Friday Morning, November 8, 2002

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+TF-FrM

Magnetic Thin Films and Surfaces
Moderator: P.A. Dowben, University of Nebraska-Lincoln

8:20am **MI+TF-FrM1 Structure and Magnetism of Ultra Thin Fe Films Grown on CoGa(100)**, ***L.K. Verheij***, *T. Balster, D.A. Kovacs, R. David, R. Franchy*, Forschungszentrum Jülich, Germany

The structure and magnetic properties of thin Fe layers deposited on CoGa(100) (misfit 0.5 %) were investigated by low energy electron diffraction (LEED), by helium scattering (TEAS), and by the magneto optical Kerr effect (MOKE). For room temperature deposition we observe well defined intensity oscillations of the specular helium intensity under anti-phase conditions. Upon increasing the growth temperature to 550 K the amplitude of the oscillations and their number increases substantially. At both growth temperatures a tendency for double layer growth is found up to a film thickness of about 10 ML. The magnetic properties of the Fe films appear to depend on the experimental conditions during growth and on the preparation of the substrate surface. Films with a magnetization with the easy axis parallel to the surface and with the easy axis perpendicular to the surface have been grown. The Curie temperature of the Fe films increases from 240 K to 600 K when the thickness is increased from 1 to 2 ML. Above 650 K, the film is unstable due to intermixing. The relation between the changes of the structure and the magnetic behavior with preparation are discussed.

8:40am **MI+TF-FrM2 Surface Morphology and Magnetization Reversal**, ***R.A. Lukaszew***, *Z. Zhang*, University of Toledo, *R. Clarke*, University of Michigan

We have studied the azimuthal dependence of the magnetization reversal on annealed and non-annealed (001) epitaxial Ni films of the same thickness and deposited under the same conditions on MgO. The coercive field in non-annealed films exhibit 4-fold symmetry as expected from the symmetry of the crystal. The annealed films exhibit an additional uniaxial symmetry superimposed to the four-fold symmetry. STM images of the surface of the annealed films indicate self-assembled periodic stripe nano-patterning, while STM images of the non-annealed films show typical mounded surfaces. Cross sectional TEM studies performed on the annealed films will be correlated with the surface morphology and with the magnetic anisotropy.

9:00am **MI+TF-FrM3 Lande g-factor Variation with Thickness in Ultrathin Permalloy Films**, ***J.P. Nibarger***, *R. Lopusnik, T.J. Silva*, National Institute for Standards and Technology

We have found a variation in the Lande g-factor with thickness in sputtered polycrystalline Permalloy films capped with Cu. The variation of the g-factor is correlated with damping in the absence of an applied bias field. Films were grown on a sapphire substrate with a 5 nm Ta adhesion layer, followed by 10, 25, 50, or 100 nm of NiFe, and finally capped with a 5 nm layer of Cu. Static anisotropy values were obtained using a static inductive magnetometer and the effective saturation magnetization was found using an alternating gradient magnetometer. A pulsed inductive microwave magnetometer (PIMM) was used to extract dynamical information.[1] Using the static values and the Kittel equation for thin films, we extracted the induced uniaxial anisotropy, the Lande g-factor, and the Landau-Lifshitz phenomenological damping parameter, α, from the PIMM measurements. The g-factor increases with decreasing thickness for films below 50 nm, as does also the damping in zero applied field. In addition, the effective saturation magnetization decreases with decreasing thickness, presumably due to surface anisotropy effects. The increase in the g-factor is interpreted as an indicator of enhanced spin-orbit coupling for thinner films: As the films become thinner and thinner, the relative magnitude of the spin-orbit coupling at interfaces becomes dominant. We will discuss the role of spin-orbit in damping by conduction electron scattering, as well as implications for the transport of spin angular momentum in nano-scale magnetic heterostructures.

[1] T. J. Silva, C. S. Lee, T. M. Crawford, C. T. Rogers, J. Appl. Phys. 85, 7849 (1999)

9:20am **MI+TF-FrM4 Determination of the Spin-Spin Coupling Strength in Ultrathin Magnetic Films**, ***N.A.R. Gilman***, *R. Zhang, R.F. Willis*, Penn State University

We present a model of spin-spin coupling in itinerant ferromagnets which provides insight into the observed linear decrease of the Curie temperature with decreasing ultrathin film thickness.[1] The slopes of plots of Tc versus ultrathin film thickness reflect the strength of the spin-spin coupling and the effective range of the spin-spin interactions. Experimental results for alloys of Fe, Co and Ni show this range of spin-spin interactions decreasing with increasing bulk Curie temperature. Measurements of their Fermi surfaces[2] show a direct correlation with the concentration of holes in the d-band.

[1] R. Zhang and R.F. Willis, Phys. Rev. Lett. 86, 2665 (2001).
[2] M. Hochstrasser et al. Phys. Rev. B 60, 17030 (1999).

9:40am **MI+TF-FrM5 Effect of Spatial Confinement on Magnetism: Films, Wires and Dots of Fe**, ***J. Shen***, Oak Ridge National Laboratory **INVITED**

The last decade has witnessed a remarkable transfer of basic science to practical devices in the area of magnetic recording. In less than 10 years, the discovery of a phenomenon that occurs in artificially structured thin films of magnetic and nonmagnetic materials, known as giant magnetoresistance (GMR), had developed into a $100B/yr business in the market of hard disk drive alone. This advance was a result of learning how to grow these films coupled with a basic understanding that allowed optimal tuning of their properties. As efforts to reduce device size scales have continued, it has become increasingly attractive to investigate the magnetic properties of artificial structures with even smaller dimensions and lower dimensionality-nanowires and dots. Using a combination of novel synthesis methods, including laser molecular beam epitaxy, step decoration growth, and buffer layer assisted growth; we have developed a generic way to grow nanometer-sized films, wires and dots on a common template with the s ame areal density. The ability to grow magnetic nanostructures with differing dimensionalities on the same template means that we can now study the effect of spatial confinement on magnetism and transport. This is crucial to the development of nanometer-scaled spintronic devices, an area in which the next breakthrough in information technology may be anticipated.

10:20am **MI+TF-FrM7 Growth and Magnetic Properties of Artificial $L1_0$ Fe-Co Alloy**, *G. Farnan*, ***Z. Gai***, *A.P. Baddorf, J. Shen*, Oak Ridge National Laboratory

Iron-cobalt alloys are of interest due to their high magnetic moment and Curie temperature, and to the strong magnetic character of both constituents. In bulk, Fe and Co are totally miscible, with B_2 structure being the only ordered alloy phase. In this work, we use modern laser molecular beam epitaxy to artificially grow a new ordered Fe-Co alloy phase, i.e., $[Fe(1ML)/Co(1ML)]_n$ $L1_0$ phase, which consists of alternatively stacked monatomic layers of Fe and Co. By monitoring reflection high energy electron diffraction (RHEED) oscillations during the growth, precise amounts of iron and cobalt were deposited onto a Cu(001) single crystal substrate in ultra high vacuum. In-situ scanning tunneling microscopy images showed almost perfect layer-by-layer morphologies, while low energy electron diffraction (LEED) patterns and Auger electron spectroscopy data collected after each whole layer deposition showed that the fcc phase with layered composition was preserved up to seven monolayers. Ex-situ X-ray diffraction results include new diffraction features confirming the existence of the Fe-Co $L1_0$ alloy. The magneto-optic Kerr effect (MOKE) results showed that the alloy was ferromagnetic with easy axis in plane. After seven monolayers deposition a structural change was observed by LEED and RHEED, and was reflected in a dramatic increase in coercivity and Curie temperature observed in the MOKE study.

[1] Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Dept. of Energy under contract DE-AC05-00OR22725.

10:40am **MI+TF-FrM8 The Effects of Growth Temperature and Composition on the Magnetic Properties of Ni_2MnIn_x Epitaxial Films Grown on InAs (001)**, ***J.Q. Xie***, *J.W. Dong, J. Lu, X.Y. Dong, T.C. Shih, S. McKernan, C.J. Palmstrom*, University of Minnesota

Injecting spin-polarized electrons into a semiconductor from a ferromagnetic material is an emerging concept for novel electronic devices.[1] InAs is the semiconductor of choice because of its high electron mobility and the ease to form an ohmic contact to it. Although no elemental ferromagnet is lattice matched to InAs, the lattice mismatch between the Heusler alloy Ni_2MnIn and InAs is only 0.2%. In bulk, Ni_2MnIn is reported to have a cubic ($L2_1$) crystal structure with a lattice constant a_0 = 6.069 Å and a Curie temperature ~ 314 K. Recent theoretical studies showed that the band structure alignment between Ni_2MnIn and InAs would enhance the injection of the minority spins, suggesting that Ni_2MnIn may be a good choice for spin injection as a ferromagnetic contact.[2] In this presentation, we report on the epitaxial growth of Ni_2MnIn thin films on InAs (001) by molecular beam epitaxy. Determination of the crystal structure of Ni_2MnIn

and effects of ordering and composition on magnetic properties of Ni_2MnIn are emphasized. Our transmission electron microscopy studies indicate the pseudomorphic growth of Ni_2MnIn in the B2 structure on InAs (001) with an orientation relationship of $Ni_2MnIn(001)$ || InAs(001) and Ni_2MnIn<100> || InAs<100>. Magnetic measurements show that the Ni_2MnIn films have a Curie temperature ~ 170 K. The lower Curie temperature compared to the bulk value (~ 314 K) is believed to be due to the growth of Ni_2MnIn in the B2 structure. To improve the ordering of Ni_2MnIn thin films, effects of substrate temperature and interfacial layer are investigated. Composition was found to affect the Curie temperature dramatically. For $Ni_2MnIn_{1.7}$, a Curie temperature as high as ~ 290 K was obtained.

[1]S. A. Wolf et al., Science 294, 1488 (2001).

[2]K. A. Kilian and R. H. Victora, J. Appl. Phys. 87, 7064 (2000).

11:00am **MI+TF-FrM9 Structure and Magnetic Properties of Thin Fe Films Grown on InAs(100)**, ***G. Witte***, *L. Ruppel, Ch. Woell, S.F. Fischer, U. Kunze, T. Last*, Ruhr-University Bochum, Germany

On account of its large spin transfer length (i.e. Rashba effect) InAs constitutes a promising material for future spintronic applications. Of particular interest in this context are details of the growth and properties of thin ferromagnetic films on this substrate. Here we report on a combined LEED, XPS and SQUID study of epitaxially grown Fe-films on the indium rich InAs(100)-c(8x2)/(4x2) surface with a particular emphasize on interface alloying and its influence on the magnetic properties. While deposition at room temperature leads to the appearance of a distinct (1x1) LEED pattern for films thicker than 2nm indicating an epitaxial growth of Fe(100) films, the corresponding XPS data reveal the presence of an iron-arsenide species which floates at the surface upon further film growth. Postdeposition annealing causes no improvement of the film quality but enhances the amount of arsenic at the surface. Surprisingly, rapid flash annealing of the films above 700K leads, however, to a thermal dissociation and desorption of the surface arsenic which is accompanied by a change of the film morphology and formation of disconnected islands. This suggests that the epitaxial growth of Fe films on InAs(100) is stabilized by the surface arsenide via a "surfactant effect". Corresponding ex-situ SQUID measurements for 10nm Fe films capped by a 20nm Ag film revealed bulk like magnetic properties over a temperature range of 5-300K. In contrast to that thin Ag films of only 1nm are not sufficient to prevent a partial oxidation of the Fe films as inferred from the XPS data and lead to the appearance of a pronounced exchange bias effect at low temperatures. This observation stress the importance of an appropriate capping.

11:20am **MI+TF-FrM10 Growth and Characterization of Ferromagnetic Fe-Doped Rutile TiO_2 Clusters and Thin Films**, ***S. Thevuthasan***, Pacific Northwest National Laboratory, *Y.J. Kim,* Taejon National University of Technology, *T. Droubay, V. Shutthanandan, A.S. Lea, M.H. Engelhard, S.A. Chambers,* Pacific Northwest National Laboratory, *J. Schneider, R. Sears, B. Sinkovic*, University of Connecticut

There is a growing interest in searching for spin injection materials with high injection efficiencies and room temperature operations. Some of the dilute magnetic semiconductors with the potential for room temperature spintronics applications include Co-doped ZnO, Mn-doped GaN and Co-doped anatase TiO_2. Although there are still some issues associated with the growth of single crystal Co-doped anatase TiO_2, recent experiments show that this material is the most promising candidate because of its room temperature ferromagnetism.[1,2] Recently, we have investigated the growth and characterization of $Fe_xTi_{1-x}O_2$ (x ~ 0.02-0.16) on single crystal TiO_2(110) at the Molecular Beam Epitaxy facility of the Environmental Molecular Sciences Laboratory (EMSL). Some of these films exhibit ferromagnetism at room temperature. The morphology of these films consist of the film proper along with Fe rich clusters containing a mixture of Fe^{2+} and Fe^{3+} valence states. These films were characterized using several surface science techniques including x-ray photoelectron spectroscopy (XPS) atomic force microscopy (AFM), scanning Auger microscopy (SAM), x-ray absorption spectroscopy (XAS), and Rutherford backscattering spectrometry (RBS)/channeling. These results with the magneto-optical Kerr effect (MOKE) measurements from these films will be discussed.

[1] M. Matsumoto et al., Science, 291, (2001) 854.

[2] S.A. Chambers et al., Appl. Phys. Lett. 79 (2001) 3467. Work supported by the U.S. Department of Energy, Offices of Basic Energy Sciences and Biological and Environmental Research and the laboratory directed research and development (LDRD) program.

11:40am **MI+TF-FrM11 MOCVD Growth of $Co_xZn_{1-x}O$ on R-plane Sapphire: Structure, Composition, and Magnetic Properties**, ***A.C. Tuan***, University of Washington, *T. Droubay, J.W. Rogers, S.A. Chambers*, Pacific Northwest National Laboratory

We have grown Al-doped $Co_xZn_{1-x}O$ films by MOCVD for application as a spintronic material. Films were grown at substrate temperatures between 750 and 825 K at a growth rate of ~6 nm/min. XRD and RBS show that up to 35% of the Zn cations can be substituted with Co without disrupting the wurtzite crystal structure of ZnO. Furthermore, XRD pole figures indicate that the films are of near-single crystal quality. Comparison of the Co 2p core-level XPS from our $Co_xZn_{1-x}O$ films with reference spectra for Co metal, Co(II), and Co(III) shows that the Co ions are in the +2 oxidation state. XPS also shows that there is no carbon contamination in the bulk of the film, which suggests that the organometallic precursors are completely oxidized/pyrolyzed. Since the Co distribution in the material strongly affects the magnetic properties, we performed SIMS depth profiling, which confirmed that the Co and Al constituents are uniformly distributed throughout the film and show no segregation at either the interface or the surface. In addition, AFM indicates that the surface is very smooth with an RMS roughness of only 3.7 nm over a 5 x 5 micron area. However, in spite of recent theoretical predictions,[1] we have yet to observe room temperature ferromagnetism in this material. These results differ from those recently obtained by Ueda et al. in which they show weak ferromagnetism that persists to ~300 K from similar PLD-grown films of slightly lower crystalline quality.[2] We are currently performing below-room-temperature magnetic measurements to determine the exact value of the Curie temperature in our material. These results, as well as the effects of post-growth annealing will be presented at the conference.

[1]Sato et al., Japanese Journal of Applied Physics 40, L334-L336 (2001)

[2]Ueda et al., Applied Physics Letters 79(7), 988-990 (2001).

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