Magnetic Interfaces and Nanostructures
Room 206 - Session MI+NS+NANO 6-TuA

Magnetic Imaging II

Moderator: F.J. Himpsel, University of Wisconsin, Madison

2:00pm **MI+NS+NANO 6-TuA1 Correlation of Ferromagnetic and Antiferromagnetic Spin Orientation Observed by Photoemission Electron Microscopy**, ***S. Anders***, *A. Scholl, F. Nolting, H.A. Padmore,* Lawrence Berkeley National Laboratory*; J. Stohr, J. Luening,* Stanford Synchrotron Radiation Laboratory*; J.W. Seo,* University of Neuchatel, Switzerland*; J. Fompeyrine, J.-P. Locquet,* IBM Research Division, Switzerland*; M. Scheinfein,* FEI Company **INVITED**

Photoelectron emission microscopy (PEEM) using polarized x rays is a unique tool for the study of ferromagnetic (FM) and antiferromagnetic (AFM) materials. FM materials are studied using x-ray magnetic circular dichroism (XMCD) and AFM materials using x-ray magnetic linear dichroism (XMLD). The elemental specificity of PEEM allows to study individual layers in multilayer structures, and to investigate the coupling between them. Increasingly complex layered structures containing magnetic and antiferromagnetic materials are used in modern magnetic devices, and knowledge of the magnetic properties of the layers and interfaces is essential for the understanding of the properties of these devices. Of particular interest is the effect of exchange biasing at the interface of an AFM and an FM. AFM materials have been difficult to study so far because of a lack of methods with sufficient spatial resolution and surface sensitivity. We have investigated the magnetic and topographic surface structure of several AFM materials, in particular thin singlecrystalline and polycrystalline NiO and LaFeO@sub 3@ films. We were able to resolve the antiferromagnetic surface structure of those materials, showing antiferromagnetic domains, and antiferromagnetic patterns, correlated to the surface topography. Local NEXAFS spectra yielded information about the antiferromagnetic orientation at the sample surface. The study of an FM Co thin film on top of an AFM LaFeO@sub 3@ film showed for the first time a direct correlation between AFM and FM domains.

2:40pm **MI+NS+NANO 6-TuA3 Magnetic Imaging of NiO/Ag(001) Thin Film using PhotoEmission Electron Microscope**, ***W. Zhu,*** University of Connecticut, US*; L. Seve, B. Sinkovic,* University of Connecticut*; A. Scholl, S. Anders,* Lawrence Berkeley National Laboratory

PhontoEmission Electron Microscope (PEEM) combined with linearly polarized synchrotron X-rays provides a powerful way of imaging magnetic domains in antiferromagentic thin films. We have performed magnetic imaging on antiferromagnetic thin film of NiO with PEEM. The 90-Å thick NiO film is of (001) orientation, epitaxially grown on a Ag (001) single crystal substrate. The magnetic contrast is found to be correlated with the topological contrast, which is caused by the local thickness variation in the film. Micro-X-ray absorption spectra (XAS) in areas of different contrast revealed that the directions of magnetic moments within these areas are differently oriented with respect to the X-ray polarization direction. The difference in Micro-XAS from these areas disappeared at temperature of ~350 °C (above the Neel temperature), where the antiferromagnetic order disappears. Experiments with the X-ray polarization direction parallel to [100] and [110] direction of the film give similar results, which indicates that the magnetic contrast is due to the in-plane vs. out-of-plane magnetic moments orientation rather than the differently oriented in-plane moments. These results are consistent with our recent spectroscopic studies of NiO/Ag(001) films of various thickness.

3:00pm **MI+NS+NANO 6-TuA4 Magnetic Imaging by Local Tunneling Magnetoresistance - A High Resolution Technique**, ***W. Wulfhekel,*** *H.F. Ding, J. Kirschner,* MPI Halle, Germany **INVITED**

We give an overview over our recent efforts of magnetic imaging using scanning tunneling microscopy with a ferromagnetic tip. Magnetic sensitivity is obtained on the basis of local tunneling magnetoresistance between a soft magnetic tip and the sample. The imaging capacities of the technique are illustrated with exemplary studies of the surface domain structure of different itinerant ferromagnets. On Co(0001) we find surprisingly narrow sections of the walls of only 1.1nm width, over an order of magnitude less than previously observed in Co. Recording quantitative profiles of the perpendicular component of the magnetization across the wall and comparing the experimental data with micromagnetic calculation, the narrow sections are identified as 20° domain walls. Besides magnetic imaging, we focus on the influence of the stray filed of the tip on the magnetic structures under investigation. In the limit of soft magnetic materials or strong stray fields, the wall mobility and magnetic susceptibility can be studied on the local scale. Finally, measurements of magnetoresistance versus tunneling voltage and tip sample distance give deeper insight into the mechanisms of spin polarized tunneling.

3:40pm **MI+NS+NANO 6-TuA6 Self-assembled Magnetic Nanowires Studied with Spin-polarized Scanning Tunneling Microscopy**, ***T.-H. Kim,*** *W.-G. Park, Y. Obukhov, Y. Kuk,* Seoul National University, Korea

In thin film of immiscible Co and Ag alloys, nanowires have been observed. The alternating stripes, magnetic Co stripes and non-magnetic Ag stripes, are formed on W(110) substrate by the driving force of the phase separation. The film can be grown sequentially, or deposited simultaneously. The periods of the stripes are found to be 20 to 30 Å, perpendicular to the long axis of the stripes. The relations between the morphology and the magnetic contrast of the self-assembled magnetic nanowires have been studied with spin-polarized scanning tunneling microscopy. Using an electromagnet for tip magnetization, the magnetic field can be applied to the soft magnetic tip both parallel and perpendicular to the axis of the tip. With this setup, we are able to image the direction of the magnetization of the sample.

4:00pm **MI+NS+NANO 6-TuA7 Direct Visualization of Magnetic Nanowires by Spin-Polarized Scanning Tunneling Spectroscopy**, ***O. Pietzsch,*** *A. Kubetzka, M. Bode, R. Wiesendanger,* University of Hamburg, Germany

While scanning tunneling microscopy (STM) and spectroscopy (STS) are the established methods of choice for the study of structural and electronic surface properties at ultimate real space resolution, no equivalent technique for magnetic imaging was available so far. The most widely applied surface sensitive methods as, e. g., magneto-optical Kerr effect (MOKE), average over comparably large sample fractions. Here we present a recent spin-polarized STS study, carried out with an STM especially designed for magnetic imaging.@footnote 1@ We will show high resolution images of a self-organized array of Fe nanowires grown on a stepped W(110) single crystal.@footnote 2@ The magnetic wires have a periodicity of 8 nm, an average width of 4 nm, and a thickness of two atomic layers. Making use of ferromagnetically coated STM tips with the appropriate anisotropy we were able to image the magnetic domain structure in detail. The magnetism of the stripe system is governed by perpendicular anisotropy.@footnote 3@ Adjacent stripes exhibit antiferromagnetic coupling mediated by the stray field. Our images allow the investigation of the influence of local structural defects as, e. g., non-uniform stripe width or dislocation lines, on the magnetic properties on a sub-nanometer scale. The width and orientation of domain walls within single stripes is determined. We will show how the domain structure is affected by applied external fields of up to 0.5 Tesla. The contrast mechanism will be explained. The imaging method is of general applicability for the study of the surfaces of magnetic nanostructures. @FootnoteText@ @footnote 1@ O. Pietzsch et al., Rev. Sci. Instrum. 71, 424 (2000) @footnote 2@ O. Pietzsch, A. Kubetzka, M. Bode, and R. Wiesendanger, Phys. Rev. Lett. , in press. @footnote 3@ J. Hauschild, U. Gradmann, and H. J. Elmers, Appl. Phys. Lett. 72, 3211 (1998).

4:20pm **MI+NS+NANO 6-TuA8 Real-Space Imaging of Two-Dimensional Antiferromagnetism on the Atomic Scale**, ***M. Bode,*** University of Hamburg, Germany*; S. Heinze,* Forschungszentrum Jülich, Germany*; A. Kubetzka, O. Pietzsch,* University of Hamburg, Germany*; X. Nie, S. Blügel,* Forschungszentrum Jülich, Germany*; R. Wiesendanger,* University of Hamburg, Germany

The ultimate limit of two-dimensional antiferromagnetism (2D-AFM) is a magnetic monolayer of chemically equivalent atoms, where adjacent atoms at nearest-neighbor sites have magnetic moments with opposite directions, deposited on a non-magnetic substrate.@footnote 1@ Since the total magnetization of this film is zero spatially averaging techniques like spin-polarized photoelectron spectroscopy cannot be used for an experimental verification of (2D-AFM). We have resolved the two-dimensional antiferromagnetic structure within a pseudomorphic monolayer film of chemically identical manganese atoms on tungsten (110) by spin-polarized scanning tunneling microscopy (SP-STM) at 16 Kelvin.@footnote 2@ While images of the chemical surface unit-cell without any magnetic contribution were obtained using a non-magnetic W-tip, spin-polarized electrons from magnetically coated tips probe the change in translational symmetry due to the magnetic c(2x2)-superstructure of Mn/W(110). Based on fundamental theoretical arguments it will be shown that SP-STM is a powerful technique for the investigation of complicated surface magnetic configurations.

@FootnoteText@ @footnote 1@ S. Blügel, M. Weinert, and P.H. Dederichs, Phys. Rev. Lett. 60, 1077 (1988). @footnote 2@ O. Pietzsch et al., Rev. Sci. Instr. 71, 424 (2000).

4:40pm **MI+NS+NANO 6-TuA9 Ballistic Electron Magnetic Microscopy Studies of Ferromagnetic Films and Tunnel Junctions***, W.H. Rippard, A.C. Perrella, R.A. Buhrman,* Cornell University **INVITED**

A new magnetic imaging technique, ballistic electron magnetic microscopy (BEMM), has been developed to study the magnetic structure in ferromagnetic multilayer films and nanostructures as a function of magnetic field H. In BEMM we exploit the hot electron transport properties of the ferromagnetic films in order to probe their magnetic structure. This technique allows not only the magnetic imaging in applied fields with nm-scale spatial resolution, but also allows the direct investigation of spin dependent transport through the ferromagnetic multilayers. As we are not using a magnetic probe to image these films, we are able to investigate very thin and soft magnetic structures which are the most relevant to technological applications. The magnetization reversal process of both continuous and patterned ferromagnetic films have been investigated. Using a UHV compatible stencil-mask technique, sub-micron structures have been fabricated and imaged with BEMM. In particular, I will discuss the switching behavior of permalloy 'diamonds' and 'rectangles' (1.5 x 0.3 microns2), as well as other shapes of smaller dimension. Using this technique the nanometer scale imaging of tunnel junctions can also be performed. Ballistic current transport through magnetic tunnel junctions will be presented, both in terms of the imaging of 'pin holes' in the junctions and spin-dependent transport through the barrier. The energy dependence of the transport in the ferromagnetic multilayer structures as well as in the tunnel junction systems will also be presented.

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