Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+NS-ThA

Magnetic Imaging
Moderator: G.D. Waddill, University of Missouri-Rolla

2:00pm **MI+NS-ThA1 Atomic-scale Surface Magnetic Structures of Mn_3N_2 Observed by Spin-polarized Scanning Tunneling Microscopy**, ***H. Yang***, *A. Smith*, Ohio University

The development of spin-polarized scanning tunneling microscopy (SP-STM) has made possible the imaging of surface magnetic structures in real space down to the atomic scale.[1] In this talk, we will discuss the magnetic structure of Mn_3N_2 (010) surface investigated using SP-STM with antiferromagnetic (AFM)-coated tungsten (W) tips. The Mn_3N_2 film was grown by molecular beam epitaxy. The surface structure of the film was studied in-situ. Normal STM images of Mn_3N_2 (010) obtained using W tips reveal row structures, corresponding to Mn atoms at the intersection of surface and N vacancy planes which occur every third atomic layer.[2] By using AFM-coated W tips, we observed a modulation in the height of the rows, which is attributed to the spin-polarized effect in which the tunneling current has a component which depends on the angle between the surface and tip magnetic moments. The row modulation implies that the Mn moments are ferromagnetic within a row but AFM from row to row. We show, using a new method, that it is possible to extract the magnetic component, which is proportional to the integrated local magnetization density of states.[3] The extracted magnetic component is compared with various surface spin models, which will be discussed. This work is supported by NSF under Grant No.9983816.

[1] S. Heinze, M. Bode, A. Kubetzka, O. Pietzsch, X. Nie, S. Blugel, and R. Wiesendanger, Science, 288, 1805 (2000).
[2] H. Yang, Hamad Al-Brithen, Arthur R. Smith, J. A. Borchers, R. L. Cappelletti, and M. D. Vaudin, Appl. Phys. Lett., 78, 3860 (2001).
[3] D. Wortmann, S. Heinze, Ph. Kurz, G. Bihlmayer, and S. Blugel. Phys. Rev. Lett., 86, 4132 (2001).

2:20pm **MI+NS-ThA2 Spin-Orbit Effects on Fe/W(110) Revealed by Scanning Tunneling Spectroscopy**, ***M. Bode***, University of Hamburg, Germany, *S. Heinze,* IBM Research Division, *A. Kubetzka, O. Pietzsch,* University of Hamburg, Germany, *X. Nie, G. Bihlmayer*, Forschungszentrum Jülich, Germany, *S. Blügel*, Universität Osnabrück, Germany, *R. Wiesendanger*, University of Hamburg, Germany

We have studied the dependence of the spin-averaged tunneling current on the direction of the magnetization experimentally on the well-defined model system Fe/W(110) with its well-known magnetic structure at the nanometer scale.[1,2] We found by scanning tunneling spectroscopy (STS) and first-principles calculations that the surface electronic structure of an Fe double layer on W(110) depends on the orientation of the magnetization. From a detailed analysis of the electronic structure we deduce how the signature of the magnetization direction is imprinted via the spin-orbit interaction. Our analysis reveals that it is not the splitting of bands but changes of the orbital character of certain bands which affects the tunneling current. As an important implication of this effect the magnetic nanostructure of surfaces can be investigated with a conventional nonmagnetic tip, similar to an earlier proposal by Bruno et al.[3] The underlying physics of the spin-orbit dependent differential conductivity can be considered as the static limit of the magnetic linear x-ray dichroism or the ballistic or tunneling analogon of the anisotropic magnetic resistance of ferromagnets.

[1] O. Pietzsch et al., Phys. Rev. Lett. 84, 5212 (2000).
[2] M. Bode et al., Phys. Rev. Lett. 86, 2142 (2001).
[3] P. Bruno, Phys. Rev. Lett. 79, 4593 (1997).

2:40pm **MI+NS-ThA3 Magnetic Imaging and Spectroscopy of $Fe_xNi_{(1-x)}$ Thin Films on Cu(111)**, ***Y. Sato***, *T.F. Johnson, S. Chiang,* University of California, Davis, *M. Hochstrasser, J.G. Tobin,* Lawrence Livermore National Laboratory, *A. Scholl,* Lawrence Berkeley National Laboratory, *J.A. Giacomo, D.B. Hoffman*, University of California, Davis

We are studying the system of FeNi/Cu(111) to understand the surface/interface magnetism relevant to the application of the giant magnetoresistive effect to magnetic recording heads. We have used X-ray Magnetic Linear Dichroism (XMLD) and Photoemission Electron Microscopy (PEEM) at the Advanced Light Source, and Low Energy Electron Microscopy (LEEM). Using XMLD, the dichroism signals from both the Fe and Ni peaks were measured, and the asymmetries were calculated. Both the Fe and Ni asymmetries as a function of temperature have been fit to the theoretical curve to extract the critical exponent β. Preliminary analysis indicates that for thicker films, the values are consistent with 3D mean-field magnetic models. As a function of Fe concentration x, the total weighted asymmetry, $A_T = xA_{Fe}+(1-x)A_{Ni}$, where A_{Fe} and A_{Ni} are the respective elemental asymmetries, shows a monotonic increase from 2% to a maximum of 8.5% for x~65%, near the bulk Invar concentration. For higher x, the asymmetry is quenched, indicating a magnetic transition taking place in the film system. This magnetic instability for high x agrees with the trends in Curie temperature as a function of x, as measured from XMLD spectra, PEEM data, and previous work on FeNi/Cu(100).[1] The PEEM images show a change in the domain structure of the films for x~42-55%. The domain structures are defined well by 180° domain walls, and their size is much bigger than for other concentrations. The magnetization appears to align along one of the crystal axes. Low Energy Electron Microscopy images of the growth of the films will also be shown.

[1] F.O.Schumann, S.Z.Wu, G.J.Mankey, R.F.Willis Phys.Rev.B 56, 2668 (1997).

3:00pm **MI+NS-ThA4 Falicov Award Presentation**

3:20pm **MI+NS-ThA5 Magnetic Resonance Force Microscopy at Millikelvin Temperatures**, ***H.J. Mamin***, *R. Budakian, D. Rugar*, IBM Almaden Research Center **INVITED**

Magnetic resonance force microscopy (MRFM) offers the promise of combining the spectral resolving power and three-dimensional imaging capabilities of magnetic resonance with the high resolution of scanning probe techniques. The greatest payoffs are expected once it is possible to detect and manipulate individual spins. There is now evidence that one of the greatest obstacles to reaching this goal is that of thermally-driven fluctuations in the magnetic tip, which interfere with the quantum state of the spins. For this reason, we have begun an effort to perform MRFM at millikelvin temperatures in a dilution refrigerator. Some essential technical improvements have been incorporated, included detection of the cantilever displacement with ultralow optical powers, and ultra-efficient generation of microwave fields using a superconducting resonator. Using this newly developed apparatus, we have successfully demonstrated MRFM on an ensemble of electron spins at millikelvin temperatures. We are investigating various nonequilibirum effects, including spin relaxation times, which will have important implications for the feasibility of single spin detection.

4:00pm **MI+NS-ThA7 Magnetic Force Microscopy Study of Various Lithography Patterned Magnet Arrays**, ***X. Zhu***, *P. Grutter,* McGill University, Canada, *V. Metlushko,* University of Illinois at Chicago, *B. Ilic*, Cornell University, *Y. Hao, F. Castano, S. Haratani, C.A. Ross, B. Vogeli, H.I. Smith*, Massachusetts Institute of Technology

Magnetic force microscopy (MFM) with in-situ magnetic field has been used to study lithography pattered magnet arrays: elongated elements, rings, disks, empty squares and sub 100 nm pseudo spin valve structures (PSV) (NiFe/Cu/Co). Great care has been taken to reduce the MFM tip stray field induced irreversible distortion by choosing a constant height mode, using small magnetic moment tips, operating in vacuum, and using a digital PLL.[1]This allows us to study the details of magnetic structures. For example, the nature of the head-to-head domain wall in a permalloy ring can be revealed, and the vortex structure with a core singularity in a permalloy disk can be found by high resolution imaging. In the PSV structures, the parallel and two different antiparallel configurations for both magnetic layers (NiFe and Co) in an element can be distinguishable. A local hysteresis loop technique has been developed to study the switching behavior of individual elements.[2] In a permalloy disk, the abrupt switching due to a nucleation or annihilation process has been revealed by monitoring cantilever frequency shift at a fixed location above the disk while sweeping the external magnetic field. In a PSV structure, the abrupt switching for both individual layers is clearly distinguishable. The hysteresis loop of patterned arrays can be obtained by MFM in the presence of an external magnetic field. The anisotropy induced by interdot coupling can be found in a closely packed square lattice disk array which shows a much smaller nucleation field along the (100) direction than the (110) direction. In the PSV structures, the layer coupling and the broad switching field distribution have been investigated through major and minor hysteresis loop obtained by MFM.

[1] X. Zhu, et al., J. Appl. Phys., May (2002).
[2] X. Zhu, et al., to be published in Appl. Phys. Lett.

4:20pm **MI+NS-ThA8 Magnetic Dipoles in Patterned Magnetic Metal Dot Arrays**, ***T.-H. Kim***, *J.H. Choi, Y. Kuk*, Seoul National University, South Korea

Magnetic dipole arrangement was studied with scanning tunneling microscope and magnetic force microscope (MFM) in patterned magnetic metal dot arrays. Magnetic dot arrays on silicon substrate were made by following procedures: (1) electron beam lithography, (2) shadow mask deposition, (3) electro-chemical anodizing of aluminum layer and successive deposition of magnetic metals. MFM image reveals individual magnetic dipole with small dot-dot interaction. The correlation between the shape anisotropy with the direction of magnetization will be discussed.

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