Magnetic Interfaces and Nanostructures Technical Group
Room 618/619 - Session MI-MoM

New Magnetic Materials

Moderator: B.T. Jonker, Naval Research Laboratory

8:20am **MI-MoM1 Role of Intergrowths in the Naturally Layered Manganites**, ***S.D. Bader,*** Argonne National Laboratory **INVITED**

Doped LaMnO@sub 3@ yields the colossal magnetoresistance (CMR) family of perovskite materials. The physics is governed by competing interactions that include double exchange, super-exchange, Jahn-Teller effects, polarons, charge and spin ordering. To gain further insights, we have been exploring the properties of the related two-dimensional (2D) analogues that form a Ruddlesden-Popper series denoted SrO(LaMnO@sub 3@)@sub n@ where SrO barrier layers separate n-layers of Mn-containing oxygen octahedra. As in the perovskites, the La@super +3@ doped with Sr@super +2@ to yield the requisite mixed valent Mn@super +3@ and Mn@super +4@ needed for the CMR. We focus on n=2 (bilayers) and x=0.4 and 0.3, denoted SrO[(La@sub 1-x@Sr@sub x@)MnO@sub 3@)@sub 2@, which can be viewed as naturally occurring superlattices. They have reduced Curie temperatures relative to the 3D perovskites. Bulk single crystals grown in an optical image furnace are used. These structures are instructive because the competing interactions are now anisotropic. We illustrate examples of fascinating intrinsic and extrinsic behavior, including the intrinsic CMR values and the role of the extrinsic intergrowths on the magnetic properties. Intergrowths are stacking faults, such as occasional missing and/or extra octahedral layers. We find that intergrowths with extra octahedral layers can simulate 2D magnetic inclusions. Their magnetic and scaling properties provide a link to the 2D magnetism of artificially layered ultrathin ferromagnetic films. This work is supported by U.S. DOE BES-MS under contract #W-31-109-ENG-38.

9:00am **MI-MoM3 XPS Study of CMR Perovskite Thin Films: La@sub 0.65@D@sub 0.35@MnO@sub 3@ (D=Ca,Sr,Pb)**, *P.A. Dowben,* University of Nebraska, Lincoln*;* ***H. Dulli,*** University of Tennessee, Knoxville*; B. Xu, Q.L. Xu, S.H. Liou,* University of Nebraska, Lincoln

Surface segregation phenomenon has been investigated in crystalline films of La@sub 0.65@D@sub 0.35@MnO@sub 3@ (D=Ca,Sr,Pb) by angular resolved XPS. We found that surface concentration of the dopant atoms is different from the bulk. Using a binary alloy model, we constructed depth profiles for the above dopants. The surface segregation was most significant in the case of Sr-doped films which also exhibit a surface insulating phase at low temperature as can be seen clearly from the binding energy shift in the core level spectra.

9:20am **MI-MoM4 Orientational Dependence of CMR Manganite Thin Films Observed with Ferromagnetic Resonance Spectroscopy**, ***E.S. Gillman,*** Norfolk State University and Thomas Jefferson National Accelerator Facility*; N. Noginov,* Norfolk State University

Previously we have observed that transport properties depend on crystal orientation and morphology in CMR manganite thin films.@footnote 1@ Here we present ferromagnetic resonance (FMR) data that shows that these films exhibit different properties that depend on thier relative orientation in an applied magnetic field. Single crystal films exhibit larger saturization magnetization when the applied field is perpendicular to the surface, but in polycrystalline films the opposite is true. On all films there is a broadening of the resonance peak near the ferromagnetic-paramagnetic transistion temperature that is characteristic of critical fluctuations. @FootnoteText@ @footnote 1@"Crystallinity and Magnetoresistance in La@sub x@Ca@sub 1-x@MnO@sub 3@ Thin Films", E. S. Gillman, M. Li and K. -H. Dahmen, J. Appl. Phys., 84, 6217 (1998).

9:40am **MI-MoM5 Ferromagnetic Semiconductor Heterostructures Based on (GaMn)As**, ***M. Tanaka,*** University of Tokyo, Japan **INVITED**

We have studied magnetic semiconductor (Ga@sub 1-x@Mn@sub x@)As thin films and III-V based magnetic heterostructures, and present their molecular beam epitaxial growth, structure, magnetic, transport, and magnetooptic properties. The present work, we believe, will give new opportunities to explore an interdisciplinary field between semiconductors and magnetics. (Ga@sub 1-x@Mn@sub x@)As thin films were grown by low-temperature molecular-beam epitaxy (LT-MBE) at 200C - 300C on GaAs(001) substrates. Homogeneous ternary alloys with the Mn content x up to ~0.10 were obtained, and the lattice constants of the zinc-blende (GaMn)As are slightly larger (< 0.4 %) than that of GaAs.@footnote 1@ The (GaMn)As thin films showed a ferromagnetic order with the Curie temperature of 10 K - 100 K. Systematic study indicates that the ferromagnetism of GaMnAs is induced by carriers (holes). The concept of bandgap engineering is well established in nonmagnetic semiconductors. Here, we demonstrate the successful growth of III-V based superlattice (SL) structures consisting of ferromagnetic semiconductor (GaMn)As and nonmagnetic semiconductor AlAs.@footnote 2,3@ Both x-ray diffraction and transmission electron microscopy showed that the SLs are formed with excellent crystal quality and abrupt interfaces. Magnetooptic spectra of these SLs have revealed that, due to quantum confinement effect, the interband transition is systematically blue-shifted with decreasing the thickness of GaMnAs, and that some higher subbands are formed. Furthermore, we have fabricated GaMnAs/AlAs/GaMnAs ferromagnetic tunnel junctions, and have demonstrated large tunneling magnetoresistance (TMR). The feasibility of preparing such magnetic quantum heterostructures based on (GaMn)As, we believe, will open up unique possibility of coupling spinrelated phenomena with the well-established band engineering in III-V semiconductors. @FootnoteText@ @footnote 1@ T. Hayashi, M. Tanaka, T. Nishinaga, H. Shimada, H. Tsuchiya, Y. Ootuka, 8th Int. Conf. on Molecular Beam Epitaxy, Malibu, August 1996, J. Cryst. Growth 175/176, 1063 (1997). @footnote 2@ T. Hayashi, M. Tanaka, K. Seto, T. Nishinaga, H. Shimada, K. Ando, Appl. Phys. Lett. 71, 1825 (1997). @footnote 3@ M. Tanaka, J. Vac. Sci. & Technol. B16, 2267(1998).

10:20am **MI-MoM7 Epitaxial Ferromagnetic Ni@sub 2@MnGa Film Grown on GaAs (001) by Molecular Beam Epitaxy**, ***J.W. Dong,*** *L.C. Chen, D.M. Carr, C.J. Palmstrom,* University of Minnesota

In the bulk, stoichiometric Ni@sub 2@MnGa is ferromagnetic with a Curie temperature 376°K. Above 202°K, the stable austenitic phase has the cubic L2@sub 1@ Heusler structure with a lattice parameter 3% larger than GaAs. This structure can be considered as a NaCl crystal structure of Mn and Ga with Ni in the tetrahedral sites. It may also be considered as an 'ordered' CsCl structure with a simple cubic lattice of Ni with every other interstitial site filled with Mn and Ga, respectively. The similarity in crystal structures suggests that metallic compounds with either the NaCl or CsCl structures should act as excellent templates for Ni@sub 2@MnGa growth. The growth of Ni@sub 2@MnGa on GaAs with a 6 ML-thick Sc@sub 0.3@Er@sub 0.7@As (NaCl structure) lattice matched to GaAs interlayer resulted in single crystal growth. In-situ reflection high energy electron diffraction patterns were streaky, indicative of high crystalline quality. Ex-situ X-ray diffraction and plan-view TEM selected area electron diffraction patterns confirmed single crystal growth and showed that a 300Å thick Ni@sub 2@MnGa grew pseudomorphically on GaAs. Considering the lattice mismatch, this seems surprising. However, we speculate that the epitaxy is stabilizing a new tetragonal phase of Ni@sub 2@MnGa with a = b = 5.65 Å, c = 6.12 Å and will present a model to explain this. Magnetic measurements using vibrating sample and superconducting quantum interference device magnetometers revealed the Ni@sub 2@MnGa to have in-plane magnetization and a Curie temperature ~320°K. The growth and properties of Ni@sub 2@MnGa films grown with a NiGa (CsCl structure) interlayer and directly on GaAs will be compared with ones grown on Sc@sub 0.3@Er@sub 0.7@As interlayers. The effect of the interlayer on the interfacial properties will also be discussed.

10:40am **MI-MoM8 MBE Growth and Characterization of bcc Fe@sub X@Co@sub 1-X@/GaAs(001) Heterostructures**, ***L.C. Chen,*** *B.D. Schultz, J.Q. Xie, C.J. Palmstrom,* University of Minnesota

We have successfully grown bcc Fe@sub X@Co@sub 1-X@ on GaAs(001) at 175°C by Molecular Beam Epitaxy. In-situ reflection high energy diffraction indicates a two dimensional growth mode of epitaxial bcc Fe@sub X@Co@sub 1-X@ on GaAs(001). A 40Å thick Al protective layer was deposited in-situ at a substrate temperature <0°C prior to removal from the MBE system. Ex-situ atom force microscopy studies show atomic steps indicative of a step-flow growth mode. X-ray diffraction data reveal an epitaxial orientation of bcc Fe@sub X@Co@sub 1-X@(001)||GaAs(001). A Rutherford backscattering spectrometry channeling minimum yield of @chi@=11% suggests good crystalline quality epitaxial bcc Fe@sub X@Co@sub 1-X@. Vibrating sample magnetometry measurements revealed in-plane magnetization and square hysteresis loops. In order to minimize interfacial reactions and diffusion during the Fe@sub X@Co@sub 1-X@ growth, we investigated the use of an epitaxial Sc@sub X@Er@sub 1-X@As diffusion barrier interlayer. Sc@sub X@Er@sub 1-X@As is thermodynamically stable on, and is lattice matched to, GaAs. Reflection high energy diffraction indicates a two-dimensional growth mode of epitaxial single crystal Fe@sub X@Co@sub 1-X@ film growth on the

Sc@sub X@Er@sub 1-X@As surface at both 175°C and 470°C. Both ex-situ Rutherford backscattering spectrometry and in-situ Auger electron spectroscopy did not detect arsenic in Fe@sub X@Co@sub 1-X@ films. The effect of Sc@sub X@Er@sub 1-X@As thickness and Fe@sub X@Co@sub 1-X@ growth temperature on the growth mode and magnetic properties will be discussed. Further studies of interfacial transportation properties will also be reported.

11:00am **MI-MoM9 Low-temperature Gaseous Nitriding and Subsequent Oxidation of Epitaxial Ni/Fe Bilayers**, ***A.V. Mijiritskii,*** *M.A. James, D.O. Boerma,* University of Groningen, The Netherlands

Fe-nitrides are of interest due to their anti-corrosive, mechanical and magnetic properties. From a technological point of view, one of the most attractive ways to form Fe-nitrides is gaseous nitriding of Fe in a NH@sub 3@+H@sub 2@ mixture. The disadvantage of this method is the necessity to apply relatively high temperatures upon the nitriding. Lately, a method has been discovered allowing fabrication of pore-free Fe-N phases in a mixture of NH@sub 3@+H@sub 2@ at relatively low temperatures (550-625 K) by using a Ni cap-layer as a catalyst. In the present work we study the behaviour of epitaxial Ni/Fe bilayers upon low-temperature gaseous nitriding as well as the subsequent oxidation of the Ni/Fe-N systems formed. A number of experimental techniques was employed including XRD, RBS, XPS, and CEMS. Epitaxial Ni/Fe bilayers were grown on MgO(100) in-situ by molecular beam epitaxy (MBE) or ex-situ by laser ablation deposition (LAD). Nitriding was done in a dedicated N-oven at 575 K at different nitriding potentials of the NH@sub 3@+H@sub 2@ mixture depending on the nitride phase to be produced. Oxidation of the Ni/Fe-N systems obtained was performed in an O-oven at 525 K in P(O@sub 2@)=1x10@sup -6@ mbar. Upon nitriding in NH@sub 3@+H@sub 2@, oxidation of Fe was observed due to small fraction of H@sub 2@O present in the N-oven. On the basis of the RBS measurements it was concluded that to prevent the oxidation, the thickness of the capping Ni layer should exceed 200 Å. XRD measurements performed on as-nitrided samples revealed that Fe-nitride phases form at higher nitriding potential values in the case of epitaxial Ni/Fe bilayers compared to policrystalline Ni/Fe bilayers. This is probably due to the absence of nucleation sites in the epitaxial layers. The epitaxial relationships of the phases produced and the details of the nitriding and oxidation kinetics are being discussed.

11:20am **MI-MoM10 Epitaxial Growth of La-Ca-Mn-O Thin Film on Out-of-Plane Twinned LaAlO@sub 3@**, ***J.-H. Song***, Korea Institute of Science and Technology, Korea*; K.K. Kim,* Korea Institute of Science and Technology, Seoul*; J.H. Song,* Korea Institute of Science and Technology*; D.-K. Choi,* Hanyang University, Korea*; Y.J. Oh, H.-J. Jung, W.K. Choi,* Korea Institute of Science and Technology, Seoul

LCMO thin film with 145 nm thickness was epitaxially grown on LaAlO@sub 3@ (100) substrate using RF magnetron sputtering. The crystalline structure of LCMO thin film on LaAlO@sub 3@ was characterized using backscattering (BS)/channeling and 4-circle X-ray diffractometer. Thin film grown at 600@sup o@C and 100 W shows the minimum channeling yield of 4.98%. XRD @theta@-rocking also showed the FWHM of 0.311@sup o@ for LCMO (200) peak, which is quite small compared to the previous reported values of 0.4@sup o@-0.5@sup o@. But the @theta@-rocking curve seemed to be composed of 2 peaks which was known due to strained-layer and relaxed-layer. In the RBS and BS/channeling study, only direction showed difference by 1.12@sup o@. In addition, we observed the substrate has the out-of-plane twinned structure from hight resolution XRD @theta@-rokcing on LaAlO@sub 3@ (200) peak. From above results, we confirmed the film with only strained layer was epitaxially grown on the out-of-plane twinned substrate. The full width at half maximum value of XRD @theta@-rocking on LCMO film (200) peak was 0.147@sup o@ after BS/channeling analysis. This value is smaller value than any other reported values of LCMO on LaAlO@sub 3@.

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