Magnetic Interfaces and Nanostructures
Room 204 - Session MI-ThA

Magnetic Oxides
Moderator: A. Hoffmann, Argonne National Laboratory

2:00pm **MI-ThA1 Doped Cobaltites: Phase Separation, Intergranular GMR, and Glassy Transport Phenomena**, ***C. Leighton***, *J. Wu,* University of Minnesota*; J. Lynn, C. Glinka,* NIST*; H. Zheng, J. Mitchell,* Argonne National Laboratory*; W. Moulton, M. Hoch, P. Kuhns, A. Reyes,* National High Magnetic Field Lab*; C. Perrey, C.B. Carter,* University of Minnesota **INVITED**
Magneto-electronic phase separation, where a chemically homogeneous material displays spatial coexistence of multiple magnetic and electronic phases, is very common in perovskite oxides and is thought to play a key role in high temperature superconductivity and colossal magnetoresistance. We have used a battery of complementary experimental techniques to tackle the problem of magnetoelectronic phase separation in the perovskite cobaltite La1-xSrxCoO3. This is a material that offers many of the desirable attributes of a model system for investigating phase separation. Co and La NMR and small angle neutron scattering unequivocally demonstrate the existence of magnetoelectronic inhomogeneity in polycrystalline, single crystal and epitaxial thin film samples, which are chemically homogeneous on nm length scales. At low doping ferromagnetic metallic clusters form in an insulating matrix. These clusters coalesce with increasing doping, leading to a percolation transition and the onset of long-range ferromagnetic order. In single crystals, this formation of isolated clusters leads to a hysteretic negative MagnetoResistance (MR), which has field, temperature, and doping dependencies consistent with an intergranular Giant MagnetoResistance (GMR) effect. We argue that this system is a naturally forming analog to the artificial structures fabricated by depositing nanoscale ferromagnetic particles in a metallic or insulating matrix, i.e. this material displays an intergranular GMR effect without the deliberate introduction of chemical interfaces. The formation of nanoscopic F clusters also gives rise to glassy transport phenomena that are reminiscent of relaxor ferroelectrics. This is discussed in terms of the known phenomenology of the magnetic phase separation. Work supported by ACS PRF and NSF MRSEC.

2:40pm **MI-ThA3 MBE Growth of Epitaxial Co@sub2@MnGe on SrTiO@sub3@ (001) and MgO (001) Substrates**, ***S.K. Srivastava***[1], *C. Adelmann, X. Dong,* University of Minnesota*; D. Schlom,* Penn State University*; C. Ahn,* Yale University*; C.J. Palmstrom,* University of Minnesota
The combination of metallic ferromagnetic Heusler alloys with metal oxides can be used for the formation of multifunctional material heterostructures. The growth of Co@sub2@MnGe with a 45° in-plane rotation results in a lattice mismatch of -3.84% and +3.82% for SrTiO@sub3@ (001) and MgO (001), respectively. Etching of SrTiO@sub3@, followed by ex-situ annealing in O@sub2@ (~1 atm) at 1223K for 1 hour was used to form a TiO@sub2@ terminated surface@footnote 1@ with straight edged steps. AFM shows terraces with step heights on the order of one unit cell (~ 4Å) and LEED images show a (@sr@5x@sr@5)R26.6° superstructure. The growth of Co@sub2@MnGe was initiated by growing alternating atomic layers of MnGe and Co in an MBE system at 298K to promote wetting of the substrate and the desired (001) atomic stacking sequence. Following the growth of 20 atomic layers, the film was annealed in-situ at 673K for 1 hour. The remaining 250Å Co@sub2@MnGe film was grown by codeposition at 723K and annealed at 823K for 1 hour. RHEED and LEED images from the Co@sub2@MnGe films showed (2x2) reconstruction. For growth on MgO, the substrates were cleaned and annealed ex-situ in O@sub2@ (~1 atm) at 1273K for 2 hours giving a (1x1) RHEED pattern. A growth scheme similar to the one mentioned above was used for the growth of Co@sub2@MnGe on MgO and resulted in a (2x2) RHEED pattern. XRD is consistent with the single crystal epitaxial growth of Co@sub2@MnGe films on SrTiO@sub3@ and MgO, with out-of-plane lattice parameters of 5.745Å and 5.758Å, respectively. Both films are ferromagnetic with no significant in-plane magnetic anisotropy as measured by VSM. This presentation will emphasize the effect of pre-treatment and deposition sequence on the structural and magnetic properties of Heusler alloy films grown on oxide substrates. Supported by ONR-MURI. @FootnoteText@ @footnote 1@G.Koster, B.L.Kropman, G.J.H.M.Rjinders, D.H.A.Blank and H.Rogalla, Appl. Phy. Lett., 73, 2920 (1998).

[1] **Falicov Student Award Finalist**

3:00pm **MI-ThA4 Characterization of Transition Metal Doped MOCVD-Grown ZnO Epifilms and Nanostructures**, ***D. Hill,*** *R. Gateau,* Rutgers University*; J.F. Veyan,* Univ. Tech. Frederico Santa Maria*; L.S. Wielunski, S. Guha, R.A. Bartynski,* Rutgers University*; D.A. Arena,* Brookhaven National Lab*; J. Dvorak,* Montana State University*; P. Wu, Y. Lu, F. Cosandey, V. Poltavets, M. Greenblatt,* Rutgers University
ZnO is a wide bandgap (~3.3 eV) semiconductor that recently has been identified as a promising DMS candidate for room temperature spintronics. We have characterized the chemical, compositional, and magnetic properties of transition metal- (TM-) doped ZnO epitaxial thin films and nanostructures grown by MOCVD. The films and nanopillars were doped with Mn or Fe either by ion implantation or in-situ during MOCVD growth. RBS ion channeling shows a minimum yield < 2% for the ZnO epi films indicating excellent crystallinity. The minimum yield is much higher for the ion implanted samples, but improves dramatically upon annealing. Soft x-ray absorption spectroscopy (SXAS) indicates that the TM dopant may be in either the 2+ or 3+ oxidation state, depending upon annealing history. In-situ doped films exhibit oxidation states similar to ion implanted films that have been annealed. SQUID magnetometry measurements show that both the implanted and annealed films and nanostructures exhibit hysteretic M vs. H curves at temperatures as high as liquid nitrogen temperature. M(T) curves show a small paramagnetic component at 5 K, but the majority of the magnetization remains up to room temperature. TM-ion implanted MOCVD-grown ZnO nanotips show relatively uniform TM concentration (<~ 5%) throughout the tip, and TEM images show no indication of secondary phase formation or metal clustering upon annealing to temperatures as high as 700C. @FootnoteText@ @footnote 1@Supported by NSF grant # ECS-0224166 .

3:20pm **MI-ThA5 Detailed Investigation of Cr-doped Anatase TiO@sub 2@ as a Potential DMS**, ***T.C. Kaspar***, *T.C. Droubay, S.M. Heald, V. Shutthanandan, C.M. Wang, D.E. McCready, J.E. Jaffe, S.A. Chambers,* Pacific Northwest National Laboratory
Since the initial discovery of room temperature ferromagnetism in Co-doped anatase TiO@sub 2@ in 2001, there has been an explosion of interest in doped transition metal oxides as potential dilute magnetic semiconductors (DMSs), which may find application in future spintronic devices. The high electron mobility in n-type anatase TiO@sub 2@ (reduced to create oxygen vacancies) makes it an attractive candidate as a oxide semiconductor host material. Doping with Cr instead of Co is advantageous since Cr metal (antiferromagnetic) is more easily oxidized than Co metal (ferromagnetic). In this talk, we present results of a detailed study of Cr-doped anatase TiO@sub 2@ deposited by oxygen-plasma-assisted molecular beam epitaxy. Phase-pure, epitaxial films are obtained with particle-free surfaces and uniform distribution of Cr. Crystalline perfection is controlled by the deposition rate; nearly perfect films can be obtained at a sufficiently slow rate. For faster deposition rates, room temperature ferromagnetism is observed, with ~ 0.5 μ@sub B@/Cr and a Curie temperature of 690 K. Regardless of deposition rate, XANES and EXAFS indicate Cr incorporates into the anatase lattice as Cr(III), requiring one oxygen vacancy for every two dopants to maintain charge neutrality. The specific site occupancy, as well as the complex role of oxygen vacancies and crystalline defects in the ferromagnetic ordering, will be discussed. The electronic properties of Cr-doped anatase have been investigated in detail by XPS, XAS/XES, XMCD, and anomalous Hall measurements, as well as theoretical calculations of the band structure. These results and the implications for spintronic applications of Cr-doped anatase will be presented.

3:40pm **MI-ThA6 Structural, Electronic and Magnetic Properties of MBE Grown Ti-doped @alpha@-Fe@sub 2@O@sub 3@**, ***S.A. Chambers***, *T.C. Droubay, S.M. Heald, C.M. Wang, K. Rosso,* Pacific Northwest National Laboratory
@alpha@-Fe@sub 2@O@sub 3@ is an antiferromagnetic wide bandgap semiconductor (E@sub g@ = 2.2 eV) which exhibits strong ferromagnetic coupling within cation layers perpendicular to the c axis, and antiferromagnetic coupling between adjacent cation layers. LSDA + U calculations predict that substituting Ti for Fe should lead to a ferrimagnetic state with a large moment per Ti because Ti is predicted to substitute for Fe preferentially in alternating cation layers perpendicular to the c axis.@footnote 1,2@ To test this prediction, we have used oxygen plasma assisted molecular beam epitaxy to grow @alpha@-Ti@sub x@Fe@sub 2-x@O@sub 3@, for which x varied between 0.01 and 0.04, on @alpha@-Al@sub 2@O@sub 3@(0001). Excellent heteroepitaxy was achieved by first growing a @alpha@-Cr@sub 2@O@sub 3@ buffer layer

to grade the lattice mismatch between @alpha@Fe@sub 2@O@sub 3@ and @alpha@-Al@sub 2@O@sub 3@. All Fe was found to be in the +3 charge state by Fe K-shell XAS and Fe 2p XPS. Ti was found to be in the +4 charge state and to uniformly substitute for Fe(III) in the lattice by Ti K-shell XAS and EXAFS, along with ion channeling. The conductivity increased monotonically with x, achieving a value of ~100 Ohm-cm at x = 0.04. All doped films were found to be weakly ferromagnetic at room temperature, as expected if Fe ions were replaced with Ti(IV) ions in a statistical fashion in all cation layers. The coercive field was found to be ~800 Oe, independent of x. The moment was found to be ~0.5 μ@sub B@ per Ti dopant, considerably lower than the 4 μ@sub B@ per Ti dopant predicted by LSDA + U theory.@footnote 1,2@. @FootnoteText@ @footnote 1@ W.H. Butler et al., J. Appl. Phys. 93, 7882 (2003).@footnote 2@ A. Bandyopadhyay et al., Phys. Rev. B 69, 174429 (2004).

4:00pm **MI-ThA7 Highly Spin Polarized Current from Tunnel Spin Injectors and in Magnetic Tunnel Junctions using MgO(100)**, ***S.S.P. Parkin***, IBM Almaden Research Center **INVITED**

Spin-based electronics, often referred to as "spintronics", is a research field of intense current interest, which aims to develop novel sensor, memory and logic devices by manipulating the spin states of electrons or holes in semiconducting materials. This talk will focus on electrical spin injection into semiconductors, which is a prerequisite for spintronics and, in particular, on tunnel based spin injectors operable above room temperature. Two types of spin injectors, formed from 3d transition metal ferromagnets and oxide tunnel barriers, are discussed: a three-terminal magnetic tunnel transistor (MTT) injector)@footnote 1,2@ and a two-terminal magnetic tunnel injector.@footnote 3@ A two terminal tunnel spin injector, comprised of CoFe/MgO(100), is shown to give more than 50% spin polarized current within GaAs (100) heterostructures at room temperature.@footnote 3@ The spin polarization of the injected current is inferred from the electroluminescence polarization (ELP) from GaAs/AlGaAs quantum well detectors. The high polarization values are consistent with giant values of tunneling spin polarization (TSP) measured in superconducting tunneling junctions in which the CoFe/MgO layers are highly textured (100). Recently, we have reported TSP values of up to 85% (at 0.25 K) and tunneling magnetoresistance values (TMR) of >220% in CoFe/MgO(100) magnetic tunnel junctions at room temperature.@footnote 4@ Such high values of TSP and TMR, previously only obtained at low temperatures using half-metallic ferromagnets, promise the development of new families of spintronic devices operating at room temperature based on conventional ferromagnets. * work carried out in collaboration with X. Jiang, R. Wang, C. Kaiser, R. Shelby, R. MacFarlane, G. Solomon and J. Harris. @FootnoteText@ @footnote 1@S. van Dijken et al., Appl. Phys. Lett. 83, 951 (2003). @footnote 2@ X. Jiang, et al., Phys. Rev. Lett. 90, 256603 (2003). @footnote 3@X. Jiang et al, Phys. Rev. Lett. 94, 056601 (2005). @footnote 4@S. S. P. Parkin, et al., Nature Mater. 3, 862 (2004).

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