Tuesday Afternoon, October 21, 2008

Magnetic Interfaces and Nanostructures
Room: 206 - Session MI+NC-TuA

Magnetic Microscopy and Magnetization Dynamics
Moderator: A.T. Hanbicki, Naval Research Laboratory

1:40pm **MI+NC-TuA1 Probing Individual Magnetic Nanostructures with Spin Excitation Spectroscopy**, ***A. Heinrich***, IBM Research Division **INVITED**

Understanding and controlling the magnetic properties of nanoscale systems is crucial for the implementation of future data storage and computation paradigms. Here we show how the magnetic properties of individual atoms can be probed with a low-temperature, high-field scanning tunneling microscope when the atom is placed on a thin insulator. We find clear evidence of magnetic anisotropy in the spin excitation spectra of individual magnetic atoms embedded in a non-magnetic surface. In extended one-dimensional spin chains, which we build one atom at a time, we find strong spin-coupling into collective quantum-spins, even for the longest chains of length 3.5nm. The spectroscopic results can be understood with the model of spin-excitations in a system with antiferromagnetic coupling, controlled on the atomic scale. High-spin atoms can show an interesting form of the Kondo effect when the magnetic anisotropy places a degenerate, low-spin Kramers-doublet in the ground-state.

2:20pm **MI+NC-TuA3 Magnetic Exchange Force Microscopy with Atomic Resolution**, ***U. Kaiser***, *A. Schwarz, R. Wiesendanger*, University of Hamburg, Germany

Magnetic Exchange Force Microscopy (MExFM) is a novel technique that allows magnetic imaging of surfaces with atomic resolution. The set-up of this microscope resembles that of a conventional atomic force microscope, but a magnetic probe tip is used to study short-ranged magnetic exchange forces between the foremost tip atom and the underlying sample atoms. Since MExFM is sensitive to the forces between tip and sample, it is not limited to well-conducting materials like spin polarized scanning tunneling microscopy (SP-STM).[1] In our study we investigated the (001) surface of the antiferromagnetic insulator NiO with an iron-coated tip.[2] The microscope was operated in ultrahigh vacuum at 8 K in an externally applied magnetic field with a flux density of 5 T. All measurements were performed in the non-contact attractive force regime between tip and sample using the frequency modulation technique. At small tip sample separations we imaged the surface oxygen and nickel atoms with an additional atomic scale modulation on neighboring rows of nickel atoms. This corresponds with the antiferromagnetic arrangement of the nickel atomic magnetic moments. Since all surface nickel atoms are structurally and chemically equivalent, we can unambiguously assign the observed contrast modulation to a magnetic exchange force between tip and sample. In this talk experimental prerequisites for this new method as well as the origin of the exchange interaction are discussed.

[1] M. Bode, Rep. Prog. Phys. 66, 523 (2003)
[2] U. Kaiser, A. Schwarz, and R. Wiesendanger, Nature 446, 522 (2007)

2:40pm **MI+NC-TuA4 Separation of Topographic Features from Magnetic Force Images using Capacitive Coupling Effect**, ***B.I. Kim***, Boise State University

Separation of topographic features from magnetic images has been an issue for the last 20 years in magnetic force microscopy (MFM). Although MFM is one of the most important imaging tools of nanoscale magnetic structures, this issue still remains largely unsolved and thus has limited the current capability of the MFM as a quantitative magnetic imaging tool. The frequent pickups of the topographic features are interpreted as transitions of the tip between bi-stable states of the tip-sample assembly in the noncontact and tapping regions in the conventional amplitude modulation MFM. The bi-stability originates from the long-range amplitude decrease due to the dc bias voltage for the uniform feedback polarity. As a method to make the amplitude increase in the noncontact region as the tip approaches the surface, an electrostatic force modulation method is introduced to utilize the capacitive coupling effect for magnetic imaging. MFM using electrostatic force modulation demonstrates the separation of the topographic features from the magnetic images with an enhanced stability. The stability is attributed to the different modulation method and servoing mechanism.

3:00pm **MI+NC-TuA5 Magnetic Reconstruction of Vortexes in Co Nanocrystals**, ***D.P. Pappas***, *L. Yuan, F.C.S. da Silva, A. Davydov*, National Institute of Standards and Technology

Co nanocrystals were prepared and MFM measurements revealed the dependence of the magnetization on the shapes of the nano-crystals. The nanodots were formed by depositing a 10 nm film of Co onto a c-axis oriented sapphire crystal, which was then annealed to 1000 C. Nanocrystals formed with average size of about 500 nm, with a variety of shapes. From the shapes, it is apparent that some random nucleation occured. The nanocrystals fall into two categories, hexagonal shaped and rectangular. The MFM images of the first type showed that the magnetization formed a central vortex core, with a magnetic reconstructions of either 3-fold or 6-fold symmetry around the core. The latter particles showed a maze-like magnetic configuration. These studies show that the strong uniaxial anisotropy persists in these particles, and the magnetic configuration is strongly dependent on the shape of the particles. Moreover, the circular dots have a strong tendency to form highly symmetric patterns.

4:00pm **MI+NC-TuA8 Complex Magnetic Order on the Atomic Scale Revealed by Spin-Polarized STM**, ***K. von Bergmann***, University of Hamburg, Germany **INVITED**

Magnetism in low-dimensions is a fascinating topic: Even in apparently simple systems -such as homoatomic monolayers- the nearest neighbor distance, the symmetry and the hybridization with the substrate can play a crucial role for the magnetic properties. This may lead to a variety of magnetic structures, from the ferromagnetic and antiferromagnetic state to much more complex spin structures. Spin-polarized scanning tunneling microscopy (SP-STM) combines magnetic sensitivity with high lateral resolution and therefore grants access to such complex magnetic order with unit cells on the nanometer scale. Different previously inconceivable magnetic structures are observed in pseudomorphic homoatomic 3d monolayers on late 5d transition metal substrates.[1,2] The broken inversion symmetry due to the presence of the surface can induce the formation of spin spirals, where the spin rotates from one atom to the next resulting in a nanometer sized magnetic period. The driving force for the canting of adjacent magnetic moments leading to such spirals is the Dzyaloshinskii-Moriya interaction and a unique rotational sense is found.

[1]K. von Bergmann et al., Phys. Rev. Lett. 96, 167203 (2006).
[2]M. Bode et al., Nature 447, 190 (2007).

4:40pm **MI+NC-TuA10 Magnetization Damping in Magnetic Multilayers**, ***T. Mewes***, The University of Alabama **INVITED**

For the application of magnetic multilayers in spintronic devices the magnetization relaxation is of great importance. Of particular practical interest are multilayers which include an exchange biased ferromagnet, i.e. a ferromagnet/antiferromagnet bilayer system for which the hysteresis loop of the ferromagnet can be shifted along the field axis. In comparison to bulk properties the magnetization relaxation in thin magnetic films can be enhanced for example by spin-pumping and two-magnon scattering due to local inhomogeneities. We investigated the magnetization relaxation in metallic ferromagnet/antiferromagnet based multilayer systems, using broadband ferromagnetic resonance measurements. By inserting a thin non-magnetic spacer layer, we find that spin-pumping contributes significantly to the damping in these multilayers, even for structures with no shift of the hysteresis loop. However, in exchange biased systems we observe a strong additional contribution to the magnetization relaxation.

5:20pm **MI+NC-TuA12 Perpendicular Anisotropy Graded CoPt/CoPtCr Magnetic Pillars Patterned by Nanosphere Lithography**, ***X. Li***, *Z.R. Tadisina, A.L. Highsmith, S. Gupta, Y. Inaba, J.W. Harrell*, The University of Alabama

Patterned magnetic nanostructures such as nanodots and nanopillars are now an extremely active area of research for applications for next generation media,[1] as well as novel logic and spintronic memory devices. Bit patterned media is one of the most promising candidates to overcome the tradeoff between thermal stability and recording writability. This work will detail the deposition of perpendicular magnetic anisotropic media, a unique patterning approach using nanosphere lithography, and magnetic characterization of the patterned nanostructures. Process optimization of perpendicular magnetron sputtered CoPt and CoPtCr films of various compositions was carried out using seed layers of Ta and Ru. The anisotropy K_u ranged from 2×10^7 erg/cm^3 to 2×10^6 erg/cm^3 as a function of film thickness and Cr concentration. Nanosphere lithography[2] was used to pattern the magnetic films into nanopillars with controlled size. A self-assembled nanosphere monolayer was first prepared, tailored to a discrete dot mask by shrinking the spheres using reactive ion etching, and then

transferred to hard masks and, finally, the magnetic media, by a combination of ion milling and reactive ion etching. Magnetic nanopillars with diameters ranging from 90 nm to those approaching 10 nm with correspondingly increasing pitch are obtained. The size dependence of the magnetization process, the thermal stability, and switching dynamics of the pillars are characterized in an alternating gradient magnetometer (AGM) and magneto-optic Kerr effect (MOKE) system by using angle-dependent and time-dependent remanent coercivity measurements fitted to Sharrock's equation over a wide range of timescales. A significant increase of thermal stability and coercivity was demonstrated with the decrease of pillar size. The reversal mechanism is similar to reported results of nucleation of a small reversed volume followed by rapid domain wall motion.[3]

[1] Robert F. Service, Science 314, 1868 (2006).
[2] C. L. Haynes and R. P. Van Duyne, J. Phys. Chem. B 105, 5599 (2001).
[3] T. Thomson, G. Hu, and B. D. Terris, Phys. Rev. Lett. 96, 257204 (2006).

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