by *O. T. Iancu* et al. The determination of stress in a ceramic to metal join is not easy. Optical methods using polarized light cannot generally be used owing to lack of transparency. However, in some cases X-ray diffraction techniques (*B. Ergermann* et al.) can be employed to determine residual surface stresses and triboelectric effects or light emission under stress may also be used (*H. Teodorescue* et al.).

In many cases ceramic to metal joins may be subjected to environmental conditions likely to cause weakening. *K. Suganamu* et al. discussed stress corrosion failure, in particular, the influence of water on Si_3N_4 joins where stress corrosion of the Si_3N_4 itself can take place. However, the results obtained showed that the joins can maintain high integrity over a long period of time. Several workers addressed the bonding of copper to Al_2O_3, an important bond in the microelectronics field. Fracture toughness values of K_{ic} up to 4 MPa $m^{1/2}$ were obtained by *L. J. Bostelaar* et al. and *A. Otszyna* et al. showed that the bonds to α-Al_2O_3 were stronger than those to β-Al_2O_3. *N. Klein* et al. also showed that thermal cycling led to deterioration in the Cu to Al_2O_3 bond owing to shear stresses in the join, but control of the crystallite orientation in the Al_2O_3 could beneficially influence thermal endurance.

The majority of the papers and posters presented have been drawn together in a volume entitled "Joining Ceramics, Glass and Metal", edited by *W. Kraft* and published by the DGM.

The conference was highly successful and provided not only an excellent venue for the dissemination of research results but also the opportunity to meet fellow workers in this wide and disparate field.

Magnetic and Magneto-Optic Thin Films and Multilayers in San Diego

By Ernesto Marinero * and Takao Suzuki *

The spring meeting of the Materials Research Society (MRS) in San Diego, April 24th to 29th, 1989, was host for two major symposia dealing with magnetic and magneto-optical materials. The symposium on "Growth Characterization and Properties of Ultrathin Magnetic Films and Multilayers" comprised 11 invited talks and 42 contributed papers over three and a half days and provided a unique and interactive forum in which to discuss recent advances in low dimensional magnetism, diluted magnetic semiconductors, epitaxial overlayers and the utilization of in situ and ex situ techniques to characterize their microstructure and electronic and magnetic properties. The other symposium on "Materials for Magneto-Optic Data Storage" was the first dedicated entirely to materials aspects of the rapidly emerging magneto-optic data technology. This symposium lasted for two days and was particularly successful in providing a well balanced forum between the industrial applications of the technology and fundamental materials research. Thirty seven papers were presented, including outstanding invited lectures, which covered the entire spectrum of materials issues relating to magneto-optical recording media. This included the magneto-optic active layers, dielectric layers and substrates. Emphasis was placed, in particular, on rare earth transition metal amorphous films, such as TbFeCo, GdTbFeCo, from the fundamental as well as the applicational point of view.

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Growth, Characterization and Properties of Ultrathin Magnetic Films and Multilayers

The study of ultrathin magnetic structures is a rapidly expanding field of materials research whose growth is synergistically driven by an increasing appreciation of the degree to which the magnetic properties depend on interfacial processes and by the utilization of growth techniques which permit the fabrication of multilayer structures with novel electronic and magnetic properties. Equally important is the fact that atomic level control of the microstructure of these layers offer new opportunities to elucidate the physics of magnetism, to rigorously test theoretical models and, in some cases, to synthesize new materials.

The symposium opened with an invited talk by *Roy Richter*, General Motors (GM) who presented recent theoretical results on the temperature dependence of the spin anisotropy of a monolayer of Fe. Changes in the magnitude of the perpendicular anisotropy as a function of temperature were attributed to changes in the Fe monolayer band structure. *Mayer* and *Gutierrez* (Johns Hopkins) presented experimental results on Fe(110)/Ag(111) superlattices (SL) grown by molecular beam epitaxy (MBE). No out-of-plane magnetization was observed for this particular system. *Krebs* (NRL), on the other hand, found that Fe(001)/Ag(001) superlattice grown on thick Ag(001)/ZnSe(001) substrates exhibited strong perpendicular anisotropy for Fe layers < 3 ML. The importance of interface roughness was highlighted by *Albert Fert* (University Paris-Sud) who reported on the measurement of giant magnetoresistance in Fe(001)/Cr(001) SL. This roughness leads to electron scattering processes at the Fe/Cr interface, and the increase in magnetoresistance for Cr < 20 Å is ascribed to a change from parallel to antiparallel orientations for the magnetization of neighboring Fe layers. In turn, the interface electron scattering is enhanced by the antiparallel orientation. Similar effects are predicted for other transition metals.

Growth of Fe (Nd, Dy, Y) SL's was reviewed by *Teruya Shinjo* (Kyoto University) who observed that for Fe < 20 Å, the Fe/Nd SL is amorphous and exhibits perpendicular anisotropy. For thicker Fe layers (30 Å) bcc ferromagnetic structures are obtained with in-plane magnetization. The growth of hcp Fe/Ru superlattices was reported for the first time by *Maurer* et al. (CNRS) with evidence for strong interactions through the Ru layers. Co/M (M = Pd, Au, Cu) SL's were also discussed and *Hoving* (Philips) pointed out significant magnetic differences between Pd/Co single crystals and polycrystalline multilayers. In particular, the anisotropy is perpendicular in the single crystal only for Co thickness of 1–2 ML vs. 8 Å for the polycrystalline system. In the case of Co/Au, *Lee* (University of Michigan) reported a transition from out to in-plane anisotropy for Co ~ 20 Å.

In situ techniques to characterize magnetic properties of thin film systems are rapidly developing. *Dan Pierce* (NIST) described the SEMPA technique (Scanning Electron Microscopy with Polarization Analysis) which permits domain imaging with intensity directly proportional to the magnetization and resolution presently ~ 400 Å. He speculated that the STM would be the ultimate magnetic tool of sensitivity to spin could be derived. An elegant demonstration of the use of STM to study ultrathin films was given by *P. N. First* (NIST) who showed images of 0.1 Å Fe layers grown on GaAs which exhibited 3D growth of 20–30 Å diameter islands at 300 K. Similarly, spin-resolved photoemission and Brillouin scattering are powerful tools to study spin-split electronic band structure as reported by *Guntherodt* (Aachen) for the case of Fe/Ni. *Eric Kay* (IBM Almaden Research Center) utilizing secondary electron spin-polarization analysis, showed that 0.1 ML of an adsorbate can alter the Curie point by as much as 30% in the case of permalloy thin films.

A combination of spectroscopies and in situ magnetic measurements were utilized in the MBE growth of Fe/Ag, Fe/Ni and Ni/Fe by *Heinrich* and collaborators (Simon Fraser University). They showed, for example, that in the case of Fe/Ni, Ni grows bcc (RHEED, REELFS) up to 6 ML. A structural transformation occurs for thicker layers giving rise to large magnetic anisotropies which from FMR studies are attributed to growth defects. The effect of strain on magnetic properties was discussed by *Farrow* (IBM) for the case of LaF_3/Dy/LaF_3 and by *Florczak* (University of Minnesota) for epitaxial (100) Fe films.

The use of ex situ techniques such as EXAFS, X-ray scattering and TEM were described by *Cargill* (IBM Watson Research Center) and *Li* (Arizona State University) to study microstructural properties of thin films. FMR and NMR studies have been applied by *de Gronckel* (Eindhoven) to Co/Pd multilayers to investigate the behavior of the anisotropy as a function of Co and Pd thickness. The spin-echo NMR studies indicate that as the Co layer thickness is decreased, structural changes take place that result in an expansion of the Co lattice. The observed magnetic changes are attributed to this structural transformation.

Werner Keune (University of Duisburg) presented results on UHV CEMS (Conversion Electron Mössbauer Spectroscopy) of fcc Fe(100) films on Cu(100) and showed that the para-, ferro- and antiferro-magnetic properties strongly depend on growth temperature. These results were discussed in terms of thickness dependent lattice relaxation.

A search for an experimental manifestation of the universality hypothesis was described by *Pescia* (Julich) who utilized spin-polarized electron scattering to measure the order parameter in < 3 ML Fe films on Au(100). It is found that although the Curie temperature exhibits a thickness dependence, the critical exponent β of the power law $M \sim (1 - T/T_c)^\beta$, is essentially independent of thickness. M is the order parameter. This is explained by the fact that as long as the film is thin enough, the system remains two-dimensional and therefore has a single set of critical exponents which are independent of the strength of the interaction.

Furdyna (Notre Dame), *Gunshor* (Purdue University) and *Jonker* (NRL) reviewed recent progress on diluted magnetic semiconductors (DMS). A typical material set belonging to this class are the $A_{1-x}Mn_xB$ alloys (where A = Zn, Cd and B = Se, Te). *Furdyna* indicated that DMS multilayer structures may be grown with pronounced field-dependent effects. Examples of such structures include, multiple quantum well structures in which the wells consist of a DMS material, or magnetic field-induced SL's. *Gunshor* reported on the intercalation of ZnTe monolayers in ZnSe/MnSe quantum wells which dramatically altered the optical emission due to excitonic self-trapping at Te sites. *Jonker* described ongoing work at NRL on Fe and Co-based DMS materials, indicating that their properties (magneto-optic, electronic) are strongly influenced by the ground state of the magnetic ion used and the energy levels it introduces relative to those of the host semiconductor. The electron-ion and ion-ion exchange parameters for the Fe- and Co-based materials are significantly larger than for the Mn-based counterparts.

In summary, the symposium was an excellent event in which the structural, electronic and magnetic properties of ultrathin magnetic materials were discussed. It brought together a dynamic collection of leading materials scientists from Europe, Japan and the USA, and it is apparent that state-of-the art growth and characterization techniques are widening our understanding of magnetic phenomena at an atomic level.

Materials for Magneto-Optic Data Storage

In the keynote talk, *M. Kryder* of Carnegie Mellon University reviewed the current status of the magneto-optical recording media based on amorphous rare earth (RE)-transition metal (TM) thin films. He pointed out that to maximize Kerr rotation, anisotropy, corrosion resistance and reflectivity, the sputtering conditions should be selected to produce so-called Zone T featureless films. *F. Lin* of IBM Almaden Research Center described in his invited talk the property requirements for the magneto-optic active and dielectric layers that are needed in order to realize high performance recording and reliable data storage. He emphasized the importance of understanding the micromagnetics and controlling the regularity of the written domains in order to achieve a high carrier to noise ratio (CNR).

While the properties of TbFeCo media appear adequate for today's MO storage devices, their rather weak magneto-optic activity at shorter wavelengths (less than 500 nm) may restrict their extension to high storage densities. One approach that has been taken in order to overcome this disadvantage involves alloying TbFeCo with a light rare earth element such as Nd and Pt which both have enhanced M-O activity due to their highly spin polarized 4f states. However, the origin of this enhancement was challenged in a paper by *D. Weller* of Siemens. He presented a systematic study using XPS and Kerr spectroscopy, to characterize in situ RE-FeCo films deposited in ultra high vacuum. His main conclusion is that the 4f-excitations of RE ions are not expected to contribute more than few tenths of a degree to Kerr rotation.

The study of the magneto-optic and magnetic properties of multilayered and exchange coupled films as candidates for higher MO activity has been gaining in interest. *D. J. Sellmyer*, University of Nebraska, and *C. Falco*, University of Arizona, discussed in detail the origin of perpendicular magnetic anisotropy and magneto-optic properties in Fe/Nd, Dy/Co, Pd/Co and other alloy systems of RE-TM. *Sellmyer* concluded that single-ion anisotropy is the major contributor except in Gd. *Falco* discussed the structure of multilayered films made by MBE in conjunction with those made by sputtering. *P. F. Carcia* of E.I. du Pont presented a paper on the wavelength dependence of Kerr activity in Co/Pt multi-layer films. The enhancement in Kerr rotation at short wavelength was shown to be due to the high M-O effect in the very thin Co layers. *S. D. Bader* of Argonne National Laboratory presented an invited talk on surface magneto-optic Kerr effect (SMOKE) of ultrathin ferromagnetic films. The result showed a dramatic example of a metallic reflector enhancement effect due to the nonmagnetic Au underlayer.

Another approach for enhancing magneto-optic activity is to use exchange coupled two-layered films. In such a film structure, optimization of Kerr rotation can be done in one layer and magnetic properties in the other. *R. Gambino* of IBM Thomas Watson Research Center and *H. Wakabayashi* of IBM Almaden Research Center discussed the mechanism for exchange coupling in CoPd/TbFeCo and Co/TbFeCo films. *Gambino* pointed out that properly designed exchange coupled films appear to provide a viable approach to high density storage media. Further extensive discussion was given on multi-layered films of TbFe, Cu/Co and Pd/Co in papers presented by *Krishnan* of CNRS, and *England* of the University of Arizona.

Bi-substituted garnet films are attracting increasing attention due to their very high Faraday activity. The Faraday signal at about 500 nm is almost one order of magnitude larger than the MO activity for RE-TM films with similar thickness. However, a large readback noise results from grains and surface roughness in these polycrystalline films. *M. Gomi* (Tokyo Institute of Technology) discussed the possibility for controlling the grain boundary structure so as to provide better domain regularity and less domain noise by using additives such as W at concentrations of less than 1 atom-%. *K. Shono* of Fujitsu presented data on the recording performance of (Bi-Dy) substituted garnet disks where 57 dB and 54 dB at 5 and 1.4 μ bit length, respectively, were achieved. Such results are encouraging for the eventual use of these materials as a future high density storage media. In addition to these technology oriented talks, *P. Wigen* of the Ohio State University described evidence for partially spin polarized Bi^3 in $Bi_3Fe_5O_{12}$ where a moment of 0.25 μ_B is formed at the Bi ion sublattice while the moment on the tetrahedral iron sublattice decreases by 0.5 μ_B.

Dielectric layers are important for MO recording media because they provide the optical enhancement of Kerr rotation and protection from oxidation for the MO active layers. The dielectric layers for these purposes require a high refractive index, stability to the environment and low internal stress. *K. Hashima* of Mitsubishi Electric Co. described a new dielectric material based on AlGeN which exhibits high refractive index (2.4–2.5) with a very small internal stress (less than 10^9 dyne/cm^2).

Polycarbonate (PC) is the most widely used substrate for MO disks. However, PC can have relatively large optical retardation depending on injection molding conditions and it also absorbs water which alters the mechanical tolerances of the disk. *Y. Togami*, Mitsui Petrochemical Ind. Co., and *M. Yamazaki* of Nippon Zeon Co. described the properties of amorphous polyolefins which overcome these drawbacks.

The oxidation and corrosion behavior of TbFeCo has been a key concern because of the high reactivity of Tb. *A. Lee* of the University of Arizona discussed the interaction of H_2O on UHV clean TbFeCo surfaces using AES, XPS and RBS. Also, *D. Majundar* of Eastman Kodak Co. described the effect additive elements such as Pt and Zr have on the oxidation in TbFeCo. Both papers suggest that such additives can reduce the reactivity of TbFeCo films.

Besides these materials oriented talks, the symposium also covered a key performance disadvantage of MO technology; that is, the lack of direct overwrite capability. *N. Imamura* of TOSOH Co., and *N. Ohta* of Hitachi discussed the current status of the direct overwrite technology. *O. Ishii* of NTT presented the new approach of the direct overwrite using a magnetic head for writing and a laser beam for reading in a two-layered film.

The symposium "Materials for Magneto-Optic Data Storage" was a very successful and exciting meeting.