Thursday Morning, November 7, 2002

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+SS-ThM

Magnetic Spectroscopies
Moderator: D.A. Hite, NIST

8:20am **MI+SS-ThM1 Photoemission and X-Ray Absorption Measurements on the CMR Materials $La_{1-x}Ca_xMnO_3$ and $La_{1-x}Sr_xMnO_3$**, ***N. Mannella***, University of California at Davis, *A. Rosenhahn*, Lawrence Berkeley National Laborarory, *S. Mun*, Intel Corporation, *S.-H. Yang*, IBM Almaden Research Center, *Y. Tomioka*, *Y. Tokura*, Joint Research Center for Atom Technology, Japan, *C.S. Fadley*, Lawrence Berkeley National Laboratory

We report core and valence photoemission results obtained with synchrotron radiation for a set of high quality single-crystal CMR samples, namely $La_{1-x}Ca_xMnO_3$ and $La_{1-x}Sr_xMnO_3$ with x ranging from 0 to 0.4. The measurements were performed after cleaving the crystals in situ in UHV, yielding very clean and stoichiometric surfaces. X-ray absorption spectroscopy (XAS) and high-resolution valence band measurements at temperatures above and below the Curie temperature will also be discussed. The Mn 3s core level spectra show the expected multiplet splitting in binding energy, an effect which can sensitively probe the spin state of magnetic atoms. Our data reveal a non-linear dependence of the multiplet splitting on the hole concentration x, contrary to what one would expect in the simplest picture according to which hole doping causes a corresponding number of Mn^{3+} ions to become Mn^{4+}. These results may indicate an inadequacy of the conventional model based on the nominal Mn^{3+} - Mn^{4+} valence states. We have also measured Mn 3s spectra as a function of temperature. Our data suggest a short-range-order magnetic transition above the bulk Curie temperature, yielding a quantitative estimate of temperatures higher than T_C at which the material shows magnetic order of local character. This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences Division, under Contract No. DE-AC03-76SF00098.

8:40am **MI+SS-ThM2 MOKE Studies of Magnetic Coupling in $Co/Cr_2O_3/CrO_2$**, ***R. Cheng***, *A.N. Caruso*, *L. Yuan*, *S.-H. Liou*, *P.A. Dowben*, University of Nebraska-Lincoln

CrO_2 is an attractive material for spin-polarized electron tunneling because of the high electron polarization and is among the predicted half metallic ferromagnets (metallic for one spin direction while insulating for the other spin direction, i.e. 100% spin polarization). Because the native surface layer of CrO_2 is Cr_2O_3, by evaporating Co thin films (5~20 nm) on top of epitaxial CrO_2 films on TiO_2 (100) substrates, a $Co/Cr_2O_3/CrO_2$ trilayer can be readily fabricated. >From in situ MOKE studies and ex situ SQUID measurements for the magnetic $Co/Cr_2O_3/CrO_2$ trilayers, the characteristic behavior of ferromagnetic-paramagnetic-ferromagnetic coupling above room temperature was observed. The thickness of Co and the temperature dependence of the magnetic hysteresis loops, obtained from MOKE, indicate different shapes, and the coercive fields show strong but not monotonic temperature dependence. These results indicate that there are changes in magnetic coupling and magnetization orientation particularly apparent as the temperature approaches the T_c of CrO_2.

9:00am **MI+SS-ThM3 Polarized X-Rays and Magnetic Interfaces**, ***H. Ohldag***, Stanford Synchrotron Radiation Laboratory, *A. Scholl*, *E. Arenholz*, Advanced Light Source, *F. Nolting*, Swiss Light Source, *Y. Acremann*, *J. Stohr*, Stanford Synchrotron Radiation Laboratory, *F.U. Hillebrecht*, Forschungszentrum Karlsruhe, Germany, *S. Maat*, *M.J. Carey*, IBM Almaden Research Center **INVITED**

While interfaces are supposed to dominate the behavior of magnetic multilayer their identification and characterization remains an experimental challenge. A prominent example is the loop shift (exchange bias) and the coercivity increase found if a ferromagnet (FM) is coupled to an antiferromagnet (AFM). Although exchange bias was discovered over 40 years ago our understanding of its origin is still poor. We use dichroism x-ray absorption spectromicroscopy in a photoemission electron microscope to study the magnetic coupling between AFM NiO(001) and FM Co. We observe large (1-20mm) AFM domains at the surface of bare NiO(001) single crystals. Upon in situ deposition of thin FM Co layers (1.5nm) a reorientation of the AFM axes takes place. The uniaxial anisotropy axes of the FM and the AFM are then aligned parallel domain by domain. Spectroscopy data show that the Co deposition causes a chemical reaction and formation of an interfacial CoNiOx layer. Microscopy images reveal its polarization to be aligned parallel to the Co layer. Upon annealing both, the uniaxial anisotropy and the amount of interfacial spins increases indicating the direct link between interfacial polarization and parallel exchange coupling. A small fraction of interfacial spins does not follow the external field. These so called pinned moments lead to an additional vertical shift in the hysteresis loop of the interfacial spins. The number of pinned spins can be diretly correlated to the size of the exchange bias field. Our findings clearly show that a proper description of magnetic coupling in Co/NiO as well as in other AFM/FM systems needs to consider the properties of a distinct interfacial layer that can deviate significantly from the bulk properties of each material.

[1]H. Ohldag, A. Scholl et al., PRL 86(13), pp. 2878, 2001.
[2]F. U. Hillebrecht, H. Ohldag et al., PRL 86(15), pp. 3419, 2001.
[3]H. Ohldag, A. Scholl et al., PRL 87 art. no 247201, 2001.

9:40am **MI+SS-ThM5 A Compact Angle Resolving Spin-Polarized Photoemission Spectrometer for "Double Polarization" X-ray Diffraction Spectroscopy of Magnetic Nanostructures**, ***S.A. Morton***, University of Missouri-Rolla, *J.G. Tobin*, Lawrence Livermore National Laboratory, *G.D. Waddill*, University of Missouri-Rolla

Recent studies of spin dependent x-ray photoelectron diffraction from magnetic nanostructures excited with circularly polarized photons have demonstrated that the technique can provide a powerful probe of element specific atomic scale magnetic structure; however, the asymmetries involved are low, typically 1-2%. Calculations suggest that combining excitation via circularly polarized photons with spin polarized photoelectron detection in a "double polarization" experiment should lead to a 5-10 fold increase in asymmetry. However combining high angular resolution XPD with spin resolving capability poses significant experimental challenges. The authors describe a unique new compact angle resolving spin spectrometer currently being developed at the Advanced Light Source, Lawrence Berkeley National Laboratory. This combines a large (11 inch) diameter fixed hemispherical analyzer with a novel rotatable input lens system allowing data with +-1 degree angular resolution to be acquired for any combination of incident and emission angles, including normal incidence/ normal emission: a geometry critical for certain magnetic measurements. The analyzer is equipped with both multichannel detection for spin integrated spectroscopies, such as magnetic linear or circular dichroism, and a Mott detector capable of resolving the photoelectron spin polarization along the two perpendicular axis of the rotational plane. Rapid switching between spin integrated and spin resolved modes is achieved by focusing the photoelectrons through a small hole in the detector of the hemispherical analyzer and into the compact mini-Mott detector situated immediately behind the channelplates. The spectrometer system also incorporates additional sample growth and characterization facilities such as co-evaporation from multiple deposition sources, LEED and Auger together with sample heating and cooling to provide a comprehensive system for the preparation and analysis of magnetic nanostructures.

10:00am **MI+SS-ThM6 In-plane Vector Magnetometry on Rectangular Co Dots using Polarized Neutron Reflectivity**, ***K. Temst***, *M.J. Van Bael*, *J. Swerts*, *D. Buntinx*, *C. Van Haesendonck*, *Y. Bruynseraede*, K.U. Leuven, Belgium, *H. Fritzsche*, Hahn-Meitner-Institut Berlin, Germany, *R. Jonckheere*, IMEC vzw, Belgium

We have measured the off-specular polarized neutron reflectivity of a periodic array of rectangular magnetic polycrystalline Co-dots, which were prepared by a combination of electron beam lithography and molecular beam deposition. The dots have a strong shape anisotropy, imposed by a length-to-width ratio of 4:1. The intensity of the off-specular satellite reflection was monitored as function of the magnetic field parallel to the rows of dots and in the plane of the film, allowing us to analyze the magnetization reversal process using the four spin-polarized cross-sections. Analysis of the neutron reflectivity provides in-plane vector magnetometry during magnetization reversal. The neutron reflectivity data are complemented by micromagnetic simulations.

10:20am **MI+SS-ThM7 Magnetism of Adatoms and Clusters**, ***P. Gambardella***, Ecole Polytechnique Fédérale de Lausanne, Switzerland **INVITED**

In the last ten years, x-ray magnetic circular dichroism (XMCD) has found widespread application as an element-specific magnetometry tool in the study of magnetic thin films. Here we show that x-ray absorption spectroscopy (XAS) and XMCD can be successfully employed to probe diluted transition-metal systems with surface impurity concentration as low as 3×10^{12} atoms cm^{-2}, thus leading to the direct characterization of the electronic and magnetic configuration of impurity systems as well as supported nanostructures. Combined XAS-XMCD provide simultaneous

information about the the d-valence state and related spin and orbital moment of transition-metal atoms that is not accessible by traditional techniques such as, e.g., magnetic susceptibility, resistivity, and electron paramagnetic resonance measurements. A first fundamental issue is how the magnetic moment of surface adatoms depends on the interaction with the host conduction electrons. We show that Fe, Co, and Ni, owing to d-electron localization, display large spin and orbital moments on low electron density simple-metal substrates which are progressively quenched as the surface electron densitiy increases.[1] A second fundamental issue is how the interaction with the substrate and adjacent adatoms influnces the magnetic anisotropy of the system. We report giant magnetic anisotropy values up to 3.3 meV/atom for Co clusters and atomic wires on Pt surfaces. A clear correlation is established between the atomic coordination, the magnitude of the orbital moment and the anisotropy energy, with implications for magnetic ordering phenomena.[2]

[1] P. Gambardella et al., Phys. Rev. Lett. 88, 047202 (2002).
[2] P. Gambardella et al., Nature 416, 301 (2002).

11:00am **MI+SS-ThM9 Probing Buried Interfaces with Soft X-ray Standing Wave Spectroscopy: Application to the Fe/Cr Interface**, ***S.-H. Yang***, *B.S. Mun*, Lawrence Berkeley National Laboratory, *N. Mannella*, University of California, Davis, *S.K. Kim, J.B. Kortright, J. Underwood, F. Salmassi, E. Arenholz, A. Young, Z. Hussain, M.A. van Hove*, Lawrence Berkeley National Laboratory, *C.S. Fadley*, University of California, Davis

We will discuss a novel type of non-destructive method for spectroscopically studying buried nanometer-scale interfaces and other nanostructures with soft x-ray standing waves. Strong standing waves with a period of 4.0 nm and approximately 3:1 contrast ratios are created via Bragg reflection from a synthetic multilayer of form [B4C/W]40. By growing a wedge-shaped Fe/Cr bilayer on top of this multilayer, the mechanical translation of the sample exposed to a fixed and finely focussed synchrotron radiation beam is converted into a translation of the standing wave through the interface. Analyzing various core photoelectron intensities as a function of angle and beam position permits deriving layer thicknesses and interface mixing/roughness scales. Magnetic circular dichroism in photoemission from the 2p and 3p levels of Fe and Cr further permits deriving the positions and widths of regions with decreased (increased) ferromagnetic alignment for Fe (Cr), showing that normally antiferromagnetic Cr becomes ferromagnetic just below the center of the interface but with antiparallel alignment with respect to Fe, and that the equal-concentration region in the center of the interface strongly inhibits magnetic alignment for both species along the direction of net magnetizations that is probed. The magnetically-altered regions in both metals are only 1-2 atomic layers in thickness. 3s spectra from Fe and Cr further indicate that the local spin moments on both atoms do not change on crossing the interface. This standing wave-plus-wedge method should have a range of applications for the characterization of magnetic and non-magnetic nanostructures and their interfaces. Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences Division, under Contract No. DE-AC03-76SF00098.

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