational and mathematical models of microstructural evolution. Several subdisciplines were covered including the new mathematical concept of gradient flow as an alternative and more powerful means of categorizing the kinds of interface motion laws that govern microstructural changes. Two sessions focused on phase-field models and provided new information on the application of systems of Cahn-Hilliard equations to model phase evolution of multicomponent alloys and on the asymptotic behavior of diffuse interface approaches applied to solidification processes. A session on multiscale simulations on materials processes compared the relative merits of bridging the length and time scales within a unified model, and of using coupled models operating at different length or time scales.

Talks in Symposium AA reported on and reviewed recent progress in epitaxial growth of metallic systems. The increasing reliance on modeling to reduce cost of new materials development was evident. The 1996 MRS Medalist, J.D. Tersoff (IBM T.J. Watson Research Center), presented simple models of the complex interplay of strain and thermodynamics. Depending on the magnitude of the effects of each factor, alloy decomposition and "spontaneous" superlattice formation (leading to

**ACRONYM KEY**

- **AFB:** air force base
- **AMD:** Advanced Micro Devices
- **ANL:** Argonne National Laboratory
- **ARO:** Army Research Office
- **ASIC:** application-specific integrated circuit
- **BNL:** Brookhaven National Laboratory
- **CMOS:** complementary metal oxide semiconductor
- **CMR:** colossal magnetoresistance
- **CVD:** chemical vapor deposition
- **DAFS:** diffraction anomalous fine structure
- **DARPA:** Defense Advanced Research Projects Agency
- **EL:** electroluminescent
- **EXAFS:** extended x-ray absorption fine structure
- **FED:** field emission display
- **FET:** field-effect transistor
- **FIM:** field ion miscroscopy
- **GE:** General Electric Corporation
- **GM:** General Motors
- **GMR:** giant magnetoresistance
- **HEMT:** high-electron-mobility transistor
- **HP:** Hewlett-Packard Company
- **HTS:** high-temperature superconductor
- **IC:** integrated circuit
- **ILD:** low dielectric constant interlayer
- **ir:** infrared
- **LANL:** Los Alamos National Laboratory
- **LBNL:** Lawrence Berkeley National Laboratory
- **LCD:** liquid-crystal display
- **LED:** light-emitting diode
- **LEEM:** low-energy electron microscopy
- **MBE:** molecular beam epitaxy
- **MEMS:** microelectromechanical system
- **MIT:** Massachusetts Institute of Technology
- **MLDAD:** magnetic linear dichroism in the angle distribution
- **MO:** magneto-optic
- **MOCVD:** metal-organic chemical vapor deposition
- **MOS:** metal-oxide semiconductor
- **MOSFET:** metal-oxide semiconductor field-effect transistor
- **MPI:** Max-Planck-Institute
- **MR:** magnetoresistance
- **NCSU:** North Carolina State University
- **NEA:** negative electron affinity
- **NIST:** National Institute of Standards and Technology (note the correction made from the Acronym Key listed in *MRS Bulletin*, March 1998, p. 60)
- **NMR:** nuclear magnetic resonance
- **NREL:** National Renewable Energy Laboratory
- **NSF:** National Science Foundation
- **OLED:** organic light-emitting display
- **ONR:** Office of Naval Research
- **PDMS:** Polydimethylsiloxane
- **PEEM:** photoelectron emission microscope
- **PEO:** polyethelene oxide
- **PLD:** pulsed laser deposition
- **RHEED:** reflection high-energy electron diffraction
- **RIE:** reactive ion etching
- **RPI:** Rensselaer Polytechnic Institute
- **rt:** room temperature
- **RTCVD:** rapid thermal chemical vapor deposition
- **RTP:** rapid thermal processing
- **SAXS:** small angle x-ray scattering
- **SEM:** scanning electron microscopy / microscope
- **SNL:** Sandia National Laboratories
- **SOI:** silicon-on-insulator
- **STM:** scanning tunneling microscopy
- **TEM:** transmission electron microscopy
- **TFT:** thin-film transistor
- **TI:** Texas Instruments
- **UCLA:** University of California—Los Angeles
- **ULSI:** ultralarge-scale integration
- **UNM:** University of New Mexico
- **UV:** ultraviolet
- **VME:** vacuum microelectronics
- **VPI:** Virginia Polytechnic Institute



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quantum wires) was seen in an ordering alloy, or stress induced surface roughening. A.F. Voter (LANL) outlined the "hyperdynamics" method suited for systems undergoing infrequent events to solve the problem of limited simulation times in molecular dynamics.

Symposium FF covered recent developments in Si-based heterostructures. Topics covered included new epitaxial growth and characterization methods for $Si_{1-x}Ge_x/Si$ heterostructures, growth and characterization of $Si_{1-x}Ge_x$ and $Si_{1-y}C_y$ alloys and Ge quantum dot structures, advances in SiGe heterojunction bipolar transistor, and BiCMOS integrated circuits for wireless telecommunications applications.

The continued miniaturization of device circuits was covered in several symposia. D. Yoon (IBM—Almaden), S. Martin (Dow Chemical), and D. Smith (Nanopore) led a lively panel discussion held Wednesday evening in Symposium E on the future of low-$k$ dielectrics on both how to achieve $k$ less than 2.0 and how the material will be processed in a way that is compatible with current semiconductor technology. The issue is important for devices as feature spacing shrinks because electrical isolation then needs to be achieved with less material between metals lines. Since air has a low dielectric constant, the panelists agreed that a porous material is needed, but the matrix material could be polymer, ceramic, or a hybrid. Regardless of material, the challenge is to control pore size and to integrate the process. Pores need to be smaller than 5 nm, with no large "killer" pores that can destroy the mechanical integrity of the small structures. Martin gave the case for using organic polymer matrices, showing that it is possible to get an effective dielectric constant of 2.0 by incorporating 20% porosity in a material of base dielectric constant of 2.6. Smith showed the relationship between dielectric constant and porosity for different morphologies, demonstrating the importance of how the pores are arranged. Yoon described hybrids combining a thermally decomposable polymer with a high-temperature polymer to create a nanotemplated film with low moisture uptake, low CMP rate, and improved crack resistance. C. Brinker (SNL) followed up by proposing a material based on a molecular template with controlled pore sizes down to 2 nm and very low diffusion through it.

According to presentations in Symposium I, new materials such as Cu and its alloys, polymer ILDs, and epitaxial contacts to compound semiconductors are under consideration to replace conventional materials for the continued miniaturization of devices. Recent developments were reported along with new processing schemes and physical layouts.

A panel discussion in Symposium Y (Advances in Laser Ablation of Materials) was held in honor of the 10th anniversary of PLD of HTS films. While PLD has not yet blossomed commercially, and even the first applications may not be for high-temperature superconductors, the tremendous practical value of this technique and the role of these superconductor materials clearly came through. As one panelist said, PLD is the "fastest thin-film prototyping technique." The technique as a research tool is able to take a material of potential interest of essentially any composition and very quickly deposit it into a thin film. One role of the superconductor frenzy was to catalyze PLD development.

Symposia J, K, and DD addressed the issues of packaging and reliability. Symposium J emphasized flip-chip technology. Important themes included debonding and crack propagation and characterization of thermomechanical behavior of electronic package structures. Interconnects were examined from the point of view of bump and underbump metallurgy, joint stresses, and mechanical reliability. S. Suresh (MIT) described how fracture and fatigue at interfaces in elec-

## Poster Prizes Awarded at the 1998 MRS Spring Meeting

The 1998 MRS Spring Meeting Chairs John A. Emerson (SNL), Ronald Gibala (Univ. of Michigan), Caroline A. Ross (MIT), and Leo J. Schowalter (RPI) awarded eight prizes for best poster presentation. Prize recipients from poster sessions received $500, a certificate, and the honor of having the winning poster displayed for the remainder of the Meeting. Poster Award recipients are **The Plasticity Response of SiC and Related Isostructural Materials to Nanoindentation: Slip vs. Densification**, T. Page (Univ. of Newcastle, UK), L. Reister (ORNL), and S. Hainsworth (Univ. of Newcastle, UK) (T5.5); **Separation of GaN Thin Films from Sapphire Substrates Using Pulsed Laser Processing**, W. Wong, T. Sands, and N. Cheung (Univ. of California—Berkeley) (F5.25); **Structure and Surface Morphology of Epitaxial Ni Films on MgO(111) and (001) Substrates: Evidence of van der Waals Epitaxy**, P. Sandstrom, E. Svedberg, J. Birch, and J-E. Sundgren (Linkoping Univ., Sweden) (AA6.10); **A Two-Step Low Temperature Process for a *p-n* Junction Formation due to Hydrogen-Enhanced Thermal Donor Formation in *p*-Type Czochralski Silicon**, R. Job (Univ. of Hagen, Germany), W. Fahrner (Univ. of Hagen, Germany), and A. Ulyashin (Belarussian State Polytechnical Academy, Minsk) (H8.6); **In-Plane Anisotropy of Giant Magnetoresistance in Co/Cu Multilayers Electrodeposited on Si(001) Substrates**, M. Shima, L.G. Salamanca-Riba (Univ of Maryland), T.P. Moffat, R.D. McMichael, and L.J. Swartzendruber (NIST) (L9.3); **Reaction Engineering Approach to Bicomponent Alkoxysilane Co-Condensation**, S. Ranking and A.V. McCormick (Univ of Minnesota) (O8.8); **A Novel System for Semiconductor Contamination Analysis**, B. Lagel (Robert Gordon Univ., Aberdeen, UK) (D12.8); and ***In Situ* Nanoindentation of Electrochemically Modified Surfaces**, S. Corcoran (Hysitron Inc.) (T5.9).



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tronic packages can be modeled and controlled. He looked first at encapsulants and the effects of roughness and then described how lasers can be used to control fatigue cracking. The aim is to ensure that cracks propagate slowly, and are prevented from reaching the interface.

The increasing complexity of present and future microelectronic devices makes it mandatory to confront materials reliability issues. These were covered in Symposium K. The differences between thin-film mechanical properties of Cu and Al were discussed by S. Baker (Cornell Univ.) while D. Brown (AMD) discussed modeling issues, particularly when knowledge gleaned from Al models is applied to other materials systems.

As the use of photonic materials proliferates, reliability of such devices—base components, hybrid integration, and packaging—has become an issue. A series of papers in Symposium DD examined materials reliability issues associated with waveguides, packaged devices, wiring, optical fibers, and other components of photonic systems. While the active Er-doped silica has relatively few reliability problems, problems with the pump laser still persist. Also, light guide fibers suffer from several problems such as defects and other variations along their length causing strength to drop precipitously and water and stress effects on surfaces to cause further strength losses.

Several symposia demonstrated various materials aspects of display technology. Organic EL devices were the focus of Symposium G, emphasizing high-performance electroluminescent polymers, the improvement of polymer OLED lifetimes and power efficiencies, and novel patterning schemes for multicolor display applications. Philips Electronics announced that a unit will be established in the Netherlands for the development and manufacture of light-emitting polymers. Researchers from Dow Chemical, Siemens, and HP described efforts to develop devices and displays. The development of a self-compensating intelligent four-transistor pixel by a group from Sarnoff Corp., Princeton Univ., Eastman Kodak, and Planar America was reported to overcome variations in large area TFTs. Also Y. Yang (UCLA) reported on a patterning scheme using an ink-jet printer to create a polymer-based LED.

The theme of most papers presented in Symposium C on Materials Issues in Vacuum Microelectronics focused on the fabrication, characterization, and modeling of electron field-emitting materials. C. Spindt (SRI Intl.) gave an overview of important issues in the fabrication and operation of field-emitter arrays. In a joint session with Symposium B, B. Gnade (DARPA) reviewed DARPA's high definition systems program. Some of the display programs currently supported by DARPA include high definition LCD, EL displays, new phosphor technologies, and newer display technologies such as OLEDs. In addition, C. Spindt (Candescent Tech.) and A. Talin (Motorola) discussed their respective programs for bringing FEDs to commercialization. R. Nemanich (NCSU) reviewed work done by his group on electron emission properties of wide bandgap materials such as diamonds and nitrides, including demonstration of negative electron affinity for epitaxially grown AlN and AlGaN.

Talks were presented in Symposium A on the development of silicon nanowires made by laser ablation of Si followed by condensation in a sharp temperature gradient, and a complete top-gate process for making a-Si:H and laser crystallized poly-Si TFTs side-by-side. S. Guha (United Solar Systems Corp.) talked about advances in materials issues in the commercialization of amorphous thin-film photovoltaic technology. Mentioning that the distinction between amorphous and nanocrystalline silicon is fading for solar cell applications, he suggested that among various architectures, a triple junction multibandgap structure offers the best promise for improved efficiency. Progress in solar cell efficiencies, photodilation effects in a-Si:H, and photodetector applications formed some of the other major issues discussed.

High-density magnetic recording is a rapidly developing field and was the topic of Symposium L. Materials advances have accelerated the pace of information storage densities. Major topics presented and discussed included performance, structure, and mechanisms for improved MR sensors, including GMR, CMR, and tunneling head sensors, effects of compositional microstructure on media performance, superparamagnetic limits on media grain size, and techniques for measuring mechanical and tribological performance of extremely thin hard carbon and lube protective layers.

Materials and devices for integrated MOs was the topic of Symposium M. Among the areas covered were a garnet crystal ion slicing technique that uses an ion bombardment damage layer to lift-off a garnet film, recently developed integrated isolators and circulators, magnetostatic wave-based integrated MO devices for microwave applications, the use of field modulation to increase the density of recording on conventional MO disks, and dilute magnetic semiconductors.

A cluster of symposia (S–V, N) focused on analysis techniques. Symposium S addressed the characterization of materials using scanning probes. A tutorial on scanning probe microscopy was also incorporated into the Symposium. H. Hess (PhaseMetrics) reported on a collaborative effort with Lucent Technologies wherein a single-electron transistor fabricated on a scanning probe tip was used as a highly sensitive electrometer with the ability to detect charges as small as a hundredth of an electronic charge with a spatial resolution of ~100 nm. Efforts to characterize carrier distributions in ultrasubmicron Si devices using scanning capacitance microscopy were described by R. Kleiman (Lucent Tech. Bell Labs). This is critical for scaling of Si electronics to the submicron regime for the characterization of dopant and carrier profiles. Novel microscopy techniques addressed included interfacial force microscopy, near-field scanning optical microscopy of optical modes in photonic crystals, magnetic force microscopy studies of field dependent magnetization in epitaxial Fe films, and scanning thermal microscopy which allows temperature distributions in devices to be probed with submicron spatial resolution.

Fundamentals of nanoindentation and nanotribology were covered in Symposium T. The Symposium included joint sessions with Symposium L on recording media and Symposium S on scanning probe microscopy techniques. Across scale analyses of the fundamental processes of dislocation emission were represented by atomistic simulations to direct measurements by mechanical nanoprobes and TEM. Several Symposium presentations also suggested a growing emphasis on numerical modeling.

Electron microscopy is critical for ULSI of electronic devices and was the topic of Symposium U. Various aspects of electron microscopy of semiconducting materials and devices were discussed, including the visualization of doping concentrations in III-V semiconductor TEM specimens prepared using focused ion beams, results obtained using the technique of crystallographic mapping of multiphase materials, the use of high-resolution TEM for optimizing diffusion barriers, and the rapid analysis of several electronic materials systems by such techniques as RHEED- and electron-beam-induced current in the TEM.

Synchrotron radiation techniques have a number of applications in materials science, as Symposium V demonstrated. D. Price reported results of a collaboration between ANL and BNL studying short- and inter-



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*Materials researchers meet for informal discussion in between technical sessions at the 1998 MRS Spring Meeting in San Francisco.*

mediate-range order in oxide and chalcogenide glasses using DAFS techniques. M. Marcus reported results of a study performed at Lucent Tech. on the use of micron and submicron monochromatic and white x-ray beams for studies such as multi-quantum-well laser diodes and electromigration in metal interconnect runners.

MEMS are an important new topic for research, and materials implications were discussed in Symposium N. The Symposium brought together the materials research and the MEMS communities, clearly demonstrating the need for the two communities to interact. Among the topics presented were creep relaxation in metal films using microbeams and approaches to address high-temperature applications for silicon in a microturbine application. A.R. Abramson (Tufts Univ.) described how MEMS can be used to measure temperature reached during high-temperature processing in the range of 1000°C. In her scheme, an array of different sized test structures are deposited through usual semiconductor processing techniques. The structures are like tiny tensile test specimens made of silicon nitride, and the difference in thermal expansion between the structure and the substrate cause deflection of the structure and then fracture when a certain temperature is exceeded. An array of structures acts as a thermometer, read by the division between broken and unbroken test structures.

Widegap semiconductor technology is becoming important for various high-power, high-temperature, and high-frequency systems applications as evidenced by the papers presented in Symposium F. Topics covered included GaN-based and SiC-based devices, processing and characterization of wide gap materials, and crystal growth issues. Significant performance improvements were reported for GaN heterojunction FETs. Bipolar diodes of 5.5 kV were fabricated from high-quality CVD 4H-SiC.

Symposium O covered the field of organic/inorganic hybrid materials, a new class of technologically important materials. The tone for the meeting was established by J. Lichtenhan's (Phillips Labs. AFB) talk on the use of partially oligomerized silsesquioxane polymers to develop new materials with good high-temperature stability, abrasion resistance, and superior mechanical properties. Among the various techniques described were the use of highly polar polymers and sol-gel processing to make completely transparent silica/polymer composites, methods of using nanocomposite hybrid materials to make extremely abrasion-resistant coatings on a variety of substrates, new routes to mesoporous materials with well-defined porosities and compositions, and the use of neutral surfactants to tailor the framework and textural mesoporosity in different molecular sieves. In the sessions on optical and electronic properties, a technique of polymerizing conducting polymers in the pores of vanadium oxide aerogels with possible battery applications was described along with the impregnation of high-temperature liquid-crystalline organic fibers with meral salts followed by chemical reduction to obtain highly conducting metal impregnated fibers that could possibly replace aircraft wiring. S.D. Burnside (École Polytechnique Fédérale de Lausanne, Switzerland) focused on self-organization in thin films of nanocrystalline titanium dioxide. The rods which are 60–70-nm high and 10–20-nm in diameter, self-organize out of a colloid to form structures on scales approaching micrometer levels in a quasi-cubic close-packed structure with the long axis of the rod oriented perpendicular to the film surface. She talked about potential application of such structures in dye-sensitized solar cells. J.L. Hedick (IBM—Almaden) described how well-defined macromolecules can be used as templates for inorganic oxides such as organosilicates to design porous materials with low dielectric constants. The macromolecules define the size and organization of the pores. The aim of the research is to achieve phase separation at the 100 Å scale. Larger pores are not acceptable as device sizes are scaled down. Hedick demonstrated living polymerizations from dendritic and hyperbranched macromolecules to produce controlled branches, star, and hyperstar macromolecules. The inorganic material is then structured around the macromolecules, and then removed by thermolysis, leaving behind a porous inorganic structure.

Nanostructured powders represent another cutting-edge materials research area as was evident from the presentations in Symposium P. One of the highlights included a talk by S. Friedlander (UCLA) who showed evidence using an electron microscope that ceramic nanostructured, mass fractal aggregates could display elasticity and some of the features of softer materials such as organic polymers. A. Hurd (SNL) discussed the physics of particle packing including the use of supercomputer simulations for understanding properties of these complex materials. In sessions on exfoliated clays and nanostructured powders in



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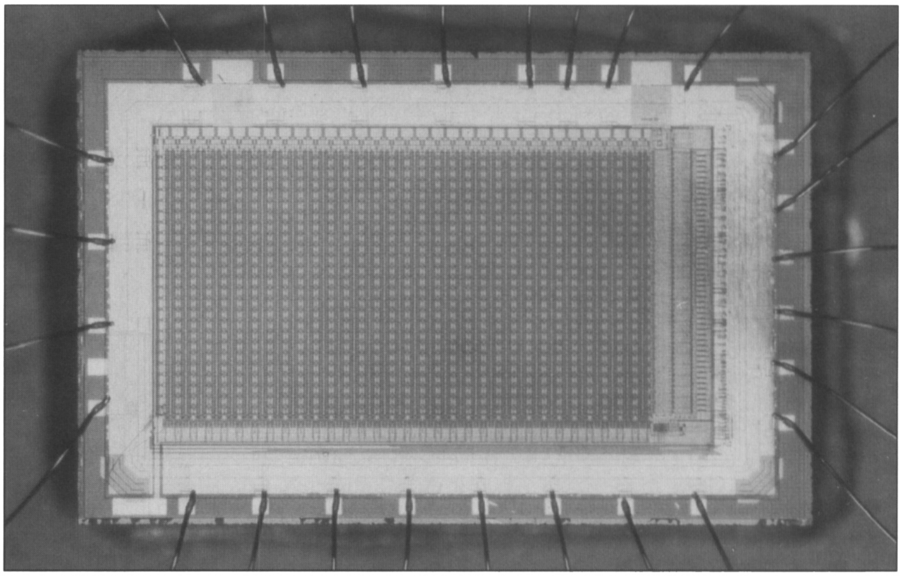
polymers, presentations included thermodynamics of clay exfoliation in the presence of polymers, the production of bone-like materials from nanostructured ceramics, and the feasibility of single-electron transistors using nanoparticles.

Structural porous and cellular materials were the focus of Symposium R, wherein recent advances in ceramic, metallic, and polymeric foams were discussed. Among the various advances reported, J. Grenestedt (Royal Inst. of Tech., Sweden), describing theoretical work on cell wall defects, showed that reduction in stiffness and strength of foamed metals could be accounted for by the preferential collapse of curved or wrinkled cell walls. H. Bart-Smith (Harvard Univ.) showed the dynamic manner by which collapse of an individual cell leads to the propagation of a band across the sample. The Symposium also included in-depth reviews of various techniques used to synthesize metal foams and structurally porous materials.

Symposium CC on biomaterials focused on regulating cell function and tissue development. Tissue engineering attempts to create natural living tissue to restore specific mechanical, metabolic, or aesthetic function to an individual. S. Peter (Rice Univ.) talked about the development of a biocompatible, degradable polymer that can be cross-linked at the time of a surgical procedure, with the polymerization reaction designed to have a low cross-linking temperature (<50°C).



*In Symposium A at the 1998 MRS Spring Meeting in San Francisco, M. Bohm (Univ. of Siegen, Germany) showed the variety of applications that can be satisfied with imagers based on a-Si:H photodetectors integrated with ASICs. Shown here is the first 64 × 48 pixel prototype of a LARS (locally autoadaptive sensor) array.*

### Amorphous and Microcrystalline Silicon Share Venue

*(See MRS Proceedings Volume 507)*

Symposium A on Amorphous and Microcrystalline Silicon Technology covered amorphous and microcrystalline silicon from materials physics to new applications. By pointing to the disappearing distinction between amorphous and nanocrystalline silicon, S. Guha (United Solar Systems Corp.) summarized the current direction of growth experiments, structural analysis, and device fabrication toward the understanding and utilization of heterogeneity in amorphous and microcrystalline films. Other presentations described the deposition of films with medium-range order from clusters formed in the glow discharge, analyzed these negatively charged silicon clusters, which contain up to 60 Si atoms, and introduced the application of variable-coherence electron microscopy to the identification of fine-grained local order. Raising the rate of growth of thin-film silicon is at the top of the industrial agenda to reduce capital investment. A new form of silicon called silicon nanowires made by laser ablation of silicon followed by condensation in a steep temperature gradient were presented.

G. Kong (Chinese Academy of Science in Beijing) explained the observation of photodilation in a-Si:H, which has stimulated a vigorous discussion of the experimental techniques employed and the possible structural changes associated with the Staebler-Wronski effect. NREL presented a new model for this effect, in which the recombination of two photogenerated diffusing hydrogen atoms on one strained Si-Si bond leaves behind two spatially separated silicon dangling bonds. X. Liu (Cornell Univ.) applied the recent discovery of extremely low internal friction in a-Si:H at cryogenic temperatures to the observation of the triple point and the ortho-para conversion of $H_2$ occluded in films grown by the hot wire technique.

The selective crystallization of a-Si:H combines the advantages of the low leakage current of a-Si:H TFTs with the high currents and CMOS capability provided by polysilicon. A complete top-gate process for making a-Si:H and laser-crystallized poly-Si TFTs, side-by-side, was illustrated.

L.E. Antonuk (Univ. of Michigan) presented an overview of the application of a-Si:H in x-ray detector arrays, which provide high-resolution real-time electronic observation and are on the verge of market introduction. M. Bohm (Univ. of Siegen, Germany) showed the variety of applications that can be satisfied with imagers based on a-Si:H photodetectors integrated with ASICs. This is a field of considerable activity at present. M. Boucinha (INESC, Lisbon) made a first step to micromachined silicon-on-glass by demonstrating an a-Si:H TFT with an air-gap gate dielectric.

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### Flat Panel Displays Pull from Silicon, Phosphors, and Other Materials

*(See MRS Proceedings Volume 508)*

Symposium B on Flat Panel Display Materials focused on materials and processes for a wide range of emerging flat-panel display technologies. In a joint session with Symposium A, invited papers focused on active-matrix display technology, including possible routes to integration of amorphous and polycrystalline silicon TFTs, process approaches to high-resolution TFT-LCDs formed with high-conductivity copper gate metalization, and processes for large-area laser-crystallized polysilicon TFT arrays. A session focused on laser crystallization showed numerous results of single-crystal silicon materials and devices formed on glass by the sequential lateral solidification technique, recrystallization, and processing of polycrystalline silicon for TFTs.

In a joint session with Symposium C, two invited papers on color FEDs lended



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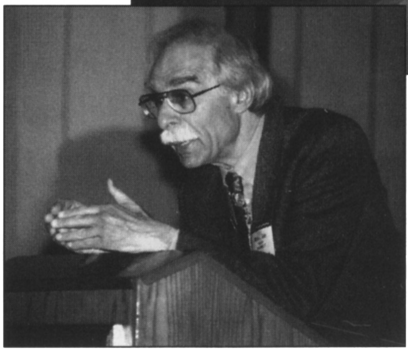
## Symposium X Focuses on Historical Themes in Semiconductors

Symposium X, Frontiers of Materials Research, traditionally held at MRS Meetings at noontime each day to present invited reviews of important technical topics specifically aimed at nonspecialists, focused on historical themes in semiconductor materials and devices. The series opened with a presentation by Martin Klein (Yale Univ.) on "Einstein, Quanta and the Beginnings of Materials Science," tracing the beginnings of basic materials science and materials physics, starting with work done by Newton. The following talk on "The Complex Foundations of Silicon Electronics" given by 1993 Von Hippel Award recipient Frederick Seitz (Rockefeller Univ.) traced the historical background of the current silicon revolution in electronics.

In his presentation, "Origins of the Semiconductor Laser," Robert Hall (GE) talked about the development of the laser starting from GaAs in the 1960s when ir emission from GaAs was detected and visible light emission became the goal of research at Lincoln Labs., GE, IBM, and AT&T. Both IBM and GE published papers on laser action in the same month, and some interesting patent disputes arose from the research. In "Development of Silicon Crystals—From Small to Very, Very Big," Harry Leamy (Univ. of North Carolina) talked about the history of single-crystal growth, which is the enabling technology for solid-state devices. In the 1940s, solidification of silicon ingots yielded $n$- and $p$-type regions, but it took some years before the role of impurities such as P and B were understood. Now scientists use 12-in wafers with extremely well-controlled impurity and defect concentrations.

Jane Shaw (IBM T.J. Watson Research Center) covered several materials science aspects of semiconductors in her presentation on "Materials Needs for Semiconductors." Shaw described the evolution of semiconductors and transistors starting with the classic "Moore's Law" showing the continued scaling down of semiconductor device feature sizes toward 0.10 $\mu$m in 2005 paralleled by the scaling up of computer speed and degree of integration, with 1 GHz clock frequencies on course for the year 2000. She talked about requirements for passive polymers used in photoresists or as electrical insulators, with the trend toward insulating materials physically on the chip, surrounding four to five levels of wiring, with polymers replacing the standard oxides. Polymers are also moving into the "active" realm, with conducting polymers that participate in the functioning of the device itself. The primary focus of her talk, however, was on improvements needed in lithography and photoresists, requiring exposure systems with smaller wavelengths and the development of new resists that respond to these different wavelengths. The next step may be building up instead of etching down the polymer, for instance, by using self-assembled polymers for patterning on the order of tens of nanometers. She said that understanding molecular architecture and polymer properties as well as continual innovation in materials is crucial for future development of ICs.

Jim Harper (IBM), in his talk entitled, "Silicon Chip Interconnections from Aluminum to Copper," described the evolution of interconnect processing at IBM and in the industry in general beginning with the lift-off technique in the 1970s, metal RIE in the 1980s, the Damascene process in the late 1980s, and the dual Damascene process to BEDL at present and in the very near future, particularly for Cu interconnects. He discussed the use of tungsten for vertical structures between interconnects. While Cu has been inherently good in terms of conductive properties, it has a catastrophic effect on transistors. In addition there is no plasma etching method for Cu. Hence Al alloyed with Cu has been used until the present. Recently, however, it has been possible to encapsulate Cu to eliminate any contact with Si thus paving the way for its use. In the future, Cu will likely be alloyed with other metals for optimum properties. Harper also described the National Technology Roadmap for Semiconductors which lists requirement by the year 2006 as well as beyond 2006 in which materials issues are prominent.



Above: Frederick Seitz

Left: Robert Hall

In a talk entitled "The Road to Silicon was Paved with Germanium," Michael Riordan (Stanford Linear Accelerator Center) displayed actual pages from laboratory notebooks of key players in semiconductor development. Riordan showed the crucial role Ge played in the development of silicon semiconductor technology, with both transistor and the IC first fabricated in germanium. Despite its relative scarcity, germanium initially proved fairly easy to purify and work with in the laboratory and on production lines. Silicon eventually became the material of choice, however, particularly because of the difficulty in growing oxides on germanium: Germanium oxide is water soluble, unfortunately flawing it, particularly when compared to the ability of silicon to form oxide films with high integrity.

A Symposium X talk that stepped away from the theme, given by Junji Kido (Yamagata Univ.), addressed organic EL devices. Kido said that nature is the most efficient architect of organic luminescence as demonstrated in fireflies. He said that while the blue LED (using III-nitrides) has received a lot of press, blue light obtained using electroluminescence was available 30 years ago. Kido described the search for different colors of OLEDs, in particular how colors are tuned by adding different dyes, and he showed some high brightness, three-color displays during his talk. These OLEDs are simpler than color-filtered LEDs, and do not need a backlight, making them ideal display devices. Other advantages of organic EL devices include large areas, low driving voltages, and fast response. These displays can be used for various applications including full color monitors and displays in car radios.

credence to the viability of high-voltage phosphor FEDs. The papers contrasted the performance of high-voltage phosphor displays with commercial FEDs that use low-voltage phosphors. High-voltage (3–4 kV) phosphors, where electrons have sufficient energy to penetrate an aluminum reflector over the phosphor, have several advantages including availability, color gamut, efficiency, and operating life. However, the high-voltage structure requires complex high aspect ratio (~20:1) internal support structures. C. Spindt reported that Candescent's displays use a low switching voltage (less than 10.5 V) which reduces display input power and enables low-cost CMOS drivers. Other papers described data demonstrating that diamondlike carbon and diamond emitters have reduced operating voltage compared to more standard emitters and are environmentally robust, although the physical mechanisms for the emission observed is still not fully understood. Another session focused on phosphor materials, discussing advances in thin-film cathodoluminescent phosphors.

In a session that included approaches for novel display generation and processing, new results were presented on electrophoretic display materials. Contributed papers on bi-static membranes, organic EL, novel polarizers (including photoluminescent and dichroic materials), and results of laser-crystallized silicon were also presented. A wide range of TFT-LCD materials topics was covered, including very low-temperature processing on plastic substrates, transparent conductors, contact metallurgy, and liquid-crystal materials.

The Symposium concluded with papers focused on electroluminescent displays and phosphors and results of combinatorial searches for phosphor materials.

*Symposium Support: Candescent Tech., Applied Kamatsu Tech., Corning, and Sharp Microelectronics Engineering.*

## Graduate Student Awards

Six Graduate Student Awards were presented at the 1998 MRS Spring Meeting. (Front row, left to right): M.N. Popescu (Emory Univ.), G.B. Palmer (Northwestern Univ.), H. Lee (Univ. of Oregon); (back row, left to right): Y. Lu (Univ. of New Mexico), J.J. Senkevich (Virginia Tech.), and C. Waldfried (Univ. of Nebraska). The other finalists were M. Griglione (Univ. of Florida), C. Flink (UC-Berkeley); B.E. Foutz (Cornell Univ.); G.E. Jabbour (Univ. of Arizona); E. Amitay-Sadovsky (Weizmann Inst. of Science); T.W. Little (Univ. of Washington); S.J. Peter (Rice Univ.); G.S. Hwang (California Inst. of Technology); and Y. Liu (Clemson Univ.).

### Electron-Field-Emitting Materials Used in Microelectronics

*(See MRS Proceedings Volume 509)*

The theme of many papers in Symposium C on Materials Issues in Vacuum Microelectronics was on the fabrication, characterization, and modeling of electron-field-emitting materials. The Symposium also featured joint sessions with Symposium B on state-of-the-art FED technologies with invited speakers from leading FED companies.

C. Spindt (SRI Intl.), one of the pioneers in the VME field, gave an overview of the pertinent issues involved in the fabrication and operation of field emitter arrays. He discussed the choice of emitter materials and their electronic properties, microfabrication issues such as lithography, and the cost of large-scale production. He presented impressive experimental results such as emitter current loading of 100 mA/tip, emission current density of 180 mA from a 10,000-tip array (35 A/cm$^2$), operation in a wide temperature range from liquid helium temperature to 700°C, and sustained operation at 50 $\mu$A/tip for eight years in UHV conditions.

B. Gnade (DARPA) reviewed DARPA's High Definition Systems Program of which the goal is to meet the diverse but specific needs for information displays of the U.S. Department of Defense by increasing power efficiency, reducing weight, and improving the overall ruggedness of the display systems (for example, surviving a bullet shot). Some display programs currently supported by DARPA include high definition LCD, EL displays, new phosphor materials, and new display technologies such as OLEDs. Representatives from two of the leading U.S. companies working on FEDs, C. Spindt (Candescent Tech.) and A. Talin (Motorola), discussed their technologies and their ongoing efforts in the race to bring a FED to the marketplace. Both companies have shown full-color, VGA FED prototypes based on the high anode voltage (>5 kV) approach. Challenging issues ahead include brightness and color purity, spacer technologies, packaging, and the cost of scaling up processes. Candescent indicated that its FED design involves the use of randomly structured, very high density (4 × 10$^8$/cm$^2$) gate holes with an impressively small average diameter of 0.15 mm. The switching voltages are as low as 10 V. An electron focusing structure compensates for the divergence of electrons. Motorola is working on a new cathode material called nanocoralline which is vapor deposited at room temperature. This material comprises highly dendritic carbon and is capable of emitting electrons at 10 V/mm for a current density of 10 mA/cm$^2$. The use of this material could lead to more readily affordable and reliable displays.

R. Nemanich (NCSU) reviewed the work of his group in the studies of electron emission properties of wide bangap materials such as diamond and nitrides.



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They have, for the first time, demonstrated NEA for epitaxially grown AlN and AlGaN. They used PEEM operating with and without uv excitation to obtain images of electron emission from nitride structures.

*Symposium Support: Lucent Tech. Bell Labs, Candescent Tech., and Motorola.*

### History of Defects Points to Greater Control

*(See MRS Proceedings Volume 510)*

A historical review of the final emergence of the solid state with the discovery of the transistor effect in 1947 and the impetus it gave to the growth of near-perfect crystalline semiconductors to astonishing levels of defect control was addressed by H.J. Queisser (MPI, Stuttgart) in Symposium D on Defect and Impurity Engineered Semiconductors and Devices.

I. Akasaki (Meijo Univ.) gave a pioneer's perspective on the evolution of GaN and related compounds, currently in hot pursuit around the world due to its dominance in blue LEDs. He specifically addressed the heteroepitaxy and doping problems that were finally overcome only after two decades of dogged efforts.

Y.H. Lo (Cornell Univ.) described an example of lattice defect engineering for semiconductor heteroepitaxy that features intentionally misaligned bonding of an ultrathin semiconductor layer to a bulk crystal where the twist boundary underneath makes the thin layer atomically springlike or compliant for overgrowth. The result is a universal substrate that can absorb high levels of lattice strain and grow dislocation-free thick epitaxial layers.

The evolution of diamond as a high-temperature and uv optoelectronic material has long been hampered by the absence of *n*-type conductivity. H. Koizumi (NIRIM, Tsukuba) outlined the recent success of his research group in incorporating phosphorus as a dopant in homoepitaxial diamond films using microwave CVD and surface treatment to remove hydrogen from the epitaxial interface.

Other innovative defect engineering ideas presented include elecronically enhanced thermal anneal of process-induced defects in GaAs, deuterium sintering to improve Si MOS hot carrier reliability, SOI using controlled fracture of a buried hydrogenated layer—the "Smart Cut" Process, and a novel nonvolatile MOS memory device using proton trapping in the gate dielectric.

*Symposium Support: HP, MEMC Electronic Materials, Mattson Tech., Hughes Research Labs., Eastman Kodak, Bunko-Keiki, Nippon Steel Corp., NREL, Shin-Etsu Handotai, Photowatt, Riber, Jobin-Yvon, Komatsu Electronic Metals, Mitsubishi Materials Silicon, and NEC Corp.*

### Performance of GaN Heterojunction FETs Improved

*(See MRS Proceedings Volume 512)*

Symposium F on Wide-Bandgap Semiconductors for High Power, High Frequency, and High Temperature covered applications of the emerging wide bandgap semiconductor technology. The papers covered GaN-based and SiC-based devices, issues related to crystal growth, and processing and characterization of wide bandgap materials. Invited speakers presented an overview of the current state-of-the-art research and made projections for future developments.

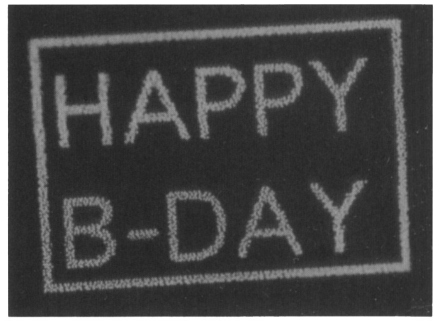
Significant performance improvements from GaN heterojunction field-effect transistors were presented, including undoped $Al_{0.3}Ga_{0.7}N$/GaN/sapphire piezoelectric HEMTs with 1.4 W/mm power and 74% optimized power-added efficiency at 3 GHz, HEMTs with 3 W/mm at 18 GHz with 0.25-$\mu$m gate length, doped channel and doped barrier $Al_{0.25}Ga_{0.75}N$/GaN HFETs with electron mobility of 1,400 $cm^2$/V-s and electron sheet density of $1.5 \times 10^{13}/cm^2$, the use of MBE-grown materials as opposed to OMVPE materials with which ~1,000 $cm^2$/V-s electron mobility in $Al_{0.15}Ga_{0.85}$/GaN structures was achieved along with success in flip-chip bonding for improved thermal management, and 5.5 kV bipolar diodes fabricated from high-quality CVD 4H-SiC.

*Symposium Support: Cree Research, Emcore, Northrop-Grumman, and Aixtron.*

### Organic Electroluminescent Devices See Lifetime and Power Efficiency Improvements

The field of OLEDs is progressing rapidly as evident by the presentations in Symposium G on Science and Technology of Organic Electroluminescent Devices. The thrust of many papers was on high performance electroluminescent polymers and the improvement of polymer OLED lifetime and power efficiency. Furthermore, emphasis was given on the understanding of device physics and on novel patterning schemes for multicolor display applications.

H. Schoo (Philips Research Labs.) announced that Philips Electronics will establish a new business unit in Heerlen, Netherlands for the development, manufacture, and sales of light-emitting polymers with the first products aiming at backlights and small segmented displays. That decision was enabled due to the enormous increase in performance of polymer LEDs. Philips together with Uniax presented an orange-emitting polymer LED with 3–4 lm/W power efficiency and a measured rt lifetime (with minimal degradation) of 8,500 h at the luminance of 20 cd/$m^2$. From high-temperature data, the extrapolated rt half-life was found to be 40,000–50,000 h. A green-emitting polymer LED with 17 lm/W at 3.2 V and luminance of 100 Cd/$m^2$ was also reported by the same team.




*In his presentation for Symposium G at the 1998 MRS Spring Meeting in San Francisco, Y. Yang (UCLA) demonstrated the use of an ink-jet printer to print polymer coatings directly onto glass and flexible substrates.*

E. Woo (Dow Chemical) presented devices based on a new family of conjugated polymers and copolymers containing 9,9-disubstituted fluorene as a key component. Single and bilayer LEDs with efficiency higher than 6 lm/W were reported. The Dow Chemical group has managed to improve the polymerization process, which now yields high molecular weight and high purity polymers from which tough, flexible, free-standing films can be obtained. Polymers and copolymers of vastly different chemical, physical, and electronic properties are accessible via this technology, enabling the construction of efficient and long-lived devices through careful matching of polymer energy levels and transport properties. Siemens and HP showed examples of monochrome pixelated displays based on fluorene copolymers. J. Sturm (Princeton Univ.) emphasized the possibility of self-heating in large displays driven by passive matrix and pointed out the need for active matrix drivers. However in large-scale active matrix OLED displays, a critical issue is the inevitable device to device manufacturing variations in large-area TFT processes, which can lead to undesirable spatial variation in pixel brightness. In a joint project between Sarnoff Corp., Princeton Univ., Eastman Kodak, and Planar America, a self-compensating intelligent four-transistor pixel has been developed which overcomes the effect of such TFT variations.



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Y. Yang (UCLA) presented a patterning scheme by using an ink-jet printer to create a polymer-based LED. Both Yang and Sturm and their teams showed schemes where ink-jet printing can be used to deposit red, green, and blue devices on a single substrate without the need for masking or etching of the emitting materials. For now, only single-color single-pixel displays have been shown by the UCLA group. Full-color displays made in one simple ink-jet printing step will have to wait until water-soluble light-emitting polymers are available.

*Symposium Support: ONR, LAN, Chemipro Kasei Kaisha, Futaba Corp., HP, IMES, Sanyo Vacuum Industries, Sumitomo Electric Industries, and Uniax Corp.*

### Hydrogen in Semiconductors and Metals Leads to Interesting Insights

*(See MRS Proceedings Volume 513)*

The application of high-resolution electron energy loss has yielded a number of insights into the structure of hydrogenated semiconductor surfaces. The heavily hydrogenated silicon shows signs of trihydrides as the first step toward etching. Similar trihydride structures have been observed in the bulk of heavily hydrogenated crystalline silicon in the formation of platelet structures. The trihydride structures are surprisingly stable up to 525°C. Thus, hydrogen not only forms trihydrides on the surface but within the bulk.

Hydrogen storage in carbon nanotubes is an important topic relevant for hydrogen fuel technology. Papers presented in Symposium H on Hydrogen in Semiconductors and Metals did not confirm the original reports of 300 wt% hydrogen storage but 5–10 wt% storage in nanotubes was reported which is still about 3–5 times better than the metal hydrides for H storage.

Rare-earth hydrides such as Gd-Mg-H exhibit remarkable optical properties related to H storage. Without H, the materials are metallic while they are transparent and colorless insulators when loaded with H. The H can be rapidly added or removed electrolytically for many cycles switching the optical properties between reflecting and transparent.

Studies of H and D desorption on Si surfaces and at $Si/SiO_2$ interfaces have fully confirmed that D is significantly harder to desorb from Si than H. This phenomenon leads to greatly improved lifetimes for deuterated Si devices operated under conditions where hot carrier degradation is significant. The difference between H and D desorption becomes significantly larger at low temperatures.

*Nearly 500 posters were presented across three evenings at the 1998 MRS Spring Meeting in San Francisco.*

### Interconnect and Contact Metallization Challenges Addressed

*(See MRS Proceedings Volume 514)*

The unprecedented growth of the semiconductor/electronics industry is the result of continued miniaturization of the devices in the circuit, increases in the chip functionality, improved performance, and decrease in perfection cost. The shrinkage has taken place both laterally and vertically, leading to similar decreases in the dimensions of interconnection wires and contact metallization. The increasingly important role of surfaces, interfaces, defects, and impurities has raised serious questions about interconnection performance (delay and crosstalk), dimensional control of the fundamental properties (e.g., resistively and contact resistance), reliability, and performance. New sets of materials are being proposed (e.g., Cu and its alloys, polymer ILDs, and epitaxial contacts to compound semiconductors) to replace the conventional materials. Limiting electronic materials choices are becoming apparent and new directions (e.g., optoelectronics, alloying to enhance the properties, and epitaxy) are sought. New processing schemes and physical layouts of the circuits are being pursued to minimize the impact of miniaturization. Symposium I on Advanced Interconnects and Contact Materials and Processes for Future Integrated Circuits was intended to provide a forum to discuss the directions taken by the interconnect and contact metallization researchers to meet the challenge. It not only provided an update on the state-of-the-art materials, processes, and technology, but also examined newer concepts in these research areas for application is silicon, GaAs, InP, and other compound-semiconductor-based electronic, photonic, and optoelectronic devices and circuits.

The first day of the Symposium was fully devoted to the interconnection-related issues addressed by nine invited speakers from academia and industry. This session addressed a variety of theoretical, materials, processing, and manufacturing issues. Research and development in aluminum copper, barriers, and new interconnect materials and schemes were covered in four other sessions. A joint session with Symposium W covered the MOSFET, source, drain, and interconnect engineering issues. Contacts to semiconductor devices were covered in three sessions.

*Symposium Support: TI, Novellus Systems, Watkins Johnson, Lucent Tech. Bell Labs, and Strem Chemicals.*

### Electronic Packaging Focuses on Flip-Chip Technology

*(See MRS Proceedings Volume 515)*

Symposium J on Electronic Packaging Materials Science was organized around advanced packaging applications, particularly emphasizing flip-chip technology. The Symposium consisted of invited and contributed papers focused on a number of topics including interfacial behavior, flip-chip interconnections, high-density substrates, thermomechanical behavior, and reliability issues.

Debonding and crack propagation was an important theme in the Symposium. Metrologies supporting basic understanding of fracture toughness, hydrothermal fatigue, mechanisms of progressive debonding, and subcritical crack growth rates highlighted the topic. The papers were data rich, focused on specific mechanisms for the observed behaviors, and related the behaviors to systems of direct interest in current packaging technology.

Another important highlight of the Symposium were those papers focused on characterization of thermomechanical behavior of electronic package structures. The use of Moire interferometry was demonstrated to be a valuable characterization tool at the global package level, as well as at the feature level of package structures (e.g., flip-chip bumps). Microshear testing of solder joints under cyclic loading in two different test configurations allowed crack propagation to be tracked as well as observed *in situ* for a combined quantitative and spatial description of



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crack growth. Interconnects were examined from the point of view of bump and underbump metallurgy, stresses in joints, as well as mechanical reliability. The underfill process known to be critical in influencing the performance of flip-chip solder joints was discussed with respect to flow behavior metrics. A dense suspension of solid particles in a liquid carrier was modeled with the flow as a complex function of the mixture properties, the wetting properties, and the flow geometry. From the models and suspension characteristics, flow issues were reviewed.

*Symposium Support: TI, Intel, and Intel Japan.*

### Advanced Microelectronics Technology Brings New Reliability Issues

*(See MRS Proceedings Volume 516)*

Symposium K on Materials Reliability in Microelectronics focused on the breadth of topics that reliability researchers must be familiar with due to the increasing complexity currently present in microelectronics. In the session on how microstructure and material composition affect electromigration lifetime, a number of papers discussed how Al texture in damascene lines becomes less strong as line width decreases.

In a session on the ability to model electromigration and temperature in interconnects, D. Brown (AMD) addressed modeling concerns encountered when using the knowledge of Al models based on the Korhonen model are applied to the new material systems being put into use in the industry.

One session focused on advanced interconnect materials, from optical to new alloys of Al. S. Baker (Cornell Univ.) showed how different Cu's thin-film mechanical properties are from the Al properties that the industry has become used to. In a session on reliability-low-*k* materials, papers pointed out the importance of understanding how the different chemical and mechanical properties of these systems will challenge researchers' conventional understanding of electromigration.

One session focused on mechanical reliability which has become more and more important as microelectronics have more metal levels and are packaged much differently than before. A joint session was held between the packaging and reliability session. As the die and the package begin to meld together, the cross-over between these groups are becoming increasingly important.

*Symposium Support: SNL/Electronic Components Center, SNL/Microelectronics and Photonics, AMD, Lucent Tech. Bell Labs, Lloyd Tech. Assoc. Aetrium, and IBM.*

### Theoretical Limits Soon to Chalenge Rapid Materials Development for High-Density Magnetic Recording

*(See MRS Proceedings Volume 517)*

High-density magnetic recording continues to be one of the fastest growing and most rapidly improving technologies in the computer industry as evident from Symposium L on Materials for High-Density Magnetic Recording. Information storage density has maintained staggering advances, doubling every two years for the past twenty. Nevertheless, recent materials advances in several areas have allowed an even faster rate of improvement during the past three years. Whole new areas of materials science endeavor are following the fast track from basic theory to practical application in products within 10 years.

Longitudinal magnetic recording is the primary technology for information storage in a computer hard disk drive. The geometry is similar to a record player, with a read/write head positioned by an actuator-controlled swing arm above a rapidly spinning (~10,000 rpm) ferromagnetic disk (media). Continued increases in recording density require improved magnetic sensor materials for recording heads, small-grain, magnetically anisotropic media for low noise and protective head/media interface tribological materials for low-flying heights.

The recent development of MR sensors, and the continuing development of GMR and CMR and spin-dependent tunneling sensors play a significant role in the present magnetic recording density surge. These technologies require a new level of understanding and control of interface structure and properties at the quantum mechanical as well as physical levels. Better understanding of the physical, crystallographic, and compositional structure of magnetic media is similarly advancing to allow controlled deposition of almost 10 trillion isolated magnetic particles per square inch. Head/disk interface materials have sufficient uniformity, mechanical toughness, lubrication, and aerodynamics to allow relative motion at over 100 mph, at 20-nm spacing. For comparison, this is often scaled up to a 747 flying low enough to touch the grass on a putting green, without touching the ground.

These discoveries and improvements are occurring so rapidly that theoretical limits to the present form of this technology, not long ago thought to be decades away, are now measureable in present products. Most magnetic recording experts now agree that a physical wall will be reached in about 10 years if the present growth rate is maintained. Rather than limiting the need for materials research, this expectation is actually spurring further materials research to reach the potential of the present technology, to extend the "superparamagnetic limit," and to develop materials for revolutionary technologies that are being proposed to supercede longitudinal-magnetic-recording-based computer memory when rapid advances are no longer possible.

Focus topics in this session included new results about the performance, structure, and mechanisms for improved GMR, CMR, and tunneling head sensors; effects of compositional microstructure upon media performance; definition and measurement issues related to the superparamagnetic limit on media grain size; and methods for probing mechanical and tribological performance of extremely thin hard carbon and lube protective layers.

*Symposium Support: IBM, Seagate, Komag, Headway Tech. StorMedia, Intevac, and Commonwealth Scientific Corp.*

### Magneto-Optics Integrated into Devices

*(See MRS Proceedings Volume 517)*

Integrated Magneto-Optics: Materials and Devices (Symposium M) included fabrication and processing of garnet materials for integrated photonics, devices for integrated photonics, MO recording media, diluted magnetic semiconductors, and other materials. Integration of the garnets with semiconductor platforms was achieved by MOCVD using an MgO buffer layer. Crystal ion slicing is a new technique presented by M. Levy (Columbia Univ.) involving etching an ion-bombardment damage layer to remove a garnet film from its substrate in a lift-off fashion. The film properties did not suffer from the process thereby allowing hybrid integration. Other processing techniques of interest included laser annealing, direct wafer bonding, selective-area growth, and rf sputtering.

A device session covered recently developed integrated isolators and circulators (NTT Opto-electronics Laboratories, Japan); the theory and experiment of several devices including nonreciprocal rib waveguide isolators, isolators based on nonreciprocal Mach-Zehnder interferometry, and radiatively-coupled waveguide circulators (Univ. of Osnabruck, Germany); magnetostatic wave-based integrated MO devices for microwave applications; and other devices including a Bragg cell modulator and a fiber magnetic field sensor.

The session on MO recording covered rare-earth-transition metal alloys, characterization, and readout by giant transversal MO nonlinear Kerr effect. M. Kaneko (Sony Corp.) discussed using magnetic



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field modulation in order to increase the density of recording on conventional MO disks. Other topics included dispersions of MO particles for MO fluids and coatings, and a near-field MO fiber probe.

Dilute magnetic semiconductors were discussed beginning with an overview by J. Furdyna (Notre Dame Univ.). These materials have an excellent potential for integrated MO applications since they are semiconductor compatible. Presentations included a new hydrothermal-electrochemical flow-cell technique of growing multilayered oxide films, and the use of the nonlinear Kerr effect to measure Co-Cu films and magnetic ordering in Gd-containing Langmuir-Blodgett films.

*Symposium Support: ARO.*

### Materials Characterized with MEMS
*(MRS Proceedings Volume 518)*

Symposium N on Microelectromechanical Structures for Materials Research was one of the first efforts to gather both materials research and the MEMS communities to discuss characterization issues and techniques. Investigators from both communities provided updates in microfatigue testing, measurement of elastic properties, fracture toughness, wear, bulge testing, creep, and test techniques. The Symposium demonstrated the wide disparity in approaches and results in the characterization of materials for MEMS and thin film applications.

Several investigators presented different methods to measure elastic properties of thin-film materials. W. Sharpe (Johns Hopkins Univ.) presented the results of a round-robin investigation composed of Failure Analysis Associates, UC—Berkeley, Cal Tech, and Johns Hopkins with widely varying results for elastic modulus and strength on the same polysilicon MEMS material. Techniques varied dramatically, demonstrating that no particular methodology has been accepted for measuring even basic properties such as elastic moduli.

Time-dependent effects were presented for thin film and MEMS applications, including measurements of creep relaxation in metal films using microbeams, approaches to address high-temperature applications for silicon in a microturbine application, and wear and friction testing. The work in rate-dependent processes emphasized the additional effort required to characterize, much less understand, the long-term stability of MEMS materials. Investigators are still evaluating test methodologies as well as materials. The Symposium demonstrated the need for the materials and MEMS communities to continue to interact—characterization techniques and results are not yet resolved.

### Organic/Inorganic Hybrids Show Their Versatility
*(See MRS Proceedings Volume 519)*

Symposium O on Hybrid Materials addressed the synthesis, characterization, and properties of organic/inorganic hybrid materials. The first two days focused on the synthesis of molecular and nanocomposite hybrids. J. Lichtenhan (Edwards AFB) set the tone for the Symposium when he described the use of partially oligomerized silsesquioxane polymers to develop a host of new materials with novel properties that include good high-temperature stability, abrasion resistance, and mechanical properties. He emphasized the applicability of these materials to satisfy both Air Force needs and commercial applications. Also discussed were very simple, low-cost synthetic routes to related silsesquioxane materials and novel studies on the use of tin-oxide cluster complexes to prepare new organic/inorganic hybrids.

In the area of nanocomposite materials, the topics included the use of highly polar polymers to make sol-gel process completely transparent silica/polymer composites at all wt. compositions of each component, the structure property relationships in sol-gel processing, how changes in the structure of organic components used in the preparation of hybrid materials by sol-gel processing could be used to design well-defined porous materials, the development of controlled porosity catalysts, and methods of using nanocomposite hybrid materials to make extremely abrasion-resistant coatings on a broad spectrum of substrates.

In the area of porous materials, presentations covered novel routes to mesoporous materials with very well-defined porosity and compositions and the use of neutral surfactants to tailor the framework and textural mesoporosity in a variety of molecular sieves.

Methods of modeling the sol-gel process that allow a true industrial analysis of the entire process was described along with talks on the use of solid-state NMR to follow transformation processes during the synthesis of hybrid materials and the use of a wide variety of analytical tools to study the dynamics of complex structures. Also, J. Livage (Paris VI) gave an overview of the use of bioencapsulation to develop novel sensors, catalysts, and biologically active, but protected, materials.

B. Dunn (UCLA) described a novel method of making vanadium oxide aerogels and then polymerizing conducting polymers in the pores to generate materials potentially of considerable use for battery applications. In contrast, J-P. Boilot (CNRS, France) discussed processing hybrid materials with optical applications. R. Vaia (Wright Patterson AFB) described the impregnation of high-temperature, high-strength, liquid-crystalline organic fibers with metal salts followed by chemical reduction to generate highly conducting metal impregnated fibers that may be used to replace simple wiring in aircraft.

### Nanostructured Powders Formed by Chemical and Pyrolytic Means
*(See MRS Proceedings Volume 520)*

Symposium P on Chemical and Pyrolytic Routes to Nanostructured Powders and Their Industrial Application sought to bring together industrial and academic researchers involved in the synthesis and use of nanostructured powders such as fumed silica, pyrolytic titania, and precipitated silica as well as less-conventional nanostructured powders such as exfoliated clays. The Symposium began with an overview of the field, including a review of uses and potential for these industrially produced materials, an overview of pyrolytic routes and current directions in the control of industrial production of silica and titania, and new directions in precipitated silica.

S.K. Friedlander (UCLA) presented a recent discovery involving elasticity of nanostructured powders. Ceramic nanostructured, mass-fractal aggregates are usually thought to have fairly rigid structures paralleling their macroscopic counterparts such as silica glass. Friedlander showed a videotape of the deformation and elasticity of a single nano-aggregate in an electron microscope which reveals that these aggregates actually display some of the features of "soft" materials such as organic polymers. Extensive elongation (>100%) and virtually complete relaxation after stress release were demonstrated.

Several noteworthy talks involving the understanding of the growth and physics properties of nanostructured powders included A. Hurd's (SNL) stimulating discussion of the physics of particle packing which included some discussion of supercomputer simulation's and development of basic physical understanding of the packing of these nanostructured powders. Hurd convinced a group of largely industrial researchers of the potential physics offers to understanding the properties of these complex materials. A. McCormick (Univ. of Minnesota) addressed growth mechanisms leading to monodisperse particle distributions in



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solution route synthesis and G. Beaucage (Univ. of Cincinnati) and T. Rieker (UNM) gave an overview of the use of SAXS to understand structure property relations in nanostructured powders.

One session focused on exfoliated clays and applications of nanostructured powders in polymers, primarily as filler materials, covering the thermodynamics of clay and exfoliation in the presence of polymers, epoxy/clay systems. There is great interest in these novel composites after Toyota's incorporation of nylon/exfoliated clays in car production last year. Other topics covered include polyimide-silica hybrid composites, *in situ* filled PDMS elastomers, the use of silica xerogels in reinforcement of PDMS, and the production of bonelike materials from nanostructured ceramics.

The Symposium brought together workers from allied industries involved in titania, alumina, silica gel, fumed, precipitated, and colloidal silica production as well as academic researchers involved in a variety of newer synthetic approaches and industrial users of nanostructured powders, finding much common ground.

*Symposium Support: Dow Corning Corp. and Millennium Inorganic Chemicals.*


*The 1998 MRS Spring Meeting exhibit was held April 14–16 at the San Francisco Marriott.*

### Metal Foams Stand Up to Scrutiny
*(See MRS Proceedings Volume 521)*

The use of porous and cellular materials in structures is rapidly expanding, especially with the emergence of novel ultralight metal structures for high-temperature applications. Symposium R on Porous and Cellular Materials for Structural Applications addressed recent advances in polymeric, ceramic, and metallic foams in addition to structurally porous materials. New methods of processing as well as mechanical, acoustic, and thermal property-cell structure relationships were the subject of numerous presentations.

L. Gibson (MIT), whose text with M. Ashby on cellular materials has done much to popularize the field, presented new results for metal foams that demonstrated that cell wall defects dramatically reduced the elastic stiffness and yield strength of aluminum foams. J. Grenestedt (Royal Inst. of Tech., Sweden) described theoretical work that has quantified the role of several types of cell wall defects upon the compressive properties of metal foams. He showed that the significant knockdown in the stiffness and strength of foamed metals could be accounted for by the preferential collapse of curved or wrinkled cell walls. In related work H. Bart-Smith (Harvard Univ.) used computerized tomography to visualize the *in situ* collapse of cells during uniaxial compression testing. She has dramatically shown the dynamic manner by which the collapse of an individual cell leads to the propagation of a band across a sample. A. Bastawros (Harvard Univ.) presented detailed experimental and theoretical analysis of the very high heat dissipation capabilities of open cell metal foams and showed this could be maximized by control of the cell morphology.

All of the main approaches to metal cellular materials synthesis were reviewed in an invited presented by J. Barhant (Fraunhofer Institute for Applied Materials). Detailed presentations on the Ukrainian gasar process, the Japanese Alporas process, hollow sphere processing, and the entrapped gas process provided an up-to-the-minute synopsis of the state-of-the-art in the synthesis of metal foams and structurally porous materials.

*Symposium Support: ONR, ARO, and Univ. of Virginia.*

### Materials Probed on the Nanoscale

Symposium S on Nanoscale Materials Characterization Using Scanning Probes addressed a broad range of topics ranging from studies of atomic-scale phenomena in epitaxial crystal growth to scanning probe characterization of surface adhesion and nanomechanical properties of materials.

Several presentations addressed atomic to nanometer scale properties of semiconductor materials and devices, including STM studies of III-V semiconductor surface during growth by MBE, work that has provided new insights into interface morphology and its relation to growth conditions and performance of devices such as resonant-tunneling diodes; STM studies of III-V nitride semiconductor surfaces grown by MBE that have provided important information about the correlation between surface reconstructions and crystal polarity; and STM studies of step structure and dynamics on Si surfaces.

In work directed toward characterization of advanced device structures, a single-electron transistor fabricated on a scanning probe tip was used as a highly sensitive electrometer able to detect charges as small as a hundredth of an electronic charge with spatial resolution of ~100 nm, providing images of surface electric fields, charge associated with individual dopant atoms, and other phenomena in GaAs/AlGaAs heterostructures. Recent efforts were made to characterize carrier distributions in ultrasubmicron Si devices by scanning capacitance microscopy; the ability to characterize dopant and carrier profiles in such devices is a key element for scaling of Si electronics to ~0.1 $\mu$m feature size and below.

A broad range of other applications and novel microscopy techniques was also addressed such as work on interfacial force microscopy and its application to quantitative studies of adhesion forces and nanomechanical properties of materials, near-field scanning optical microscopy of optical modes in photonic crystals and spatial distribution of emission



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intensity in vertical-cavity surface-emitting lasers, magnetic force microscopy studies of field-dependent magnetization in <111> epitaxial Fe films, and scanning thermal microscopy in which a thermocouple fabricated on a scanning probe tip allows temperature distributions in devices to be probed with submicron spatial resolution.

*Symposium Support: Institute of Atomic and Molecular Sciences, Academia Sinica; Park Scientific Instruments; TopoMetrix; Digital Instruments; Molecular Imaging; and Omicron Assoc.*

### Nanoindentation, Nanotribology Touch on Recording Media, Numerical Modeling, and Technique

*(See MRS Proceedings Volume 522)*

Some highlights of Symposium T on Fundamentals of Nanoindentation and Nanotribolgy included joint sessions with Symposium L on recording media and with Symposium S on scanning probe microscopy. Across-scale attacks on nanorheology by both the nanoindentation and scanning probe communities were in evidence. Analogously, across-scale analyses of the fundamental processes of dislocation emission were represented by atomistic simulations to direct measurement and observation by mechanical nanoprobes and TEM. Similarly, friction in terms of phenomena at the jump-to-contact scale to larger scale ploughing were addressed.

In contrast to previous symposia, greater emphasis was placed on numerical modeling addressing such issues as pile-up, nonlinear or time-dependent behavior including slip nucleation, polymer viscoelasticity, and tip shape effects on strain distributions. New techniques for probing multilayers including measures of adhesion and fracture were also presented.

*Symposium Support: Nano Instruments, Hysitron, Dow Corning Corp., Digital Instruments, and Applied Materials.*

### Electron Microscopy Illuminates Semiconductors

*(See Mrs Proceedings Volume 523)*

The Materials Research Society held a new symposium this year, entitled Electron Microscopy of Semiconducting Materials and ULSI Devices (Symposium U). The Symposium started with a discussion of the most important problem in applying TEM to materials analysis and the preparation of high-quality thin foils, and continued with examples showing the great power of TEM in defect analysis. The session included talks on plan-view specimen preparation and on cross-sectioning specific devices. Applications of TEM and SEM to the analysis of polycrystalline metal films, silicides, and diffusion barriers were discussed. The quantitative results available using the technique of crystallographic mapping of multiphase materials and the use of high-resolution TEM in optimizing diffusion barriers were illustrated.

Analytical TEM, making use of energy-filtered imaging and field-emission sources, and high-resolution SEM were the focus of one session, including how doping concentrations may be visualized in TEM specimens of III-V semiconductor structures prepared using the focused ion beam and a description of the issues related to defect analysis with high-resolution SEMs. The final session provided reports on the application of these techniques to a variety of semiconductor systems, illuminating phenomena such as epitaxy, dislocation formation, and compositional ordering. The influence of strain on epitaxial growth as revealed by TEM was described along with rapid analysis of several electronic materials systems by techniques including RHEED and electron-beam-induced current in the TEM.

As semiconductor structures become smaller and performance issues more critical in the future, researchers anticipate an even more important role for electron microscopy in the analysis of semiconducting materials and ULSI devices.

*Symposium Support: R.J. Lee Instruments, Noran Instruments, AMRAY, Nissei Sangyo America, JEOL, Leo Electron Microscopy, Philips Electron Optics, and Kevex Instruments.*

### Synchrotron Radiation Techniques are Revealing

*(See MRS Proceedings Volume 524)*

Symposium V on Applications of Synchrotron Radiation Techniques to Materials Science reported on experimental techniques that included EXAFS, high-temperature x-ray diffraction, fluorescence and microprobe, MLDAD of core level photoemission, and SAXS while the types of materials systems studied ranged from inorganic materials to polymers to semiconductors. In one example, studies were reported of short- and intermediate-range order in oxide and chalcogenide glasses using DAFS techniques. This experimental approach combines the short-range selectivity of EXAFS with the long-range structural analysis of x-ray diffraction. Another talk highlighted the use of micron- and submicron white and monochromatic x-ray beams for studies such as multi-quantum-well laser diodes and electromigration in metal interconnect runners.

*Symposium Support: Luxel Corp., BNL, ANL, Blake Ind., and LBNL.*

### Rapid Thermal Processing Contributes to Next-Generation Thin Films

*(See MRS Proceedings Volume 525)*

The papers presented at Symposium W, Rapid Thermal and Integrated Processing, illustrated how the range of RTP applications in silicon device manufacturing is rapidly expanding, and how mature the technology has become. Modeling of RTP equipment and techniques for temperature measurement and control were covered. Many characteristics of RTP technology arise from the impact of the optical properties of semiconductor wafers on the thermal response and on pyrometric temperature measurement. One presentation demonstrated a remarkably wide-ranging study of the spectral emissivities of coatings commonly encountered in microelectronics, showing that their properties can be predicted to a high degree of accuracy using simple optical models. Other papers covering temperature measurement and calibration illustrated that the problems in these areas, traditionally viewed as limitations for RTP technology, are well on the way to being resolved. One particularly interesting paper showed a method for linking measurements from thermocouple-instrumented wafers in an RTP system to a NIST-traceable calibration, and established that the systematic error involved in the use of these wafers can be as low as ~3°C when the wafer is at 1000°C.

One of the most exciting and dynamic areas of RTP research is in the field of gate dielectrics where RTP offers a new path for the creation of the very thin films needed for advanced MOS devices. J. Hauser (NCSU) gave an excellent overview of the requirements for nanometer-scale devices, including a gate dielectric with thicknesses equivalent to only ~10 Å of $SiO_2$, for 50-nm devices. At this thickness $SiO_2$ ceases to be a viable material because of the large tunneling current, and new materials have to be introduced. This technological barrier was one of the key themes which emerged at the panel discussion on advanced gate stack processes which was held during the symposium. The discussion suggested that silicon nitride could provide an important stepping-stone on the path to more radical alternatives such as $Ta_2O_5$ or $(Br,Sr)TiO_3$, materials which were covered in other papers in this session. Several papers showed that RTP is already providing unique capabilities for dielectric formation, including the use of a steam ambient for growth of thin oxides at high temperatures and the use of NO ambients to introduce nitrogen into very thin oxide films. Plasma-assisted techniques to create thin dielectrics were also discussed and a


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technique for forming silicon nitride-based films at 300°C was presented in which a post-deposition RTP anneal drives out the hydrogen leaving a high-quality dielectric film.

The Symposium also included sessions covering the other vital ingredients for advanced MOS devices, including the gate electrode and the source/drain regions and contacts. Several papers showed how optimized integration of salicide and source/drain process modules can lead to significant improvements in electrical device characteristics even without other changes in device design. The formation of shallow junctions by the combination of low-energy ion-implantation and RTP anneal is an especially important process for advanced devices. In this arena the effects of transient- and oxidation-enhanced diffusion on junction depth were the focus of several papers, which analyzed the impact of the heating rate during anneal and the composition of the gas ambient. Gas ambient purity also emerged as a key parameter in the paper presented by K. Maex (IMEC, Belgium) who discussed the formation of silicides and illustrated how the wafer itself can act as a source of impurities which can interfere with the silicidation process. RTCVD techniques were also presented with a range of applications in the formation of MOS channels, source/drain structures, and contacts. Another presentation showed the use of novel RTCVD techniques for forming advanced devices including vertical MOSFET structures.

The Symposium ended with a session on new applications of RTP. Some of these applications are within the field of silicon device processing, such as the selective oxidation of silicon when tungsten gate structures are present, while others involved the application of RTP in nonsilicon applications, such as the formation of $SiFeO_x$ glassy films where RTP allows the creation of structures inaccessible through conventional thermal processing.

*Symposium Support: ASM America, AG Assoc., Applied Materials, CVC Products, Dainippon Screen, Eaton Thermal Processing Systems, JIP-ELEC, Philips Lighting, Philips Research Lab., SensArray Corp., STEAG-AST Elektronik, TI, and Textron Systems.*

## Diffusion Fundamentals Examined

*(See MRS Proceedings Volume 527)*

Diffusion Mechanisms in Crystalline Materials (Symposium Z) covered the most recent achievements in fundamental understanding of atomic transport in materials. Ten sessions of the Symposium considered specific features of atomic motion in a wide range of materials, including metals, alloys, intermetallic compounds, semiconductor materials, ionic crystals, and even quasicrystals. The growing interest in diffusive phenomena in semiconductor materials motivated the organizers to include a joint session with Symposium EE, Silicon Front-End Technology—Materials Processing and Modeling (Proceedings Volume 532). H. Mehrer (Univ. of Munster) opened the Symposium with a general overview of fundamentals and recent developments in diffusion science. Several authors described recent advances in experimental techniques which give direct access to microscopic characteristics of point defects and diffusion in materials such as nuclear scattering of synchrotron radiation, positron lifetime measurements, and perturbed angular correlations of gamma rays. Essential progress has been made in modeling and simulation of diffusion, particularly in using first-principles electron theory calculations. Diffusion in ordered intermetallic compounds was probably the hottest topic of the Symposium. Yet, the talks and discussions on this topic revealed that there is still no consensus regarding the diffusion mechanisms, particularly in such practically important compounds as $Ni_3Al$, NiAl, and FeAl. Much interest was shown in diffusion along grain boundaries and dislocations in metals and alloys. The most impressive achievement in this area is the implementation of simultaneous measurements of grain boundary diffusion and segregation characteristics. This long-awaited possibility, which is especially important for nonbrittle materials, is due to the use of carrier-free radioactive isotopes and advanced detection techniques in radiotracer measurements.

*Symposium Support: VPI and Technology Modeling Assoc.*

## Modeling and Experimentation Seek Coherent Views on Epitaxy

*(See MRS Proceedings Volume 528)*

Symposium AA on Mechanisms and Principles of Epitaxial Growth in Metallic Systems brought together theorists and experimentalists to review recent progress in understanding metallic thin-film growth starting from the atomistic level. This is an increasingly important area of research because of the potential to reduce the costs of new materials development by increasing reliance on modeling. Atomic level measurements provide essential information to make such modeling accurate.

Several talks showed that experimental techniques such as scanning tunneling and FIM yield a wealth of information needed to develop reliable computational models. Measured data includes static features (island distribution) as well as dynamics (diffusion of atoms and islands). A number of speakers addressed efforts to coordinate these experimental observations to computational approaches, with realistic theories such as the Kinetic Monte Carlo method, complementing traditional techniques such as Mean Field Theory and continuum mechanics.

J. Tersoff (IBM) elucidated simple models that demonstrate the complex interplay of strain and thermodynamics. Depending on the magnitude of the two effects, one may find alloy decomposition and spontaneous superlattice formation (leading to quantum wires) in an ordering alloy, or stress-induced surface roughening.

G. Ehrlich (Univ. of Illinois) discussed FIM results for Ir on Ir(111), particularly focusing on the different diffusion behavior of compact and noncompact clusters. In the latter, diffusion occurs via the motion of edge atoms while in the former, mobility is lower and the cluster tends to move as one unit.

The problem of limited simulation times in molecular dynamics was addressed by A.F. Voter (LANL) who outlined the hyperdynamics method which is particularly suited to deal with systems undergoing infrequent events (such as barrier crossings). In combination with a new parallel replica dynamics method, speed increases of factors of several thousand were reported, permitting the study of kinetic phenomena that were hitherto theoretically inaccessible.

*Symposium Support: IBM, Hitachi, NEC, Sun Microsystems, and NIST.*

## New Mathematical Concepts Help Model Microstructure

*(See MRS Proceedings Volume 529)*

Symposium BB on Computational and Mathematical Models of Microstructural Evolution was conceived as an opportunity to assemble a diverse group of materials researchers and applied mathematicians who share an interest in modeling and simulating microstructure evolution in bulk and thin-film materials. The Symposium focused not only on advances in the understanding of microstructural phenomena, but also on innovations in the mathematical foundations and numerical algorithms that are responsible for dramatic improvements in the accuracy and efficiency of the simulation of materials. For example, the new mathematical concept of gradient flow was presented as an alternative and powerful means of categorizing the kinds of interface motion laws that govern microstructural changes. Later in the meeting, examples were given



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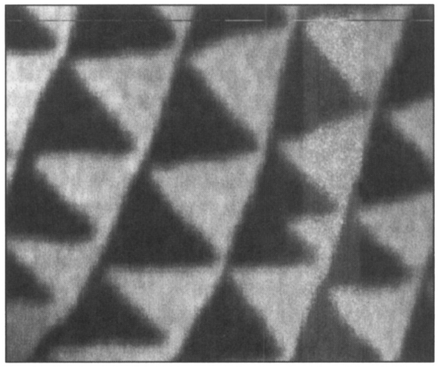
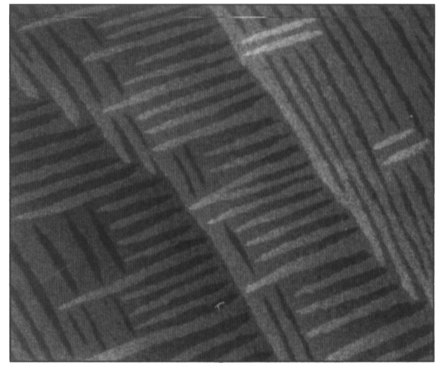
of how gradient flow concepts and variational methods can be incorporated within numerical simulations to track interface motion. Two sessions focusing on phase field models provided new information on the asymptotic behavior of diffuse interface approaches applied to solidification processes on the application of systems of Cahn-Hilliard equations to model phase evolution of multicomponent alloys, and on the application of spectral methods to improve both the accuracy and speed of phase field simulations. A session on multiscale simulations of materials processes compared the relative merits of bridging of length and time scales within a unified model and of using coupled models, each of which operates at a different length and / or time scale.

*Symposium Support: NIST.*

*In Symposium FF at the 1998 MRS Spring Meeting in San Francisco, J. Pelz (Ohio State Univ.) talked about the use of LEEM and STM to study the effect of strain on the step structure of a Si surface. Shown here are triangular and striped step structures on Si(001) surfaces, enhanced by boron doping and tensile strain. The triangular structures were formed at a sample temperature of ~930°C while the striped structures were formed upon cooling to room temperature.*

### Biomaterials Promote Human Body's Regenerative Response

*(See MRS Proceedings Volume 530)*

The primary goal of tissue engineering is to create natural living tissue to restore normal mechanical, metabolic, or aesthetic function to an individual. Biomaterials play a key role in regulating cell behavior and tissue regeneration. Consequently, the realm of tissue engineering has come to encompass many materials-based disciplines such as polymer chemistry, surface chemistry, foam processing, and thin-film fabrication.

Symposium CC on Biomaterials Regulating Cell Function and Tissue Development focused on the modification and characterization of both natural and synthetic materials to alter the human body's regenerative response. This may be achieved through a variety of means including modification of the material surface to influence cell binding or controlled delivery of pharmaceutical agents to enhance cell migration, growth, and tissue development. Many excellent presentations demonstrated the feasibility of such approaches to tissue regeneration.

A.M. Mayes (MIT), recipient of the Outstanding Young Investigator Award, gave an insightful presentation on tailoring the surface characteristics of commonly used biomaterials. Using practical fabrication techniques to achieve a surface layer of PEO star molecules, she was able to achieve a high density of functional groups which may be further modified with peptide ligands to promote specific interactions of cells with the biomaterial surface.

Graduate Student Award Finalist S.J. Peter et al. (Rice Univ.) discussed the development of a degradable, biocompatible polymer which may be cross-linked at the time of a surgical procedure. The material was designed primarily for orthopaedic use as a bone cement and may find applications in aiding fracture stabilization and repair as well as fixation of prostheses. The polymerization reaction was designed to have a low cross-linking temperature (<50°C) in order to avoid the problem of local tissue damage associated with conventional bone cements.

The Symposium was highlighted by a number of invited talks from both academic and corporate institutions. The participation of researchers from the biomedical industry reflects the emergence of the first biomaterial products specifically designed to regenerate living tissue.

### Quantum Dots, Wireless Communication Share Si Heterostructure Base

*(See MRS Proceedings Volume 533)*

Symposium FF on Epitaxy and Applications of Si-Based Heterostructures covered the broad spectrum of recent developments in Si-based heterostructures ranging from new epitaxial growth and characterization methods for $Si_{1-x}Ge_x/Si$ heterostructures and the growth and properties of $Si_{1-x}Ge_x$ and $Si_{1-y}C_y$ alloys and Ge quantum dot structures to advances in SiGe heterojunction bipolar transistor and BiCMOS ICs for application in wireless telecommunications. The opening session focused on current applications of SiGe/Si heterostructures, including a review of the current status of SiGe heterojunction bipolar transistors and FETs and the outlook for SiGe RF-Electronics, the role of SiGe bipolar and BiCMOS circuits for datacom and wireless applications, and the process integration issues in SiGe BiCMOS with the goal of system-level integration. Performance expectations for $n$-channel FETs fabricated from strained Si quantum wells were presented along with device processing issues and performance of $p$-channel FETs. The observation of multiple-exciton complexes confined by alloy fluctuations in relaxed UHV/CVD-grown SiGe layers was reported. New results on the growth and characterization of relaxed SiGe buffer layers for a variety of applications were also presented. Highlighting the session on photonics and optoelectronic applications, a variety of passive photonic circuits on SOI was reported.

New results on epitaxial growth of $Si_{1-x}Ge_x$, on growth and band structure of $Si_{1-x-y}Ge_xC_y$ and $Si_{1-y}C_y$, and on growth of Ge quantum dot structures were also emphasized. Various methods for the epitaxial growth of $Si_{1-x-y}Ge_xC_y$ and $Si_{1-y}C_y$ were reported. High-quality films grown by CVD at low temperature and high silane partial pressures was reported, along with a description of the use of applied strain with photoluminescence to measure the band offsets $Si_{1-x-y}Ge_xC_y$ and $Si_{1-y}C_y$. Others presentations provided results using a variety of measurement methods, indicating concensus among various groups on the band structure of these alloys. Highlighting sessions on the fundamentals of epitaxial growth were talks by J. Pelz (Ohio State Univ.) using LEEM and STM to study the effect of strain on the step structure of a Si surface and B. Voightländer (Jülich, Germany) using *in vivo* STM to study the dynamics of MBE growth of Ge on Si(001) and Si(111).

*Symposium Support: Bede Scientific, Philips Electronic Instruments, SiGe Microsystems-Tech., IBM Microsystems-Tech., IBM Corp., Blake Ind., Charles Evans & Assoc., Leybold Systems GmbH, and Epigress.*