AMI Holds Its First Industry-University Materials Conference

Colorado's Advanced Materials Institute (AMI) held its first Industry-University Materials Conference in Denver, February 25–27, 1987. Cosponsored by the Solar Energy Research Institute (SERI), National Bureau of Standards, and Colorado Advanced Technology Institute, the conference addressed five topical areas: interfacial phenomena, materials and processes for high-speed electronic devices, amorphous materials, ceramics, and new high performance composites. Highlights of all sessions are described below.

AMI is the materials research arm of the Colorado Advanced Technology Institute, a state agency created in 1983 by the state General Assembly as an economic development initiative involving academic, industry, and government sectors. AMI represents a unique process in academic research: long-term materials needs of industry members are addressed by university investigators, with federal agencies providing the major source of funding.

AMI is a consortium of four research universities (Colorado School of Mines as the lead institution, Colorado State University, and the Universities of Colorado and Denver) and a present industrial membership of nine corporations.

See "Up Close: The Advanced Materials Institute" by J.G. Morse in the February/March BULLETIN, Vol. XII No. 2, p. 89.)

Interfacial Phenomena

Chairs: G.C. Rauch, Digital Equipment Corporation, Colorado Springs; F.D. Schowengerdt, Colorado School of Mines, Golden.

Keynote speaker G.W. Rubloff (IBM T.J. Watson Research Center) discussed the roles of "Microscopic Bonding, Structure and Reaction at Microelectronic Interfaces." He showed how an understanding of microstructure and local chemical composition could be combined with consideration of competing interface reactions to optimize the figures of merit for various microelectronic applications. C.W. Wilmsen (Colorado State University) presented "The Insulator-Semiconductor Interface," in which he emphasized the importance of chemistry of interface formation to successful device application. He described examples in which either thermodynamics or kinetics determined the resultant structure, and pointed out the importance of considering both.

In a paper describing work on "Laser Probing of Gallium Spin Orbit State Desorption and Scattering from Silicon (100) Surfaces," K. Carleton (University of Colorado) detailed measurements of the desorption energy for gallium-silicon interactions, which yielded a value of 67 kcal/mole. Hypothesis was made for measurement of the pre-exponential factor of gallium/Si(100), indicating that gallium surface atoms are mobile in only one direction along rows of Si pairs on a 2 × 1 reconstructed surface of Si(100).

T.J. Coutts (SERI) described "Contact Resistance Studies in p-InP," the goal of which was to develop a metallization system capable of maintaining low contact resistance to p-InP. He showed that Au:Be contacts prepared by evaporation are not ideal for p-InP, but other systems do show promise. Work on a different aspect was discussed in a paper by A. Banerji (Technical University of Berlin). "A New Grain Refiner of Al-Ti-C for Aluminum and Its Alloys" described the development of a process yielding highly effective, fine TiC dispersoids in a hardener alloy designed to nucleate many small grains in solidifying aluminum alloys.

P.J. Wilbur (Colorado State University) reviewed "The Effects of Ultrahigh Current Density Ion Implantation on Bulk Microstructure," describing his broad-beam, ultrahigh-current-density ion implanter (1,500 $\mu A/cm^2$. He showed that ultrahigh current implantation can yield superior surface properties associated with short implantation times and deeper ion penetration, compared with more usual ion beam currents.

B. Clemens (GM Research) gave an invited talk on interfacial research in metal multilayers. He described the effects of structural coherence on the x-ray diffraction patterns from metal-metal superlattices. In several cases, amorphous interfaces have been observed. Also invited was T. Furtak (Colorado School of Mines), who discussed recent developments in Raman scattering from surfaces and interfaces. This technique employs surface optical enhancement of the Raman effect to probe the vibrational structure of molecules within a monolayer of the surface or interface.

Examples from a wide range of microelectronics, electrochemistry, and corrosion problems were described. In a paper on electrorheological fluids, H. Conrad (North Carolina State University) reported electrical characteristics of these materials, focusing on the electroviscous and other effects. B. Koel (University of Colorado) presented a paper on the chemical tailoring of materials to produce unique surface properties. He described co-adsorption of small molecules with potassium and bismuth on Pt(111) surfaces, showing the influence of geometric and electronic structure on the process. G.D. Turner (U.S. Air Force Academy) discussed the nature of interfacial energies between solidifying immiscible liquids and their effects on microgravity solidification. The work was directed toward developing a new class of alloys based on liquids that are immiscible in the earth's gravity, but which present potential candidates for processing in space.

The Fe-SiC interface was the subject of a paper presented by K.M. Geib (Colorado State University). He reported the presence of an interfacial layer of Fe_3C acting as a diffusion barrier in this system to prevent reaction of the iron with the silicon carbide. In a paper on vaporization characteristics of solids, T. Wildeman (Colorado School of Mines) described a new atomic absorption spectrophotometric approach to the study of interfaces through analysis of vapors over compounds at various temperatures. He reported Te_2 as the dominant species in the vapors over Te, Ag_2Te and $AuTe_2$. The last paper of the session was by C. Reid (University of Colorado) on interactions between a polymeric matrix and rigid reinforcing particles in elastomeric composite

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Colorado governor Roy R. Romer speaks at the AMI Conference. Former head of the Governor's High Technology Cabinet Council, Romer played a key role in funding AMI.

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materials. He presented data on differential scanning calorimetry and dynamic mechanical spectroscopy, used to determine the glass transition temperatures. His results indicate effects from the filler particles extending beyond the interfacial region to affect the properties of these materials.

Materials and Processes for High-Speed Electronic Devices

Chairs: A. Majerfeld, University of Colorado, Boulder; C. Ito, Ford Microelectronics, Colorado Springs.

The papers in this session covered a wide range of interrelated materials properties and processing topics of key importance to high-speed electronic devices. Starting with the physics of ultrasmall devices, various speakers presented results on electrical and optical properties of GaAs and $Al_xGa_{1-x}As$ and processing techniques for epitaxial growth, deposition of dielectrics, and fabrication of ohmic contacts for III-V semiconductors and Si.

The keynote speaker for the session, G.J. Iafrate (U.S. Army Electronics Lab), spoke on the "Physics of Microelectronics." He pointed out that as semiconductor technology continues to pursue the reduction of IC device dimensions into the submicron and ultrasubmicron [<1,000Å] regions, many new and interesting questions will emerge concerning the physics of small dimensions, such as nonequilibrium transport, quantization effects arising from geometrical size constraints, and proximity effects due to high-density ICs. Iafrate highlighted futuristic device concepts based on the properties of III-V semiconductors as well as the processing technologies, e.g., MBE and MOCVD, used to fabricate heterojunction quantum-well and superlattice device structures.

Two interesting papers were presented on the GaAs on Si technology. A.S. Yue (University of California) discussed "Multilayer Structure of GaAs/Epi-Si/SiO_2/Si for MMIC and Millimeter-Wave Devices." He reported the successful deposition of crystalline CVD Si on SiO_2 with windows over the seed. Epitaxial growth of GaAs was accomplished by the MBE process. D. McIntyre (Ford Microelectronics) reported the "MOCVD Growth of GaAs Directly on 3- to 6-Inch Si Substrates." This work demonstrated that single crystal GaAs can be grown on large diameter Si substrates, which is one of the advantages of this technology. Selective epitaxial growth of crystalline GaAs on a Si substrate was also demonstrated.

A group of papers on MOCVD GaAs and $Al_xGa_{1-x}As$ was presented by A. Majerfeld (University of Colorado) and coworkers. One analyzed the photoluminescence of heavily doped GaAs and showed that for $n>3\times10^{18}$ cm^{-3}, there is lattice dilation and a corresponding increase of the electron effective mass. It was also shown that this increase in the mass limits the mobility. T.Y. Sheng (Colorado State University) reported on a laser-assisted CVD technique for deposition of AlON films on InP at much lower temperatures than those used in the conventional CVD process.

Two papers were presented on ohmic contacts. D.W. Langer (AFWAL/AADR) discussed the "Structure of Ohmic Contacts at AlGaAs/GaAs MODFET Channel Interface," and R.L. Gillenwater (Colorado State University) presented a theoretical and experimental study on "Ohmic Contacts to Si Using MBE Heterostructure of n^+Ge/n^+Si. M.V. Rao showed a detailed study of rapid lamp annealing of Si-doped InP.

A group of papers dealt with theoretical and simulation analyses of materials and their characterization. In the "Effect of Inelasticity on Thermal Stresses During Czochralski Crystal Growth," J.C. Lambropoulos (University of Rochester) examined the generation of dislocations during bulk growth of Czochralski crystals [Si, GaAs, or InP] in detail. R. Hayes (University of Colorado) discussed the use of "Admittance Spectroscopy to Determine Deep-Level Characteristics in Semiconductor Heterojunctions," e.g., GaAs/AlGaAs as a novel application for interface studies. R.C. Sundahl (Allied Signal) described a new class of low dielectric constant, high thermal stability thermoset copolymers for high-speed electronic interconnects and presented a computer-aided technique for their design.

Amorphous Materials

Chairs: J.U. Trefny, Colorado School of Mines, Colorado; T. McMahon, Solar Energy Research Institute, Golden.

The diversity of papers presented in the session on amorphous materials reflected the pace and breadth of this fast-moving field. Talks covered aspects of amorphous semiconductors as well as metals and a variety of applications including photovoltaics, photoconductors, transistor arrays, and metal surfaces of improved quality.

Keynote speaker J. Pankove (University of Colorado) described one of the oldest unsolved problems of amorphous semiconductors, namely their metastability and degradation under light soaking. This is a problem of growing importance as amorphous silicon photovoltaics become increasingly popular. Pankove reported the results of some of his own recent experiments which tend to disconfirm models based on the idea of negative electron correlation energies. Contributed papers by G. Moddel and R. Jones (University of Colorado) and J.P. Xi and A. Madan (Glasstech Solar) complemented Pankove's presentation with descriptions of new laboratory procedures for testing the quality of amorphous silicon films.

In another invited talk, D. Pai (Xerox) contrasted the material properties desired for photovoltaics with those needed in photocopier applications. In the latter, interests lie in highly resistive materials with small carrier densities. The effects of light degradation are less problematic here than in solar applications since the typical exposure of a drum over a lifetime of one million copies is less than three minutes of full sunlight! A striking measure of the versatility of hydrogenated amorphous silicon is the fact that this material may be adapted to both photovoltaics and photocopiers.

A third invited speaker, M. Thompson (Xerox) extended the applications even further with numerous examples of uses in large-area FET arrays. The low cost of amorphous silicon and its relatively simple processing requirements make it extremely attractive for use in small television screens, transistor-controlled displays, and facsimile machines. Every set of applications entails specific material requirements. In amorphous silicon transistor technology, according to Thompson, the outstanding problems are low yields, metallization defects, and device speeds limited by carrier mobilities.

The final speakers of this session were concerned with the formation of amorphous metals, but by quite different techniques. W. Sampath and P. Wilbur (Colorado State University) in collaboration with F. Kustas (Martin Marietta) have been studying the formation of amorphous materials by ion beam sputtering and by ion implantation methods. Their emphasis is on developing intrinsic surface layers which have superior corrosion and wear characteristics. In contrast, D.L. Cocke and D.G. Naugle (Texas A&M) have developed co-condensation techniques for a variety of refractory metal alloys with exciting applications in catalysis and other fields.

Since much of the session was devoted to discussions of work in progress, it is clear that many applications of amorphous materials remain to be discovered. The scope of this single session was truly impressive, suggesting the need for future meetings on the subject.

Ceramics

Chair: W.J. Plichta, Manville Corporation, Denver.

The session was keynoted by S.M. Hsu (NBS) with a paper on "Advanced Ceramics Research Needs" emphasizing materials processing. Control of processing might encompass the entire gamut from raw material purity through fabrication and inspection, the ultimate goal being mass production or reliable, durable parts at

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reasonable costs. "Advanced Automotive Ceramics" are here today, according to J. Howitt (Corning), because of developments in cordierite honeycomb catalytic converter supports, diesel engine particulate filters, and gas turbine engine regenerator disks. R.B. Schulz (DOE) described "Ceramic Technology for Advanced Heat Engines," focusing on developments of reliable cost-effective materials and attributed to extensive industry involved in DOE's program. "Development of Whisker-Toughened Ceramic Composites" was reported on by A.C. Schauffhouser (Martin Marietta), which resulted from research at universities and industry in concert with Oak Ridge National Laboratory.

Use of neutron diffraction to determine "Effect of Dopants on the Lattice Thermal Expansion of Cordierite" was described by P. Predecki (University of Denver) and J. Faber, Jr. (Argonne National Laboratory). The application of acoustic emission to "Monitoring Damage Growth Processes in Alumina" was presented by M. Hamstad (University of Denver) and R.D. Young (ALCOA). A. Norman (University of Colorado) discussed a bridge linking traditional ceramics to chemistry in his paper, "New Syntheses of Ceramics from Well-Characterized and Defined Inorganic Polymer Precursors."

Reference was made in several of the early papers to policy and philosophy changes to improve the competitiveness of U.S. industry. These include: a relaxation of anti-trust laws that now allow companies to collaborate without fear of collusion; and retention of proprietary rights to products developed by industry when it works with federal agencies.

New High-Performance Composites

Chairs: R. Merschel, Martin Marietta Corporation, Littleton; R.H. Frost, Colorado School of Mines, Golden.

A.K. Dhingra (du Pont) presented the keynote address titled "The Future of Advanced Composites." Composite designs based on the molecular structure/property relationships and advanced processing technologies are able to meet specific advanced engineering needs. Advanced composites provide unique capabilities for applications such as aircraft structures, cutting tools, biomedical end items, and reinforced cement buildings. Dhingra provided examples of many breakthroughs achieved by the knowledgeable design of composite materials.

O'Connor (Phillips Petroleum) described new developments in the polyarylene sulfide family of thermoplastics, which provide high temperature matrix materials for fiber composites at lower costs than thermosetting resins. P. Zoller (University of Colorado) provided an in-depth discussion of the thermal stresses induced into composites by the processing of the polymer matrix, and identified the factors that must be included to model the resulting stress buildup.

D. Nicholls (U.S. Air Force Academy) presented the effects of rubber modified interlayers on the strength, toughness, and vibration damping capability of epoxy/graphite composites. Y.M. Hadded (University of Ottawa) described an analysis technique which predicts the mechanical response of composite materials as influenced by the properties of the matrix, fibers, and interactions of the components.

The second session started with an invited presentation by E.E. Underwood (Georgia Tech) on techniques for quantitative metallographic analysis of fiber-reinforced, metal matrix composites. These metallographic analysis procedures lead to an improved characterization of the anisotropic nature of fiber composites.

C. Lee (New Mexico Institute of Mining and Technology) reported on the reaction of FP/Mg composites to thermal cycling as defined by microhardness profiles, and G.B. Cook (New Mexico Institute of Mining and Technology) provided insight on the response of FP/Al-Li composites to thermal cycling. F. Ko (Drexel) and G. Layden (United Technologies Research Center) detailed the influence of 2-D and 3-D weaving techniques on the properties of glass fiber reinforced ceramic matrix composites, and showed that a 3-D braid can increase both the strength and toughness. The final paper by S.C. Weaver (American Matrix) compared the properties of silicon carbide and boron carbide platelets and fibers as fillers for aluminum matrix composites.

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