Magnetic Interfaces and Nanostructures Technical Group
Room 618/619 - Session MI+NS-ThA

Magnetic Imaging

Moderator: P.N. First, Georgia Institute of Technology

2:00pm **MI+NS-ThA1 Cryogenic Magnetic Force Microscopy Instrumentation***, **M. Roseman**, P. Grutter,* McGill University, Canada

We describe our cryogenic magnetic force microscope, operating between 4 and 300 Kelvin. The instrument is designed to fit within a 3" diameter bore of an 8 Tesla magnet. Cooling is achieved through the use of He exchange gas, which is pumped out prior to imaging in order to provide a vacuum of better than 10@super -5@ mbar during operation. The instrument uses a fibre optic interferometer to measure cantilever deflections. Through the use of a phase lock loop, this interferometric signal allows for the tracking of the cantilever resonant frequency with a resolution of 0.25 Hz in a 100 Hz measurement bandwidth. Our cantilevers are commercially available, made of single crystal silicon coated with a magnetic film, and routinely exhibit Q-factors of greater than 100,000 at 4 Kelvin. Piezoelectric-based clamping linear positioners, with step sizes of 50 nm (at 77 Kelvin) and capable of operation in high magnetic fields, perform in-situ tip and fibre approaches. As an effective means of vibration isolation, we suspend the microscope from a soft bellows. Comprised of 70 convolutions, the bellows damps out vibrations by more than an order of magnitude, effectively isolating the microscope from the surrounding environment, including pump vibrations and liquid helium boil-off. Particular attention has been paid to optimizing the signal to noise ratio through a systematic study of various noise sources, with the intent of achieving a thermally limited sensitivity.

2:20pm **MI+NS-ThA2 Modified Tips for High Resolution In-plane Magnetic Force Microscopy***, **L. Folks**,* IBM Almaden Research Center*; J.N. Chapman,* University of Glasgow, UK*; M.E. Best, P.M. Rice,* IBM Almaden Research Center*; B.D. Terris,* IBM Almaden Research center*; D. Weller,* IBM Almaden Research Center

Commercial batch-fabricated coated MFM tips have been modified to allow high resolution imaging of the in-plane components of stray field above a sample. A hole of diameter ~ 20nm was milled through the magnetic coating layer to the underlying silicon at the apex of each tip with a focussed gallium ion beam. The tips were then magnetized in the direction parallel to the sample plane. The hole at the apex forms a small pole gap and it is the interaction of the stray field from this gap with the sample stray field which produces the MFM signal. Accordingly, the resolution achievable is determined by the diameter of the hole milled at the apex. Note that such a controlled modification of the magnetic tip coating was suggested by Hill.@footnote 1@ High and low density data tracks, with transition spacings ranging from 1 micrometer to 50 nanometers, written in longitudinal granular recording media have been used to demonstrate the utility of the tips. By comparison of experimental results with simple theoretical models it is shown that the tips are strongly sensitive to the in-plane components of stray field. Furthermore, the modified tips exhibit better resolution than the unmodified tips, as may be seen from a side-by-side comparison of data collected from high density written transitions. The modified tips offer an inexpensive route to high resolution imaging of stray fields associated with in-plane domain structures. Hence they are of particular value for high density magnetic recording media investigations since the in-plane component of stray field is closely related to the signal detected by the recording head. @FootnoteText@ @footnote 1@ E. W. Hill, IEEE Trans. Magn. 31, 3355 (1995).

2:40pm **MI+NS-ThA3 Progress Toward Achieving Single-Spin Force Detection***, **B.C. Stipe**, D. Rugar, H.J. Mamin, C.S. Yannoni,* IBM Almaden Research Center*; T.D. Stowe, T.W. Kenny,* Stanford University

Magnetic resonance force microscopy was originally proposed@footnote 1@ as a method for imaging individual electron or nuclear spins. This talk will focus on recent progress toward achieving the necessary force sensitivity, tip field gradient, and spin lifetime to detect a single electron spin under real experimental conditions (i.e., with a sharp, submicron-size magnet mounted on an ultrasensitive cantilever within 100 Å of a sample surface). Characterization of the magnetic tip is especially important since the field gradient from the tip determines of the force from the spin. In addition, the spin relaxation rate can increase in the presence of magnetic field fluctuations from the tip. We have characterized the magnetic fluctuations of the tip at the cantilever frequency based on field dependent dissipation measurements on both Co thin film and NdFeB particle tips. NdFeB tips showed greatly reduced dissipation/fluctuations due, in part, to their high crystalline anisotropy. These tips should generate field gradients greater than 3 G/Å at the target spin, resulting in a force of more than 30 aN. Using custom fabricated single crystal silicon cantilevers at 2.5 K, we have achieved a force resolution of 2.8 aNHz@super -1/2@ far from the sample surface. However, within 500 Å of the sample, tip-surface interactions can significantly increase the force noise and cantilever frequency jitter. The origin of these effects and methods for reducing them will be discussed. This work is supported, in part, by the Office of Naval Research. @FootnoteText@ @footnote 1@ J.A. Sidles, Phys. Rev. Lett. 68, 1124 (1992).

3:00pm **MI+NS-ThA4 Magnetic Imaging by Spin-polarized Scanning Tunneling Microscopy***, **W. Wulfhekel**, J. Kirschner,* MPI fur Mikrostrukturphysik Halle, Germany

A new approach to spin-polarized scanning tunneling microscopy based on the magneto tunnel effect between a ferromagnetic tip and a ferromagnetic sample is demonstrated. By periodically changing the magnetization of the tip in combination with a lock-in technique, topographic and spin-dependent parts of the tunnel current are separated. This allows to simultaneously record the topography and the magnetic structure of the sample. First results are given for polycrystalline Ni and single crystalline Co(0001) surfaces, revealing a high spin contrast of up to 20% of the tunneling current, low data acquisition times of few ms/pixel and a resolution down to 10nm. The magnetic origin of the observed signal is proven rigorously by recording the domain wall motion due to an applied magnetic field during scanning. Potentials and limitations of this new technique are discussed.

3:20pm **MI+NS-ThA5 Spin-Polarized Scanning Tunneling Spectroscopy: Magnetic Domain Imaging and Beyond***, **R. Wiesendanger**, M. Bode, M. Getzlaff,* University of Hamburg, Germany **INVITED**

Spin-polarized vacuum tunneling from ferromagnetic thin film probe tips into exchange-split surface states of rare-earth thin films is demonstrated and applied to magnetic domain imaging with a spatial resolution below 20 nm. The bias dependence of the spin polarization extracted from tunneling spectroscopy data is found to be in surprisingly good agreement with results from spin-resolved (inverse) photoemission indicating that spin-dependent density-of-states effects dominate over matrix element effects. It is also shown that spin-polarized electronic states can yield high tunneling magnetoresistance. On the other hand, surface contamination leads to a strong decrease of the measured spin-polarisation by impurity-assisted scattering which influences strongly the vacuum-TMR effect as well as the contrast in spatially resolved magnetic imaging applications.

4:00pm **MI+NS-ThA7 Scanning-aperture Photo-emission Microscope for Magnetic Imaging***, **G.M. McClelland**, C.T. Rettner,* IBM Almaden Research Center

We have demonstrated a new technique for magnetic imaging that is ultimately capable of spatial resolution better than 5 nm. In our instrument, photoemission is excited by a laser focused to a 10-micron spot. A scanning aperture above the magnetic surface allows only electrons from a small selected region to reach the electron detector. The magnetization in this region is determined from the dependence of photoemission on the circular polarization of the laser. Images of 10-nm-thick Co-Pt multilayer thin films on sapphire have been obtained. From a cesiated film, a high quantum efficiency of 0.002 was observed from 458 nm laser light. Circular dichroism of +/- 2 % is recorded by alternating the circular polarization of the light while scanning. The tip distance above the surface is maintained by advancing the tip until 1-nA tunneling to a positive sample is observed, then withdrawing 15 nm and switching polarity to detect photoemission through the tip. The resolution we observe agrees well with the 35-nm-sized aperture in the gold tip. From the observed noise, we project that there is enough signal to image at 5 nm resolution if a small enough aperture can be fabricated. Recent calculations show that image forces on the electron from the aperture walls act to make the effective aperture even smaller than the physical diameter. The insensitivity of the instrument to varying magnetic fields should make it ideal for time dependent magnetization measurements in an applied field.

4:20pm **MI+NS-ThA8 Magnetic and Chemical Microanalysis Using SEMPA and SAM**, ***G. Steierl***, *W. Lutzke, H.P. Oepen, J. Kirschner,* Max-Planck-Institut für Mikrostrukturphysik, Germany

Industrial demands led to an enormous interest in micromagnetic analysis tools that can be applied to a wide range of samples including lithographically produced samples with complex chemical compositions. To meet these requirements a new instrument was designed that combines Scanning Auger Microscopy (SAM) and Scanning Electron Microscopy with Polarization Analysis (SEMPA). The core elements are a Schottky thermal field emitter electron gun with coaxial cylindrical mirror analyzer (PHI-SAN 670), a retractable electron-lens system and a spin detector based on Spin Polarized Low Energy Electron Diffraction (SPLEED). The characteristics of these core elements are described and the performance of the entire system is demonstrated by high-resolution chemical and magnetic analysis of Ni@sub 80@Fe@sub 20@- and Co elements. The microstructures of 50nm thickness were produced by using electron beam lithography and lift-off. Oxidized Si(111)-wafers were used as substrate material with an oxide layer thickness ranging from about 10nm (natural oxide layer) to 1200nm (thermally oxidized). It is demonstrated that the electrical insulation of the microstructures due to the oxide-layer does not impede high resolution domain microscopy, if suitable surface preparation techniques are used. Several details of the domain patterns encountered in microstructures of different geometry (squares, rectangles, disks) and of lateral length ranging from 500nm to 10 µm are reported.

4:40pm **MI+NS-ThA9 Low Temperature Magnetic Domain Imaging with Spin Polarized Low Energy Electron Microscopy**, ***E.D. Tober,*** NCEM, Lawrence Berkeley National Laboratory; *G. Witte,* Ruhr-Universität Bochum, Germany; *H. Poppa,* NCEM, Lawrence Berkeley National Laboratory

Spin Polarized Low Energy Microscopy (SPLEEM) has for the first time been employed to examine magnetic surfaces below room temperature. With the recent addition of a liquid nitrogen based cooling stage for our instrument, we have the ability to achieve sample temperatures in the range of 110 - 2200 K. SPLEEM has the advantages of high spatial resolution (~10.0 nm) and atomic height resolution combined with image acquisition at near video rates. A full description of the system design as well as its application in exploring the magnetic domain formation in thin films of Co grown in situ on Pt(111) and Au(111) surfaces will be presented.

5:00pm **MI+NS-ThA10 Ballistic Electron Magnetic Microscopy: Imaging Magnetic Domains with Nanometer Resolution**, ***W.H. Rippard***[1], *R.A. Buhrman,* Cornell University

A new magnetic imaging technique with nanometer resolution, ballistic electron magnetic microscopy (BEMM), is introduced and used to image magnetic structure in copper-cobalt multilayer films. Magnetic domains are clearly observed and are found to give more than 300% contrast in the resulting BEMM images. Domain wall motion is also studied as a function of applied magnetic field. Magnetic contrast is observed on length scales of less than 100 nm and fluctuations of the ballistic transport in the system are observed on scales of less than 10 nm. The magnetic contrast is found to be strongly dependent on magnetic layer thickness while only weakly dependent on the number of layers in the multilayer stack. An energy dependent difference in the electron transport as a function of the relative alignment between the magnetic layers is also reported, revealing the effects of the Co band structure on the ballistic current transport. Strong magnetic contrast is observed at energies as high as 4 eV, demonstrating a large asymmetry in the effective spin-dependent mean free paths in this system. The local nature of the technique also allows the direct imaging of the effects of interfacial dopants on the ballistic transport in the multilayer films. Results from such dusting studies are also presented.

[1] **Falicov Student Award Finalist**

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