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

### Magnetic Spectroscopies

**Moderator:** D.P. Pappas, National Institute of Standards and Technology

8:20am **MI-ThM1 Magnetic Characterization from Polarized Soft X-ray Scattering**, ***Y.U. Idzerda,*** Naval Research Laboratory **INVITED**

With the explosive growth in spin-polarized electron transport studies for spin-tunneling, spin-transistor, and magnetoresistive device applications, the importance of layer switching, interfacial magnetic roughness, and magnetic domain correlation is becoming increasingly apparent. Since the spin conductance of a magnetic heterostructure is controlled by the relative orientation of the magnetic moment directions of the component layers on a local scale (within a few spin mean-free-paths), quantifying these mechanisms on this length scale would be very advantageous. Combining magnetic circular dichroism and resonant x-ray scattering, soft x-ray resonant magnetic scattering (XRMS) has a demonstrated capability to determine the order of layer switching, extract parameters which independently characterize the magnetic and chemical roughness of an interface, and statistically quantify magnetic domain correlations. Recent results for CoFe/Cu/SiN3/Si thin films grown with different Cu buffer layer thicknesses show conclusively from both the perpendicular roughness parameters and the in-plane correlation lengths that the interfacial magnetic roughness is much smoother than the interfacial chemical roughness. In Co/Cr/Co trilayer structures, angle and magnetic field dependent XRMS scans used in conjunction with MCD element-specific magnetic hysteresis loops are used to statistically determine that magnetic domains are vertically anti-correlated (preferrentially anti-aligned), indicating the presence of interlayer anti-ferromagnetic exchange coupling.

9:00am **MI-ThM3 Magnetic Structure of Cr Layers in Fe/Cr(001)Superlattices from X-ray Magnetic Dichroism**, ***F. Perjeru,*** *M.M. Schwickert, W.J. Antel, T. Lin, G.R. Harp, M.A. Tomaz,* Ohio University*; W.L. O`Brien,* SRC Madison, Wisconsin

Element-specific magnetometry is used to determine the magnetic moments of Fe and Cr in Fe/Cr(001) superlattices as a function of Cr thickness from 0-50Å, using x-ray magnetic circular dichroism (XMCD) and x-ray magnetic linear dichroism (XMLD). XMCD and XMLD are sensitive to the average magnetization, , and average of squared magnetization,, respectively. High quality Fe/Cr(001) multilayers are prepared by sputter epitaxy and several AF coupling peaks between Fe layers are observed in these films. If antiferromagnetism is present in the Cr layer, it is expected that will be enhanced relative to , that is @sr@ (this assumes layer antiferromagnetism in the Cr with 180° alignment of atom-thick Cr layers). Comparatively, roughness at the experimental Fe/Cr interface might cause frustration which could suppress the antiferromagnetism in the Cr. From measurements of XMCD and XMLD from sputter deposited films, it was found that the Cr atoms have net spin polarization only near the Fe/Cr interface and @sr@ = . This leads to the conclusion that the Cr layers are mainly paramagnetic in the present multilayers, at room temperature. Further experiments are underway to repeat these measurements at 100K, where the tendency to antiferromagnetism within the Cr layer may be enhanced. Both room temperature and low temperature results will be presented.

9:20am **MI-ThM4 On the Nature of Resonant Photoemission in Gd**, ***J.G. Tobin,*** *K.W. Goodman,* Lawrence Livermore National Laboratory*; S.R. Mishra, W.J. Gammon,* Virginia Commonwealth University*; T.R. Cummins, G.D. Waddill,* University of Missouri, Rolla*; G. van der Laan,* Daresbury Laboratory, England, UK

The phenomenon of "resonant photoemission" occurs when, in addition to a direct photoemission channel, a second indirect channel opens up as the absorption threshold of a core level is crossed. A massive increase in emission cross section can occur, but the nature of the process remains clouded. Is it truly "resonant photoemission" or merely the incoherent addition of a second emission channel? Using novel magnetic linear dichroism in photoelectron spectroscopy experiments and computational simulations, we can now clearly demonstrate that temporal matching of the processes as well as energy matching is a requirement for true "resonant photoemission." The photoemission of 4f and 5p electrons from rare-earth metals and their compounds is strongly enhanced when the photon has just enough energy to excite a 4d electron to an unoccupied 4f level, leading to a process called "resonant photoemission". In a generic picture, the indirect channel of the resonant photoemission is interpreted as due to a process where a 4d electron in the initial state is first excited to the unoccupied 4f level, forming a tightly coupled, bound intermediate state, 4d core hole plus 4f electrons. Then a decay via autoionization occurs into the final state, thus producing a final state indentical to that obtained by a direct photoemission process for the ejected electron. The transition rate is greatly enhanced if the excited state decay is by a Coster-Kronig or a super-Coster-Kronig process. The key question is whether these processes are coherent or incoherent: should the overall intensity be treated as a squaring of the sum of the amplitudes (coherent) or summing of the squares of the amplitudes (incoherent)? A true "resonant photoemission" process should be coherent, involving interference terms between the direct photoemission and indirect photoemission channels. Possibly, incoherence would give rise to the loss of photoemission characteristics in the process, with a domination of auger-like properties. To this problem we have applied the new photoelectron spectroscopy technique of magnetic linear dichroism in angular distributions (MLDAD). This technique is related to but distinct from the techniques of magnetic xray circular dichroism (MXCD) in photoelectron spectroscopy and xray absorption. The key is that while large dichroic effects in ferromagnets can be observed with MXCD-photoemission and MXCD-absorption, the large MLDAD effects in ferromagnets is solely a photoemission, not an absorption-driven, process. This is because the chirality which gives rise to magnetic sensitivity is due to the vectorial configuration in MLDAD as opposed to the intrinsic chirality of circularly polarized xrays in the MXCD techniques. In absorption, where there is an essential averaging over all emission angles, the vectorial chirality is lost. Thus, MLDAD is the perfect measurement to distinguish between photoemission and absorption processes. Angle-resolved photoemission in a magnetic system should show an MLDAD effect: xray absorption and thus auger emission will show no MLDAD effect. It is this test which we have applied to the "resonant photoemission" of the Gd5p and Gd4f emissions.

10:00am **MI-ThM6 Combined Spin Polarized Photoemission and Inverse Photoemission of Rare Earth Surface States**, ***T. Komesu,*** *C. Waldfried, P.A. Dowben,* University of Nebraska, Lincoln

The surface of gadolinium has been a subject of much controversy over past years, as to what extent spin mixing and/or Stoner-like exchange coupling are the predominant ingredients of magnetic ordering. The contention is stimulated by the complication that the Gd(0001) surface state is located in the direct vicinity of the Fermi level. For strained Gd(0001) grown of Mo(112), the situation is far worse.@footnote 1@ The surface state is composed of partially occupied spin majority and minority states that extend across the Fermi level into the unoccupied region. Consequently, the magnetic and electronic structure of the Gd(0001) surface cannot be studied by a single experimental technique. Rather the two complementary techniques of photoelectron spectroscopy (PES) and inverse photoemission spectroscopy (IPES) are necessary for a comprehensive investigation of the Gd(0001) surface electronic structure. In this work, we study the surface magnetic structure of strained Gd(0001) through a combination of spin-polarized PES, and spin-polarized IPES. We also find that oxygen antiferromagnetically aligns the surface for strained Gd(0001) which is distinctly different from the case of unstrained Gd(0001).@footnote 2@ @FootnoteText@ @footnote 1@C. Waldfried, T. McAvoy, D. Welipitiya, E. Vescovo and P. A. Dowben, submitted; C. Waldfried, T. McAvoy, D. Welipitiya, P. A. Dowben and E. Vescovo, Europhys. Lett. (1998) in press @footnote 2@D. N. McIlroy, C. Waldfried, D. Li, J. Pearson, S. D. Bader, D. -J, Huang, P. D. Johnson, R. F. Sabirianov, S. S. Jaswal and P. A. Dowben, Phys. Rev. Lett. 76, 2802 (1996)

10:20am **MI-ThM7 X-ray Dichroism Studies of Induced Magnetism in Magnetic Multilayers**, ***G.R. Harp,*** *M.A. Tomaz, W.J. Antel, M.M. Schwickert, T. Lin, F. Perjeru,* Ohio University **INVITED**

X-ray magnetic circular dichroism (XMCD) and linear dichroism (XMLD) are applied to study the element-specific magnetization in Fe/TM(001) superlattices (here TM = V, Cr, Co, Ni, Nb, Mo, Ru, Rh, Pd, Ta, W, Pt). Within the Fe layers (5-20 Å thickness) we observe a wide variety of behaviors, from strong enhancement to complete suppression of the magnetic moment. The details depend on the spacer material and the crystal structure of the superlattice (bcc, fcc, or hcp). The real power of x-ray dichroism, however, is seen in studies of the spacer layer moments, which are often quite small. Various behaviors are observed depending on the spacer material. For ferromagnetic elements (Ni, Co) a strong moment enhancement is sometimes observed (Ni) or sometimes not (Co). For nonmagnetic elements, the induced magnetization may be parallel or antiparallel to that of the Fe. This induced magnetic moment may be

confined to the interface region (e.g. Cr), may decay slowly toward the layer interior (e.g. V), or may be almost ferromagnetic, in the sense that the average moment per atom is constant over a range of thicknesses (e.g. Pt). Additionally, x-ray magnetic LINEAR dichroism can probe antiferromagnetic arrangements within spacer layers. As an example, XMLD is applied to the Fe/Cr system to search for commensurate antiferromagnetism within the Cr layers.

11:00am **MI-ThM9 A Controversy Over the Magnetic Structure of Mn Overlayers on Fe and the Role of Oxygen Impurities@footnote 1@***, **S. Banerjee**,* University of Wisconsin, Milwaukee*; W.L. O'Brien,* University of Wisconsin, Madison*; B.P. Tonner,* University of Wisconsin, Milwaukee

The magnetic coupling across the Fe-Mn interface for ultrathin films of Mn grown on Fe has recently been the focus of both experimental and theoretical research efforts, but without substantial agreement. For example, experimental results claim both parallel@footnote 2@ and antiparallel@footnote 3,4@ magnetic coupling between a submonolayer Mn film and the Fe substrate. This disagreement is made even more interesting by a theoretical analysis which shows that the interlayer magnetic coupling between Mn and Fe is very sensitive to both lattice spacing and valence band structure.@footnote 5@ In an effort to better understand the interface magnetic coupling of this model system we have made a series of x-ray magnetic circular dichroism (XMCD) measurements on the Mn-Fe interface for different Mn coverages, on Fe substrates with both the fct and bcc crystal structures. In addition we investigated the effects of small exposures to oxygen on the magnetic order and coupling for coverages up to one monolayer. The Mn/Fe system is extremely reactive, and shows changes in magnetic state with exposures times as low as 10 minutes at 2 X 10@super -10@ Torr. Our findings show that the chemical state of Mn has a tremendous effect on the magnetization at the Fe-Mn interface while the in plane lattice constant and crystal structure do not. The effect of oxygen exposure is to ferromagnetically align the Mn atoms with an orientation antiparallel to the Fe. The intrinsic magnetic state of Mn on Fe, found by extrapolation to zero exposure to contaminating gases, is that of zero magnetic moment at room temperature. @FootnoteText@ @footnote 1@Work supported by the National Science Foundation DMR and performed at the Wisconsin Synchrotron Radiation Center. @footnote 2@S. Andrieu et. al., Phys. Rev. B 57, 1985 (1998). @footnote 3@O. Rader, W. Gudat, D. Schmitz, C. Carbone, and W. Eberhardt, Phys. Rev. B 56, 5461 (1997). @footnote 4@J. Dresselhaus et. al., Phys. Rev. B 56, 5461 (1997). @footnote 5@ R. Wu and A.J. Freeman, Phys. Rev. B 51, 17131 (1995).

11:20am **MI-ThM10 Morphology of Mn Films on Fe(001)@footnote 1@***, **A.D. Davies**, D.T. Pierce, J.A. Stroscio, R.J. Celotta,* National Institute of Standards and Technology

Manganese and iron thin film structures have shown promise for studying indirect exchange coupling and for investigating novel magnetic thin film systems. As a function of temperature and stress, Mn has a large variety of structural and magnetic states, so it is particularly important to fully characterize the structure in these films to understand the magnetic behavior. Here we report on scanning tunneling microscopy (STM) measurements of epitaxial Mn films up to ~10 atomic layers grown on Fe(001) at 155 ± 10 °C. The film growth and structure varies dramatically with film thickness and exhibits a range of unusual spatial inhomogeneities. At this growth temperature, the growth is nearly layer-by-layer and shows a decrease with thickness in the island density of ~25 times. Concurrent with this length scale change, the island shape changes from facets along directions to  oriented facets. While the atomic-layer height for submonolayer films is difficult to define due to electronic differences, the atomic step height of the second Mn layer is 1.44 ± 0.07 Å and surface step heights of all subsequently thicker films are 1.61 ± 0.03 Å. For films beyond ~2 atomic layers, curious small regions are observed that are a fraction of an atomic step high. The height, shape, frequency, and location of these regions vary with film thickness. The film structure is markedly different in the vicinity of steps on the Fe substrate at almost every coverage. This difference and other observed aspects of the growth suggest that the growth is very sensitive to local stress. @FootnoteText@ @footnote 1@ Supported in part by the Office of Naval Research.

11:40am **MI-ThM11 Light Scattering Cross Section for Mode Crossing of Spin Waves in Magnetic Films***, **F. Nizzoli**,* University of Ferrara and INFM, Italy*; J.M.V. Ngaboyisonga,* Makerere University, Uganda*; L. Giovannini,* University of Ferrara and INFM, Italy

The dispersion curves of spin waves in magnetic films show a typical behavior as a function of the surface wave vector, film thickness and in-plane propagation angle, i.e. mode repulsion between the surface mode and bulk modes. The purpose of this work is to study theoretically the Brillouin light scattering (BLS) intensity from spin waves versus the surface wave vector Q in case of mode repulsion in a magnetic film of thickness d, under the condition Qd nearly equal to 1. In such a case both dipole and exchange interactions are equally important and must be included. The calculations, for a 85 nm thick iron film, are performed within the macroscopic partial waves approach of Rado-Hicken and Cochran-Dutcher, based on the solution of the Landau-Lifshitz equation of motion of the magnetization with the proper boundary conditions. It is found that the BLS cross section shows an antiresonant behavior close to the gap between the modes. We have investigated the physical meaning of this behavior by analyzing the different contribution of the partial waves to the cross section . For Q below the gap three relevant partial waves interfere destructively, while the opposite occurs for a wave vector above the gap. The interference effects, responsible for the Fano-type antiresonant behavior of the total scattering intensity, are explained in terms of a sudden change of the dynamic magnetization across the film, when mode repulsion occurs. The effect of the magnetic anisotropy on the antiresonant behavior of the BLS cross section is also investigated.

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