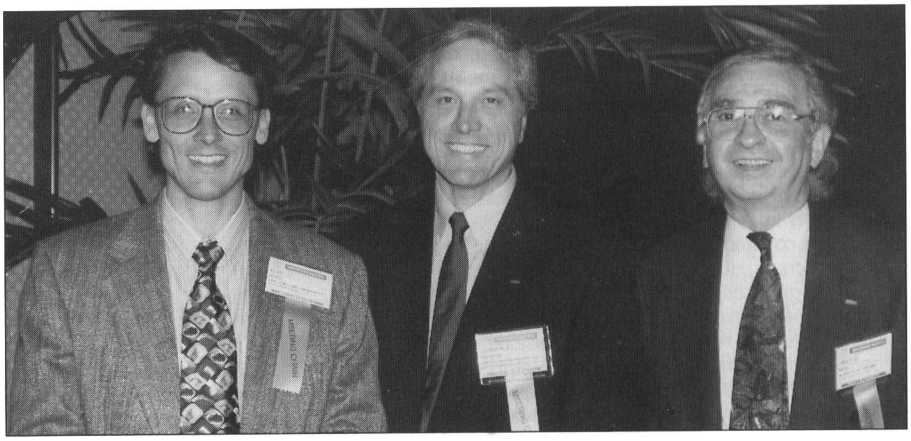
Materials Developments Resonate Through 1994 MRS Spring Meeting

The 1994 MRS Spring Meeting held the week of April 4–8, 1994, offered 23 topical symposia to more than 2,500 meeting attendees. The meeting was chaired by James M.E. Harper of IBM T.J. Watson Research Center, Alan J. Hurd of Sandia National Laboratories, and James E. Mark of the University of Cincinnati.

Literally resonating through the meeting was Symposium Q, Materials for Musical Instruments. Researchers, musicians, and crafters looked for common ground relating to musical instruments—pianos, woodwinds, strings, and even the more recently developed steel pans. The role of materials in music quality is still highly debated, and this symposium stimulated a dialogue within this diverse community of experts. And, in addition to experts, a steady flow of meeting attendees outside this technical arena drifted through to learn the science behind their musical hobbies or just for a change of pace from their own technical areas.



1994 MRS Spring Meeting Chairs (left to right): Al Hurd, Sandia National Laboratories; Jim Harper, IBM T.J. Watson Research Center; and Jim Mark, University of Cincinnati.

Flat panel displays is a rapidly developing technology, and the first MRS symposium on this topic covered active matrix liquid crystal display technology and recent developments in emissive displays. A broad range of technologies from new varieties of glass for flat panel display substrates to materials for self-emissive and phosphor displays was covered. Related symposia covered electroluminescent polymers, scintillator and phosphor materials, and amorphous silicon.

Everything from soot and interstellar dust to foams, fullerenes, fibers, and diamond, was covered in Symposium T, Novel Forms of Carbon. High diamond deposition rates were achieved using the combustion flame process.

Time-dependent processes over a range of length and time scales were the focus of Symposium W on Theory and Simulation, which brought together physicists and mechanical engineers. Molecular dynamics was used to model specific behavior such as high-speed sliding of head-disk interfaces. Other topics included microstructure/property links, the brittle-ductile transition, and fracture.

Rapid thermal processing has grown in scope and application, yet finding ways to accurately measure the temperature remains a challenge. A lively panel discussion addressed this problem, but left many open questions.

Manufacturing challenges relating to reliability of integrated circuits and interconnect metallization were addressed and alternative technologies were considered. The industry is trying to simplify structure and processing, for example by reducing the number of processing steps for Al-based interconnects. Other researchers are developing copper technology to meet demands of electromigration resistance for ever smaller interconnects.

Wide bandgap semiconductors are offering short wavelength optoelectronics (including the elusive blue laser) and electronics operation at high temperatures and high power. *In situ* and real-time monitoring, particularly of molecular beam epitaxy, promise better control of compound semiconductor growth.

"Epi films get all the glory, but polycrystalline films do all the work," declared one researcher, but polycrystalline films did receive more visible attention at this meeting than in previous ones in a symposium specifically addressing polycrystalline films. Topics included microstructure evolution, nanocrystalline structures, structure/property links, grain growth, diffusion, and nucleation.

Two symposia covered materials solutions to environmental problems, such as controlling car exhaust emissions and recycling. Advanced ceramic materials are being developed to improve energy efficiency in extreme environments, while recovered rubber is turning up in pavement material.

Microwave processing continues to build momentum, with participants in the symposium on this topic discussing whether microwave processing is an emerging technology. National Research Council findings in evaluating microwave processing were presented. Other topics included microwave vulcanization—one of the most successful uses of microwaves for processing—remediation of hazardous waste, and transferring technology, such as radar, from military to consumer sectors.

Self-assembly, a new concept in materials science but the rule in biology, was a part of Symposium V, Molecularly Designed Ultrafine/Nanostructured Materials. Self-assembly enables fabrication of defect-free structures not possible in other ways. Vesicles for drug delivery and other uses were demonstrated.

Other symposia covered ceramics, superconductors, intermetallic matrix composites, and materials for separation technology. For highlights of the symposia, read the summaries on the following pages. More detailed information is available in the published proceedings.

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Panel Addresses Environmental Impact of Automotive Materials

A panel discussion at the 1994 MRS Spring Meeting addressed environmental concerns and developments in the automotive industry. It featured presentations by John L. Sullivan, principal research scientist associate for Ford Motor Company; Kathleen C. Taylor, head of the Physical Chemistry Department at General Motors Research Laboratories; and Patrick G. Grimes, research associate at Exxon Research and Engineering Company. The panel addressed life-cycle analysis, control of emissions, alternative propulsion, recycling, weight reduction, and federal programs relating to innovative automobile technologies for the future.

Sullivan talked about "Life-Cycle Assessment," which involves inventory, impact, and improvement. The first step is to inventory all environmental burdens associated with a product by identifying and quantifying energy and materials used, and waste products throughout the process. Then the environmental impact is assessed, generally using the principle of "less is better," until comparative risk assessment and impact analysis can be used to weigh competing hazards. Finally, ways to improve the process are identified. Improvements may involve materials substitutions, modified processes, or other changes. Life-cycle analysis permits cradle-to-grave quantification of environmental metrics, which in turn provide opportunities to reduce environmental impact.

Taylor covered "Exhaust Emissions Control," primarily the issue of reducing tail pipe emissions such as HC, CO, and NO_x. She described progress in exhaust emission control, the technologies responsible for the progress, new emission requirements and goals, and improvements expected in the future. She cited a comparison of 1983 and 1993 emissions, showing a 90% reduction in the emissions of carbon monoxide and hydrocarbons over that period. One technology that has led to emissions improvements is the catalyst in catalytic converters which reduces nitric oxide to nitrogen and oxidizes carbon monoxide and hydrocarbons. This "three-way" catalyst will still be the centerpiece of the future, Taylor said, but there may be additional catalysts, more integration of the catalytic converter with the vehicle, and fuel changes.

Taylor reviewed legislation and regulations such as the 1990 Clean Air Act Amendment and the 1994 low exhaust standards that must be met by the automobile industry. Regulations specify such things as permissible emission quantities, fuel requirements, and on-board diagnostics. Also the federal test procedure is being revised to include higher driving speeds, which are more representative of typical driving.

Technologies that are expected to contribute to further emission reduction and compliance with new regulations may include heated converters to reduce emissions from cold start-up, hydrocarbon traps, reformulated gas, and on-board diagnostics.

Taylor also described the "Partnership for a New Generation Vehicle," which involves U.S. government agencies headed by the Department of Commerce, General Motors, Ford, Chrysler, and suppliers. The partnership was announced by the Clinton administration in September 1993, and plans are now being defined. The technical objective is to develop and apply advanced manufacturing technology and to move new ideas into the marketplace quicker and at lower cost. A specific goal is to develop a vehicle which achieves 82 mpg with the size, performance, and cost of a comparable vehicle in use today, such as a four-door sedan. Features expected in such a car include more computer-based design and testing, flexible automatic control systems for lower production costs, lightweight recyclable materials, advanced energy conversion (e.g., gas turbines and fuel cells), and advanced batteries

Grimes spoke about "Materials challenges in electric propulsion." While the majority of work on electric cars is going into converting existing vehicles to electrical propulsion, such conversions put a huge stress on the electrical subsystems, so new materials and innovative designs are needed to significantly improve the technology. Electrical vehicles need low weight, thermal management for internal climate control and maximum efficiency of components, and low drag coefficient, for example, through use of improved underside aerodynamics and low rolling resistant tires.

Awards

David J. Eaglesham of AT&T Bell Laboratories, the recipient of the Outstanding Young Investigator Award, gave a presentation on "What We Still Don't Know About Si." Although silicon has been studied intensely for a long time, each question seems to pose two more, he said. He gave examples from his own experiences, specifically looking at epitaxy using Si molecular beam epitaxy, crystallization and its connection to roughness. Despite the vast base of knowledge of silicon, more questions remain relating to diffusion, activation energy, and crystallization.

Morris Cohen, MIT, delivered the Turnbull Lecture—an award he received at the 1993 Fall MRS Meeting. His talk, "Societal Issues in Materials Science and Technology," reflected on the field of materials, its place in the scheme of things, its changing nature, and its novel role in national and societal issues. He touched on the global materials cycle, the merits of basic versus strategic research, federal R&D initiatives in civilian technologies, and the status of materials R&D. The Turnbull Lecture will be published in a future issue of the *MRS Bulletin*.

Graduate Student Awards were also presented, and the recipients are listed elsewhere in this report.

Plenary Presentation

James F. Gibbons, dean of the Stanford University School of Engineering, focused his plenary address on the history of Silicon Valley startups and strategic alliances. He described how the Silicon Valley high-tech firms began, the types of firms that started and their keys to prosperity, how their individual economies developed, and what impact these companies have, as a whole, on the economy of Silicon Valley and the country. The text of his plenary address is published in Material Matters in this issue.

Forums

Several forums were held during the meeting. See From Washington in this issue for coverage of the Forum on the Changing Federal Initiatives for Materials Science Programs. The panel discussion which addressed the environmental impact of automotive materials is summarized elsewhere in this report.

Solar Panels, Flat Panel Displays Benefit from Amorphous Silicon Technology

(See MRS Proceedings Volume 336)

Participants representing many nations presented more than 150 papers during Symposium A, Amorphous Silicon Technology-1994, the 10th in a series of symposia. The papers represented a balance among fundamental aspects, electronic device, and mass production issues.

Amorphous silicon continues to make great strides in its commercialization, particularly in its use as thin-film transistors (TFT) in active matrix liquid crystal displays. Reflecting the importance of this aspect was the opening half-day joint session with Symposium M, Flat Panel Display Materials. This session, "From Research and Development to Manufacturing," began to address the mass production theme with an opening talk by N. Ibaraki (Toshiba) on the use of self-aligned ion doping to manufacture TFT displays. S. Guha (United Solar Systems Corp.) then reported on a large-area (square foot) solar panel with an efficiency of about 10% after continuous illumination of several hundred hours.

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New applications for the versatile a-Si material continue to be explored and developed with such excellent results as a large-area high-resolution a-Si:H array for x-ray imaging reported by groups from the University of Michigan and Xerox.

In an attempt to improve the optoelectronic properties of this material, novel deposition techniques are being actively explored, such as the use of pulsed plasmas, inclusion of halogens in the gas feed, and the control of ion flux during deposition. Using the latter technique, the Electrotechnical Laboratory (Japan) group reported an electron drift mobility in excess of 6 cm^2/s V, which is considerably higher than usually found in material conventionally produced using plasma-enhanced CVD.

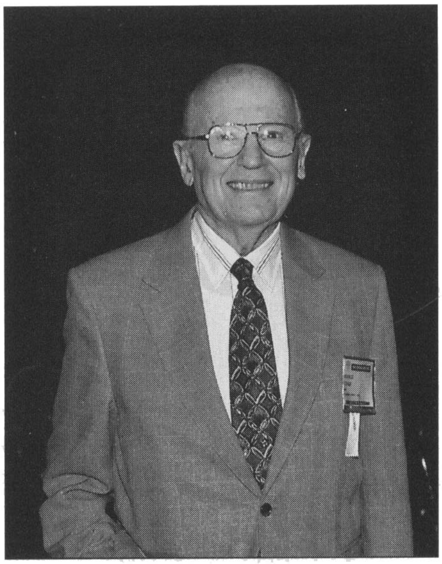
Understanding of the instability phenomena remains elusive although considerable progress has been made; mass-produced solar panels are now reported with a solar conversion efficiency of about 8%. Some papers reported that H dilution of the silane gas in the plasma or changes in the p-layer of a p-i-n device structure could significantly change the stability characteristics of solar cells, and the stability does not appear to correlate with the changes of bulk defect state density in a-Si:H commonly thought to be associated with the instability phenomena.

Symposium Support: Advanced Photovoltaic Systems, ARPA, EPRI, Fuji Electric Corporate R&D, Mitsui-Toatsu Chemicals Inc., MVSystems, n & k Technology, Sanyo Electric Company, Solarex, Sharp Corporation, United Solar Systems Corporation, Voltaix Inc., Xerox PARC.

Interconnect Metallization Poses Challenge for Advanced Integrated Circuits

(See MRS Proceedings Volume 337)

Symposium B, Advanced Metallization for Devices and Circuits—Science, Technology, and Manufacturability, included about 100 oral and 40 poster presentations. Conventional metallization issues were covered in sessions on diffusion barriers for Cu and Al technologies, contacts to GaAs and InP, silicides, deposition of refractory metals and alloys, and characterization techniques and etching. Other sessions on manufacturability/challenges of interconnections, chemical-mechanical polishing/advanced planarization technology, and copper interconnection metallization addressed the latest issues regarding interconnections, their manufacturability, and their reliability—issues which have become key factors in further miniaturizing semiconductor devices and integrated circuits. A session on "Metal on Polymer Dielectrics/Glass/ Ceramics" was also organized since these materials will play a key role in advanced interconnection schemes. Papers in a session on "Novel Metal Schemes on Semiconductors" covered metallization for CVD diamond, GaAs, InN, and $BaTiO_3$.



Morris Cohen, who was awarded the MRS Turnbull Lectureship at the 1993 MRS Fall Meeting, spoke at the MRS Spring Meeting on "Societal Issues in Materials Science and Technology."

The first session on manufacturability brought invited authors from industry and universities to advance the challenges, key issues, and possible solutions to metallization in silicon integrated circuits. Planarization on the surfaces, use of low-resistivity metal such as copper, and use of low-dielectric-constant polymer as the interlayer dielectric were the key issues discussed, together with the issues of reliability and manufacturability.

Symposium Support: Advanced Micro Devices, SEMATECH.

Reliability of Metal Lines and Polymer Coatings Analyzed

(See MRS Proceedings Volume 338)

The fourth symposium on Materials Reliability in Microelectronics, Symposium C, was a great success. Contributed oral presentations were organized around a total of 25 invited talks, drawing audiences of up to 170.

Z. Suo (Univ. of California-Santa Barbara) talked about the possible roles of dislocations in electromigration, particularly in bamboo structure interconnects. Estimates suggest that existing dislocations may be too few for pipe diffusion to significantly affect the mass transport, but dislocation migration and multiplication in the "electron wind" may alter that substantially. The growth of transgranular voids in near-bamboo line structures is increasingly being recognized as a serious concern for very narrow lines, and several presentations addressed the issue. Y-C. Joo (MIT) isolated the phenomenon under accelerated electromigration test conditions by studying single-crystal lines. In his study, passivated and unpassivated lines exhibited identical lifetimes and activation energies (0.98±0.2 eV). A comparison with results for polycrystalline lines suggests that the interface diffusion coefficient for pure aluminum lines is a factor of 10^4 smaller than the grain boundary diffusion coefficient. It was questioned, however, whether failure may in fact be affected by the rather large dislocation concentrations in the single-crystal lines.

G.M. Pharr (Rice Univ.) discussed the effects of residual stress on nano-indentation experiments. He demonstrated that apparent increases in modulus with depth are caused by changes in the effective contact area because of pile-up effects. Correction for this leads to a constant modulus, as expected of an intrinsic parameter. The same correction eliminated variations in hardness, suggesting that triaxiality of the stress state has no significant effect.

Two sessions focused on the reliability of polymers in microelectronic applications. J.A. Rogers (MIT) discussed a noninvasive optical technique for investigating mechanical properties, thermal diffusion, and adhesion properties in polymer coatings. This novel and relatively simple-to-use technique is based on the measured acoustic and thermal responses to picosecond laser pulses. From measurements made in less than a millisecond, information can be derived about in-plane and out-of-plane elastic and loss moduli, and about thermal diffusivity. D.Y. Yoon (IBM) discussed the anisotropy in the dielectric constant of BPDA/PDA films and the implications for device performance.

Finally, a large number of presentations comprehensively covered stress evolution and damage in semiconductors, metals, polymers, and gate oxides, and at interfaces.

Symposium Support: Advanced Micro Devices, Digital Equipment Corporation, Materials Research Corporation, Motorola, Sandia National Laboratories, SEMATECH, Tencor Instruments.

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David J. Eaglesham, recipient of the 1994 MRS Outstanding Young Investigator Award, gives his presentation: "What We Still Don't Know About Si."

Wide-Bandgap Semiconductors Offer Bright, Hot Applications

(See MRS Proceedings Volume 339)

Significant technical advances and increased interest in the field were evident in Symposium D, Diamond, SiC, and Nitride Wide-Bandgap Semiconductors. This class of semiconductors offers tremendous potential in short wavelength optoelectronics (including the elusive blue laser), high-temperature electronics, and high-power devices, including microwave.

Progress in growth of single-crystalline thin films of diamond continues to be hampered by lack of a suitable substrate. However, D.L. Dreifus (Kobe Steel USA) reported results from field-effect transistors (FETs) fabricated on highly oriented polycrystalline diamond. This material had the highest room temperature mobility reported for polycrystalline diamond (280 cm^2/V s). While the electrical properties of single-crystalline diamond are superior, the FETs fabricated on the highly oriented polycrystalline material exhibited high current levels (8 mA), complete pinch-off of channel currents, and high-temperature operation (500°C).

Silicon carbide is the most mature of these materials primarily because relatively large (2-inch) single-crystal substrates are available which yield high-quality SiC homoepitaxial layers for device fabrication. Devices ranging from high-temperature thyristors to microwave MESFETs were reported by J.W. Palmour (Cree Research). The thyristors operated to 500°C, and 6H-SiC MESFETs had a maximum operating frequency of 13.8 GHz. 4H-SiC MESFETs demonstrated an RF output power density of 2.8 W/mm at 1.8 GHz. This is the highest power density reported for SiC and is 2–3 times higher than reported for comparable GaAs devices.

Exciting results were reported on GaN as a material for both bright blue emitters and microwave devices. The double-heterostructure light-emitting diodes reported and demonstrated by S. Nakamura (Nichia Chemical Industries, Japan) are the first blue LEDs with a brightness of more than one candella. The first AlN/GaN heterojunction FETs designed for microwave operation were reported by M.A. Kahn (APA Optics). These devices had a maximum operating frequency of 35 GHz.

Symposium Support: Cree Research, Kobe Steel, Motorola, Nichia Chemical Industries, Office of Naval Research.

Nanoscale Characterizations, Modeling, and Process Control Improve Compound Semiconductor Epitaxy

(See MRS Proceedings Volume 340)

Symposium E, Compound Semiconductor Epitaxy, addressed the issues of growth mechanisms, modeling, nanoscale characterizations of surfaces and interfaces, *in situ* monitoring and control, processing issues, and device applications of III-V and II-VI compound semiconductors. Fourteen invited speakers anchored each session, and the poster presentations were integrated into the regular sessions.

The session on "Material Issues and Modeling" opened with a talk by J.Y. Tsao (Sandia National Laboratories), who, unlike most of the other speakers on operational and device aspects of molecular beam epitaxy (MBE), talked about the delicate balance between thermodynamics and kinetics in MBE. High attendance for the session on "Nanoprobes and Surface/Interfaces" indicated the growing interest in and research on using scanning tunneling microscopy (STM), atomic force microscopy (AFM), and other nanoscale scanning probes to study surfaces and interfaces. In particular, C. Orme (Univ. of Michigan) found that large multilayered features, such as mounds, are present on MBE-grown films, contradicting the usual notion that these films are flat. When the growth conditions favor island formation, mounds develop, whereas during step-flow growth they are absent.

Besides MBE, metal-organic vapor phase epitaxy (MOVPE) and metal-organic MBE (MOMBE) or chemical beam epitaxy (CBE) were covered in two sessions. The unique aspects of these techniques make them applicable for selective-area growth on patterned substrates for advanced devices (e.g., buried-grating distributed-feedback lasers), and for alternative sources to the toxic arsine and phosphine (e.g., tris-dimethylaminoarsenic). In addition, the paper of Graduate Student Award winner P.E. Gee (Univ. of California-Los Angeles) dealt with site-specific chemistry in GaAs MOVPE.

Many papers in the symposium discussed strained, pseudomorphic heterostructures and strain-relaxed layers, which are decoupled from the substrates. F.A. Ponce (Xerox PARC) proposed a new cooperative mechanism for the generation of periodic distribution of misfit dislocations in growth of GaP on GaAs. This mechanism involves a long-range phase transformation from strained GaAs-like to relaxed GaP-like states. In the session on "Processing and Novel Techniques," J.L. Gray, Graduate Student Award finalist (Univ. of Washington, Seattle) used van der Waals Epitaxy to grow low-temperature GaAs(111) layers on a GaSe-coated GaAs(111)B substrate. The eventual goal of this process is to decouple the interface by growing a van der Waals bonded crystal layer (GaSe) between the two materials with dissimilar lattice constants, thereby

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accommodating the lattice mismatch. A more conventional approach in heteroepitaxy involves growing compositionally linearly graded or step-graded buffer layers. These layers, however, are usually of the order of several microns thick. T. Bryskiewicz (MPB Technologies, Canada) presented $In_xGa_{1-x}As$ (x up to 0.2) layers up to 3 mm thick, which were grown on SiO_2-patterned GaAs substrates by liquid-phase electroepitaxy (LPEE). The ternary seeds originated in the oxide-free seeding windows, extended over the SiO_2 coating, and merged to become a continuous, monocrystalline layer with no apparent trace of boundaries of the merged islands.

As MBE or MOVPE are being considered or used for production of device-quality layers, *in situ* monitoring and control as well as screening before fabrication become increasingly important. Composition and thickness uniformity, surface defects, and other topics were discussed. In particular, N. Kobayashi (NTT Basic Research Laboratories, Japan) presented an *in situ* surface photo-absorption study of MOVPE surfaces, and K.R. Evans (Wright Laboratory, Wright-Patterson AFB) showed application of desorption mass spectrometry to compositional control in MBE.

Finally, and perhaps most news-worthy, as indicated by several press inquiries, was a talk by R.L. Gunshor (Purdue Univ.), who announced pulsed and continuous-wave laser operation at room temperature from a (Zn,Mg)(S,Se)-based II-VI laser diode with a new wavelength record of 480 nm. His talk also described the evolving development of the II-VI blue lasers, explaining how researchers arrived at the current device status with a threshold voltage of 4.2 volts. Gunshor pointed out that the now ubiquitous III-V laser diodes were once at the same point in development that these II-VI lasers are now.

Symposium Support: Air Products & Chemicals, Aixtron Inc., American Xtal Technology, Bandgap Technology Corporation, Blake Industries, EMCORE, Instruments SA, Morton International, Sumitomo Electric USA Inc., Superior Vacuum Technology.

Temperature Measurement Still Elusive for RTP

(See MRS Proceedings Volume 342)

Interest in rapid thermal processing (RTP) continues to grow as the demands on IC processing technology become more stringent. The ability to process at high temperatures for short periods of time 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 diffusion of unwanted species through the chamber walls. Also, cracking of reactant gases occurs only at or near the sample surface. The latter can critically reduce such undesirable effects as auto doping during the deposition of thin films. The fact that RTP is ideally suited for single-wafer processing is also a driving force.

Temperature measurement and control remains one of the most challenging problems 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 described in Symposium G, Rapid Thermal and Integrated Processing III. And though theoretical predictions and laboratory measurements are encouraging, much work remains 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 the much needed design information that will lead to better wafer temperature uniformity. This includes the ability to control the temperature uniformity during heat-up and cool-down as well as at processing temperatures. The symposium featured a number of papers that address this subject and indicated the direction one can expect the equipment to take in the future.

The number-one use of RTP systems is annealing, which is being employed very successfully to form silicides where short-time anneals at intermediate temperatures are required. Several papers discussed silicide formation. Another major and routine use of RTP systems is for dopant activation and radiation damage removal of ion implanted samples.

Rapid thermal oxidation and nitridation are showing much promise; it appears that the high-temperature short-time attributes can be used to improve device performance. As the 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 much more attention, due to the importance of the cold-wall nature of RTP reactors. Moreover, 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.

Symposium Support: Addax SA, AG Associates, AST Elektronik, CVC Products Inc., Dainippon Screen Mfg. Company Ltd., Peak Systems Inc.

Polycrystalline Thin Films—Microstructure Related to Observable Properties

(See MRS Proceedings Volume 343)

Polycrystalline thin films are found in a variety of products that, taken together, comprise a major commercial market. Symposium H, Polycrystalline Thin Films: Structure, Texture, Properties, and Applications, emphasized the relationships between film microstructure and the observable properties, within the context of technologically relevant applications.

It was made clear that grain growth should be considered on an equal footing with nucleation and growth as a mechanism for establishing the observed structure and preferred orientation of polycrystalline films. The applicability and limits of Hillert's model of normal grain growth were discussed. The roles of interfacial energy, strain, and grain boundary energy on grain growth were demonstrated via simulations. The link between macroscopic properties and the structure and arrangement of grain boundaries is beginning to be addressed. Orientation imaging in the SEM offers a powerful tool for obtaining both the grain size and grain orientation distribution.

While it has been popular in the past to ignore the role of nucleation during thin-film reactions and phase transformations, recent work demonstrates the important and often dominant role that nucleation plays in phase selection and in the formation of metastable phases. In turn, nucleation kinetics were shown, both experimentally and through detailed modeling, to depend sensitively on the microstructure of polycrystalline films.

Magnetic recording and storage represents a market of equivalent magnitude to the semiconductor industry. Optimizing the magnetic properties and increasing storage density will require tai-

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Graduate Student Award Recipients at the 1994 MRS Spring Meeting. Seated (left to right): Zhiyong Ma, Gretchen E. Fougere, Suzette Keefe Pangrle, Minh Q. Tan. Standing (left to right): M.V. Ramana Murty, Michael V. Glazov, Andrew M. Gabor, Paul Gee. Not in the picture are Neil C. Greenham and Andrew G. Johnston.

loring and control of thin-film microstructure and preferred orientation. The establishment of texture in the initial film layer, and subsequent grain-to-grain epitaxy, were discussed by a number of speakers. Ordering of magnetic alloys can result in films with useful and novel properties. Giant magnetoresistance (GMR) has recently received significant attention within the community. GMR at low saturation fields has been demonstrated in NiFe/Ag multilayers, with Ag penetration and entrainment in the permalloy grain boundaries responsible for the observed behavior.

Electromigration-induced failure in integrated circuits poses a significant limit to reliability. Control of grain size, texture, and strain is essential for reducing electromigration failures due to voiding or hillock formation.

Symposium Support: Balzers AG, Gatan Inc., IBM ADSTAR, IBM Storage Systems, JEOL USA Inc., Komag Inc., Philips Electronic Instruments, Rigaku USA Inc., Thermionics Laboratory Inc.

James F. Gibbons, dean of Engineering at Stanford University, considers lessons learned from the history of Silicon Valley in his plenary address to a near-capacity crowd. See the text of his address in this month's Material Matters.

Materials Developments Contribute to Pollution Control and Recycling

(See MRS Proceedings Volume 344)

Symposium I, Materials and Processes for Environmental Protection, was concerned with the materials and materials issues related to the protection of the environment. Three days of sessions saw technical contributions on materials for air and water pollution control, and on recycling of materials to reduce solid, liquid, and gaseous waste by-products.

Papers were presented in a broad number of areas, including advanced ceramic materials that function in extreme environments to improve energy efficiency, provide supports for pollution control catalysts, and filter hot gases to remove entrained particles; high-temperature stable materials for combustion catalysts to significantly reduce NO*x* emissions from natural-gas-fired turbine power generators; using recycled rubber as an additive in concrete to recover this waste material and to correlate with the rebuilding of this country's infrastructure; and materials and process strategies in the microelectronics industry for environmentally friendly, large-scale MOCVD.

Symposium Support: Advanced Research Projects Agency, Dow Corning Corporation, Englehard Corporation, Exxon Research and Engineering Company, Novapure.

Environmental Needs Include Methods of CO_2 Reduction and Exhaust Conversion

Symposium J, Environmental Science, addressed CO_2 chemistry and materials for Exhaust Gas Conversion. In the session on "CO_2 Chemistry," several papers dealt with novel methods for selectively reducing CO_2 to useful organic compounds. A.G. Atanasyants (Mendeleev Univ. of Chemical Technology, Moscow) described schemes for electrochemical reduction of CO_2 to formaldehyde, formic acid, or methanol. Any of these products can be produced selectively with an appropriate choice of cathode material, promoter ions, and electrolyte. D.L. DuBois (National Renewable Energy Lab., Colorado) illustrated routes for reducing CO_2 to CO using homogeneous palladium phosphine compounds which are regenerated at electrode surfaces. Current efficiencies up to 99% are possible with certain phosphine ligands. Bimetallic systems were offered as candidates for electroreduction of CO_2 to methanol. The mechanism of CO_2 photoreduction to CO was elucidated by T. Ogata et al. (Brookhaven National Lab., USA and Osaka Univ., Japan). In this system, a photoexcited aromatic molecule transfers an electron from triethylamine to a cobalt macrocycle compound. The reduced cobalt compound is an effective catalyst for CO_2 reduction. R.C. Prince (Exxon Research and Engineering) reviewed the nonphotosynthetic routes that living organisms employ to convert

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CO_2 into organic compounds. These organisms utilize high-energy chemical reductants available in unique biological or geological environments.

In the session on "New Materials for Exhaust Gas Conversion," S.H. Oh (General Motors R&D) outlined the novel requirements of catalytic converters for natural-gas-fueled vehicles. Rhodium added to platinum/palladium is especially effective in converting unburned methane. New converter control strategies are needed because these catalysts work best under reducing (fuel-rich) conditions. P.G. Harrison (Univ. of Nottingham, United Kingdom) discussed gel-synthesis methods for producing auto exhaust catalyst materials that do not contain precious metals such as rhodium, palladium, or platinum. The new catalysts contain oxides of chromium, tin, and copper. Synthetic strategies for optimizing materials composition, structure, and performance were presented.

Symposium Support: Exxon Research and Engineering Company, General Motors Corporation.

Panelists (left to right) Martha A. Krebs, DOE; Lyle H. Schwartz, NIST; and Karl A. Erb, NSF, discuss the role of materials in federal programs in a forum on "Changing Federal Initiatives for Materials Science Programs." See this month's From Washington for a summary of this forum.

Theory and Design of Liquid Crystal Polymers Illuminate Path Toward New Optical Effects

The thrust of many papers in Symposium K, Liquid Crystal Polymers, was synthesis, characterization and modeling to understand basic properties of polymer liquid crystal systems. The longer term objective for most researchers was to find optical effects and applications, three of which are summarized here.

H. Mazaki et al. (Nippon Oil) developed a method for preparing a large-area, monodomain cholesteric liquid crystal polymer film on a flexible, tracetylcellulose roll (dimensions 40 cm wide by 300 m long). A key to their success was the use of a single-alignment layer of rubbed polyimide which could enforce planar alignment of the cholesteric structure for film thicknesses of 3–4 μm. The thermotropic polyester LC materials used in this work were synthesized with a left- or right-handed structure. The researchers were able to tune the selective reflection band throughout the visible or near infrared by annealing at the appropriate temperature near 200°C. This anneal also allowed the monodomain to become established. The authors anticipate that their films will have commercial applications as dichroic mirrors and notch filters.

Using a liquid crystal side-chain polymer doped with suitable photosensitive chromophores, C. Bräuchle et al. (Univ. München, Germany) demonstrated the ability to perform "cold poling," in which the normally centrosymmetric liquid crystal/dye blend is reoriented with light and an electric field (but no heat) into a stable, noncentrosymmetric form. Small regions exhibiting second harmonic generation were achieved, with possible applications for waveguiding.

R.A.M. Hikmet (Philips Research) demonstrated how a conventional Wollaston prism, manufactured from suitably cut and oriented crystal quartz prisms, converted incident light into orthogonally polarized and diverging beams. The conventional device was cubic and 4 mm on a side. The author then demonstrated similar optical performance, after photopolymerization, from a sheet of anisotropic liquid crystal gel, whose thickness was 20 times less. Potential applications are for microoptics and integrated optics.

Symposium Support: AKZO International, Consortium für Elektrochemische Ind., Fergason Consulting, Nippon Oil Company.

Flat Panel Displays Dominated by Active Matrix LCDs

(See MRS Proceedings Volume 345)

Symposium M, a new symposium on Flat Panel Display Materials, was designed to bring together the established materials research and emerging flat panel display communities. The symposium's strong emphasis on "active matrix" (AM) LCDs reflected the widespread use of this technology in products such as notebook computers. In such displays the active element is usually a thin-film transistor, and papers covering the materials and device aspects of both amorphous and polycrystalline silicon thin-film transistors dominated the first day. The first two sessions were held jointly with Symposium A, Amorphous Silicon Technology, and described, among other things, the relatively recent transition made by amorphous silicon devices from the R&D arena to large-scale manufacturing. The session on "Polysilicon TFT Technology" had a strong device emphasis and was complemented by a number of related papers in the evening poster session.

In a session on materials and processes for AMLCDs, D.M. Moffatt (Corning Inc.) introduced her company's new substrate material, code 1737 glass, and described its enhanced durability and temperature stability. The symposium concluded with a series of papers on emissive displays, where the major theme was the preparation and properties of a range of phosphor materials.

Symposium Support: IBM T.J. Watson Research Center.

Precursor Chemistry Yields Diverse Ceramics, from Synthetic Bone to Superconductors

(See MRS Proceedings Volume 346)

The sixth symposium on Better Ceramics Through Chemistry, Symposium N, extended over five days and attracted more than 100 oral presentations and 150 posters.

The technical program began with sessions on "Precursor Chemistry" and "Novel Chemical Routes," whose theme was controlling the microstructure and

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composition of ceramics by the subtle manipulation of chemistry during sol-gel processing. M.J. Hampden-Smith (Univ. of New Mexico) set the tone by describing how a variety of metal alkoxides, carboxylates, and other derivatives have been used in nanocomposites by intercalating polymer precursors into montmorillonites. His talk reflected a growing interest in hybrid organic-inorganic materials and composites, which provided the topic for the third session and remained a dominant theme throughout the symposium. B.M. Novak (Univ. of Massachusetts), for example, described some of the strategies that are being used to avoid shrinkage effects during the processing of hybrid gel composites, and U. Schubert (Univ. Würzburg, Germany) discussed recent developments in the area of organically modified silica aerogels.

The session on "Design and Processing of Advanced Ceramics" was opened by A.M. Stacy (Univ. of California-Berkeley) who described some of the advantages of using molten hydroxide fluxes for the synthesis of superconducting oxides. Other researchers emphasized the steps that can be taken to improve the quality of thin films prepared by sol-gel processing. A later session focusing on "Sol-Gel Optics and Electronics" included such topics as the novel, encapsulated sensors described by D. Avnir (The Hebrew Univ. of Jerusalem), and the reactions of trapped molecules in porous xerogels explained by B. Dunn (Univ. of California-Los Angeles). A similar theme was taken up in the session on "Porous Materials," where K.J. Shea (Univ. of California-Irvine), G. Férey (Univ. du Maine, France), M.E. Davis (California Institute of Technology), and others explored some of the novel chemical approaches that are yielding a wide range of new materials, both crystalline and glassy, in which nanoporosity can be controlled and manipulated. These materials include the new generation of mesoporous molecular sieves, with pore sizes of up to 100Å, which were first synthesized by scientists at Mobil using self-assembling surfactant "templates."

Other sessions in this wide-ranging meeting included discussions on non-oxide ceramics, especially carbides, nitrides, and sulfides; design of nanoscale materials, such as semiconductors in zeolites, described by N. Herron (DuPont); and *in situ* methods of characterization. The final afternoon highlighted recent work in biomaterials, with topics ranging from synthetic bone, described by L.L. Hench (Univ. of Florida) and M. Yoshimura (Tokyo Institute of Technology), to embedded biosensors reported by J.I. Zink (Univ. of California-Los Angeles). The large poster sessions illustrated the extraordinary diversity of current activities in this area.

Symposium Support: Allied Signal, Inc., Chemat, Gelest Inc., Hughes, National Science Foundation, Sandia National Laboratories, 3M.

Microwave Processing: An Emerging Technology?

(See MRS Proceedings Volume 347)

Symposium O, Microwave Processing of Materials IV, focused on assessing the microwave processing of materials as an emerging technology. In addition to a plenary session that featured five papers specifically addressing this topic, 14 other sessions addressed various aspects and applications of microwave processing technology. These sessions included scale-up and technology transfer, microwave nondestructive testing, dielectric properties measurements, computer simulation and modeling of microwave heating, microwave remediation of hazardous waste, and several sessions that addressed the various applications of microwave processing, including sintering and joining of ceramics, plasma processing, and curing of polymers.

Among several special features highlighting this year's symposium were the presentation of the findings of the National Research Council Materials Advisory Board committee on the "Assessment of the Microwave Processing of Materials as an Emerging Technology"; the workshop on "Alternative Microwave Sources," funded by the Technology Transfer Program of the Energy Research Laboratory/DOE Office of Energy Research; the special session sponsored by Hewlett-Packard on "Simulation and Measurement of Microwave Processing Systems"; and the participation of a large delegation from France, sponsored by Electricité de France (EDF).

A record number of more than 130 papers were presented at this symposium, and participants from 11 countries, including the United Kingdom, Germany, Canada, France, Japan, China, Korea, Australia, Taiwan, Russia, and the United States, shared their recent findings in the emerging areas of microwave processing technology. Some of the technical topics attracting great participation and, in some cases, intense discussion included the value-added contribution of the microwave processing technology, difficulties involved in scale-up and technology transfer, difficulties in making accurate temperature measurements in a microwave environment, aspects of controlling microwave processing systems, and the role of microwave heating technology in the remediation of hazardous waste. It was generally felt that significant progress has been made toward the effective utilization of microwave processing, including the use of broad-frequency generators, and that this technology offers unique capabilities, which accounts for the fast-growing interest in this area of research. Some current efforts are focusing on computer simulation and modeling of microwave processing systems and on understanding some of the more complex aspects of microwave interaction with materials. It is hoped that these efforts will result in a better understanding of this technology, leading to its improved control, scale-up, and ultimate commercialization.

Symposium Support: Cober Electronics Inc., Hewlett-Packard Company, Martin Marietta Energy Systems (Energy Research Laboratory Technology), Microwave Laboratories Inc., Microwave Materials Technologies Inc., Oak Ridge National Laboratory (Advanced Industrial Materials Program), SUPELEC, Varian Associates Inc.

Fundamental Properties of Scintillator and Phosphor Materials Displayed

(See MRS Proceedings Volume 348)

Scintillator and phosphor materials are important in a large number of radiation detection, lighting, and display applications. Symposium P, Scintillator and Phosphor Materials, addressed the fundamental physics and chemistry of these materials in an effort to increase our understanding of the processes governing their spectral and temporal characteristics and overall efficiency under excitation by ionizing radiation. Intrinsic and activated materials of interest included crystals, glasses, and plastics. Methods of preparing these materials in the forms required for specific applications such as large single crystals, powders, fibers, or thin films are also important considerations for their use.

The three-day symposium of 100 papers included reports of new inorganic and organic scintillator and phosphor materials, photoluminescence and radioluminescence investigations of the physical processes governing scintillation efficiency, theoretical calculations and modeling of scintillators and scintillation phenomena, radiation-induced damage studies, and the growth, processing, and fabrication of materials. Authors were from 15 countries, reflecting the worldwide interest and activity in the field. The largest

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representations were from the United States and countries of the former Soviet Union.

Scintillator crystals are used in high-energy physics, astrophysics, geophysical exploration, medical imaging, security inspection, and industry. One of the largest applications of these materials is in calorimeters associated with high-energy and nuclear physics experiments. Present and proposed detectors for high-energy high-luminosity colliders, such as the Large Hadron Collider (LHC) at CERN in Europe, incorporate arrays of thousands of scintillator crystals and volumes of materials measured in cubic meters. A key material requirement for this application is radiation hardness, the ability of scintillating crystals and plastics to maintain their properties and survive in the high-radiation environment characteristic of high-resolution electromagnetic and hadronic calorimeters. The need for economic production of large, high-quality crystals was also noted.

Symposium Support: Bicron/Harshaw, Brookhaven National Laboratory, Centre European pour le Recherche Nucleaire, Nihon Kessho Koogaku Company Ltd., Optovac Inc., Schlumberger-Doll Research, Siemens.

Patrick G. Grimes, Exxon Research & Engineering (left), Kathleen C. Taylor, General Motors Research Laboratories (center), and John L. Sullivan (right), Ford Motor Company, address the environmental impact of automotive materials during a panel discussion.

Researchers, Musicians, Artisans Sing Different Tunes

Stories abound which claim that during string quartet practices Heifetz would complain that Einstein couldn't count. Another story relates that Donald Glaser, when asked what he would do with his physics Nobel Prize money, reportedly said: "Buy a new viola." Such keen interest in the arts on the part of scientists informed the spirit of Symposium Q, Materials in Musical Instruments. The symposium was a marvelous confluence of arts and science, with participation from the scientific community, represented by recognized researchers in the field of musical acoustics, and from the arts community, represented by industrial artisans, company representatives, and respected performers on several instruments. The audience was enthusiastic about this effort to bring scientific understanding, particularly with materials relevance, to the ears of industry and performing artists, and conversely to bring the concerns of manufacturers and performers to the researcher. While that bridge may not yet be open in all areas to unimpeded two-way information traffic, the symposium certainly widened the path to an increased dialogue. Complementing 18 invited and seven contributed papers, a panel discussion provided an opportunity to air concerns on a less formal basis as well as hear performances on selected instruments. This included a performance by internationally recognized steel pan artist Andy Narell, performing on a set of E. Mannette's double second pans. Among the researchers were T.D. Rossing (Northern Illinois Univ.), an ASA silver medalist, who also gave a Symposium X presentation on materials in musical acoustics; C.M. Hutchins (Catgut Acoustical Society, Inc.), another ASA medalist, who discussed some of her pioneering work on violin plate tuning; C. Besnainou (Univ. Paris), who presented work on composite materials applied to violin bodies; D.E. Hall (California State Univ., Sacramento), who discussed piano hammer-string interactions; N.C. Pickering (Bowed Instruments Co., New York), who talked about materials problems in musical strings; and P.L. Hoekje (Univ. of Northern Iowa), who presented some of his work on brass instruments. Other topics included reed materials, old varnishes, violin wood characteristics, materials in Caribbean steel pans, alternative materials for bass hand bells, and materials loading of an Indian drum. Manufacturers were represented in presentations by W.Y. Strong (Steinway & Sons, New York), D.G. Monette (D.G. Monette Corp., Oregon), showing his trumpet design, B.W. Brannen (Brannen Brothers Flutemakers, Massachusetts), S.A. Wasser (Verne Q. Powell Flutes, Massachusetts), J.A. Decker (Kuau Technology, Hawaii), demonstrating a graphite/epoxy acoustic guitar, and E. Mannette (artist-in-residence, West Virginia Univ.), illustrating his Caribbean steel pans.

Symposium Support: Acoustical Society of America, Fox Products Corporation, National Science Foundation.

Microstructure Control Essential to Materials for Separation

The second MRS symposium on Materials for Separation Technology, Symposium R, featured about 50 presentations on the synthesis and properties of membranes and adsorbents. Two-thirds of the meeting was devoted to inorganic membranes, with standing-room-only attendance at the four inorganic membrane sessions indicating the high level of interest these materials hold for separations applications. A major aim of the symposium was to encourage discussion of membrane materials issues from a multinational perspective. This goal was facilitated by including researchers from the United States, Japan, France, China, and The Netherlands, a total of 16 speakers representing major research groups from universities, industry, and national laboratories.

Polymeric membrane research is focused on the development of next generation materials requirements. Inorganic membrane researchers are concentrating on materials development, with many engineering issues yet to be resolved prior to large-scale commercial applica-

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tion. Several approaches to the preparation of inorganic membranes were described, including sol-gel techniques, controlled pyrolysis of polymeric precursors, zeolite crystal growth inside support pores or on the surface of mesoporous ceramic membranes, and deposition or modification of membranes using CVD techniques. Inorganic membrane synthesis included materials ranging from boron nitride to silica, titania, zirconia, and alumina as well as metal and composite membranes. Novel techniques such as field emission SEM, atomic force microscopy, dynamic light scattering, small angle x-ray scattering, and ^{129}Xe NMR, are being used to characterize membrane microstructure.

Highlights of the symposium included several presentations on the synthesis and properties of hydrogen (Pd/Ag) or oxygen ((La, Sr) (Co, Fe)$O_{3-\delta}$) semipermeable membranes. Hydrogen or oxygen permeation fluxes through these inorganic membranes under certain conditions are of the same order of magnitude as those through commercial mesoporous ceramic membranes, and several orders of magnitude larger than those through commercial polymeric membranes. A CH_3OH/H_2 separation factor greater than 1,000 could be achieved for the polycrystalline zeolite membranes reported in the presentation. This symposium showed that great progress is being made toward defining desirable membrane microstructure, controlling defects, and depositing and growing optimized materials.

Symposium Support: Air Products & Chemicals, DOE Office of Industrial Technology–Advanced Industrial Concepts Materials Program, Golden Technologies Company, Inc.

Superconductors Interface with Applications

Symposium S, High Temperature Superconductors: Multilayers, Interfaces, and Applications, featured more than 200 papers and opened with a talk by A.P. Malozemoff (American Superconductor Corp.), who reviewed recent progress in the manufacturing of long lengths (hundreds of meters) of high J_c BSCCO wire for power and magnet applications. L.R. Motowidlo (IGC Advanced Superconductors) reviewed recent developments and improvements in BSCCO 2212/2223 tapes and wires, also in long lengths with high J_c. K. Togano (National Research Institute for Metals, Japan) reviewed recent Japanese work on 2212 BSCCO/Ag composite tape fabrication and properties. The steady improvements are very encouraging for practical HTS applications requiring high-current and magnetic field performance.

R.J. Cava (AT&T Bell Labs) gave a stimulating talk on recent work in developing new superconducting materials related to the cuprates. Phase stability and high T_c were seen to be correlated in the Y-Pd-Ba-Cu and Y-Ni-Ba-Cu systems. The Hg-based cuprates continue to be of great interest, although no one reported confirmation of the recent reports of higher T_c's (over 200 K) in these compounds.

X.D. Wu (Los Alamos National Lab.) reported recent work on the growth of in-plane oriented YBCO films with high J_c (> 500,000 A/cm^2) on metal substrates. Properties of ultrathin films and superlattices were reviewed by Q. Li (Univ. of Maryland). A variety of *in situ* diagnostic techniques were also presented. Two joint sessions were held with Symposium F, Epitaxial Oxide Films and Heterostructures. There was a great deal of interest in attempts to integrate HTS materials with ferroelectrics to produce new types of devices.

W.L. Holstein (DuPont) reviewed important thermodynamics and processing considerations in producing large-area Tl-based superconductor films for high-power microwave applications with surface J_c up to 1 million A/cm^2. M.M. Eddy (Superconductor Technologies Inc.) discussed a variety of passive microwave device applications of HTS thin films, including those needing high-power handling. MOCVD film deposition processes continue to make steady progress although surface roughness remains a problem. An interesting talk by J.K. Truman (Conductus) highlighted recent progress on single-source MOCVD. Tunneling and interface effects for YBCO step-edge junctions were discussed in an enlightening talk by K. Char (Conductus). L.H. Greene (Univ. of Illinois) reviewed interesting work on proximity effect tunneling vs. crystallographic orientation. Junction device work at IBM Research Division was reviewed by W.J. Gallagher, who highlighted a number of interesting measurements including magnetic "microscopy" of trapped flux in SQUIDs. J. Talvacchio (Westinghouse STC) reviewed recent work on building practical HTS junction-based electronic circuits such as an A/D converter. R.H. Ono (NIST) reviewed progress on making reproducible step-edge SNS junctions with high values of J_cR_n.

Symposium Support: Argonne National Laboratory (Superconductivity Partnership Program), Los Alamos National Laboratory, Oak Ridge National Laboratory/MMES.

From Dust to Diamond

(See MRS Proceedings Volume 349)

Symposium T, Novel Forms of Carbon II, was devoted to the promotion of closer ties among those working across the spectrum of the carbon allotropes. The symposium consisted of nine half-day oral sessions and a poster session.

In the session on "Novel Allotropes, Mixed Phases, and Exoatmospheric Carbon," A.N. Witt (Univ. of Toledo) described the recent astronomical observation of faint red emission from regions of interstellar space characterized by high densities of grains and high densities of stellar ultraviolet photons. It has been suggested that this red emission originates from photoluminescence from hydrogenated amorphous carbon. Witt reported that hydrogenated amorphous carbon, produced in his laboratory under simulated astronomical conditions, exhibited many of the radiation characteristics observed in space.

R.J. Lagow (Univ. of Texas at Austin) described the synthesis, crystal structures, and physical properties of acetylenic carbon species capped with bulky end groups. The unexpectedly high stability of these materials suggests the possibility of producing high molecular weight "carbyne" materials.

In the session on "Fibers, Foams, and Films," F.T. Wallenberger (Univ. of Illinois) described a process for producing uniform carbon fibers directly from the vapor phase via laser-assisted chemical vapor deposition. Using a Nd YAG laser and reaction chamber pressures of 1–7.5 bar, strong uniform fibers were formed at rates of >0.3 mm/sec.

The fullerene and tubule talks were kicked off by D.R. Huffman (Univ. of Arizona), one of the discoverers of the carbon arc technique for producing macroscopic quantities of fullerenes. As Huffman pointed out, fullerene soot itself is a different and interesting form of carbon, containing a wide range of new carbon materials which are just now beginning to be isolated and studied by scientists around the world. These include higher fullerenes C_{76}, C_{78}, and C_{84}, giant fullerenes containing hundreds to thousands of atoms, endohedral metallofullerenes M@C_x, single-walled and multiwalled carbon nanotubes, and hollow and metal or metal/carbide-filled carbon nanoparticles. Huffman and his collaborators have recently created macroscopic amounts of the first fullerenes with an odd number of carbon atoms: C_{119}, C_{129}, and C_{139}. His and other research groups are exploring techniques to help under-

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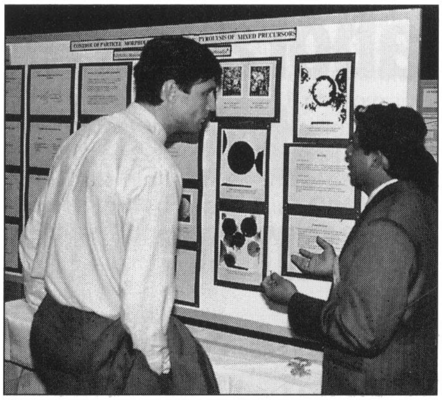
stand the physics and chemistry involved in the growth and formation of fullerenes and other novel forms of carbon now being discovered in carbon soot.

Considerable attention was paid to halogenated fullerenes. R.N. Compton (Oak Ridge National Lab) reported the first production and isolation of a single isomer of a highly fluorinated fullerene, $C_{60}F_{48}$, in greater than 60% yield. This chiral $C_{60}F_{48}$ molecule represents the highest degree of fluorination yet achieved, in which none of the C-C bonds in the carbon shell have been broken. R. Taylor (Univ. of Sussex, United Kingdom) reported intriguing chemistry of chlorinated C_{60}. Previously, Taylor prepared the hexachloro adduct of C_{60} after reacting six equivalents of iodine monochloride with the fullerene. Using this material, Taylor now reports facile substitution of five phenyl groups for chlorine after treating the hexachloroadduct with iron trichloride and benzene. G.P. Miller (Exxon Research and Engineering) reported an alternative method for fullerene chlorination. ^{13}C NMR studies show that the first structure formed in the superacid is a chloronium cation, $C_{60}Cl^{+}$, the first example of a stable fullerene-based cation. Compton, in discussing results aimed at elucidating the physics of fluorinated C_{60}, reports that the doubly charged anion of $C_{60}F_{48}$ is more stable with respect to electron loss than is the singly charged $C_{60}F_{48}$ anion. This is attributed to the creation of a large coulombic barrier for removing an electron from $C_{60}F_{48}^{2-}$, a barrier substantially larger than that observed for the singly charged $C_{60}F_{48}^{1-}$.

Two sessions were devoted to the growth and analysis of diamond materials. R.V. Ravi (Lockheed Missiles & Space Co.) gave a presentation on combustion flame synthesis, a technique used to form high-quality diamond films at high-growth rates. Emphasis was placed on the microstructure, control of phase purity, and factors influencing the growth rate and quality. M.A. Tamor (Ford Motor Co.) proposed that the quality of diamond films was controlled by the rates at which penetration twins were formed and grown–growth being influenced by the (relative) diamond growth rates in the <100> and <111> directions.

The final session focused on diamond-like films. W.A. McGahan (J.A. Woollam Co. and Univ. of Nebraska) gave a presentation on the optical characterization of amorphous hydrogenated carbon films grown on different substrates. Ellipsometric and transmission data were used to determine the optical constants of the films. Modified models, which accounted for the states in the energy gap and the energy bands, were also used to determine the optical properties of the films.

Symposium Support: Exxon Research and Engineering Company, Kobe Steel, Sandia National Laboratories.



Attendees share their expertise at the poster sessions.

Biology, Chemistry, Physics Knit Together Nanostructured Materials

(See MRS Proceedings Volume 351)

Symposium V, Molecularly Designed Ultrafine/Nanostructured Materials, brought together an interdisciplinary focus on this emerging area of materials science. Materials scientists, chemists, physicists, and biologists, including an MD (N. Kossovsky) provided a refreshing interpretation of these materials from their respective vantage points. L. Kabacoff (Office of Naval Research) introduced the symposium by describing the direction the field was taking, as well as its future applications. R.W. Siegel (Argonne National Lab.) presented the more fundamental aspects of nanostructured materials and clusters. The sessions on the synthesis of these materials focused on physical methods, primarily vapor phase methods, and chemical methods including the potential for the scale-up of non-oxide ceramics and alloys. Taking the biological point of view, I.A. Aksay (Princeton Univ.) spoke on the concept of self-assembly/biomolecular engineering and the nanodesigning of ceramics with the aid of complex fluids. Other materials scientists and chemists further elaborated on these concepts, relative to the design of synthetic polymer nanocomposites that display nonlinear optical effects, and to their potential electronic/ionic properties. M.J. Yacamán (Univ. Nacional Autónoma de Mexico) gave a talk on high-resolution imaging, one of an impressive array of characterization and modeling techniques presented. R.D. Shull (NIST) advanced an intriguing idea, the possibility of using magnetic nanocomposites as refrigerants. Another area of strong interest was nanostructured electronic materials. S. Nozaki (Univ. of Electro-Communications, Japan) spoke on blue-light emission from silicon ultrafine particles.

Symposium Support: Office of Naval Research, Precision Manufacturing Center (University of Connecticut).

Time-Dependent Processes Modeled

Symposium W, Theory and Simulation of Time-Dependent Processes in Materials, brought together scientists who study time-dependent processes at different length and time scales, from the microscopic regime of electrons and atoms, through the intermediate or mesoscopic scales, to the macroscopic continuum.

Participants reported calculations of atomic-scale dynamical phenomena based on both quantum and classical molecular dynamics. In quantum dynamics, the electrons are maintained in the ground-state wavefunctions while the nuclei move under the influence of forces arising from the electron density and the other nuclei. In classical molecular dynamics, electrons are averaged out and the interactions between "atoms" are modeled in terms of interatomic potentials. The symposium covered a number of frontier issues in methodology (such as the latest algorithms that allow larger numbers of atoms to be treated, and the construction of interatomic potentials) and in applications. Researchers considered a variety of problems, including the mechanisms of surface diffusion, dislocation motion, melting, and martensitic transformations.

Discussions on mesoscopic theory and simulations covered such topics as grain-boundary dynamics, void growth, surface evolution, powder consolidation and sintering, dislocation emission, and dislocation interactions.

The topic of continuum calculations involved exchanges on viscous flow, stress relaxation, creep modeling, and a variety of plasticity problems. A number of noteworthy papers explicitly addressed issues relating to the linking of length scales using rigorous statistical mechanical methods, mean field theories and semi-empirical models.

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