Thursday Afternoon, November 5, 1998

Magnetic Interfaces and Nanostructures Technical Group Room 324/325 - Session MI-ThA

Structure & Magnetism of Surfaces & Interfaces

Moderator: J.G. Tobin, Lawrence Livermore National Laboratory

2:00pm **MI-ThA1 Exchange Coupling in Co/Au/Co Sandwiches**, ***T. Duden***, *E. Bauer,* Arizona State University

The evolution of the magnetic domain structure during the growth of the Co layer on top of (111)-oriented Au spacer layers deposited onto a W(110) surface is studied by spin-polarized low energy electron microscopy. Pronounced biquadratic coupling is found not only at the nodes of the bilinear coupling but generally above the spin reorientation transition in the top layer. This produces a wrinkled magnetization or magnetization waves in the top layer. The results are discussed in the light of the various mechanisms which can lead to biquadratic coupling.

2:20pm **MI-ThA2 Experimental and Model Theoretical Dispersions of Unoccupied Metallic Quantum Well States in Cu/fccCo/Cu(100) and Related Systems**, ***A.G. Danese***, *F.G. Curti, R.A. Bartynski,* Rutgers University

The dispersion with parallel momentum (k @sub ||@) of unoccupied metallic quantum well (MQW) states in the Cu/fccCo/Cu(100) system has been measured using inverse photoemission and modeled using a phase accumulation approach. For Cu films in the 2 - 4 monolayer range, a state close to the Fermi level is observed to have a flat dispersion near the neck of the Cu Fermi surface along the @GAMMA@-BAR X-BAR direction of the two dimensional Brillouin zone. Appearance of this state coincides with a hybridization gap in the Co minority spin bands. The calculation shows that the large effective mass of this state is the result of the rapid change in the scattering phase shift across the gap. The periodicities with which MQW states cross the Fermi level at the center and at the neck of the Cu Fermi surface, which correspond to the long and short period oscillatory magnetic coupling in this system, are well reproduced by the calculation. Furthermore, the observed phase shift of the short period magnetic coupling when the ferromagnetic layer is changed from Fe to Co to Ni layers can be attributed to changes in the position of this hybridization gap with respect to the Fermi level across this series. The effect of this behavior on the strength of the short period magnetic coupling in these systems is discussed.

2:40pm **MI-ThA3 Spin-Polarized Quantum Well States**, ***K.N. Altmann***, *W.L. O'Brien, D.J. Seo, J. McKay,* Synchrotron Radiation Center, Univ. of Wisconsin, Madison*; F.J. Himpsel,* University of Wisconsin, Madison*; P. Segovia, A. Mascaraque, E.G. Michel,* Univ. Autonoma Madrid, Spain*; A. Naermann, J.E. Ortega,* Univ. del Pais Vasco, San Sebastian, Spain

Quantum well states are intimately connected to the oscillatory magnetic coupling observed in magnetic multilayers.@footnote 1,2,3@ The spin-polarization of these states is non-trivial since they reside in a non-magnetic spacer material. We have grown Cu/Co/Cu-(100) quantum wells in a chamber containing RHEED, SMOKE, MBE, and sputtering facilities. The high quality of our fcc-Co(100) layers is evidenced by the extremely low coercivity of < 1 Oe, which indicates minimal pinning of the domains at defects. These films were transferred in situ to a spin-polarized, angle-resolved photoemission system that uses undulator radiation from the SRC. Quantum well states with s,p and d character were observed when depositing films with sharp interfaces at low temperature and annealing them to room temperature. Also, a surprisingly-strong photon energy dependence was observed, even at energies of 70-80 eV, which needs a rethinking of the excitation process for "two-dimensional" quantum well states. Some of the quantum well states appear to be split, either due to multiple layer thicknesses, or due to a highly-unusual "inverted" magnetic splitting. Scanning tunneling spectroscopy measurements are in progress to find the layer-by-layer change in the energy of quantum well states. @FootnoteText@ @footnote 1@J.E. Ortega and F.J. Himpsel, Phys. Rev. Lett. 69, 844 (1992). @footnote 2@P. Segovia, E.G. Michel, and J.E. Ortega, Phys. Rev. Lett. 77, 3455 (1996). @footnote 3@F.J. Himpsel, J.E. Ortega, G.J. Mankey, and R.F. Willis, Adv. Phys., in press.

3:00pm **MI-ThA4 Systematic Measurement of Exchange Coupling Across the Periodic Chart of 3-d Transition Elements to Understand Magnetization In Ferromagnetic Mn Alloys@footnote 1@**, ***W.L. O'Brien***, University of Wisconsin, Madison*; S. Banerjee, B.P. Tonner,* University of Wisconsin, Milwaukee

Ultrathin films of Mn alloyed with Fe, Co and Ni have magnetic properties quite distinct from their bulk counterparts with same composition. Even the sign of exchange coupling in the ultrathin films are opposite to those of bulk alloys. For example, Mn impurities in bulk Fe are ferromagnetic with the magnetization of Mn parallel to the Fe magnetization, while we find that ultrathin alloys of the same composition are ferrimagnetic with an antiparallel coupling between Mn and Fe. Bulk Mn-Co alloys with dilute Mn concentration are ferrimagnetic with antiparallel coupling between Mn and Co whereas ultrathin films of same composition have the magnetization of Mn parallel to the Co. Finally, bulk 1:1 MnNi is an antiferromagnet, while the ultrathin alloys of same composition are ferromagnetic with Mn magnetization parallel to the Ni magnetization. To explore how widespread are these substantial differences in the magnetic phase diagrams of the ultrathin films, as compared to bulk, we performed a systematic measurement of the magnetic coupling for V, Cr, Mn, Fe, Co and Ni overlayers to Fe, Co and Ni substrates. The sign of the exchange coupling can be summarized by a simple electron counting rule. In this analysis of the periodic chart, we do not find parallel magnetic coupling when the sum of the formal atomic number of d electrons per atom (overlayer plus substrate) is less than 12. Considering this d=12 rule, Mn is located in a special position in the periodic table near the transition region between parallel and antiparallel coupling with Fe, Co and Ni. This rule works both for atomically clean surfaces, and surfaces modified by chemisorption. @FootnoteText@ @footnote 1@Work supported by the National Science Foundation, DMR, and performed at the Wisconsin Synchrotron Radiation Center.

3:20pm **MI-ThA5 Epitaxial Fe and Co Layers on Cu Crystals**, ***J. Kirschner***, Max-Planck-Institut für Mikrostrukturphysik, Germany **INVITED**

Fe and Co exhibit a multitude of structural and magnetic phases when deposited on to high-index planes of fccCu. Much work has been done on films made by thermal deposition or sputter deposition. We added pulsed laser deposition (PLD) in UHV and chemical deposition, and studied similarities and dissimilarities. Most striking effects are observed for pulsed laser deposition, which may alter the growth mode (from 3D growth for thermal deposition (TD) to layer-by-layer growth for PLD), magnetic anisotropies (from perpendicular (TD) to in-plane (PLD) for Fe/Cu(100), and magnetic moments (from low-spin (TD) to high-spin (PLD) for Fe/Cu(111). Co deposited electrochemically on to Cu(100) grows pseudomorphically up to 5 monolayers and non-pseudomorphically beyond. This has been found by in-situ surface x-ray diffraction. Effects of reduced dimensionality ocurr at surfaces and at steps. In the former case an oscillatory behaviour of the surface magnetization with one monolayer period has been observed by magneto-optical second harmonic generation. Magnetic nano-wires may be created by step edge decoration on stepped Cu(111). These resemble one-dimensional Ising chains (which has no net magnetization at thermal equilibrium), but show magnetic hysteresis at low temperature.

4:00pm **MI-ThA7 Fermi Surface Study of Pseudomorphic Fe@sub 1-x@Ni@sub x@ and Co@sub 1-x@Ni@sub x@ Thin Films on Cu(100)**, ***M. Hochstrasser***, *F.O. Schumann*, R.F. Willis,* Pennsylvania State University*; T.R. Cummins, G.D. Waddill,* University of Missouri, Rolla*; S.R. Mishra, J.G. Tobin,* Lawrence Livermore National Laboratory*; E. Rotenberg,* Lawrence Berkeley National Laboratory

We report angle resolved photoemission studies of the electronic behavior of ultrathin epitaxial layers of fcc structured binary alloys, Fe@sub 1-x@Ni@sub x@ and Co@sub 1-x@Ni@sub x@, deposited by molecular beam epitaxy on Cu(100) substrates. In particular, we have used Fermi surface mapping to monitor changes in the Fermi surface with increasing magnetization density. Fermi surface mapping has shown to be a valuable method to investigate for example the collapse of the exchange splitting between the upper and lower d-band in Ni@footnote 1@ and surface electronic states of hydrogen adsorbed on W(110).@footnote 2@ Co@sub 1-x@Ni@sub x@ and Fe@sub 1-x@Ni@sub x@ binary alloys show a different behavior in the bulk. Co@sub 1-x@Ni@sub x@ is structurally and magnetically well-behaved. In particular the magnetic moment varies linearly as a function of concentration. This is in sharp contrast to fcc Fe@sub 1-x@Ni@sub x@ which displays a magnetic instability at ~65% Fe content. An extended regime of fcc stability is possible via epitaxy on Cu(100).@footnote 3@ We investigated the changes in the Fermi surfaces of Fe@sub 1-x@Ni@sub x@ and Co@sub 1-x@Ni@sub x@ pseudomorphic film alloys depending on various concentrations of Ni in a large photon energy regime and compared these measurements with the known Fermi surface of Ni(100), Cu(100) and Co(100). We observe a change in the Fermi surface with increasing magnetization density e.g. number of holes in the d-band by changing the stoichiometry of our samples. @FootnoteText@ *present address: Department of Chemistry and Material Science, Lawrence Livermore National Laboratory, U.S. @footnote 1@T. Greber et al., Phys. Rev. Lett. 79, 4465 (1997). @footnote 2@E. Rotenberg et al., Phys. Rev. Lett. 80, 2905(1998). @footnote 3@F.O. Schumann et al., Phys. Rev. Lett. 79, 5166 (1997).

4:20pm **MI-ThA8 Growth Study of FePt(001) L1_0 ordered alloys using a Temperature Wedge Method**, ***M.M. Schwickert,*** Ohio University; *M.F. Toney, M.E. Best, J.-U. Thiele, L. Folks,* IBM Almaden Research Center; *G.R. Harp,* Ohio University; *D. Weller,* IBM Almaden Research Center

The L1_0 ordered phase of FePt has unique properties like enhanced magneto-optical Kerr effects and large magnetic anisotropy. Of particular interest is the formation temperature and growth kinetics of this phase. Fully ordered material has been synthesized using MBE growth at temperatures as low as 500oC. Spontaneous ordering induced by surface diffusion with a 0.2 eV barrier height was found.@footnote 1@ The present study aims at a combinatorial mapping of growth temperatures and seed techniques of MBE type, (001) and (110) oriented FePt films on MgO substrates. We have developed a temperature wedge technique in which temperature gradients of several hundred Kelvin can be established. Respectively, electron beam evaporated films show systematic dependencies of magnetic, magneto-optic and structural properties as function of "wedge" position, corresponding to temperature. Magnetic hysteresis properties and anisotropy fields were characterized with a polar and transverse Kerr looper with spatial resolution. Structural data including quantification of the long range chemical ordering S as function of temperature were obtained from x-ray diffraction measurements. Finally we report on a combined AFM/MFM study of these films, revealing the equilibrium magnetic domain structure in correlation with topographic features. @FootnoteText@ @footnote 1@R.F.C. Farrow et al., Appl. Phys. Lett. 69, 116 (1996)

4:40pm **MI-ThA9 The Effect of Oxygen on the Growth and the Surface Magnetism of Iron Films**, *R. Moroni, F. Bisio, M. Salvietti, M. Canepa,* ***L. Mattera,*** University of Genova, Italy

The effect of oxygen on the growth and the surface magnetism of iron films has been investigated by Helium Reflectivity (HR) and Spin Polarized Metastable Deexcitation Spectroscopy (SPMDS) during the growth of Fe on an O(1X1)-Fe adlayer. HR and SPMDS measurements are performed contemporarily, providing real time information on defect density (HR) and electronic and magnetic properties (SPMDS) at surface as the growth proceeds. At room temperature, on O(1X1)-Fe, iron grows layer-by-layer, the oxygen atoms acting as surfactants. The intensity of the features induced by O@sub 2p@ and Fe@sub 3d@ states in the electron distribution curves detected following the deexcitation of metastable atoms remain unchanged during the growth indicating that the surface composition is constant: the oxygen atoms remain segregated at surface by position exchange with incoming iron atoms. Helium reflectivity and magnetization intensity oscillate in-phase during growth: significant oscillations of the magnetization intensity are observed in perfect phase with the cyclic order/disorder transitions. Such a behaviour provides a real time, direct experimental evidence of the strong correlation between structural order and magnetization intensity.

5:00pm **MI-ThA10 Magnetic Properties of Ultrathin Fe/Gd and Gd Thin Films**, ***C.S. Arnold,*** National Institute of Standards and Technology, US; *D.P. Pappas,* National Institute of Standards and Technology

Ultrathin films of magnetic transition metals are known to grow amorphously on rare-earth substrates. Magnetically, these films exhibit a strong perpendicular anisotropy and antiferromagnetic coupling of the transition metal to the rare earth atoms at the interface. Fe films 1- 4 monolayers thick grown on Gd substrates conform to this behavior, but also exhibit a reorientation phase transition (RPT) with temperature. This RPT is unlike those of ultrathin films on non-magnetic substrates because it is driven by the loss of magnetic order in the substrate as the bulk Gd Curie temperature is approached. Spin-polarized secondary electron polarimetry and SMOKE susceptibility measurements are employed to study the surface, bulk and interfacial magnetization as a function of temperature and Fe thickness. A partial thickness-temperature phase diagram is constructed. A second focus of the work is a comparison of surface and bulk magnetization vs. temperature in thin Gd films. The existence of a magnetic surface state is well established by spin-polarized spectroscopies, but direct comparisons of surface and bulk macroscopic magnetizations are rare in the literature. An earlier experiment using MOKE and electron spin-polarimetry to measure M(T) for the bulk and surface respectively is repeated.

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