SYMPOSIUM E

Ion Implantation and Ion Beam Processing of Materials

The symposium Ion Implantation and Ion Beam Processing of Materials attracted 131 contributed and invited papers in which new and technologically important effects of ion beams on a wide variety of materials were presented and discussed. The number of papers was almost double that presented to the same conference in the fall of 1981. This, and the significant industrial support for the symposium, indicate an expanding interest in ion-beam oriented materials research and materials processing.

The opening day featured ion mixing and the formation of metastable and amorphous materials by ion implantation. M-A. Nicolet from Cal Tech gave an introductory overview of ion mixing in the low temperature regime and suggested that a simple thermal spike model adequately accounts for the data for metals mixed with silicon. For a balanced view, H. Wiedersich from Argonne National Labs gave an invited talk on the high temperature regime and provided a comprehensive review of the possible compositional changes which can occur during bombardment by means of the interaction of defect fluxes with the substrate atoms. It was clear that ion mixing of almost any combination of materials are of current research interest, including metal/semiconductor, semiconductor/semiconductor, metal/insulator, and metal/polymer combinations.

In the afternoon, S.T. Picraux from Sandia Labs reviewed mechanisms of formation of metastable materials and D.I. Potter from the University of Connecticut demonstrated the use of high resolution transmission electron microscopy techniques for monitoring the evolution of microstructures during implantation. A highlight was a spectacular movie by J. Bentley of Oak Ridge National Lab, who used transmission electron microscopy to monitor in real time a phase transformation front in Al that had been implanted with Mo to a concentration of 11 atomic %. This video was "R-rated" because it recorded the demise of the metastable solid solution phase as it was devoured by the relentless growth of the $Al_{12}Mo$ intermetallic phase during in-situ annealing.

B.R. Appleton from Oak Ridge National Lab opened an eventful day of semiconductor papers by demonstrating that deep columnar voids are created under certain conditions during ion implantation of Ge, and J.M. Williams from Royal Melbourne Institute of Technology and C. Jaussaud from LETI, Grenoble, France, reported the voids of Ge and Si, and III-V compound layered structures, respectively. One important message was that one must be careful to check for fine scale morphological changes when ion implanting thin films. Progress on the understanding of the amorphization and regrowth of amorphous semiconductors was noteworthy with new aspects generated from papers on

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atomic imaging of displacement damage in Si and GaAs, regrowth models for Si and GaAs, thermodynamics of the crystallization of amorphous Si and Ge, and the dependence of the properties of amorphous Si and Ge on thermal history after implantation. It is evident that the thermal relaxation and the concomitant property changes of amorphous Ge and perhaps Si may need to be factored into models of regrowth behavior and measurements of the melting temperature by rapid heating techniques. A potentially very useful characterization technique was presented by P.J. McMarr from Penn State involving quantitative ellipsometric measurements on implanted Si.

In the Wednesday morning session on implantation of novel materials, Carl McHargue of Oak Ridge gave an invited review on the implantation of ceramic materials. From this paper and contributed papers it is clear that mechanical properties such as hardness, durability, toughness, and even wear resistance of many ceramic materials are improved by ion implantation. M.S. Dresselhaus from MIT presented an invited review on electrical properties of ion implanted polymers and indicated that the enhanced conductivities observed are caused by a hopping mechanism between conducting islands. The characterization of ion-implanted graphite was carried out for the first time and presented in a series of papers, and a novel way to produce inorganic films by means of ion bombardment induced decomposition of polymer films was described by T. Venkateson from Bell Labs.

Toshinori Takagi gave an encyclopedic review of the materials he has produced by an ionized-cluster beam

deposition process. The characteristics of low temperature deposition, excellent process control, ability to synthesize compounds, and application to three-dimensional structures are but a few of the advantages of the method. A historical review of the circumstances which led to the development of ion beam assisted deposition techniques at IBM was presented by J.J. Cuomo. Ion beam assisted deposition shares the advantages listed above for cluster-beams but is also more readily adapted to existing deposition apparatus. In view of the discussion during the meeting it is clear ion beam assisted deposition is a trend of the future in that many university, industrial, and government labs are developing the capabilities that were pioneered in part by these two invited speakers. Other papers discussed the improved adhesion of thin films by ion irradiation surface smoothing of Mo by high energy Mo-ion bombardment, the improvement of superconductivity in non-transition metals, and the reduction of zero voltage current in Josephson tunnel junctions.

The poster session on Wednesday evening ran from 7 to 11 p.m. and was a smashing hit. A lively and active crowd of participants assembled in the aisles and were seen engaged in sometimes heated discussion of the papers—usually after first collecting their thoughts be means of a visit to the food and beverage bar.

Thursday morning opened with a review talk on tribomechanical properties by I.L. Singer from the Naval Research Laboratory. The general conclusion of this and the contributed talks was that progress has been made in understanding why ion implantation improves wear, in the sense that some mechanisms thought to be responsible have been eliminated. Wear improvements are *not* in general caused by increases in hardness (W.C. Oliver, United Technologies), and wear improvements that have been claimed by measurements of volumetric material removal may be measures of deformation rather than wear, because implantation can prevent deformation of the surface under high loads (D.M. Follstaedt, Sandia Lab, and I.L. Singer). This fact casts doubt for some reported cases that implanted nitrogen migrates beneath a wear scar since the original surface containing the nitrogen is just depressed beneath the plane of the original surface by deformation. It is evident that research on the mechanisms must in the future focus on changes in surface chemistry, and how the implanted surface deforms under stress (J.A. Spitznagel, Westinghouse, W.C. Oliver, I.L. Singer).

Progress on introducing ion beam processing into the industrial setting centers on wear improvement of expensive punching dies (such as for punching beer can tops) and plastic extrusion molds, according to the invited speaker for applications, J.K. Hirvonen, Zymet, Inc. Nitrogen implantation of many metal forming tools and tungsten carbide tools enhanced tool lifetime by factors of three to 10. Many of the contributed papers showed that Ti implanted into steels yields significant wear improvements. Creation of a Ti-Fe-C surface amorphous layer by this treatment seems responsible but the actual wear mechanism is unclear.

In the final session Thursday afternoon, J.A. Cairns from Harwell, U.K., reviewed ion beams in catalyst research and indicated that the extreme complexity of catalytic reactions and in the fabrication of catalysts, and the large surface areas required for experiments, are the reasons why ion implantation has not had much impact as yet in catalyst research. A noteworthy paper described wear improvement of ion implanted Ti-alloy surgical implant hip joint replacements (J.M. Williams, Oak Ridge), and for the first time the surface modification of uranium by ion implantation was reported for the purpose of modifying oxidation and hybriding properties.

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