Wednesday Afternoon, November 4, 1998

Magnetic Interfaces and Nanostructures Technical Group
Room 324/325 - Session MI+NS-WeA

Nanoscale Magnetics: Imaging and Fabrication

Moderator: S. Foss, Seagate Technology

2:00pm **MI+NS-WeA1 Using the Magnetic Force Microscope as a Quantitative Micromagnetic Probe**, ***R. Proksch***, Digital Instruments **INVITED**

The Magnetic Force Microscope (MFM) has developed into a popular tool for nanometer scale resolution imaging of a wide variety of magnetic samples. The routine <50nm spatial resolution rivals and sometimes exceeds electron based microscopies while not requiring operation in a vacuum or special sample preparation. Since the MFM is sensitive to the external magnetic field gradients of a sample, however, it does not directly yield quantitative values of either the external field or a sample's magnetization. A recent advance@footnote 1@ has allowed quantitative imaging of the localized field from a sample. It based on a magnetically soft tip that acts as a fluxgate sensor. An external field is applied to the MFM tip and sample until the response of the MFM is zeroed. This zeroing occurs when the external field cancels the local field at the MFM tip. The resulting quantitative images have the same spatial resolution of the MFM. Another recent development in MFM was the realization that the energy dissipated by an oscillating cantilever was quantifiable.@footnote 2,3@ Measurements of the energy dissipated by the MFM tip have been quantitatively compared to micromagnetic models.@footnote 4@ Measurements of other fundamental quantities such as the moment of a single magnetic particle and nucleation volumes in relaxing domain structures through dissipation observations will be presented. @FootnoteText@ @footnote 1@R. Proksch, G. Skidmore et al., Appl. Phys. Lett. 69, 2599 (1996). @footnote 2@P. Grutter, Y. Liu, P. LeBlanc, and U. Durig, Appl. Phys. Lett. 71, 279 (1997). @footnote 3@J. P. Cleveland et al., Appl. Phys. Lett. in press (1998). @footnote 4@Y. Liu, B. Ellman and P. Grutter, Appl. Phys. Lett. 71, 1418 (1997).

2:40pm **MI+NS-WeA3 Imaging Current Flow in Polycrystalline Bi2Sr2CaCu2Ox Superconductors by Magnetic Force Microscopy**, ***F. Král***, *D. Perednis,* ETH Zürich, Switzerland; *D.A. Bonnell,* The University of Pennsylvania, US; *G. Kostorz, L.J. Gauckler,* ETH Zürich, Switzerland

The measurement of magnetic fields induced by current flow can be used to visualize current transport paths in complex microstructures. Magnitudes of fields induced by currents typical of metallic conductors and of superconductors are within the range accessible by magnetic force microscopy. Finite element calculations indicate that conducting grains separated by as little as a hundred nm will be distinguished. The fields emanating from current in the complex textured microstructure of a Bi2Sr2CaCu2Ox based thick film in the superconducting state at temperatures below 60 K were clearly delineated. Magnetic field variations with the size and orientation of the textured grains that carry current were quantified. Obstructions to current flow are imaged.These measurements were accomplished on a commercial instrument modified to connect to a He cryostat and operate in medium vacuum.

3:00pm **MI+NS-WeA4 Imaging Magnetic Domains by Spin-Polarized Scanning Tunneling Spectroscopy**, ***M. Bode***, *M. Getzlaff, R. Wiesendanger,* University of Hamburg, Germany

The concept of spin-polarized scanning tunneling spectroscopy (SP-STS) promises the unique capability of magnetic imaging with a resolution down to atomic scales. We will show that the (0001)-surface of Gadolinium, which has a bulk Curie-temperature T@sub C@ = 293K, is ideally suited for the realization of SP-STS since Gd(0001) exhibits a d@sub z@@super 2@-like surface state. This surface state is exchange split in an occupied majority (spin-up) and an empty minority (spin-down) spin-part below T@sub C@. Already in a previous publication we have shown that both spin-parts appear as a double-peak structure in the tunneling spectra.@footnote 1@ Here we report on our experiments with magnetic thin film probe tips. In accordance with the spin-valve effect@footnote 2@ we found characteristic variations in the tunneling spectra which correlate with the direction of the external field, i.e. the differential conductivity of the particular spin-part of the surface state being parallel with the tip is enhanced on the expense of the counterpart being antiparallel. This allows the imaging of magnetic domains with the STM. The resolution obtained so far is approximately 20nm. The measured spin-asymmetry of approximately 40% (20%) at the majority (minority) part of the surface state is in good agreement with former spin-resolved (inverse) photoemission experiments. We will show that the application of thick Fe-coatings on the tip leads to a sudden contrast reversal probably caused by a switching of sample domains due to the strong magnetic interaction between tip and sample. @FootnoteText@ @footnote 1@R. Pascal, Ch. Zarnitz, M. Bode, M. Bode, and R. Wiesendanger, Appl. Phys A 65, 603 (1997). @footnote 2@M. Julliere, Phys. Lett. A 54, 225 (1975).

3:20pm **MI+NS-WeA5 Imaging Magnetization in Fe and Layered Fe/Co Films Using an Element-Specific Scanning Transmission X-Ray Microscope**, ***J.B. Kortright***, *S.-K. Kim, T. Warwick, G. Meigs,* Lawrence Berkeley National Laboratory

Magnetization distributions in demagnetized polycrystalline Fe films and in the individual Fe and Co layers of layered films were imaged with a scanning transmission x-ray microscope and circular polarizing filters using the strong magnetic circular dichroism at the Fe and Co 2p3/2 levels. Transmission images were obtained at roughly 200 nm resolution with high contrast that was reversed by reversing the saturated magnetization in the polarizing filters. Large, regular 180 degree domains dominate Fe films 20-30 nm thick. Smaller magnetization features (swirls, ripples, etc.) are observed at grain boundaries and near the tip of needle-shaped domains growing into or being consumed by larger domains. In layered films consisting of Fe and Co layers separated by a 2 nm SiC spacer the magnetization in each layer is entirely different from the single Fe film, revealing significant interaction between the two different layers in the demagnetizing process. Large 180 degree domains are absent, and are replaced by much smaller, more irregular magnetization distributions having characteristic dimensions of several microns and somewhat resembling stripe domains. The domains in the Fe and Co layers show some degree of spatial correlation, and some degree of antiferromagnetic alignment. These first imaging studies using a scanning transmission x-ray microscope in conjunction with a high resolution grating monochromator complement other recently demonstrated imaging techniques using x-rays, and point to new opportunities to quantitatively study magnetization distributions in a variety of samples. Technical aspects underlying these new capabilities will be reviewed. This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Division of Materials Science, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

3:40pm **MI+NS-WeA6 Substrate and Growth Related Nanostructural and Magnetic Properties in La@sub 0.67@SR@sub 0.33@MnO@sub 3@ Thin Films**, ***M.E. Hawley***, *G.W. Brown, C. Kwon, Q.X. Jia,* Los Alamos National Laboratory

Beyond achieving a target chemical composition, optimization of metal oxide thin film properties depends on a number of growth-determined factors: microstructure, defects, and stress. For CMR materials, these factors can lead to low Curie temperature, non-ideal temperature-dependent magnetization, undesirable domain structures, higher coercivity, and magnetic anisotropy. In particular, growth of these materials, which possess fairly large positive magnetostrictive constants, on lattice-mismatched substrates can result in residual stress-induced maze-like domains. This type of domain was observed by magnetic force microscopy (MFM) for some La@sub 0.67@Sr@sub 0.33@MnO@sub 3@ films grown on LaAlO@sub 3@ (compressive mismatch) and tied to substrate-induced stress and film thickness. Stress-induced elongation of the out-of-plane lattice parameter may be necessary but is not sufficient to produce these domains. Their existence has also not been correlated with processing parameters. To address some of these issues, we have grown films over a range of temperatures by pulsed-laser deposition on LaAlO@sub 3@ and SrTiO@sub 3@ (tensile mismatch) to determine the correspondence of lattice-induced strain and degree of granularity to magnetic properties. Nanostructure characterization (STM, AFM, and MFM) magnetization, and coercivity will be presented to show the relationship between growth and properties. Maze-like domain structures, with 150 to 200 nm separations, were observed for thicker films grown at 800@degree@C on LaAlO@sub 3@ versus weak diffuse domains for thin films and all films grown on SrTiO@sub 3@. Application of an increasing in-plane external magnetic field converted the maze-domains first into stripe domains with decreased spacing (with reduced out-of-plane magnetization) and then into diffuse in-plane structures. Field orientation versus magnetic structures will be included.

4:00pm **MI+NS-WeA7 Monodisperse Cobalt Nanocrystals and Their Assembly into Nanocrystal Superlattices: Building with Magnetic Artificial Atoms**, ***C.B. Murray***, *S. Sun,* IBM T.J. Watson Research Center **INVITED**

We present chemical methods which yield cobalt nanocrystals uniform in size to + or - one lattice constant while simultaneously controlling crystal shape, structure and surface passivation. We use high temperature (200 - 300° C solution phase synthesis and size selective processing to produce organically passivated nanocrystals with size distributions less than 5%. These monodisperse transition metal nanocrystals self-organize during controlled evaporation to produce three dimensional superlattices (colloidal crystals, opals). The cobalt nanocrystals resemble "artificial atoms" sitting on regular close-packed superlattice sites, each separated by a selected organic spacer. The superlattices retain and enhance many of the desirable mesoscopic properties of individual cobalt nanocrystals and provide a model system for studies the electronic coupling of neighboring particles. The inter-particle spacing can be varied from intimate contact up to 40 Å separation. Superlattices can be prepared as either faceted colloidal crystals or as ordered nanocrystal thin films on a variety of optically and electronic addressable substrates (sapphire, silicon, etc.). Structural and magentic investigations of both dispersed and assembled nanocrystal systems will be presented.

4:40pm **MI+NS-WeA9 Fabrication and Characterisation of Micron Scale Magnetic Features**, ***C.N. Borca***, *P.A. Dowben,* University of Nebraska, Lincoln

Different methods can be adopted to fabricate patterned thin films with features spatially restricted in the micron-scale regime. We are studying ferromagnetic films of cobalt and cobalt - palladium heterostructures fabricated by selective area deposition from organometalic compounds. We have developed this one-step deposition technique sufficiently to deposit pure metal features with excellent spatial resolution and in multilayer geometries. From the comparison between the continuous and patterned films we can conclude that the patterning of the films into arrays of discrete micron-scale features has a greater influence on the magnetic properties of the films than changes microstructure and film growth. We propose that this organometallic chemical vapor deposition (CVD) method represent a new approach for novel devices fabrication.

5:00pm **MI+NS-WeA10 Domain Behavior in Magnetic Nanostructures as Revealed by MOIF Observations**, ***R.D. Shull***, *A.J. Shapiro,* National Institute of Standards and Technology*; V.I. Nikitenko, V.S. Gornakov,* Institute of Solid State Physics RAS, Russia

A magneto-optical indicator film (MOIF) technique has been used for imaging magnetic domains and applied to magnetic nanostructures, including granular metals, magnetic multilayers, and antiferromagnet (AF)/ferromagnet (FM) bilayers. In this technique, the sample domains are imaged by their effect on a garnet film with in-plane magnetization located immediately above the sample. In addition to static domain structures, dynamic information has been obtained by monitoring the domain pattern evolution upon the application of an external magnetic field. Fractal type domain walls were observed in Co/Ag granular metals with a two-step remagnetization process, non-homogeneous nucleation processes were observed in AF/FM bilayers with remagnetization behavior dependent upon field direction, and non-collinear spin configurations were detected in Cu/Co multilayers (electrodeposited on Si substrates) displaying giant magnetoresistance (GMR) effects during the remagnetization process. In these latter samples, the GMR magnitude was correlated with the spin reorientation mechanism. In all samples the effects of crystal lattice defects on the remagnetization process was documented, and found to be significant. The MOIF technique was also found to be capable of detecting not only the domain structure of the surface layer, but also that of subsurface layers in a multilayer morphology. In this presentation, a review of the domain statics and dynamics which have been observed in a variety of nanostructured material types will be discussed. Particular attention will be given to the origin of enhanced coercivity in a bilayer system with unidirectional anisotropy.

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