Applications Emerge From Materials Research at the 1993 MRS Spring Meeting

The 1993 MRS Spring Meeting held in San Francisco, California, April 12–16, featured optical and electronic materials, polymers, biomaterials, superconductors, fullerenes, ferroelectric materials, magnetic materials, rocks, and ceramics—from fundamentals to applications. The meeting, chaired by Martin L. Green, AT&T Bell Laboratories; Merrilea J. Mayo, Pennsylvania State University; and Stephen M. Shapiro, Brookhaven National Laboratory, attracted 2,500 people to the 29 symposia, which were complemented by special lectures, forums, short courses, and an equipment exhibit.

Silicon-based optoelectronic technologies showed progress using materials such as Si-Ge, rare-earth-doped silicon, nanoparticles, and porous silicon. Room-temperature 1.54-micron emission was achieved from a Si:Er LED and new approaches were presented to incorporate Er into semiconductors. The origin of luminescence from porous silicon is still in question, but a consensus that quantum confinement is in some way involved appears to be emerging.

Circuits with very high speeds and excellent microwave power performance have been achieved with both GaAs/AlGaAs and InGaAs/AlInAs HBTs (heterojunction bipolar transistors). Now, effort is going into understanding the reliability characteristics of III-V electronic and photonic devices. Devices made from nonstoichiometric GaAs grown at low temperatures are also being tested for reliability and some are already in production because of their unique electrical and optical behavior.

For solar cell applications, it was reported that $CuInSe_2$ and CdTe showed efficiency exceeding 15%, and that these materials are ready to be introduced in demonstration products. Multijunction structures were shown to be a likely technology for large-scale application of amorphous silicon-based solar cells. Each layer in the multijunction structure is tailored to respond to a different wavelength of light. In the area of infrared detectors, in addition to CdTe, research on other materials such as silicides, Pb salts, and GeSi were presented.

The symposium on ferroelectric thin films showed a shift in emphasis from nonvolatile memories to smart applications using the pyroelectric, piezoelectric, or electrooptic properties of these films. An early commercial application is an air conditioner humidity sensor, which is based on a surface acoustic wave (SAW) device using the pyroelectric property of highly oriented $(Pb,La)TiO_3$ thin films.

Giant magnetoresistance (GMR) continued to be a central theme in the symposia on magnetic materials. Although large values of giant magnetoresistance have been reported in heterogeneous alloys, problems such as the high fields necessary to create the large GMR keep multilayers the primary structure of interest for studying GMR.

Topics covered in polymers included polymer/inorganic interfaces, high-temperature polymers and composites, and nonlinear optics. A recurring theme was the need for nondestructive probing of solid/solid interfaces. In the nonlinear optics arena, organic salts were described that have electrooptic coefficients of up to 400 pm/V. Cable TV transmission was demonstrated through an electrooptic phase modulator fabricated from a custom chromophore in a commercial polymer, and holographic storage was shown to store three images in the same volume simultaneously.

Discussions on the device performance of room-temperature semiconductor x-ray and gamma-ray detectors indicated that the quality of these devices now meets the specifications required for several applications

MRS President Tom Picraux (far left) recognizes the Meeting Chairs (from left) Stephen Shapiro, Merrilea Mayo, and Marty Green for their work in coordinating the technical program.

Charles Lieber (left) receives the 1993 MRS Outstanding Young Investigator Award from MRS President Tom Picraux before giving his award talk on STM Studies of Low-Dimensional Materials. Lieber received the award for "exceptional initiative, leadership, and accomplishment in materials research, with pioneering contributions to the understanding of novel materials through synthesis and elegant determination of complex local structure and electronic properties."

in spectroscopy, environmental monitoring, mineral exploration, medical instrumentation, imaging, space, and industrial process control.

Developing new materials and processes for x-ray masks dominated the symposium on x-ray lithography. Membrane materials discussed included Si, SiN, SiC, and CVD diamond.

New techniques presented for characterizing mechanical properties of thin films included the film bulge tester and novel indentation instruments. A special evening session drew lively discussion on current nanoindentation techniques. Reliability issues are turning to dielectric reliability, diffusion barriers, and corrosion, in addition to more traditional issues such as metal-film stress and electromigration.

Similarities in interests and approaches far outweighed the contrasts of mechanisms of deformation and failure in rocks and ceramics, although coverage spanned km to nm, and the behavior of earth mantle material to nanoindentation. Common ground was found in areas of fracture, stress corrosion, and high-temperature deformation mechanisms such as creep.

Progress continued on fullerene materials, with research presented on nanotubes, fullerene composites, optics, superconductivity, synthesis, and endohydrals, as well as fundamental chemistry, physics, and surface behavior.

Superconductor research covered flux pinning, critical currents, wires, tapes, thin and thick films, junctions, weak links, and device processing.

The symposium on hydroxyapatite and related compounds covered the chemistry, formation, properties, biocompatibility, and processing of this material. Hydroxyapatite can be used in dental, orthopedic, and other novel applications.

Researchers are currently at the threshold of a quantitative and predictive theory of phase stability. Other theoretical topics focused on mechanical properties and magnetic multilayers.

Also covered were cleaning of semiconductor surfaces, rapid thermal processing, applications of synchrotron radiation, thermodynamics and kinetics of phase transformations, epitaxial growth, and joining inorganic materials.

■ **Plenary Address.** The plenary presentation "Silicon Valley, What Next?" was given by Craig Barrett, chief operating officer of Intel Corporation. Barrett vividly presented the predominant trends in the semiconductor industry, which show continuing rapid growth. He also predicted the eventual dominance of large semiconductor companies over small startups because of the billion-dollar price tag for new manufacturing facilities. In addition to escalating capital investment costs, he described the exponential growth of worldwide semiconductor revenue, a continuing trend in which the number of transistors in an integrated circuit has doubled every 18 months, and the anti-inflationary trend, represented by the cost per bit, has fallen by a factor of 1,000 over the past 20 years. Barrett cited many materials problems yet to be solved, such as the growth of 12-inch diameter defect-free silicon wafers, photolithography for submicron features, and the production of devices with five or six metallization layers. His full presentation appears elsewhere in this issue.

■ **Education Session.** A noon session on science education for K–12 students brought speakers from the Science Carnival Project (Sandia National Laboratories, Livermore) and from the Lawrence Hall of Science (Berkeley) to demonstrate hands-on activities that scientists or teachers can do with students to increase their interest in and understanding of science.

Susan Brady, Lawrence Hall of Science, described the importance of guided discovery, which helps kids make their own decisions based on evidence instead of emotion.

THANKS . . .

To all the symposium organizers who contributed summaries for the 1993 MRS Spring Meeting report. Your help is greatly appreciated.

To explain safety limits, scientific sampling, and risk (pointing out that "safe" is not a scientific term, but a societal question), she had the audience taste different dilutions of salt water to determine when they could taste the salt, generally around 2,000 or 3,000 ppm.

Ray Ng, Sandia National Laboratories, talked about the Labs' participation in science and math school carnivals. The two-year-old program involves bringing about 10 activities to a school and having the students circulate through the activities. The aim is to (1) show students that science is fun, (2) show how science is part of everyday life, and (3) have them interact with role models. Activities include using infrared cameras; studying bugs, pennies, etc. under a microscope; playing with a demonstration model of magnetic levitation (showing it is scientific, not magical); using a string-and-cup telephone to study sound, voice, and vibration; and making waves using a Slinky™.

■ **Manufacturing Forum.** This forum, held at noon on Thursday, examined the role materials research can play in manufacturing. Technology transfer, partnering, defense conversion, and appropriate roles for the government, industry, universities, and professional societies in the changing manufacturing environment were topics raised during the presentations and subsequent discussions. The panelists were Charles L. Hamermesh, technical director, Society for the Advancement of Material and Process Engineering (SAMPE); Thomas J. Young, manager, Advanced Manufacturing Technology, Sandia National Laboratories; and Gerald Hane, professional staff, House Committee on Science, Space, and Technology. Meeting Chair Merrilea Mayo mediated the forum.

■ **Awards.** Charles M. Lieber from Harvard University received the 1993 MRS Outstanding Young Investigator Award for "exceptional initiative, leadership, and accomplishment in materials research, with pioneering contributions to the understanding of novel materials through synthesis and elegant determination of complex local structure and electronic properties." His award presentation examined scanning tunneling microscopy studies of low-dimensional materials. Eight students received graduate student awards (see photo on page 63), and the new chapter and section of the University of Western Ontario and East Tennessee, respectively, were presented charters.

■ **Technical Sessions.** For a taste of what went on in specific technical sessions, read the summaries that follow. More detailed information is available in the published proceedings (listed elsewhere in this issue).

Students meet and mingle at the late afternoon student mixer.

Solar Cells, Active Matrix Displays Gain from Amorphous Silicon Research

(See MRS Proceedings Volume 297)

Several important advances were reported in Symposium A, Amorphous Silicon Technology. Discussed here are advances in three areas: thin-film transistors, solar cells, and electronic characterization.

The first, hydrogenated amorphous silicon (a-Si:H) thin-film transistors, are widely used in "active matrix" displays in such products as laptop computers. In these displays, each pixel has its own associated electronics. The thin-film transistors are commonly prepared using plasma decomposition of silane, but other deposition technologies are being actively studied in the hope of improving product yields. M. Matsumura of the Tokyo Institute of Technology reported substantial progress in improving thin-film transistors through a technology based on the chemical vapor deposition of "higher" silanes, with a subsequent "hydrogen annealing" processing step.

The greatest hope for the large-scale application of amorphous silicon-based solar cells lies in "multijunction" structures, which consist of several thin-film cells deposited one on top of another. Each cell can have a different optical bandgap and thus, in principle, can exploit the solar spectrum more efficiently. Most prior research on such structures has emphasized a-Si:H and amorphous silicon-germanium (a-$Si_{1-x}Ge_x$:H) alloys; the latter have a narrower bandgap than a-Si: H. At the symposium, Y-M. Li of Solarex Corp. reported on progress in preparing cells based on amorphous silicon-carbon (a-$Si_{1-x}C_x$:H), which has a larger bandgap than a-Si:H. Such cells can now contribute about 3% to the total stabilized efficiency of a solar cell.

Despite great progress in developing devices based on amorphous silicon, finding models for these devices based on fundamental materials measurements has proved difficult. J.D. Cohen of the Univ. of Oregon presented research that may offer one explanation for this difficulty: atomic relaxation of the electrically active defects in a-Si:H near room temperature apparently occurs on a time scale of seconds and even minutes—many orders of magnitude slower than what is typically observed in crystals. As a consequence, the "gap" states which are central to device modeling shift slowly in the bandgap in response to charging or photoexcitation of the material.

Silicon-Based Optical Devices Struggle to Close the Gap with Compound Semiconductors

(See MRS Proceedings Volume 298)

Although silicon is at the heart of the microelectronics revolution, its low optical efficiently has limited its use in optoelectronic applications. The potential significance of combining communications and display technology with microelectronics technology has generated considerable activity directed toward developing a silicon-compatible optoelectronic material. The past few years have seen some interesting and potentially important advances in this area. Symposium B, Silicon-Based Optoelectronic Materials, was organized to bring together the various groups studying the physics, materials science, processing, and applications of silicon-based optoelectronic materials. Talks were organized into five basic areas: $Si_{1-x}Ge_x$, rare-earth-doped silicon (jointly with Symposium E, Rare-Earth-Doped Semiconductors), silicon nanoparticles, porous silicon, and applications.

Theoretical work has predicted that a properly constructed $Si_{1-x}Ge_x$ superlattice can have a direct bandgap and a significantly enhanced optical matrix element relative to silicon. The question of whether this can be achieved experimentally received considerable attention at the MRS meeting primarily because of work by U. Menczigar of the Walter Schottky Institut. His luminescence studies of such superlattices showed an increase in efficiency relative to superlattices in which the periodicity was not optimized, and relative to $Si_{1-x}Ge_x$ alloys. The role of alloy fluctuations in the low-temperature excitonic luminescence from $Si_{1-x}Ge_x$ heterostructures was also discussed in many of the talks.

Introducing erbium (Er) into silicon leads to luminescence at 1.54 μm—an important wavelength for communications technology. L.C. Kimerling, MIT, presented a summary of the physical and optical properties of Er-doped silicon. His work and that of others highlighted the importance of co-doping the silicon with other defects (e.g., oxygen) for obtaining a high luminescence efficiency.

Reducing the dimensions of silicon crystals until they are comparable to the wavelength of the carriers provides another method for modifying silicon's electronic characteristics; it is also the motivation for much of the work on the preparation of silicon nanoparticles. The properties of nanoparticles prepared by techniques ranging from plasma CVD to MBE were presented. Particularly intriguing was the liquid-solution phase synthesis of germanium wires presented by J.R. Heath from IBM. Heath displayed several micron-long wires with tightly clustered widths of less than 10 nm.

Visible room-temperature luminescence from porous silicon has been a topic of great interest at MRS meetings since it was first reported in the fall of 1990. The origin of the luminescence remains an open question, although a consensus appears to be emerging that quantum confinement is in some way involved. Highlights of Symposium B included discussions of: (1) the origin of the fast luminescence band responsible for the blue luminescence observed in porous silicon, (2) the influence of the surface chemistry and termination on the luminescence properties, (3) observations of phonon-assisted luminescence, and (4) luminescence from porous silicon carbide.

D. G. Hall, Univ. of Rochester, gave a summary of the state of the art in applications of silicon in optoelectronics. He emphasized that passive components such as waveguides have been much more successful than active devices. Room-temperature electroluminescence (EL) from $Si_{1-x}Ge_x$ heterostructures was presented by J.C. Sturm, Princeton Univ. In Er-doped silicon, L.C. Kimerling showed a room-temperature (EL) device. Several examples of room-temperature LEDs operating in the visible, which were fabricated from porous silicon, were also presented. Although electroluminescent devices from silicon-based materials continue to show marked improvement, researchers are still quite far from the ultimate goal of fabricating optical devices from silicon with efficiencies comparable to those attainable with compound semiconductors.

$CuInSe_2$, CdTe Ready for Photovoltaic Product Demonstration

Symposium C1, II-VI Compound Semiconductor Photovoltaic Technology, emphasized the material understanding of two compound polycrystalline thin-film semiconductors: $CuInSe_2$ and CdTe. These two materials are in the precommercial development stage or about to be introduced as a first-generation product in demonstration projects. The symposium showed that creative engineering design for the manufacturing of large-area photovoltaic (PV) modules is as important as the materials science for successful use of these materials. Impressive progress was demonstrated in understanding the growth mechanisms of the two materials in films thinner than five microns. A thorough analysis of the microstructure using state-of-the-art characterization tools was put to work to elucidate growth mechanisms and to characterize the bulk and free surfaces of the grains.

It was shown that several reaction pathways for forming each of the two compounds can be used to produce device-quality thin-film material. Some of those pathways showed a potential for low-cost, large-area processing.

Several speakers showed that these materials, used as PV solar cells, exhibit light to electrical conversion exceeding 15% based on AM1.5 global irradiation standard. This is an impressive achievement for low-cost, scaleable PV technology.

Alternative applications to PV were also demonstrated for these materials. Examples were shown for memory devices based on $CuInSe_2$; micro-sized p-n and p-n-p structures with phototransistor action; and CdSe thin-film transistors.

III-V Electronic and Photonic Devices Achieve High Speeds and Quality Performance

(See MRS Proceedings Volume 300)

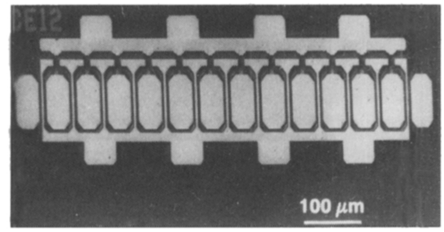
Symposium D1, on III-V Electronic and Photonic Device Fabrication and Performance, covered such topics as fabrication techniques for compound semiconductor devices and circuits, which was summarized in review talks by F. Ren (AT&T Bell Laboratories), W.E. Stanchina (Hughes), and C.S. Wu (Hughes); ohmic contact formation; dry etching, reviewed by C. Constantine from Plasma Therm; and laser results, summarized by W.S. Hobson from AT&T Bell Laboratories and H. Temkin from Colorado State Univ. Many electronic and photonic devices have reached a fairly sophisticated stage, and now much effort is being put into understanding their reliability characteristics. Circuits with very high speeds and excellent microwave power performance have been realized with both GaAs/AlGaAs and InGaAs/AlInAs HBTs (accompanying figure shows a GaAs/AlGaAs HBT power circuit). To fabricate such circuits requires the use of doping techniques such as ion implantation (reviewed by W. Wesch, Friedrich-Schiller Univ. and T.E. Haynes, Oak Ridge National Laboratory) or diffusion (reviewed by M.D. Deal, Stanford Univ.; T.Y. Tan, Duke Univ.; H.G. Robinson, Univ. of Florida; and E.L. Allen, San Jose State Univ.). The formation of amphoteric defects at high doping levels in III-V semiconductors explains many dopant activation trends and diffusion results; this area was reviewed by W. Walukiewicz from Lawrence Berkeley Laboratory. A lively joint session was held with Symposium G, Rapid Thermal and Integrated Processing, on RTA/RTP and integrated processing. Junction formation in Si by RTA was a key topic covered by R.B. Fair of MCNC. Key to all of the device work was the application of gas-source MBE methods like MOMBE. The fascinating chemistry of this technique was covered in a plenary talk by C.R. Abernathy (AT&T Bell Laboratories), who reviewed the outstanding progress achieved in the past three to five years. There was a general feeling that, as the need for III-V products in military applications lessens, efforts to develop them commercially must be accelerated.

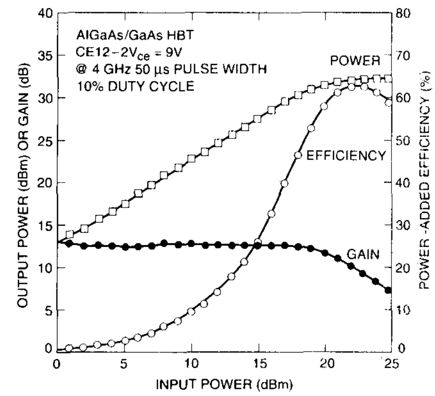
Unique Electrical and Optical Behavior of III-V Compounds Grown at Low Temperatures Lead to Device Applications

(See special issue of the Journal of Electronic Materials, *November 1993)*

Spanning two days, Symposium D2 on Low-Temperature-Grown and Highly Nonstoichiometric GaAs and Related Materials, covered GaAs, InP, GaP, $Al_xGa_{1-x}As$, $In_xGa_{1-x}As$, $In_{0.5}Ga_{0.5}P$, $In_xAl_{1-x}As$, and other III-V compounds grown by molecular beam epitaxy at temperatures from 150 to 400°C. Perhaps the two most outstanding features of low-temperature-grown (LT) GaAs are very high concentrations ($\sim 10^{20}$ cm^{-3}) of point defects (As antisites and Ga vacancies), as grown, and high densities ($\sim 10^{17}$ cm^{-3}) of large (~60-Å diameter) As precipitates after an anneal at about 600°C. One of the main points of discussion (or contention?) during the first LT-GaAs MRS symposium (Fall 1991) was the relative importance of point defects and precipitates in explaining the electrical and optical properties of the material. At the Spring 1993 symposium, an evening rump session addressed this issue, with lively discussions on both sides. The point-defect gallery seemed to hold sway in debates on most of the older electrical and optical issues, while the precipitate side claimed victory with respect to three new developments, namely, high-field conductivity, excitonic electroabsorption, and scanning-tunneling microscopy (STM) imaging of the regions around precipitates. It is likely that another debate will ensue once participants have had time to consider the implications of these new experiments.

Besides the high-field conductivity, elec-





Micrograph and microwave power performance of a GaAs/AlGaAs HBT circuit designed for commerical applications. (Courtesy of F. Ren, AT&T Bell Laboratories.)

troabsorption, and STM results, several other experiments were discussed for the first time in an MRS symposium: (1) real-time substrate temperature measurement by ellipsometry, (2) high-resolution diffuse x-ray scattering, (3) positron annihilation, (4) growth of high-resistivity $In_{0.5}Ga_{0.5}P$, (5) isolation by As implantation, (6) photoquenching of hopping conduction in GaAs, and (7) identification of the P antisite levels in InP by pressure experiments. Also, many of the earlier investigations, e.g., those involving growth and annealing, were brought to new levels of refinement, with revised interpretations in some cases. Thus, many of the materials issues are much better understood now, but others are just beginning to emerge.

The LT-III-V effort is motivated by several device applications. Those discussed at this meeting included power GaAs MESFETs (gate-drain breakdown and low-frequency noise), excitonic electrooptics, coherent microwave generation, and GaAs-on-Si MESFETs. A few LT-GaAs devices are already in production circuits and others are being tested for reliability.

Room-Temperature 1.54-μm Emission from Silicon: Erbium LED

(See MRS Proceedings Volume 301)

Advances in doping techniques, developments in models and theory, and growth and fabrication of novel structures highlighted the symposium on Rare-Earth Doped Semiconductors, Symposium E. Special interest focused on erbium-doped silicon, microprecipitates of erbium arsenide in the gallium arsenide matrix, and the potential of GaAs:Er in high speed photoconductive applications. Attention was also on Group II-VI semiconductors, due to demands on electroluminescent devices for flat-panel displays and rare-earth-doped fluoride insulators for optical-waveguide applications.

Incorporating rare earths into semiconductors was highlighted with three new approaches, including electron cyclotron resonance plasma enhanced CVD, magnetron sputtering, and laser doping. I.G. Brown of Lawrence Berkeley Laboratory gave an excellent overview of metal plasma techniques for ion implantation with upscaling possibilities for large-scale industrial implantation. Significant developments were reported for metalorganic epitaxy, which allows large rare-earth doping concentrations in III-V compounds. F. Scholz of the Univ. of Stuttgart, reported desirable vapor pressure and melting point parameters for methyl-cyclopentadienyl and isopropyl-cyclopentadienyl compounds as rare-earth precursors. Others reported data on successful erbium doping and deposition using tris(n-butyl cyclopentadienyl)erbium and an erbium amide source.

L.C. Kimerling of MIT reported the demonstration of the first efficient, sharp-line, room-temperature light emission from a silicon LED. This light emission and possible amplification using erbium in a silicon host demonstrates a technology for optoelectronic integration and interconnection. Important materials problems were addressed, including the diffusivity and solubility of erbium, the incorporation of high concentrations ($>10^{20}$ cm^{-3}) of erbium in the silicon host, optically and electrically active sites, and the importance of adding oxygen to enhance the erbium 1.54-μm emission. *Ab initio* calculations by M. Lannoo (IEMN, France) established the stability of tetrahedral interstitial erbium in silicon, in agreement with channeling studies.

Several papers focused on understanding the excitation mechanism of GaAs:Er and InP:Yb. T. Gregorkiewicz of the Univ. of Amsterdam, Netherlands, elaborated on this latter system and the role of bound excitons, nonradiative Auger processes, and electron and hole traps. Co-doping with oxygen also appears to enhance the erbium signal in different III-V systems. S.J. Allen, UC–Santa Barbara, and C.J. Palmstrom, Bellcore, addressed a new rare-earth-based material system which is emerging and which combines semimetallic rare-earth monoarsenides with compound semiconductors like GaAs and AlAs. These rare-earth monopnictides will enable buried structures for quantum multifunctional high-speed electron devices.

Room-Temperature Semiconductors Broaden Applicability of Radiation Detectors

(See MRS Proceedings Volume 302)

The symposium on Semiconductors for Room-Temperature Radiation Detector Applications, Symposium F, provided a forum for presenting and evaluating the most recent results on semiconductor radiation detectors for use in the energy range of a few eV to 1 MeV. The symposium emphasized the development of x-ray and gamma-ray detectors which combine the advantages of room-temperature operation with the excellent energy resolution of cryogenically cooled spectrometers. The elimination of the cryogen allows the instruments to be portable, easy to operate, and relatively maintenance free so they can be used in a wide range of applications. Some of the issues central to this technology include the choice of detector material and the role of defects in the materials and how the defects may limit the ultimate performance of the detector, as well as that of the pulse-detecting electronics and data-acquisition systems.

The symposium was organized into technical sessions on mercuric iodide, cadmium telluride, diamond, cadmium zinc telluride, silicon, new detector materials, and device applications. The discussions on device performance indicated that the quality of room-temperature semiconductor x-ray and gamma-ray detectors now meets the specifications required for several applications in spectroscopy, environmental monitoring, mineral exploration, medical instrumentation, imaging, space, and industrial process control. Progress was also demonstrated in the processing of electronic pulses to improve the energy resolution of the detectors, and in the availability of compact low-noise circuits for packaging field instruments, which results in the instruments having significantly less weight than they would with conventional technology. Indeed, a number of systems which incorporate either single detectors or arrays of detectors were described at this symposium. New results were also reported on the relationships between material properties and detector quality and on improved techniques for purification, crystal growth, and processing technology. These developments generated confidence that continued advances in the performance of room-temperature semiconductor detectors and an expanded commercial market for these detectors are forthcoming.

Temperature Measurement and Control Remains a Challenge in Rapid Thermal Processing

(See MRS Proceedings Volume 303)

Interest in rapid thermal processing (RTP) continues to grow as demands on IC processing technology become more stringent. The ability to process at high temperatures for short times becomes more attractive as thermal budgets are reduced. In addition, the process chambers of most RTP systems are cold-wall or near cold-wall, which gives them a distinct advantage over hot-wall systems. Specifically, cold-wall systems are not as susceptible as hot-wall systems to the diffusion of unwanted species through the chamber walls. Also, the cracking of reactant gases occurs only at or near the sample surface. The latter can critically reduce such undesirable effects as autodoping during the deposition of thin films. The fact that RTP is ideally suited for single-wafer processing is also a driving force. These issues were discussed in Symposium G, Rapid Thermal and Integrated Processing II.

Temperature measurement and control remains one of the most challenging prob-

Craig R. Barrett, chief operating officer of Intel Corporation, presents the plenary address, "Silicon Valley, What Next?", showing that the semiconductor industry is alive and well. (See "Material Matters" in this issue for article based on his presentation.)

lems facing RTP equipment manufacturers and potential users. The problem arises because the emissivity of the wafer changes with temperature as well as with film thickness and film material. The wafer's ability to absorb and radiate energy from and to the RTP system is directly related to the emissivity of the wafer. Consequently, dynamic control of temperature is a desirable attribute for most applications. A number of approaches are being investigated and were reported. Optical and acoustical methods are being considered for indirect measurement, and thermal expansion for direct measurement, of temperature. Theoretical predictions and laboratory measurements are encouraging; much work remains, however, to make them practical in real RTP commercial equipment.

The design of RTP systems continues to receive attention. Thermal and ray trace models are maturing and are providing much-needed design information that will lead to better wafer-temperature uniformity. This information includes the ability to control temperature uniformity during heat-up and cool-down, as well as at processing temperatures. A number of papers were presented that address this subject and indicate the expected future direction of equipment design.

Annealing remains the number one use of RTP systems. It is being applied successfully to form silicides where short-time anneals at intermediate temperatures are required. It is now routinely used for dopant activation and radiation damage removal of ion-implanted samples. Rapid thermal oxidation and nitridation are showing much promise. Here it appears that the high-temperature short-time attributes can be used to improve device performance. As device dimensions shrink, critical parameters such as gate insulator thickness become more important. RTP is being considered as a tool in forming gate stacks where dopant diffusion through the insulator can be catastrophic.

Rapid thermal chemical vapor deposition (RTCVD) is receiving increased attention. Here the cold-wall nature of RTP reactors is an important issue. In addition, RTCVD reactors tend to be cleaner than conventional LPCVD reactors since they are often vacuum chambers in which a low base pressure is possible. RTCVD is being used to deposit high-quality silicon epitaxy and polysilicon as well as oxides, nitrides, and oxynitrides. It is also being used to deposit device-quality silicon/germanium alloys. It appears that RTCVD has potential for use in a number of applications required for the fabrication of advanced integrated circuits.

Nondestructive Probes Important for Analysis of Polymer/Inorganic Interfaces

(See MRS Proceedings Volume 304)

Symposium H explored polymer/inorganic interfaces from the incipient formation of the interface to final use in, for example, aircraft bodies or optical fiber transmission. One recurring theme in all of this work was the need for a nondestructive, experimental probe of solid/solid interfaces. The last session on Friday explicitly addressed this issue and was well attended despite its late hour.

Several strategies for probing solid/solid interfaces became apparent. Nonlinear optical properties were used to probe the molecular interactions of a polymer at an interface. F.J. Boerio, J.T. Young, and K.M. Jackson from the Univ. of Cincinnati used surface-enhanced Raman spectroscopy to show that the curing of polyimide films was inhibited near a silver surface. Second harmonic generation was used by C. Dressler and co-workers at Univ. Heidelberg to show that polyimide cured in preferential orientations near a metal surface. J.F. Evans, M. Tirrell, and L.A. Zazzera at the Univ. of Minnesota used infrared radiation to study the adsorption of polymers on Si(100) surfaces, with important applications for microelectronics packaging. The interaction of liquid crystals with a rotating solid surface was studied by reflectometry measurements at the liquid crystal/substrate interface by D.A. Hill and M.A. Abad at Notre Dame.

For metal-on-polymer interfaces, the interface was characterized using energetic radiation. Konstadinidis and co-workers at AT&T Bell Laboratories and Brookhaven National Laboratories showed how the reactions between metals and polymers depended specifically not only on the chemical properties of each component, but also on physical properties of the polymer, such as glass transition temperature using x-ray absorption measurements. G.E. Mitchell of Dow Chemical Company and co-workers used soft x-rays to study how the polymer reacted with a metal overlayer.

While all of these techniques are relatively new and specialized, nondestructive analysis of chemistry at buried polymer/inorganic interfaces is an important and rapidly expanding field.

High-Temperature Stability, Processibility, Flame Retardency Offered by High-Performance Polymers

(See MRS Proceedings Volume 305)

High-temperature polymers and composites are becoming increasingly important materials for the aerospace and electronics industries. Advanced aircraft such as the High-Speed Civil Transport, a cost-effective supersonic commercial aircraft being developed for use in the early 2000s, rely heavily on the use of lightweight, processable, durable composite materials. Recent research in high-temperature polymers and composites is driven by this need for materials with good high- and low-temperature properties, long-term durability (greater than 60,000 hours at temperatures around 200°C), and processability. Symposium I, High-Performance Polymers and Polymer Matrix Composites, dealt with recent advances in the development of new materials. Specific sessions covered: high-temperature polymers and composites, polymer processing and characterization, the role of the resin-fiber interface in polymeric composites, aging and degradation in polymers and composites, inorganic polymers, rigid-rod polymers, molecular composites, and high-performance blends.

Researchers at Virginia Tech (among them J.E. McGrath) have been investigating the effects of fluorinated alkyl groups (3F groups) and phosphoryl groups in polyimides. Both groups yield polymers with high glass transition temperatures and good high-temperature stability. Moreover, polymers having the phosphoryl groups possess the potential for good flame retardency. Other promising systems discussed in this symposium included poly(arlene ether benzimidazoles) (P.M. Hergenrother at NASA Langley, and J.L. Hedrick at IBM Almaden), and toughened, processable polyimides (P. Delvigs at NASA Lewis).

Graduate Finalists Present Research; Eight Receive Graduate Student Awards at 1993 MRS Spring Meeting

At the 1993 MRS Spring Meeting, 21 finalists competed for MRS Graduate Student Awards. The finalists, all authors or co-authors of papers presented at the meeting, were selected on the basis of the quality and thoroughness of their research, the originality and independence of their contributions, and their promise for future achievement in materials research.

During special sessions, the finalists gave brief talks explaining their research to a panel of judges, who selected eight award recipients (shown in accompanying photo). The awards were presented during the Plenary Session on Tuesday evening, April 13.

Following is a list of the finalists, where they are studying, the titles of their papers, and the symposium in which each participated.

Graduate Student Award winners at the 1993 MRS Spring Meeting. Left to right: Archisman Bagchi, Dongqi Li, Peter D. Fuqua, Meenam Shinn, Maohui Ge, Joong W. Lee, John H. O'Haver, Chengzeng Xu.

Graduate Student Award Finalists—1993 MRS Spring Meeting

Archisman Bagchi, University of California–Santa Barbara, "A Novel Testing Technique to Measure the Interfacial Toughness of Thin-Film Systems" (Symposium M1)

Wirote Boonkosum, Chulalongkorn University, "Visible-Light Amorphous Silicon-Nitride Thin-Film Light-Emitting Diode" (Symposium A)

Garo J. Derderian, University of California–Irvine, "Microstructural Changes Due to Process Conditions in Sol-Gel-Derived $KNbO_3$ Thin Films" (Symposium N)

Peijun Ding, State University of New York–Albany, "Differences Resulting from Ramped Annealing and Isothermal Annealing on Al/Hf/Al Interdiffusion" (Symposium O)

Peter D. Fuqua, University of California–Los Angeles, "Synthesis and Spectroscopy of Metallophthalo-Cyanine-Doped Sol-Gel-Derived Materials" (Symposium J)

Maohui Ge, University of Hawaii, "Nanometer-Sized Tubes of Carbon" (Symposium S)

Feng Hong, North Carolina State University, "Self-Aligned Epitaxial $CoSi_2$ Formation from Multilayer Co/Ti-Si(100) by a Two-Step RTA Process" (Symposium G)

Ronald J. Kelley, University of Wisconsin–Madison, "High-Resolution Photoelectron Study of the Optimum Oxygen Doping Levels in High T_c Superconductors" (Symposium L)

Joong W. Lee, University of California–Davis, "Chemical Modifications of Fullerenes, C_{60} & C_{70}: Synthesis, Structure, and Characterization" (Symposium S)

Dongqi Li, Syracuse University, "Spin-Polarization and Hydrogen Adsorption Effects of a Gd Surface State" (Symposium Q1)

Matthias Müllenborn, University of California–Los Angeles, "Recombination at Heterojunction Interfaces" (Symposium D1)

John H. O'Haver, University of Oklahoma, "Formation of Ultrathin Polystyrene Films in Adsorbed Surfactant Bilayers on Silica" (Symposium H)

Joseph M. Schwartz, University of Minnesota, "Microstructural Evolution of Sol-Gel-Derived Lead Titanate" (Symposium N)

Jung Shin, California Institute of Technology, "Defect Dynamics in Irradiated Amorphous Silicon: Implications for Defect Annihilation" (Symposium O)

Meenam Shinn, Northwestern University, "Growth and Mechanical Properties of Single-Crystal $NbN/V_{0.6}Nb_{0.4}N$ Superlattices" (Symposium M1)

Paul S. Thomas, Imperial College, "Solvent-Induced Morphological Changes to Polycarbonate Interfaces" (Symposium H)

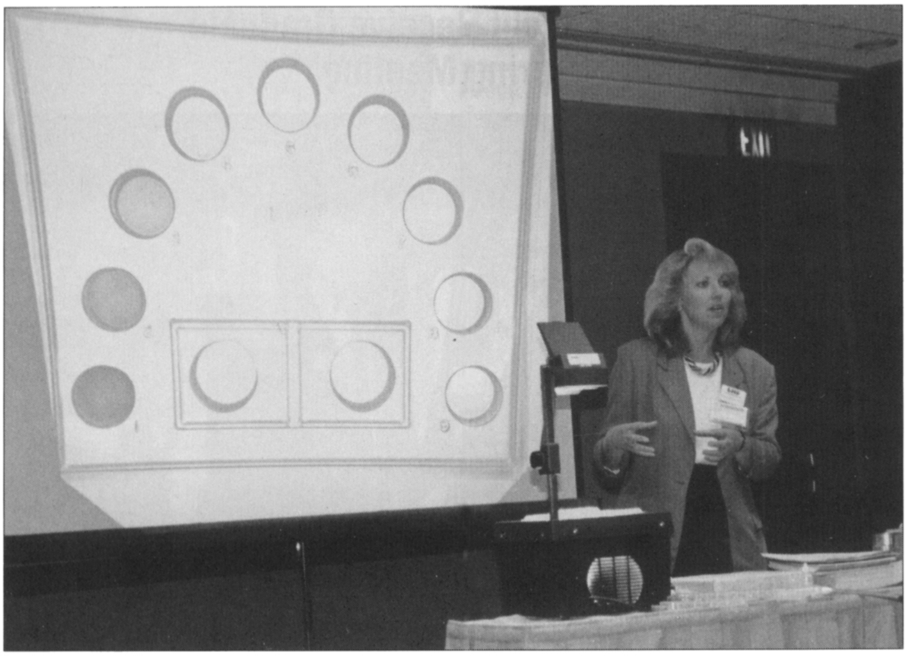
Michael T. Umlor, Michigan Technological University, "Variable Energy Positron Beam Characterization of Defects in As-Grown and Annealed Low-Temperature GaAs" (Symposium D2)

Steven Verhaverbeke, Catholic University of Leuvan, "HF-Last Cleanings: A Study of the Properties with Respect to the Difference Variables" (Symposium Y)

Kirkland W. Vogt, Georgia Institute of Technology, "Low-Temperature Deposition of Group III and Transition Metal Nitride Films" (Symposium D1)

Chengzeng Xu, Univeristy of Southern California, "New Crosslinkable Polymers for Stabilizing Second-Order Nonlinear Optical Effects" (Symposium J)

Jengyi E. Yu, University of Florida, "Growth and Characterization of Rare-Earth Sulfide/Zinc Sulfide Superlattices" (Symposium E)



At the Grass Roots Education Session, Susan Brady from the Lawrence Hall of Science demonstrates how to teach students about detection levels and risk by observing what dilution level of dye is visible with the unaided eye.

Organic Materials Show Promise for Nonlinear Optical Applications

The Organic Materials for Nonlinear Optical Applications symposium (Symposium J) both started and ended on a strong note. C.P. Yakymyshyn of General Electric opened the meeting with a presentation on crystalline organic salts, revealing that organic materials with electrooptic coefficients of up to 400 pm/V have been demonstrated. B.A. Smith of IBM completed the transition from new materials to their application by demonstrating cable TV transmission through an electrooptic phase modulator fabricated from a custom chromophore in a commercial polymer. The successful transmission of analog data is a more demanding application than the transmission of digital data, and shows that the potential of organic nonlinear optical materials is starting to be realized.

In addition to electrooptical applications, nonlinear materials have potential use in holographic storage. W.E. Moerner of IBM presented the first work showing net gain for photorefractive polymers, and demonstrated the storage of three images in the same volume simultaneously. C. Bräuchle of the Univ. of Munich won the Best Contributed Talk award for his presentation of pattern recognition and holographic storage using bacteriorhodopsin as the nonlinear optical material. G.W. Rayfield of the Univ. of Oregon used hyper-Rayleigh scattering to measure the nonlinearities of such genetically engineered bacteriorhodopsins.

A variety of novel compounds with substantial hyperpolarizabilities were described. A.K-Y. Jen of EniChem spoke on thiophene derivatives, which exhibited values of $\mu\beta$ up to $9{,}100 \times 10^{-48}$ esu. L-T. Cheng of Du Pont described measurements on thioarbiturate derivatives prepared by S.R. Marder and co-workers at Caltech; some of these derivatives have been incorporated into polymers at Du Pont. Andrew Persoons of the Univ. of Leuven (Belgium), the developer of hyper-Rayleigh scattering, used the new technique to measure hyperpolarizability β for a couple of mixed-valence inorganic compounds, including one whose hyperpolarizability was $1{,}400 \times 10^{-30}$ esu. Among the variety of talks concerning methods of physically aligning nonlinear chromophores, particularly original was the presentation by J.K. Whitesell of the Univ. of Texas describing the use of a "molecular spider," derived from polypeptides, to orient molecules.

Challenges in X-Ray Lithography Involve Mask Materials and Processing

(See MRS Proceedings Volume 306)

Worldwide activities for developing new materials and processes for x-ray masks dominated the symposium on Materials Aspects of X-Ray Lithography, Symposium K. Membrane materials discussed included Si, SiN, SiC, and CVD diamond films. Fabrication of multilayer mirrors for soft x-rays was also well represented.

E.A. Dobisz of the Naval Research Laboratory reviewed the scope of the national x-ray lithography program and described x-ray mask fabrication and materials issues. G.M. Wells, Univ. of Wisconsin, reviewed work being conducted at the Center for X-Ray Lithography (under the direction of F. Cerrina), in particular, materials issues for beam lines, mirrors, x-ray mask substrates, and absorbers. Y. Vladimirsky from Louisiana State Univ. presented some work on characterization of materials from the radiation damage point of view. He showed a correlation between the bandgap and the degree of radiation damage. L.K. Wang from IBM presented work on radiation damage in CMOS devices fabricated with x-ray lithography. He concluded that radiation damage to the gate oxides is not an issue for oxides thinner than 70 Å. A.E. Novembre from AT&T Bell Laboratories discussed performance characteristics of x-ray sensitive resists and showed that parameters that determine resist performance include postbake and environmental conditions. L.E. Ocola, Univ. of Wisconsin, presented work on the modeling of photoelectron effects in x-ray lithography exposures. His work is in agreement with experimental results by K. Early and H.I. Smith from MIT, indicating the importance of Auger electrons on resist exposure. More work on radiation damage on MOS oxides was presented by A.J. Lelis from the Army Research Laboratory. He concluded that x-ray radiation damage was negligible for devices fabricated with x-ray lithography.

H.I. Smith presented pioneering work on x-ray lithography at MIT. X-ray mask issues, in particular, were discussed, including the fact the SiN-substrates may not be suitable for x-ray masks because of radiation damage. M. Oda gave a paper on x-ray mask fabrication at the newly formed mask company, NTT Advanced Technology Corporation. Mask substrates with Ta absorber on SiN and SiC membranes are routinely fabricated there, with 0.2-micron features etched in the metal. A. Usami from NTT presented a new method for measuring the stress on SiN-coated wafers using a noncontact microwave measurement of the lifetime of minority carriers injected by an infrared laser diode. A few papers examined diamond films for x-ray masks, showing their unique qualities.

N.M. Ceglio from Lawrence Livermore Laboratories described an x-ray reduction system, using five reflecting mirrors. E. Spiller from IBM spoke about multilayer mirrors and said he was optimistic about the future of x-ray mirror fabrication; he was, however, concerned about multiple-mirror systems for x-ray projection lithography. Work on multilayer Mo/Si x-ray mirror degradation was presented by D.L. Windt from AT&T Bell Laboratories. A top coating was found necessary to improve the mirror lifetime. B.J. MacGowan from Lawrence Livermore National Laboratory reported improved mirror lifetime with a Si layer top coating for x-ray multilayer mirrors.

M. Chaker from INRS in Canada discussed the tradeoffs involved in materials choices for optimizing x-ray production efficiency for laser plasma source targets. The new field of capillary x-ray lens material characterization was covered by C.M. Dozier from NRL. He pointed out that a very large number of capillary tubes ($>10^6$) is needed to obtain good exposure uniformity. The development of a collimator for x-ray lithography point sources was described by R.D. Frankel from Hampshire Instruments. The collimator incorporated 1,000 capillaries that provided a 3% illumination uniformity.

I. Amemiya from HOYA Corp., Japan, reported on SiC films and the use of SiO_2 antireflection coatings. M. Chaker from INRS, Canada and R.A. Levy from the New Jersey Institute of Technology, presented work on depositing SiC films by laser ablation and LPCVD, respectively. J. Melngailis, MIT, who prepared a paper on focused ion beam techniques for mask repair, mentioned that there appears to be a fundamental limit on the minimum linewidth that can be written with an ion beam.

Synchrotron Radiation Provides Powerful Tool for Materials Analysis

(See MRS Proceedings Volume 307)

Symposium L, Applications of Synchrotron Radiation Techniques to Materials Science, highlighted a large variety of applications for synchrotron radiation-based studies used to characterize a varity of materials. One session, Topography and Tomography, contained papers dealing with x-ray topographic studies of bulk single crystals of such materials as phosphates and arsenates as well as semiconducting metal tellurides. X-ray tomographic imaging can be used to monitor chemical vapor infiltration into woven fiber ceramic composites and to investigate the effectiveness of dental laser treatment of caries/lesion formation in root dentin; in the latter study, work centered on the amount of mineralization in the root dentin. Microtomography was also used to study microelectronic packaging materials. Fatigue cracking geometries and openings were studied using x-ray tomographic microscopy, while grain boundaries in brass were examined using x-ray topography; this approach also was used in investigating indium antimonide crystals and silicon bipolar diodes.

A successful joint session was held with the magnetic materials symposia, Q1 and Q2, to focus on the applications of synchrotron radiation to the study of magnetic materials. Topics highlighted in this field included magnetic thin films, magnetic imaging approaches involving metal alloy recording disks, and ultrathin magnetic films. Other metal systems studied were cobalt/copper multilayers, iron single crystals, and cobalt and iron films, many of which exhibit giant magnetoresistance.

Thermal diffuse scattering, grazing incidence x-ray scattering, and Bragg scattering, along with angle-resolved photoemission-extended fine structure approaches, were used to study a series of materials that included metallic single crystals and sulfur/nickel interfaces. X-ray fluorescence approaches were used to investigate thin-film deposition processes in real time and the trace detection of elements in geological and biological materials.

Other papers were dedicated to studies of materials using x-ray absorption fine structure (EXAFS) and x-ray absorption near-edge structure (XANES). EXAFS was used to investigate dopants in amorphous silicon during the various stages of annealing, while both EXAFS and XANES were used to conduct research regarding local atomic structure, dopant effects, cation ordering, and static/dynamic distortion in ceramics based on ceria and zirconia.

Current and New Techniques Examined for Measuring Stresses and Mechanical Properties of Thin Films

(See MRS Proceedings Volume 308)

The symposium Thin Films—Stresses and Mechanical Properties, M1, now in its fourth generation, was expanded even further this year. Three joint sessions were organized and special group discussions were held throughout the week. To help accommodate most of the 150 authors during daytime sessions, a new oral/poster format was adopted that incorporated poster previews and viewing into the late morning and late afternoon programs.

The symposium began with presentations that described the effects of surfaces, growth processes, and phase transformations on stress generation in metal and oxide films. Stress effects were discussed further in two joint sessions with symposium M2, Materials Reliability in Microelectronics III. The sessions focused on the characterization of voiding and electromigration in metallization interconnects and on stress relaxation and thin-film deformation.

Many contributors proposed new techniques for characterizing the mechanical properties of films. Thin-film bulge testers and novel indentation instruments drew particular interest. On Tuesday evening, a lively discussion group exchanged many ideas on current nanoindentation techniques.

A joint session was held with Symposium W, Theory of Materials Properties, on the mechanics and microstructure of epitaxial films. The next session, which addressed the mechanical properties of polymer films, revealed the difficulties that arise when characterizing these strongly anelastic materials.

A variety of mechanical properties such as wear, fracture, and adhesion were examined, with presentations covering a range of materials that included single crystals, polycrystals, amorphous alloys, metastable materials, semiconductors, and ceramics. Discussion of multilayered materials covered both theoretical and experimental results and concentrated on structure-strength relations.

Corrosion, Interdiffusion, Stress All Affect Reliability

(See MRS Proceedings Volume 309)

Now in its third year, the symposium on Materials Reliability in Microelectronics, M2, has seen an increased interest in dielectric reliability, diffusion barriers, and corrosion, as well as continued interest in traditional metal film stress and reliability issues relevant to microelectronics. The reliability and mechanical stability of SiO_2, adhesion measurements (R.J. Ferris, Univ. of Massachusetts) and characterization methods of oxides and thin films were presented. The symposium emphasized such areas as microstructure, including grain size and grain size distribution (C.V. Thompson, MIT), and crystallographic texture (D.B. Knorr, RPI) of blanket layers and patterned lines (including single crystal Al lines); aluminum alloy additions (Cu, Fe, Mg, Pd, Sc); and the use of refractory metal layers (e.g., Ti, TiN). In a late paper, S. Ogawa, Matsushita Electric, presented mechanical and reliability data for Al-Sc containing 0.025, 0.05, 0.10 and 0.15%Sc which showed Al_3Sc precipitates to be coherent with the Al lattice. Compared to Al-Cu films, the Al-Sc films had a higher degree of hardness, a higher recrystallization temperature, and an improved reliability (both stress voiding and electromigration). The precipitate morphology and location of the solute (i.e., within the grain or at the grain boundary) was shown to influence the electromigration behavior of Al-Cu lines. The use of $1/f$

noise and the detection of early resistance changes during electromigration to predict the reliability of Al films was addressed. Finally, papers on the corrosion and passivation of Al and Cu films (V. Brusic, IBM), diffusion barriers, and silicide formation were presented.

Ferroelectric Thin-Film Research Shifts to Smart Applications

(See MRS Proceedings Volume 310)

This year, Symposium N, Ferroelectric Thin Films III, hosted approximately 100 presentations over three days. Since the last ferroelectrics thin film symposium 18 months ago, an understanding of structural and microstructural effects on ferroelectric properties has evolved. Invited speakers N. Setter, Laboratoire de Céramique, and A.I. Kingon, North Carolina State Univ. presented their work on unraveling the complicated material interdependencies.

A shift in emphasis was observed from nonvolatile memories to "smart" applications of ferroelectrics utilizing the pyroelectric, piezoelectric, or electrooptic properties. Talks on integrated smart devices included microactuators by M. Sayer, Queen's Univ.; pyroelectric applications by A. Patel, GEC-Marconi, and R. Asahi, Toyota Central R&D Laboratories; and optoelectronic devices by D. Dimos, Sandia National Laboratories, S.L. Swartz, Battelle (Columbus), and D.K. Fork, Xerox Palo Alto Research Center. K. Ijima, Matsushita Corporation, reported on the first commercial application for ferroelectric thin films. The device is a humidity sensor in an air conditioner, based on a surface acoustic wave (SAW) mechanism utilizing the pyroelectric property of highly oriented (Pb, La)TiO_3 thin films.

Universal advances in high-quality thin-film fabrication continued with OMCVD taking the leading role as the preferred deposition technology (M. de Keijser, Philips Research Laboratories; S.B. Desu, Virginia Tech; and J. Zhang, Advanced Technology Materials). The maturing of the technology was especially evident in one session dealing with the process integration of ferroelectric thin films. The reactive ion and chemically assisted etching of lead zirconate titanate, and lithium tantalate films were reported (P.K. Larsen, Philips Research Laboratories; P.F. Baude, Univ. of Minnesota; and S.B. Desu, Virginia Tech). P. Maniar, Motorola, reported on the impact of the backend processing of integrated ferroelectrics on silicon.

Emerging trends observed during the symposium included rapid advances in high-quality film deposition by ECR-assisted and plasma-enhanced MOCVD techniques. High-quality thin films were grown on an expanding range of electrode materials which included conductive oxides and epitaxial growth on high-temperature superconductors. Surface topography studies using atomic force microscopy (AFM) and advances in accurate models for the physical and electrical ferroelectric responses were also presented.

Poster session attendees discuss fabrication of quantum devices.

The Ferroelectric Thin Films III symposium was pleased to be able to acknowledge the outstanding efforts of many students participating in this year's symposium. The student awards, which were supported by the Advanced Research Projects Agency, went to Leo Archer, Univ. of New Mexico; Garo Derderian, Univ. of California–Irvine; Vikram Joshi, Univ. of Minnesota; Jai-Chan Lee, Rutgers Univ.; Lynnette Madsen, McMaster Univ.; Mauricio Pilleux, Univ. de Chile; Joseph Schwartz, Univ. of Minnesota; Michael Vestel, Univ. of California–Los Angeles; and Laura Wills, Northwestern Univ.

Evening poster sessions provide an opportunity for exchanging research results in a casual atmosphere.

Thermodynamics and Kinetics of Phase Transformations in Thin Films

(See MRS Proceedings Volume 311)

Phase formation and stability in thin films were the subjects of Symposium O, Phase Transformations in Thin Films: Thermodynamics and Kinetics. In nearly 80 papers, theoretical and experimental investigations of various aspects of phase transformations were presented. W.C. Johnson of Carnegie Mellon Univ. presented a theoretical analysis of phase stability in strained, epitaxial films. He showed that Gibbs' phase rule is not applicable to a stressed solid and that several linearly stable phase equilibria can exist. Other papers addressed an interfacial reaction in a stressed system, martensitic transformations, and stress effects on solid-solid phase transformations and on the growth of quaternary semiconductor alloys. One session was dedicated to the fundamental aspects of film growth. Simulations of surface diffusion and phase separation during deposition were presented in several papers. The growth of non-bcc Cr films was studied and compared with previous reports, leading to the conclusion that contamination can bring stabilization to the A15 structure. A series of papers addressed the crystallization of amorphous phases. The Sinclair group of Stanford Univ. used *in-situ* TEM to monitor metal-mediated crystallization of amorphous group-IV materials. Several papers dealt with laser-driven crystallization of materials for optical storage applications. In a paper by J.A. Kittl of Harvard Univ., the interface response functions for rapid solidification of Si-As alloys were determined by simultaneous measurements of the interface velocity and temperature.

A number of issues concerning metal silicide phase formation and transformation need to be addressed in order for these alloys to be applied successfully in microelectronic devices, as reflected in the large number of papers on the subject. L.A. Clevenger of IBM presented the results of a comprehensive investigation of the kinetics of metal-Si reactions. Numerous additional papers reported studies of low-resistivity $CoSi_2$ and $TiSi_2$ phases. For the latter, phase formation sequence, transformation into its low-resistivity C54 structure, and sensitivity to surface cleanliness were addressed. R. Sinclair of Stanford Univ. reviewed experimental results on interfacial reactions in metal-metalloid diffusion couples. Also discussed were the formation of SiC on sharp Si tips, morphological stability during interfacial reactions, the design of multilayers for studies of ternary phase diagram, and the formation of ordered intermetallic compounds by reactions in epitaxial multilayers. Theoretical treatments of the role of grain boundary diffusion in thin-film reactions were also presented.

W.L. Johnson of Caltech reviewed the thermodynamic and kinetic aspects of amorphous alloy formation by interdiffusion, and its analogy with superheating and melting. Several experimental papers discussed amorphization during deposition, multilayers which include a third phase in order to elucidate kinetic aspects, and measurements and modeling of thermodynamic functions. The contribution of grain boundaries to the heat of reaction was pointed out. The effects of energetic particles on phase formation and atomic transport were addressed in a session on irradiation effects. P. Bellon of Saclay presented a theoretical study of phase equilibria in irradiated solids, including the effect of cascades. R. Averback of the Univ. of Illinois discussed radiation-enhanced diffusion in amorphous and crystalline alloys. He presented recent results on tracer diffusion in single-crystalline Cu_3Au both below and above the order-disorder transition temperature. He also pointed out the difficulty of identifying a diffusion mechanism in amorphous metal alloys, which is still an open issue. J. Shin of Caltech presented results of the continuous monitoring of defect dynamics in irradiated amorphous Si. Several aspects of phase formation under irradiation were reported, including ion mixing, implantation low-energy ion bombardment during deposition, and electron-beam-induced crystallization.

Researchers Seek Common Themes About Epitaxial Growth

(See MRS Proceedings Volume 312)

Symposium P, Common Themes and Mechanisms of Epitaxial Growth, had as its goal the exploration of themes and mechanisms common to epitaxial growth, even when performed under a wide variety of physical conditions. It was hoped that by sharing experiences and insights gained from many different points of view, a better understanding of the science of epitaxy would result.

The two-and-a-half-day symposium began with a talk by D.D. Vvedensky, Imperial College, on Monte Carlo simulations of homoepitaxial growth of GaAs by MBE, MOMBE, and MOCVD. While the final adatom dynamics during growth by the various techniques appear to be qualitatively similar, it appears that for MOCVD it is also important to include the dynamics of mobile precursors. This and other differences were also brought out to various degrees in the subsequent two talks by B.G. Orr, Univ. of Michigan, and G.B. Stephenson, IBM, who discussed the microscopic mechanism of homoepitaxial growth of GaAs by MBE and MOCVD, respectively.

One part of the symposium focused on kinetic roughening during growth. D.J. Eaglesham, AT&T Bell Laboratories, gave a thorough discussion of their experiments in looking at the low-temperature growth of Si and GaAs, in which roughening has been observed to occur faster than can be explained by existing theoretical models. This was followed by a lively question-and-answer period which set the tone for the following talks by M.T. Kief, NIST; M.A. Cotta, AT&T Bell Laboratories; and D.P. Adams, Univ. of Michigan, on the roughening of surfaces during growth.

Within the topic of composition and strain effects in growth, G.B. Stringfellow, Univ. of Utah, surveyed compositional ordering in GaInP and examined the role of different chemistries and surface miscuts in controlling the degree of compositional order. Other authors discussed the interplay between strain, segregation, and ordering.

Of special interest were two late-morning poster sessions, which focused on the issues discussed in the morning and afternoon oral sessions. This was an experiment designed to couple the posters more closely with the symposium, and resulted in animated discussion throughout the lunch break.

In the session on the role of surface chemistry in epitaxial growth, P.D. Dapkus, Univ. of Southern California, discussed a wide range of experiments on the growth of GaAs using atomic layer epitaxy. This was followed by G.A.D. Briggs' (Oxford Univ.) presentation showing STM images of trimethylgallium molecules adsorbed onto GaAs surfaces, discussions of the deposition of carbon, and several talks discussing the role of surface structure on the subsequent growth processes.

P.I. Cohen, Univ. of Minnesota, began the session on growth modes and step motion during growth with a discussion of reentrant layer-by-layer growth as a function of temperature. This was followed by a number of theoretical and experimental talks discussing the dynamics of surfaces during growth. A distinctive talk by H.G. Busmann, Frelburg Materials Research Center, focused on the growth of C_{60} films on mica by molecular beam epitaxy. Frelburg researchers find that the C_{60} grows by a Volmer-Weber mechanism.

The final session concerned surface structures. R. Nötzel, Max-Planck-Institut, discussed the stability of GaAs surfaces with respect to faceting, and described the use of these patterns for forming quantum wires. P.F. Miceli, Univ. of Missouri–Columbia, discussed the development of a scattering formalism to describe order in very thin, disordered films and in thicker films. C.A. Lucas, Lawrence Berkeley Laboratory, discussed the growth of CaF_2/Si(111) interfaces.

Giant Magnetoresistance in Heterogeneous Alloys Adds New Dimension to Magnetic Thin Films

(See MRS Proceedings Volume 313)

The field of magnetic ultrathin films continues to be an exciting one, with recent advances in novel materials and structures as well as the demonstration of magnetic sensors and recording media based on these materials. Symposium Q1, on Magnetic Ultrathin Films, Multilayers and Surfaces, brought together representatives of the leading groups in the field from Europe, Japan, and the United States.

The symposium extended over four days, featured 135 papers, and included a series of joint sessions with related symposia (Q2—Magnetic Interfaces, L—Applications of Synchrotron Radiation, W—Theory of Materials), topical sessions, a special evening session on a "hot" new area (Giant Magnetoresistance in Heterogeneous Alloys) and an interactive and full poster session.

Highlights included discussions of several symposium areas that currently point the way to progress in the field. Giant magnetoresistance (GMR) continues to be a central theme. This effect was discovered in 1988 in MBE-grown multilayers of Fe/Cr and is the large reduction of resistance in the multilayer when a magnetic field is applied. The effect was reproduced in sputtered multilayers and offers prospects for magnetic field sensors useful for a variety of applications, including magnetic recording read heads, and sensors in automobiles. For a sensitive device, the multilayer should have a large resistance change in a small (<100 Oe) change of magnetic field. This can be achieved by incorporating a magnetically soft alloy in the multilayer. Papers were presented on multilayers incorporating Permalloy (Ni 80%-Fe 20%)/Ag or a ternary alloy (Ni 66%-Fe 16%-Co 18%)/Cu. In both cases, a low-field GMR was obtained: ~10% in 100 Oe in the former case, and in 40 Oe in the latter. A rotating-shaft sensor based on the permalloy/Ag multilayer was reported.

At the special session on Tuesday evening, the recent discovery of GMR in heterogeneous alloys was discussed. Although very large GMR values (comparable with the best multilayers) have been reported in such alloys, high fields have been necessary to maximize GMR. The panel discussion resulted in general agreement that it will be difficult to achieve low-field GMR in alloys with near-spherical magnetic particles because GMR requires smaller particles which unfortunately exhibit paramagnetic behavior. The discussion ended on an optimistic note when it was pointed out that a variety of particle shapes and distributions need to be explored, through growth and processing, to achieve a recipe for GMR in low fields. If this can be done while retaining the simplicity of alloy deposition, multilayer GMR sensors will have strong competition.

It is interesting to note that the field of metallic magnetic multilayers seems to be developing in a way similar to that of semiconductor multilayers and quantum well heterostructures. For example, an entire session was devoted to the new discovery of spin-polarized, quantum-well states in epitaxial metal-metal structures. Indeed, the long-range oscillatory coupling of ferromagnetic films (Fe,Co) through noble metals may be mediated by a spin-density wave arising from these states. Furthermore, optical detection of these states was reported using the Kerr effect. Other papers reported the use of Kerr spectroscopy to monitor changes in the electronic structure of metallic, magnetic compounds, some of which (Co_3Pt and CoPt) are natural superlattices. MBE provided a route to low-temperature synthesis of these compounds, some of which (Co_3Pt) have no bulk analog. In MBE-grown magnetic semiconductors, chemical ordering also has been discovered. Natural superlattices (CuAu-I and CuPt types) composed of alternating ZnSe and FeSe (001) planes were reported for MBE-grown (001) $Zn_{1-x}Fe_xSe$ films grown on (001) InP and GaAs.

Interfaces Play Key Role in Magnetic Materials

(See MRS Proceedings Volume 313)

Symposium Q2, Magnetic Interfaces—Physics and Characterization, focused on the role that magnetic interfaces play in defining the behavior of magnetic thin films. Emphasis was given to the physical phenomena unique to interfaces and to the characterization tools utilized in modern magnetic research to establish structure-property relationships. This symposium complemented the technical program of Symposium Q1 (Magnetic Ultrathin Films, Multilayers and Surfaces) and jointly constituted the fifth international gathering in this series of meetings, which has alternated between California and Europe.

The symposium provided a forum for discussing recent theoretical advances in our understanding of ultrathin-film magnetism and the mechanisms for magnetoresistance in ferromagnetic thin films as well as a singular environment for presenting the latest contributions from a variety of surface- and magnetically sensitive tools. The first session of the two-day symposium concentrated on overviews of theoretical magnetism and the utilization of spin-polarized spectroscopies. The effect of reduced dimensionality at surfaces and interfaces was shown to be critical in that it leads, among other effects, to strong hybridization of d-band ferromagnets with transition metal substrates, and strong proximity effects on both magnetic moments and magnetic anisotropy. Techniques such as spin-polarized electron energy loss spectroscopy (SPEELS), electron capture spectroscopy (ECS), spin-polarized metastable atom deexcitation (SPMDS), and spin-resolved x-ray photoelectron spectroscopy (SRXPS) are used to determine estimates of surface magnetic moments with unprecedented surface resolution.

A joint session with symposia Q1, Magnetic Ultrathin Films, Multilayers and Surfaces, and L, Applications of Synchrotron Radiation Techniques to Materials Science, covered recent applications of synchrotron radiation techniques to magnetic materials. This is an exciting field in that it not only permits the study—from a crystallographic point of view—of the structure of films of interest, but coupled to spin-polarized photoemission, it also yields for the first time information on interface states and their role in the magnetic behavior of films as a function of coverage and the nature of overlayers. The session also featured contributions on magnetic circular dichroism ranging from the description of a new element-specific magnetic microscope, to measurements of exchange splitting of the Fe 2p and 3p core levels.

Also reviewed was recent progress in the area of magnetic phenomena resulting from the use of polarized neutron reflection studies, Mössbauer spectroscopy, Auger and photoelectron scattering, HRTEM, and STM. A tremendous wealth of information has emerged as a consequence of the utilization of these methodologies, ranging from atomic-level knowledge of the initial stages of growth in ultrathin films, and details of the coupling between ferromagnetic layers and nonmagnetic spacers in giant magnetoresistance (GMR) structures, to details about the magnetic properties of overlayers and their intimate dependence on structure and growth morphology. Presentations on mechanistic details of the origin of perpendicular anisotropy in several systems were also given.

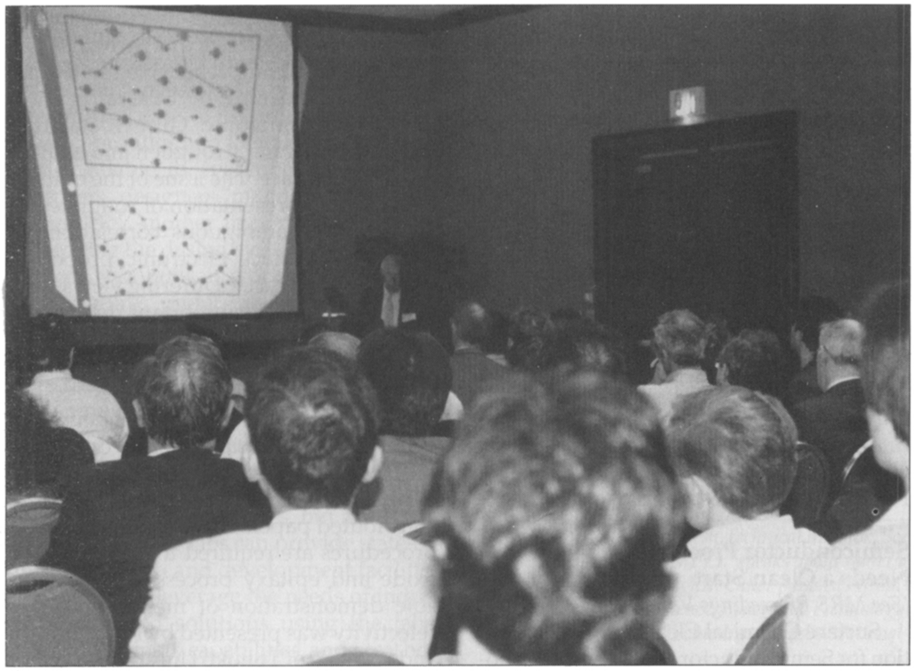
Joining Methods Affect Quality, Durability of Advanced Inorganic Materials

(See MRS Proceedings Volume 314)

The joining of advanced materials is a critical but often overlooked technological problem. Topics ranging from the fundamentals of adhesion to mechanical properties and stress states in joints were addressed in Symposium R, Joining and Adhesion of Advanced Inorganic Materials. This was the first time that a symposium on this topic was offered at an MRS meeting. Over 40 presentations were made over two and a half days.

The presentations varied from basic science to specific technological applications and spanned a broad range of systems, including electronic materials and complex glasses, in addition to structural ceramics, intermetallics, and composites. One of the most lively discussions concerned the importance and role of various factors in the actual failure of structural joints. The contribution of chemical forces to fracture energies appears to be minor compared to energy dissipation by plastic stress relief, but first-principles modeling nonetheless provides valuable information about electronic transfer and segregation at interfaces. In addition to suggesting trends for structural materials, such calculations may shed light on other properties that are more critical for nonstructural applications.

Another important point that was raised is that novel materials are useless if their desirable properties have to be compromised in order to incorporate them into real structures. Ideally, then, a materials designer would consider the issue of joining during materials development. Moreover, a wide variety of ingenious joining techniques have been developed to take advantage of the advanced materials that are now available. Methods discussed in this meeting included



While not yielding a simple route to the creation of magnetic devices, the late news session on giant magnetoresistance in magnetic alloy thin films offers an approach other than heteroepitaxy.

reaction bonding, capacitor-discharge welding, self-propagating high-temperature synthesis (SHS) processes, microwave joining, infrared-assisted bonding, and the chemical vapor composite process.

As joining issues have increased in importance in recent years, more systematic and in-depth studies have been conducted to gain an understanding of how and why the current empirically derived processes work. Several talks on interfacial thermodynamics, chemistry, and microstructural development provided new insights in these areas. Further analyses of this sort will be critical in learning how to both predict and control the properties of joints in advanced materials.

Similarities Between "Rocks" and "Ceramics" Interests of Researchers Outweigh Contrasts

The similarities and contrasts between the technical interests of researchers in the structural ceramic materials community and those of the experimental geophysics community were explored in Symposium U, Mechanisms of Deformation and Failure in Rocks and Ceramics. Spanning the range of thermodynamic potentials (differential stress, temperature, and hydrostatic pressure) and of physical scale (nm to km scale), the symposium addressed the physics of the kinetic responses in ionic solids ranging from crack nucleation and propagation in polyphase monolithic ceramics to deep-focus earthquakes in Earth-mantle material; from nano-indentation experiments with mN loads to shock-wave formation in polyphase ceramics at pressures greater than 10 GPa; from high-temperature flow in ceramic composites to the mechanisms of magma migration during deformation of partial melts.

The similarities in interests and approaches of the two research communities far outweigh the contrasts. As examples: (1) the impact of microstructure on the evolution/growth of single cracks, and the most recent theories of fracture evolving from such studies (S.J. Bennison, Du Pont, and R.F. Cook, IBM) constitute the foundation of statistical and spatial studies of microcracking and the genesis of faulting and failure in rock (D.A. Lockner, U.S. Geological Survey; T-F. Wong, SUNY-Stonybrook; and P.G. Meridith, Univ. College, London) and (2) phenomenological "equation-of-state" models of plasticity, and their theoretical foundation (D.S. Stone, Univ. of Wisconsin) could become the primary approach for performing the long extrapolations in time required to apply laboratory rheology data to the design of long-duration engineering components, and for constraining models for the solid-state convection of Earth's mantle that drives plate tectonics (J.D. Fitz Gerald, Australian National Univ.; and D.H. Green, Ohio Univ.). The impact goes both ways: high-resolution studies of fluid-grain boundary interaction within the geophysics community (S. Hickman, U.S. Geological Survey) place substantial constraints on models of physical properties of glass-ceramics and liquid-phase-sintered ceramics (M.L. Mecartney, UC–Irvine); rheology studies on mineral systems having reasonable ambient-temperature lubricity (e.g., micas—A.K. Kronenberg, Texas A&M Univ.) will have a substantial impact on the design of oxidation-resistant fiber-reinforced ceramic composites.

Theory Gives Insight into Phase Stability, Magnetism, Mechanical Properties

Symposium W, Theory of Materials Properties, involved four topics in materials theory that were chosen for their overlap with other symposia and for their relevance to activities in the San Francisco Bay area. Three sessions were held jointly with other symposia.

Two sessions, one of which was conducted jointly with the Thin Film—Stresses and Mechanical Properties symposium, covered fracture and related properties. In the first session, L.B. Freund, Brown Univ., gave a paper on the roughening of films due to diffusion—an important matter for processing of these systems. J. van der Merwe, Univ. of South Africa, outlined the circumstances under which single crystals may be grown epitaxially, emphasizing the role played by favorable equilibrium conditions.

In the second session G. Beltz, Brown Univ., discussed his work on the ductile/brittle criterion for materials. This topic has been causing considerable excitement in the field. J. Langer, UC–Santa Barbara, who has had considerable success in modeling earthquakes, and has applied some of the ideas relevant to earthquakes to fracture in more conventional materials, has discovered a new analytic solution to the equation which describes the dynamical properties of a crack in a lattice with dissipation. This is likely to be a major development in the theory of cracks, simply because analytic solutions are so rare.

There were two joint sessions with Symposium Q1 on the magnetism and magnetoresistance of multilayers. Y. Yafet of Maplewood, N.J. suggested in his talk that the theory of the magnetism in such systems is well in hand, providing one goes beyond the simplification of Ruderman and Kittel's original derivation, and providing the roles of "nesting" and of Fermi surface calipering are kept straight. There was a certain lack of unanimity as to how satisfactory classical transport theories are for magnetoresistance.

Two sessions were dedicated to phase stability, in many respects the one area of materials theory where the most progress has been made. Several talks in these sessions carried the message, implicitly or otherwise, that we are currently at the threshold of a quantitative and predictive theory of phase stability. As emphasized by D.G. Pettifor, Univ. of Oxford, in the opening session of the symposium, such capabilities should indeed alter the role of computational materials science in alloy design. Thus, it appears that the investment of the last several decades in fundamental research in solid-state physics is beginning to bear fruit on the engineering front.

The talks of the last two sessions pivoted about *ab initio* theories that allow the computation of ground-state and finite-temperature properties, including phase diagrams, in simple and complex intermetallic compounds, disordered alloys, carbides and ceramic oxides. That is, a variety of material types were represented and discussed at the most fundamental level. Although the different approaches discussed during the symposium are in fact rooted in the same basic tools of solid-state physics, there were some differences and preferences with regard to the details. Practitioners of the coherent potential approximation were well represented by D. Johnson of Sandia National Laboratory, who convincingly showed how this electronic theory of disordered (random) alloys can reproduce even the fine details of concentration fluctuations at high temperature. At the other end of the spectrum were the practitioners of the cluster expansion method, whereby the configurational thermodynamics is described using a set of ordered compounds. An overview of the method, with several applications, was given by A. Zunger, of the National Renewable Energy Laboratory. Several other papers using the same method were also presented, including work on the phase stability of transition metal carbides and nitrides by J. Häglund, of the Royal Institute of Technology, Sweden, which made contact with the CALPHAD School of Phase Diagram Predictions.

Semiconductor Processing Needs a Clean Start

(See MRS Proceedings Volume 315)

Surface Chemical Cleaning and Passivation for Semiconductor Processing, Symposium Y, endeavored to cover both technological and scientific aspects of the area that were lightly covered in 1992, when the first symposium on this topic was held. A few areas of emphasis from this year's symposium are mentioned below.

The review paper by R.P. Donovan of Research Triangle Institute provided a thoughtful analysis of the mechanisms that can cause adherence of particulates to a substrate. A comprehensive invited paper on wet cleaning by D. Gräf et al. of Wacker-Chemitronic GmbH clarified which process steps roughen and smooth a Si wafer surface. The issue of the uniqueness of the representation of roughness is crucial for unambiguous correlations of film and interface electronic properties with rough surfaces. Differing views were presented and this important debate will continue. Interesting new results from S. Watanabe et al. of Fujitsu Laboratories Ltd. showed that hot water etches Si to produce flat surfaces; J.H. Eisenberg et al. from AT&T Bell Laboratories correlated the etch rate in water with oxygen content. It became clear from many invited and contributed papers that different cleaning procedures are required to optimize gate oxide and epitaxy processes. A remarkable demonstration of metal deposition selectivity was presented by K. Tsubouchi and K. Masu of Tohoko Univ., in which the power and potential for exploiting surface chemistry for selective deposition was demonstrated. There was continued international interest in correlating gate oxide processes with electronics properties and reliability. The use of S and related compounds continues as an important III-V passivation technology.

Materials Manufacturing: Shall We Dance?

As more emphasis is placed on moving research to the marketplace, competing in a global economy, and converting from a defense to a commercial technology base, scientists, engineers, and research managers are faced with accepting roles that extend beyond research. Likewise, since the establishment of the MRS task group on manufacturing about a year ago, MRS has been seeking to determine its own role in the manufacturing arena. To move the discussion forward, front-line participants in the national effort to integrate research and manufacturing participated in a forum on materials manufacturing held Thursday at noon during the 1993 MRS Spring Meeting. Technology transfer, partnering, defense conversion, and appropriate roles for the government, industry, universities, and professional societies in the changing manufacturing environment were topics raised during the presentations and subsequent discussion.

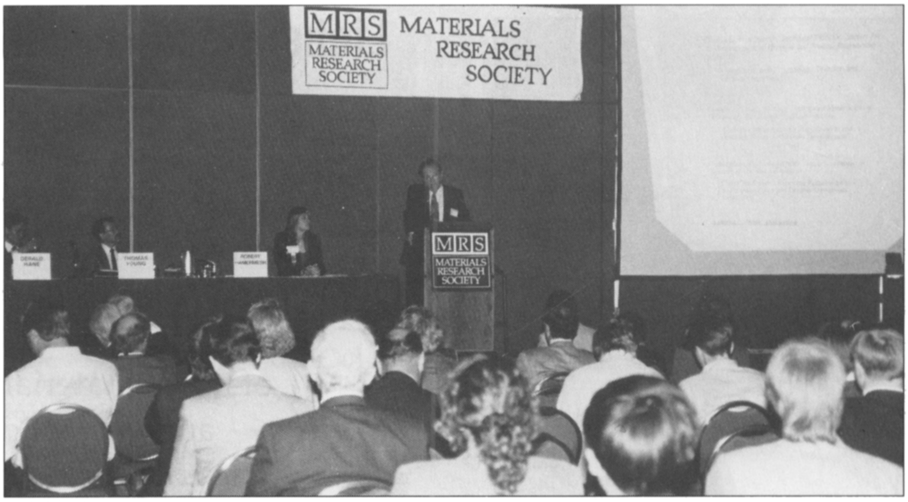
The panelists were Charles L. Hamermesh, technical director, Society for the Advancement of Material and Process Engineering (SAMPE); Thomas J. Young, manager, Advanced Manufacturing Technology, Sandia National Laboratories; and Gerald Hane, professional staff, House Committee on Science, Space and Technology. Meeting Chair Merrilea Mayo chaired the forum.

"Shall We Dance?" was the theme of Gerald Hane's presentation, which focused on the federal government's recent emphasis on partnering with state and local governments, with industry, and with universities by sharing ideas, jointly executing projects, and sharing the risks of bringing technologies to market.

One of the driving forces for partnering is the shift from defense-based technology to commercial technology. Charles Hamermesh (SAMPE) talked about the advantages and disadvantages of the previous decades of aerospace and defense-driven materials technology. That era produced major advances in materials science, but it also encouraged "performance at any cost" and the mentality that every part is custom designed, which is counter to the needs of new commercial customers who seek cost-effective manufacturing and "stock shapes." Hamermesh's advice to the defense industry is to change its mindset—which he admits is a difficult task. In particular, the industry needs to address what he calls the "meeting problem"—the problem of meeting performance requirements, meeting scheduling requirements, and meeting cost requirements.

Stressing the importance of technology transfer, Hamermesh also pointed out some of the hurdles that exist, such as helping suppliers identify where the technology should go and helping the recipients overcome their innate conservatism and unfamiliarity with new technology. "It is going to take patience, perseverance, and most of all, lots of money," he said.

Panelist Thomas Young from Sandia said that what is needed is a smooth connection through the various steps of research, development, prototyping, and manufacturing. Researchers need to consider how research results can be used to create practical products that are low cost, high quality,



Charles L. Hamermesh, technical director, Society for the Advancement of Material and Process Engineering (SAMPE), speaks about materials manufacturing at a noon forum mediated by Merrilea Mayo (right). Other panelists (from left) were Gerald Hane, professional staff, House Committee on Science, Space and Technology, and Thomas Young, manager, Advanced Manufacturing Technology, Sandia National Laboratories.

adaptable to customized environments, and environmentally friendly.

To achieve rapid time-to-market, Young said that it is necessary to provide information from all parts of the process required to create a product, and to make this information available to everyone involved: researchers, designers, manufacturers, marketers, etc. Another important element is improving the design cycle such that when a product is built, it works the first time. This requires understanding process parameters and being able to simulate the process. At the same time, materials research and development needs to keep pace with rapid advances in other aspects of product development.

Young sees technology transfer not only as a new mission for the Department of Energy (DOE) Laboratories, but also as an opportunity. The labs can provide state-of-the-art research and development facilities for helping to leverage the needs of industry, integrated solutions using the labs' multidisciplinary capabilities, and a test bed for developing processes before making large capital expenditures. Also, the labs can be neutral ground for precompetitive technology.

A member of the audience said he resented the assumption that doing high-quality research is a part-time job, which is implied by requiring researchers to engage in technology transfer activities. Hamermesh sees technology transfer simply as part of a scientist's work. However, he was critical of the usual attempt at technology transfer, the technical brief, which he compared to junk mail or a baby left on a doorstep. Too often, research project results are written up and distributed with the hope that someone will come along, pick them up, and use them. Instead, one must find a suitable niche for the technology and from there appeal to the specific technology recipient.

One audience participant noted that cooperative research and development agreements (CRADAs) seem to be designed to get industry and government labs to create the baby together, but wondered if anyone has plans for what the baby should do when it grows up. Hamermesh did not express much optimism about the CRADA process, saying success is highly clouded at this moment.

Another audience member pointed out the importance of the people/people relationships, describing technology transfer as a contact sport, and suggested that government try to understand the personal element. Young built on that idea, adding that while technology transfer can be a difficult sport, it offers the opportunity to increase the value of research and can be fun.

Hane said that he has heard concerns from the research community that research funding will be damaged by the technology policy and defense conversion, but he dismissed those concerns. He warned, however, of persistent dangers such as earmarking projects. In 1982, academic pork barreling was less than $10 million, but in the 1993 federal budget it surpassed $800 million. Another problem he cited is counterproductive nationalism, a result of legislation intended to return the benefits of technology programs to the taxpayer. For example, restrictions on participation in the programs or the end use of technology may stifle growth in a global market, eliminating any benefit both globally and nationally. Congress and the Administration continue to struggle with this problem.

Hamermesh gave examples of what professional societies can do, using SAMPE as an example. The primary function a society can perform is to disseminate information, he said. A few years ago SAMPE began a diversification program, which meant moving away from the Society's traditional heavy emphasis on aerospace defense and toward commercial applications. SAMPE has begun to introduce market studies as a portion of the presentations at their meetings, thus incorporating the business end of research developments. SAMPE is also trying to expand its membership into nontraditional fields such as biomaterials and civil engineering.

Hane said it is extremely valuable to have professional societies perform independent evaluations. For example, the American Society of Mechanical Engineers is helping with an independent evaluation of the different proposals for the national aerospace plane. Professional societies have a role to play by interacting with policymakers in such areas as education and basic research and in areas where they have special knowledge. He sees a trend toward increased productive engagement of the government with the engineering and scientific communities. Another valuable route is to support fellowships for sending scientists to Washington, D.C. to participate in activities in the legislative and executive branches of government.

Hane sees the government having a role in many phases of innovation, including the generation of technology, processing and integration, information diffusion, and the actual adoption of technologies. He described several initiatives in Congress and in the Administration's technology policy that relate to a national information infrastructure, enhanced civilian R&D, modernization of manufacturing, new missions for the major national laboratories, technology education, taxes, standards, and trade.

Hamermesh gave his view of how government can facilitate technology transfer. First, government can support information programs designed to familiarize potential users with materials terminology and concepts. Next, government could support market research to find market niches for advanced materials. And, finally, government should support the training of materials technologists, which will be needed if the introduction of advanced materials into commercial areas is successful. □