SYMPOSIUM F

Spintronics

November 26 – 29, 2001

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* Invited paper

SESSION F1: SPINS IN SEMICONDUCTORS
Chair: James G. Tobin
Monday Morning, November 26, 2001
Room 207 (Hynes)

8:30 AM *F1.1
SPINTRONICS AND QUANTUM INFORMATION PROCESSING IN SEMICONDUCTOR NANOSTRUCTURES. David D. Awschalom, University of California, Department of Physics, Santa Barbara, CA.

There is a growing interest in the use of electronic and nuclear spin in semiconductor nanostructures as a medium for the manipulation and storage of classical and quantum information. Femtosecond-resolved optical experiments reveal a remarkable resilience of electronic spin states to environmental decoherence in a variety of bulk semiconductors, heterostructures, and quantum dots. Optical pulses are used to create a superposition of the basis spin states defined by an applied magnetic field, and to follow the phase, amplitude, and location of the resulting electronic spin precession in these systems. Spin lifetimes can exceed hundreds of nanoseconds, enabling the transport of coherent spin packets over hundreds of microns. Furthermore, coherent spin information can flow across interfaces of dissimilar materials in engineered structures [1]. The interfaces appear surprisingly permeable over a broad range of temperatures, and the transport of spin information can be controlled with both electric and magnetic fields. Even in materials where momentum scattering is strongly enhanced by defects, spin coherence persists to room temperature [2]. Nuclear spin lifetimes, which are orders of magnitude longer than those of electrons, may ultimately enable long-term storage of quantum information. Local manipulation of nuclei can be achieved by periodic optical excitation of precessing electrons that surround the atomic sites. Changes in the magnetization of resonantly tipped nuclei demonstrate the ability to perform all-optical nuclear magnetic resonance (NMR) [3]. This sensitive and spatially selective NMR technique may serve as a basis for the coherent manipulation of nuclear moments at the atomic level. Finally, the capability to integrate ferromagnetism within semiconductor nanostructures may create new schemes for operating on electron and nuclear spins. [1] I. Malajovich et al., Nature, in press (2001). [2] B. Beschoten et al., Phys. Rev. Rapid Commun. B63, 12102-1, (2001). [3] G. Salis et al., Phys. Rev. Lett. 86, 2677 (2001).

9:00 AM F1.2
MONOPOLAR SPIN ORIENTATION AND DETERMINATION OF SPIN RELAXATION TIMES IN QUANTUM WELL STRUCTURES. Sergey D. Ganichev, Sergey N. Danilov, Martin Sollinger, Dieter Weiss, Werner Wegscheider, and Wilhelm Prettl, Institut fuer Experimentelle und Angewandte Physik, University of Regensburg, GERMANY; Vasily V. Bel'kov, Eugenius L. Ivchenko, A.F. Ioffe Physico-Technical Institute, St. Petersburg, RUSSIA.

It is shown that optical spin orientation of free carriers in zinc-blende structure based quantum wells (QWs) causes an electric current which reverses its direction upon changing the helicity of the radiation from left to right circular polarization resulting in a circular photogalvanic effect (CPGE) [1]. This conversion of spin orientation of carriers into directed motion allows to determine spin relaxation times of electrons in *n*-type materials and of holes in *p*-type materials. The monopolar non-equilibrium population of spin-up and spin-down states has been achieved by far-infrared optical excitation of *p*- and *n*-type GaAs/AlGaAs QWs structures. In contrast to usually applied methods of optical spin orientation, in the present case of terahertz excitation only one kind of charge carriers is involved in spin orientation and relaxation processes. The experiments have been carried out on QWs of different width at temperatures varied from 4.2 K to 300 K. As a radiation source a pulsed far-infrared molecular laser has been used delivering 100 ns pulses at wavelength $\lambda = 148\,\mu$m. Spin relaxation times in the range between tens of ps to 1 ns have been derived depending on QW width, mobility and temperature. [1] S.D. Ganichev, S.N. Danilov, J. Eroms, W. Wegscheider, D. Weiss, W. Prettl, E.L. Ivchenko, Phys. Rev. Lett. **86**, 4358 (2001).

9:15 AM F1.3
MAGNETIC GaN AT ROOM TEMPERATURE. N.A. El-Masry, M.L. Reed, M.K. Ritums, H.H. Stadelmaier, M.J. Reed, North Carolina State University, Materials Science and Engineering Department, Raleigh, NC; C.A. Parker, J.C. Roberts, and S.M. Bedair, Electrical and Computer Engineering Department, North Carolina State University, Raleigh, NC.

Dilute magnetic semiconductors (DMS) have received attention because of their potential applications in combining both information processing and data storage within one material system. Most of the work in this area has been concentrating on the (Ga,Mn)As materials system with Curie temperatures about 100 K, thus limiting the potential application of this new field only to cryogenic temperatures. We will report on a new dilute magnetic semiconductor (Ga,Mn)N with a Curie temperature above room temperature which will allow a broader application for spin electronic field. GaN used in this study was grown by MOCVD on (0001) sapphire substrates. Post growth doping of GaN by solid state diffusion of Mn was applied. SIMS results of the Mn-doped samples were found to have a doping profile that levels down to 1-2% Mn. Both x-ray and electron diffraction indicated that secondary phases, such as Mn_3GaN, MnGa, or Mn_4N are not present and (Ga,Mn)N is achieved as a solid solution. The magnetic properties of (Ga,Mn)N films were studied by extraordinary Hall effect (EHE) and vibrating sample magnetometry (VSM). The room temperature hysteresis curves confirmed the magnetic properties of the (Ga,Mn)N films. The sheet resistance measurements at a zero applied field indicated Curie temperatures in the range of 250 - 320 K depending on the sample preparation procedure. We will report on the effect of the sample preparation on the magnetic properties of this new DMS (Ga,Mn)N and its Curie temperature. M.L. Reed, M.K. Ritums, H.H. Stadelmaier, M.J. Reed, C.A. Parker, S.M. Bedair, and N.A. El-Masry, accepted for publication in Materials Letters.

9:30 AM F1.4
AB INITIO MAGNETIC EXCHANGE INTERACTIONS IN Mn DOPED GaAs AND GaN. Mark van Schilfgaarde, Sandia National Labs, Livermore CA.

Exchange interactions of Mn and other TM doped doped GaAs and GaN were calculated within the local spin-density approximation, using an an ab initio linear response technique, and the critical temperature estimated within mean-field theory. It is found that the pairwise interactions are anomalous, decreasing with Mn concentration, thus leading to a saturation in the coupling with Mn concentration. The interactions are found to be much better described according to the Zener double exchange/Anderson superexchange picture than an RKKY description. The reason for this is described in terms of the electronic structure. Using a rigid band model, the counterdoping dependence of the exchange and Tc are estimated. It is found to quickly fall from a ferromagnetic interaction to antiferro with increasing electron content. With increasing hole content the interactions increase to a maximum at about 1/2 hole per Mn, in agreement with a simple double exchange/superexchange picture.

10:15 AM F1.5
FABRICATION AND CHARACTERIZATION OF GaMnP. M.E. Overberg, Univ of Florida, Dept of Materials Engineering, Gainesville, FL; N. Theodoropoulou, Univ of Florida, Dept of Physics, Gainesville, FL; S. Arnason, Univ of Florida, Dept of Physics, Gainesville, FL; B.P. Gila, Univ of Florida, Dept of Materials Engineering, Gainesville, FL; K.T. McCarthy, Univ of Florida, Dept of Physics, Gainesville, FL; C.R. Abernathy, Univ of Florida, Dept of Materials Engineering, Gainesville, FL; S.J. Pearton, Univ of Florida, Dept of Materials Engineerning, Gainesville, FL; A. Hebard, Univ of Florida, Dept of Physics, Gainesville, FL; S.N.G. Chu, Agere Systems, Murray Hill, NJ; R.G. Wilson, Consultant, Stevenson Ranch, CA.

In this paper, we will report on the growth of GaMnP:C thin films by gas source molecular beam epitaxy (GSMBE) utilizing phosphine as the group V source, and co-doped with C via a CBr_4 source for enhanced p-type doping. Results of the epitaxially grown films will be compared to GaMnP films produced via direct implantation of Mn into GaP:C. X-ray diffraction (XRD) of the epitaxial films shows no evidence of second phases in the epitaxial films with Mn concentrations up to 9%. Similarly, selected area diffraction patterns taken in XTEM show only the presence of GaMnP. At Mn concentrations of 6% or less, the material is single crystal as determined by XTEM and RHEED, but with a very rough surface morphology. Analysis of the GaMnP:C by SQUID magnetometry suggests the presence of a ferromagnetic ordering with a Curie temperature above 250 K. Magnetotransport measurements will also be discussed. This is the highest Curie temperature yet reported for a III-V based DMS.

10:30 AM F1.6
CONDITIONS FOR EFFICIENT SPIN INJECTION FROM A FERROMAGNETIC METAL INTO A SEMICONDUCTOR. Albert Fert, Henri Jaffres, Unité Mixte de Physique CNRS-THALES, Domaine de Corbeville, Orsay, FRANCE and Université Paris-Sud, Orsay, FRANCE.

We adapt the spin accumulation model of the perpendicular transport in metallic magnetic multilayers to the problem of spin injection from a ferromagnetic metal (F) into a semiconductor (SC). We show that the problem of the conductivity mismatch between F and SC can be solved by introducing a spin dependent interface resistance (tunnel junction preferably) at the F/SC interfaces. In the case of a F/SC/F structure, a significant value of the magnetoresistance can be obtained if the junction resistance is chosen between two threshold values depending on the resistivity, spin diffusion length and thickness of SC. These results on F/SC/F structures are at odds with recent theoretical results of Rashba and we explain the origin of the discrepancy. We will illustrate the results of our model with numerical calculations for Co/GaAs/Co structures for several types of geometry (vertical or lateral F/SC/F structures with various geometrical parameters).

10:45 AM F1.7
SPIN POLARIZATION AND INJECTION IN ZnMnSe/ZnCdSe HETEROSTRUCTURES. I.A. Buyanova, W.M. Chen, I.G. Ivanov, B. Monemar, Linkoping University, Dept of Physics, SWEDEN; A.A. Toropov, Y. Terent'ev, S.V. Sorokin, A.V. Lebedev, S.V. Ivanov and P.S. Kop'ev, A.F. Ioffe Physico-Technical Institute, Russian Academy of Sciences, St. Petersburg, RUSSIA.

We present our recent results from a detailed study of spin polarization and spin injection in II-VI semiconductor heterostructures consisting of diluted magnetic semiconductor (DMS) barriers and a non-magnetic quantum well (QW), by magneto-optical spectroscopy in combination with tunable laser excitation. The DMS barriers serve as spin polarizers as a result of the giant Zeeman effect, where spin-polarized carriers can be selectively excited via resonant photo-excitation and can thereafter undergo spin relaxation and transfer to the QW. The non-magnetic ZnCdSe QW is employed as a detector of spin injection by monitoring its spin-dependent excitonic recombination. Two types of DMS barriers were examined, one is a ZnMnSe layer and the other is a 10-period ZnMnSe/CdSe superlattice (SL). The composition of Mn is up to 4%. Between the DMS barriers and the non-magnetic quantum well, a non-magnetic ZnSe spacer is inserted to ensure a predominant role of the spin injection as the source of spin polarization in the QW. It is shown that the spin population and polarization in the QW is largely determined by the spin injection from the DMS barriers leading to a reverse in sign of the circular polarization of the QW exciton emission. Up to 30% spin polarization can be achieved at 5T in both types of structures when spin undergoes a tunneling transfer from the semimagnetic barriers of which the bandgap energy is lower than that of the spacer. It was indicated that spin relaxation seems to be faster in the DMS SL barrier, as compared to that in the ZnMnSe barrier. This has led to the difference that spin relaxation precedes spin injection in the former case whereas the opposite occurs in the latter case. A phonon bottle-neck effect has also been observed in the experiment when spin relaxation can be significantly affected.

11:00 AM F1.8
CaB_6: A NEW SEMICONDUCTING MATERIAL FOR SPIN ELECTRONICS. H.J. Tromp[a], P. van Gelderen[a,b], P.J. Kelly[a], G. Brocks[a], and P.A. Bobbert[c]; [a]Faculty of Applied Physics and MESA Research Institute, University of Twente; [b]Faculty of Sciences and Research Institute for Materials, University of Nijmegen; [c]Department of Applied Physics and COBRA Research School, Eindhoven University of Technology, THE NETHERLANDS.

Ferromagnetism was recently observed[1] at unexpectedly high temperatures in La-doped CaB_6 and a number of theoretical proposals were made to explain these observations. The starting point for all three proposals is an electronic band structure calculated within the local density approximation which describes the undoped hexaboride as a semimetal with a very small overlap between the highest boron-derived valence band and the lowest calcium-derived conduction band. Here we report the results of parameter-free quasiparticle calculations of the single-particle excitation spectrum which show that CaB_6 is not a semimetal but a semiconductor with a band gap of 0.8 eV[2]. This finding has far-reaching consequences for understanding the basic properties of the doped, ferromagnetic phase and for applications. The magnetism in $La_xCa_{1-x}B_6$ occurs just on the metallic side of a Mott transition in the La-induced impurity band. As a magnetic semiconductor $La_xCa_{1-x}B_6$ has some remarkable properties compared to the magnetic semiconductors which have recently been used to study spin-injection, most notable of which is the Curie temperature of 900 K which should make room-temperature device operation possible.
[1]D.P. Young, D. Hall, M.E. Torelli, Z. Fisk, J.L. Sarrao, J.D. Thompson, H.-R. Ott, S.B. Oseroff, R.G. Goodrich, and R. Zysler, Nature **397**, 412 (1999).
[2]H.J. Tromp, P. van Gelderen, P.J. Kelly, G. Brocks, and P.A. Bobbert, Phys. Rev. Lett. **87**, 16401 (2001).

11:15 AM F1.9
INTERFACE STATES IN INVERTED MAGNETIC QUANTUM WELLS TYPE $A^{II}{}_{1-x}Mn_x\ B^{VI}/\ A^{II}\ B^{VI}/A^{II}{}_{1-x}Mn_x\ B^{VI}$. Natalia Malkova, Materials Research Laboratory, University Park, PA; Ulf Ekenberg, Department of Microelectronics and Information Technology, Royal Institute of Technology, Kista, SWEDEN.

The electronic band-edge spectrum of the interface states in the magnetic semiconductor quantum wells based on narrow-gap semiconductors with mutually inverted band arrangement is studied within the envelope-function formalism. Interface states are shown to appear in these structures in the case of overlapping bulk bands of the constituents. The hybridization between the bare *sp*-electron states and the *d*-states of the Mn atoms leads to spin-splitting. The spin-splitting effect of the interface states as a function of external magnetic field, well width, the band offsets and fraction of the magnetic atoms, is studied. The results give evidence of the perspective for using the magnetic semiconductor structures in spin electronics.

11:30 AM F1.10
FIRST PRINCIPLES STUDIES OF RASHBA EFFECT IN SUPERLATTICES. Jacek A. Majewski, Peter Vogl, Walter Schottky Institute, Technical University of Munich, Garching, GERMANY.

We present first-principles calculations of k-linear zero-field spin splittings of electrons and holes in semiconductor heterostructures and superlattices. The most commonly cited contribution to the k-linear zero-field spin splitting is the Rashba effect [1]. However, its magnitude, physical origin, the role of interfaces, and dependence on macroscopic electric fields have remained controversial [1]. We have studied the spin splittings in the conduction and valence bands by performing fully relativistic pseudopotential local density functional calculations of cubic GaAs/AlGaAs and GaN/AlGaN as well as wurtzite GaN/AlGaN superlattices. In zincblende superlattices with a common anion or cation, the Rashba effect vanishes and the k-linear zero-field spin splittings are entirely caused by the Bulk Inversion Asymmetry (BIA) term that originates from the bulk Dresselhaus term. The corresponding BIA constants α_{BIA} are of the order of 0.03 - 0.10 eV Å, and we find them to vanish in the limit of large superlattice periods. Furthermore, we find external electric field to induce Rashba constants α_R that are typically smaller than α_{BIA}. In the wurtzite structure, the Rashba effect is a bulk effect, in contrast to the situation in zincblende crystals. The calculations for wurtzite GaN/AlGaN superlattices demonstrate that the presence of interfaces enhances the Rashba constant. Furthermore, we have developed a simple tight-binding model of the k-dependent spin splitting effects that sheds light on the physical origin of the Rashba effect and clarifies its dependence on the *local* microscopic structural details. [1] P. Pfeffer, Phys. Rev. B **59**, 15902 (1999), and references therein.

11:45 AM F1.11
GROWTH AND PROPERTIES OF FERROMAGNETIC (Ga,Mn)As/ZnSe HETEROSTRUCTURES. S.H. Chun, K.C. Ku, S.J. Potashnik, P. Schiffer, and N. Samarth, Department of Physics and Materials Research Institute, The Pennsylvania State University, University Park, PA.

Recent interest in spin dependent phenomena in semiconductors has resulted in great attention on $Ga_{1-x}Mn_xAs$, a ferromagnetic semiconductor with a Curie temperature as high as 110 K. Optical spin injection has already been demonstrated in a light emitting diode structure employing $Ga_{1-x}Mn_xAs$ as a spin aligner. Other spin dependent devices using this new material are also expected for demonstrating proof-of-concept semiconductor "spintronics" applications. However, the growth of homogeneous $Ga_{1-x}Mn_xAs$ epilayers requires low substrate temperatures (200°C~300°C), limiting the quality of the other III-V semiconductor components in complex heterostructures. Here, we report the fabrication of $Ga_{1-x}Mn_xAs$/ZnSe heterostructures in either sequence along the growth axis. Since the optimal growth temperatures of both materials are compatible with each other, this may allow flexibility in the fabrication of complex heterostructures that include both semiconductor and ferromagnetic components. While the growth of ZnSe on top of a $Ga_{1-x}Mn_xAs$ epilayer is readily achieved using standard MBE procedures, the homogeneous growth of the reverse sequence is more demanding. We have successfully achieved the latter by using a thin re-crystallized GaAs template prior to $Ga_{1-x}Mn_xAs$ deposition. We find that – under the same flux conditions – the ferromagnetic transition temperature of $Ga_{1-x}Mn_xAs$/ZnSe is higher than that of $Ga_{1-x}Mn_xAs$/GaAs. We discuss the effect of Mn concentration, ZnSe surface termination, and low temperature post-annealing on the physical properties of $Ga_{1-x}Mn_xAs$ on ZnSe, as well the effects of n-doping the ZnSe layer. Supported by grants from ONR, DARPA and NSF.

SESSION F2: SPIN DEPENDENT TUNNELING
Chair: Albert Fert
Monday Afternoon, November 26, 2001
Room 207 (Hynes)

1:30 PM *F2.1
INTERFACE EFFECTS AND SPIN FILTERING IN MAGNETIC TUNNEL JUNCTIONS. Patrick R. LeClair, Henk Swagten, Juergen Kohlhepp, Wim de Jonge, Department of Applied Physics and

COBRA Research Institute, Eindhoven University of Technology, Eindhoven, THE NETHERLANDS.

Since the recent demonstration of large magnetoresistance effects in Magnetic Tunnel Junctions (MTJs), consisting of two ferromagnetic electrodes separated by a thin (~1nm) insulating barrier, there has been a renewed technological and fundamental interest in the tunneling phenomenon. Within 5 years of the reproducible experiments, prototypes of non-volatile Magnetic Random Access Memories (MRAMs) and read-heads for ultra-high density magnetic recording based on MTJ's have already been demonstrated. Although the basic principles behind the large magnetoresistance effects are understood, and considerable progress has been made in utilizing these effects, the exact mechanisms remain elusive. The first portion of the talk will outline the key ingredients leading to large magnetoresistance in these structures as well as the historical development of these concepts in relation to tunneling structures. The second portion of the talk will focus on recent results using ultra-thin interfacial layers ("dusting layers") and interfacial engineering to demonstrate the dominant role of the interfacial electronic structure in magnetic tunnel junctions. Using Co/M/ Al_2O_3/Co and Co/M/M′/Al_2O_3/Co (M,M′=Cu,Cr,Au,Ru) structures, we have demonstrated that the tunneling spin polarization, and thus tunnel magnetoresistance, is determined by only the outermost monolayers of the electrode in contact with the insulating barrier. With the use of "interfacial engineering" one can correlate the transport properties of these devices with the local interfacial electronic structure and perform unique, fundamental studies of spin polarized transport through ferromagnet-nonmagnet interfaces. Finally, time permitting, a new magnetoresistance effect using spin filter barriers will be discussed.

2:00 PM *F2.2
ELECTRONIC PROPERTIES OF MAGNETIC TUNNEL JUNCTIONS. E.Y. Tsymbal, I.I. Oleinik, and D.G. Pettifor, Oxford Univ, Dept of Materials, Oxford, UNITED KINGDOM.

The factors that control the spin polarization of the conductance in magnetic tunnel junctions will be discussed. It will be shown that the spin polarization and tunneling magnetoresistance depend not only on the ferromagnets alone but are affected strongly by the electronic properties of the insulator and the ferromagnet/insulator interface. This will be illustrated by comparing the electronic structure of the cobalt/alumina and cobalt/strontium titanate tunnel junctions, which is known to have a different sign of the spin polarization [1]. Disorder within the ferromagnetic electrodes affects the spin polarization by breaking the symmetry and by intermixing the surface and propagating states, which will be demonstrated by considering tunneling between Fe electrodes. The influence of the localized states due to defects or impurities within the insulator on tunneling magnetoresistance will also be addressed. It will be shown that the local magnetoresistance is very sensitive to the electronic state of the impurity, which can be detected by STM [2].
[1] J.M. De Teresa et al., Phys. Rev. Lett. 82, 4288 (1999).
[2] W. Wulfhekel et al., Appl. Phys. Lett. 78, 509 (2001).

3:00 PM F2.3
BALLISTIC ELECTRON EMISSION MICROSCOPY OF ULTRA-THIN ALUMINUM OXIDE TUNNEL BARRIERS FOR MAGNETIC TUNNEL JUNCTIONS. A.C. Perrella, W.H. Rippard, R.A. Buhrman, School of Applied and Engineering Physics, Cornell University, Ithaca, NY.

Ballistic electron emission microscopy has been used to study thin aluminum oxide tunnel junction barriers formed by the natural oxidation of both sputter deposited and thermally evaporated aluminum. We have investigated the formation of these barriers as a function of both aluminum thickness and oxygen dosage. We have found that a complete barrier with a uniform barrier height of 1.2 eV can be made with 0.6 nm of Al and ~30 mTorr - sec exposure to oxygen. Longer oxygen exposures, which are generally used to produce MTJ barriers, do not alter the barrier height. If magnetron sputtering is employed to produce the metallic layers then 1 nm of Al is required for a uniform barrier. In addition to transport measurements, scanning tunneling spectroscopy of exposed aluminum oxide was done to investigate the density of states. We have found that finite states exist below the barrier height which indicates a transition from local to extended states with increasing voltage.

3:15 PM F2.4
INVERSE TMR EFFECT IN $Co_{0.9}Fe_{0.1}/SrTiO_3$ /$La_{0.7}Sr_{0.3}MnO_3$ TUNNEL JUNCTIONS. M. Sugiyama, H. Asano, M. Matsui, Dept. of Crystalline Materials Science, Nagoya University, Nagoya, JAPAN; J. Hayakawa, M. Ichimura, S. Kokado, K. Itou, Hitachi Ltd., Tokyo, JAPAN; and A. Sakuma, Hitachi Metals Ltd., Saitama, JAPAN.

Magnetic tunnel junctions have been fabricated with half-metallic $La_{0.7}Sr_{0.3}MnO_3$ and $Co_{0.9}Fe_{0.1}$ electrodes. The junctions have a spin valve structure with an antiferromagnetic $Mn_{0.8}Ir_{0.2}$ layer. The measurements have shown that the junctions exhibit spin-valve type R-H loops with inverse TMR effect. The TMR ratio is 22% at 4.2 K, and its bias dependence is highly asymmetric with respect to the bias direction. A negative spin polarization for $Co_{0.9}Fe_{0.1}$, deduced from inverse TMR observed, is consistent with the band structure calculation using the LMTO-CPA method.

3:30 PM F2.5
FIELD SENSORS BASED ON SPIN DEPENDENT TUNNELING: ON THE USE OF EXCHANGE BIASED TOP ELECTRODE. D. Lacour, H. Jaffrés, O. Durand, P. Etienne, J-L. Maurice, F. Petroff, A. Vaurés, J. Humbert, F. Nguyen Van Dau, Unité Mixte de Recherches CNRS-THALES, Domaine de Corbeville, Orsay, FRANCE.

The rapid development of spin dependent tunneling technology is associated with needs for at least three types of related devices, namely read heads, non-volatile memories and low-field sensors. In this later case, and contrary to the other ones, one expects to develop an analog device which will deliver an output signal proportional to the magnetic field to be detected. The linearisation of the tunnel magnetoresistance signal requires a very careful control of the magnetic properties in each electrode of the junction. In practice, one has to introduce an uniaxial or unidirectional anisotropy in each electrode in such a way that the two easy axis are perpendicular. We are developing such a concept of linear magnetoresistive sensor, wherein the bottom (soft) electrode has its magnetization direction controlled by a deposition on top of a non planar substrate[1], whereas the top (hard) electrode is exchange biased due to a contact with an antiferromagnetic layer. We will show to what extend the use of such a stack allow to control the angular dependence of the tunnel magnetoresistance. The proof of concept of this sensor was achieved using CoO as the antiferromagnetic layer blocking the top electrode[2]. In order to obtain room temperature operation, we have recently concentrated on the use of IrMn instead. We will discuss the correlations between the magnetic properties of the exchange biased top electrode and its structural properties, in particular with respect to the fact that it is deposited on top of an amorphous aluminium oxide barrier. [1] F. Montaigne et al., Appl. Phys. Lett., 76, 3286 (2000) [2] H. Jaffrés et al., Phys. Rev. B, (August 2001), to appear. Work partially funded by the European Community under grants BRPR-CT98-0657 ("Tunnelsense") and E-32464 ("Massdots").

3:45 PM F2.6
FIRST-PRINCIPLES MODELING OF $Co/SrTiO_3/Co$ MAGNETIC TUNNEL JUNCTIONS. I.I. Oleinik, E.Y. Tsymbal and D.G. Pettifor, Oxford University, Department of Materials.

Experimental results show that the spin-polarization (SP) of the tunneling current in magnetic tunnel junctions (MTJs) depends on structural and electronic properties of the entire junction including the insulator and the ferromagnet/insulator interface. In particular, positive values of the SP were obtained when tunneling occurs through an alumina insulating layer whereas it is negative when a $SrTiO_3$ barrier is used[1]. We have performed first-principles density functional calculations of the atomic and electronic structure of $Co/SrTiO_3/Co$ MTJs in order to elucidate the factors controlling the SP of the tunneling current. Full optimization of the atomic structure of the MTJs was made for different types of interface terminations and the thermodynamically stable structures were identified. The spin-polarized electronic structure for the most stable TiO_2 terminated $Co/SrTiO_3/Co$ is analyzed including layer- and atom-projected densities of states, local charges and magnetic moments. Finally, we make comparisons of electronic and magnetic properties of $Co/SrTiO_3/Co$ and $Co/Al_2O_3/Co$ MTJs. [1] J.M. De Teresa et al, Science, 286, 507 (1999), Phys. Rev. Lett. 82, 4288 (1999).

SESSION F3: IN-ROOM POSTER SESSION
Chair: Evgeny Y. Tsymbal
Monday Afternoon, November 26, 2001
4:00 PM
Room 207 (Hynes)

F3.1
THEORY OF OSCILLATORY MAGNETORESISTANCE IN TUNNEL JUNCTIONS WITH A NONMAGNETIC SPACER. H. Itoh, J. Inoue, Nagoya Univ, Dept of Applied Physics, Nagoya, JAPAN; A. Umerski, J. Mathon, M. Villeret, City Univ, Dept of Mathematics, London, UNITED KINGDOM.

Recent experiments have shown clear oscillations of the tunnel magnetoresistance (TMR) as a function of the thickness of the spacer layer inserted between the insulator and one of the ferromagnets[1]. The purpose of this work is to clarify the origin of the oscillation in

TMR based on a microscopic theory and to show the difference between the characteristic features of the oscillatory TMR and those of exchange coupling and GMR in magnetic multilayers. It is also investigated how the oscillation is affected by the randomness.
We consider a junction consisting of two semi-infinite ferromagnetic leads separated by a thin insulating barrier and a nonmagnetic spacer layer. The system is described by a single-orbital tight-bind Hamiltonian on a simple cubic lattice. Substitutional randomness inserted at the interface and within the barrier is treated by the coherent potential approximation and a numerical simulation for finite size clusters. We calculate the spin-dependent tunnel conductance and TMR ratio of the junction using the linear response theory (Kubo formula).
It is shown that TMR oscillates with increasing spacer layer thickness due to the interference effect caused by the quantum well in the spacer layer. In addition to a period determined by the Fermi wave vector in the spacer layer, which is responsible to the oscillation of the exchange coupling, a period given by the height of the quantum well is found in the oscillation. In the absence of the randomness, the asymptotic value of the TMR ratio is not zero in contrast to the asymptotic behavior of the oscillatory exchange coupling. However, it turns out that the randomness rapidly decreases TMR and makes the asymptotic value of the TMR ratio zero.
[1] S. Yuasa et al., to be published.

F3.2
SPIN-DEPENDENT TUNNELING EXPERIMENTS IN FULLY EPITAXIAL Fe/MgO/FeCo(001) TUNNEL JUNCTIONS. M. Bowen, V. Cros, F. Petroff, A. Fert, UMP CNRS/THALES, Orsay, FRANCE; C. Martinez-Boubeta, J.L. Costa-Krämer, J.V. Anguita, A. Cebollada, F. Briones, IMM, CNM-CSIC, Tres Cantos, Madrid, SPAIN; J.M. de Teresa, ICMA-CSIC, Zaragoza, SPAIN.

The magnetoresistance of magnetic tunnel junctions (MTJs) is of uncontested interest for important applications with, in particular, promising perspectives for the fabrication of nonvolatile memories (MagneticRAM). Up to now, most studies have been performed on MTJs in which the insulating barrier between the ferromagnetic electrodes is a layer of amorphous alumina. MTJs with alumina provide large and reproducible tunneling magnetoresistance (TMR). However, to understand the physical mechanisms of spin-dependent tunneling, a transport study through an amorphous insulator is hardly accessible in a theoretical approach. Towards this end, much work has been expended to characterize the growth and electrical behavior of ultrathin MgO layers [1]. Here, we present experimental results showing large TMR values in Fe(001)/MgO(001)/FeCo(001) epitaxial tunnel junctions grown by a combination of laser ablation and triode sputtering onto MgO-buffered GaAs(100). As evidenced by RHEED, x-ray diffraction and TEM analyses, optimized growth conditions result in entirely epitaxial samples of high crystalline quality with flat, sharp interfaces [2]. Fe(100)/MgO(20Å/FeCo(100) junctions show up to 60% TMR at 30K, to be compared with 13% obtained recently by Yuasa et al. on (100)-oriented Fe/amorphous-Al_2O_3/FeCo tunnel junctions [3]. This difference demonstrates that the spin polarization of tunneling electrons can not be directly correlated with the spin-polarized DOS of a free metal surface, but depends on the actual electronic structure of the barrier/electrode system. Furthermore, we construe from the bias dependence of the TMR, previous experimental results and recent calculations [4] that s-character electrons are predominantly tunneling in the case of a 20Å MgO(100) barrier. [1] W. Wulfhekel et al, Appl. Phys. Lett. 78, 509 (2001) [2] C. Martinez Boubeta, J. of Crystal. Growth, 226, 223 (2001) [3] S. Yuasa et al, Europhys. Lett. 52, 344 (2000) [4] W.H. Butler et al, Phys. Rev. B, 63, 54416 (2001).

F3.3
INFLUENCE OF SINTERING CONDITIONS ON MAGNETO-TRANSPORT OF Sr_2FeMoO_6. Amit Sharma, Karen Yates, Imperial College, Dept of Physics, London, UNITED KINGDOM; L.F. Cohen, Imperial College, Dept of Physics, London, UNITED KINGDOM; J.L. MacManus-Driscoll, Imperial College, Dept of Materials, London, UNITED KINGDOM.

Sr_2FeMoO_6 (SFMO) is a conducting ferromagnet with an ordered double perovskite structure and a transition temperature of 420K. A high spin-polarisation of carriers is beneficial for the potential application of tunneling magnetoresistance. While the optimum processing of SFMO is not fully understood, it is clear that oxygen is critical for maintaining the desired cation oxidation state and the level of doping. In this work, we report on the low field MR and structure of SFMO fabricated under different sintering conditions (pO2 and temperature).

F3.4
METAL-INSULATOR PHENOMENA OF ORDERED DOUBLE PEROVSKITES $(Sr_{1-y}Ca_y)_2FeReO_6$. H. Kato, T. Okuda, Y. Okimoto, Y. Tomioka, JRCAT, Tsukuba, JAPAN; K. Oikawa, T. Kamiyama, KEK, Tsukuba, JAPAN; Y. Tokura, University of Tokyo, Department of Applied Physics, Tokyo, JAPAN.

Recently, ordered double perovskites Sr_2FeMoO_6 and Sr_2FeReO_6 have been reported as a new class of prospective magnetoelectronic compounds, which show tunneling magnetoresistance at room temperature in polycrystalline form due to the half-metallic nature with high magnetic Currie temperature Tc. Among these materials, Ca_2FeReO_6 has been known as a ferromagnetic oxide with high Tc=538K. Although the insulating nature of this compound was reported recently, the magnetic and electronic properties of Ca_2FeReO_6 have not been clearly understood as yet. In this study, we have prepared the A-site solid solution $(Sr_{1-y}Ca_y)_2FeReO_6$, and investigated their magnetic and electronic properties. Polycrystalline $(Sr_{1-y}Ca_y)_2FeReO_6$ (0<y<1) were prepared by the solid state reaction. Crystal symmetry was changed from tetragonal to cubic and orthorhombic with increasing Ca content, y at room temperature. Rietveld analysis indicated that degree of ordering of Fe and Re on the B-site was more than 95%. We have found that all the compounds are in a ferromagnetic metallic state at room temperature, while the ferromagnetic insulating state emerges for y>0.4 below 150K. The metal-insulator transition at the ground state may occur via the change of the one-electron bandwidth. We have also found the end compound Ca_2FeReO_6 (y=1) shows the thermally induced metal-insulator transition associated with the lattice-structural transition around 150K. This work, supported in part by NEDO, was performed in JRCAT under the joint research agreement between AIST and ATP.

F3.5
THICKNESS DEPENDENCE OF MAGNETIC AND TRANSPORT PROPERTIES OF EPITAXIAL $SrRuO_3$ FILMS. G. Herranz, B. Martínez, J. Fontcuberta, Institut de Ciencia de Materials de Barcelona - CSIC, SPAIN; F. Sanchez, M.V. García-Cuenca, C. Ferrater, M. Varela, Depto. de Física Aplicada, F. Física, U. de Barcelona, Barcelona, SPAIN.

Spin-dependent devices based on manganites have an important drawback in the strong decrease of the tunnel magnetoresistance (MR) with temperature, making them almost useless at temperatures near to the Curie temperature. It has been suggested that double exchange (DE) materials are prone to display spin depolarization at interfaces and therefore, alternative materials not based in DE mechanism will be desirable. The itinerant ferromagnet $SrRuO_3$ seems to be a promising alternative but not much is known about the role of surfaces and interfaces in this material. To address these issues we have prepared epitaxial thin films of $SrRuO_3$, with different thickness ranging from 2 to 300 nm, on top of STO and LAO substrates by using pulsed laser deposition. The quality of the samples has been checked by using X-ray diffraction obtaining rocking curves of about 0.08° to 0.11° with surface roughness of 2-4 $Å$. For samples grown on top of STO substrates both magnetic and electronic transport measurements indicate a ferromagnetic transition temperature that varies between about 145 K and 160 K shifting up as the films thickness increases. On the contrary, films grown on top of LAO substrates do not show any correlation between transition temperature and thickness. Resistivity values of about 300 $\mu\Omega$cm at room temperature are found for the thicker samples, nevertheless it rises up as thickness decreases and a semiconducting behavior is observed at low temperatures for samples with thickness below about 20 nm. Values of saturation magnetization at low temperatures are found to be decreasing when reducing the film thickness. These results may indicate that also in SRO there is a non-conducting and poorly magnetic layer close to interface with the substrate.

F3.6
LATTICE-MISMATCH STRAIN EFFECTS IN COLOSSAL MAGNETORESISTIVE MANGANITE THIN FILMS. M. Rajeswari, Towson University, Dept. of Physics, Astronomy and Geosciences, Towson, MD; A. Biswas, A. Sharma, R.L. Greene and T. Venkatesan, University of Maryland, NSF MRSEC and Center for Superconductivity Research, College Park, MD; A.J. Millis, Rutgers University, Dept. of Physics and Astronomy, Piscataway, NJ; C.S. Nelson, J.P. Hill and Doon Gibbs, Physics Department, Brookhaven National Laboratory, Upton, NY; F. Yokaichiya and C. Giles, Universidade Estadual de Campinas, Campinas, BRAZIL.

Electrical and magneto-transport properties of epitaxial manganite thin films on lattice mis-matched substrates show a systematic dependence on the film thickness. There have been attempts to use this thickness dependence to quantify the effect of lattice-mismatch induced bi-axial strains under the basic assumption that a film of a given thickness represents a well-defined strained-state. Contrary to this assumption, our studies indicate that the manganite thin films on lattice-mismatched substrates are characterized by inhomogeneous strain distribution both laterally and along the film thickness. We will present systematic data on the thickness dependence of the structure, microstructure, magnetic and transport properties of $La_{0.67}Ca_{0.33}MnO_3$ thin films on lattice-mismatched substrates. Not surprisingly, our attempt to analyze the thickness dependence using a model of thickness dependent uniform strain is not very successful. For a certain thickness range, the electrical transport properties of such strained films can be described by a parallel resistor model comprising of a fully strained insulating layer close to the substrate and an overlying strain-relaxed layer with bulk-like properties. We conclude that while the physical origin of the thickness dependence of the transport properties is clearly the Jahn Teller type component of the lattice mismatch strain, quantification of this strain and its correlation with transport properties is rendered complicated by the inhomogeneous distribution of strain in partially strain-relaxed films. We will also discuss our on-going work on the influence of lattice mismatch strain on charge and orbital ordering in thin films of $Pr_{1-x}Ca_xMnO_3$. Acknowledgement: Work at the University of Maryland was supported by the NSF MRSEC (DMR-00-8008). Work at Brookhaven National Laboratory was supported by the U.S DOE, Division of Materials Science, (Contract #DE-AC02-98CH10886). F.Y and C.G. acknowledge support for this work from LNLS (Brazil) financed by CNPq and FAPESP (Contract #96/05586-6)

F3.7

PHOTOINDUCED SWITCHING IN CMR MATERIALS.
N. Noginova, E. Arthur, R. Ulysse, E. Gillman, C.E. Bonner, Center for Materials Research, Norfolk State University, Norfolk, VA.

Fast switching from conductor to insulator induced by laser light illumination has been studied in colossal magnetoresistance crystals and thin films of $La_{1-x}Sr_xMnO_3$ in the range of ferromagnetic phase transition. Based on our experimental data on the photoresponse as a function of temperature, electric current and laser light intensity, we have demonstrated that the switching and relaxation processes are determined by spin-lattice relaxation and heat conduction. The relaxation time constants for the films and single crystals in study as well as the specific heat of the phase transition have been determined.

F3.8

TWO CURIE TEMPERATURES IN A SINGLE IRON THIN FILM.
Stéphane Andrieu, Christophe Chatelain, Mohamed Lemine, Bertrand Berche, Lab. de Physique des Matériaux, CNRS-Univ H. Poincaré, Nancy, FRANCE; Philippe Bauer, Univ de Franche-Comté, Montbéliard, FRANCE.

Due to size effect, the decrease of the Curie temperature of a ferromagnetic film with its thickness is now well established on both experimental and theoretical points of view [1]. However, the Curie temperature variation with the thickness is always considered as continuous when the thickness is varied from n to n 1 atomic planes. In other words, the Curie temperature is assumed to only depends on the quantity of deposited material. We show here that in the particular case of thin Fe films grown on Ir(100) by MBE, two magnetic transitions are observed in a thin Fe film with a fractional number of deposited monolayers (ml). The Curie temperatures (Tc) are determined by both Mössbauer spectroscopy and ac susceptometry. For an integer number of Fe atomic planes, we observed only one peak in the susceptibility measurement, corresponding to Tc=65K for 4 ml and Tc=145K for 5 ml. For a 4.5ml thick deposit with a smooth surface, we do not observe a unique peak located between 65 and 145K as usually observed, but two peaks, one located near 65K and the other near 145K. In fact, as the growth is layer by layer, the morphology of a 4.5 ml thick film is a mixing of areas of 4 ml thick and areas of 5 ml thick. If we assume that the magnetic coherence length is smaller than the 4 and 5ml thick areas, these areas seem to be magnetically “independent” and two Curie temperatures should be observed. We performed Monte carlo simulations to justify this assumption.

F3.9

INTERDIFFUSION IN EXCHANGE BIASED NiFe/IrMn/CoFe ELECTRODE IN MAGNETIC TUNNEL JUNCTIONS. H.D. Jeong, J.H. Lee, I.L. Rho, C.S. Yoon, C.K. KIm, Hanyang Univ, Dept of Materials Science and Engineering, Seoul, KOREA.

Auger Electron Spectroscopy (AES) and Rutheford Backscattering Spectroscopy (RBS) analysis were carried out to elucidate the extent of interdiffusion during thermal treatment of the pinned electrode(Ta/NiFe/IrMn/CoFe)of the magnetic tunnel junction multi-layer. From concentration profile results from RBS and AES, a significant amount of Mn-CoFe interdiffusion was observed when the sample was annealed at 200-400deg. under vacuum. The multi-layer we completely intermixed at 400deg., losing the exchange bias between IrMn and CoFe layers. It was showmn that the migration of Mn was enhanced by the preferential oxidation of Mn on the Surface. When Ta oxidation protection was deposited on top of the electorde, the Mn diffusion was minimized up to 300deg. Our experiment suggests that the Mn diffusion to the insulation layer could be enhanced by the presence of the free oxygen radicals in the insulation layer remaining from the plasma oxidaion of the Al layer in magnetic tunneling junctions.

F3.10

SHOT NOISE IN FERROMAGNET - NORMAL METAL SYSTEMS.
Yaroslav Tserkovnyak and Arne Brataas, Harvard University, Lyman Laboratory of Physics, Cambridge, MA.

We formulate a semiclassical theory of the low frequency shot noise in ferromagnet - normal metal systems. Non-collinear magnetization directions of the ferromagnetic leads, arbitrary junctions and the elastic and inelastic scattering regimes are considered. The shot noise is governed by a set of mesoscopic parameters that are expressed in terms of the microscopic details of the junctions in the circuit. Explicit results in the case of ballistic, tunnel, and diffusive junctions are evaluated. The shot noise, the current and the Fano factor are calculated for a double barrier ferromagnet - normal metal - ferromagnet system. It is demonstrated that the shot noise can have a non-monotonic behavior as a function of the relative angle between the magnetizations of the ferromagnetic reservoirs.

F3.11

CIRCULAR PHOTOGALVANIC EFFECT IN Si/Ge SEMICONDUCTOR QUANTUM WELLS. Sergey D. Ganichev, Franz-Peter Kalz, Wilhelm Prettl, Institut fuer Experimentelle und Angewandte Physik, University of Regensburg, Regensburg, GERMANY; Robert Neumann, Karl Brunner, and Gerhard Abstreiter, Walter Schottky Institute, TU Munich, Garching, GERMANY; Eugenius L. Ivchenko, A.F. Ioffe Physico-Technical Institute of the RAS, St. Petersburg, RUSSIA.

We report on the observation of circular photogalvanic effect (CPGE) in p-type Si/Ge quantum well structures in response to absorption of circularly polarized far infrared radiation. Direct inter-subband transitions at wavelengths between 76 μm and 280 μm have been excited by a high power pulsed NH_3 laser optically pumped by a TEA-CO_2 laser. CPGE, recently observed in GaAs based quantum well structures [1,2], is caused by the conversion of optically induced spin polarization into a directed motion of free carriers in the plane of a quantum well, perpendicularly to the direction of light propagation. Due to spin selection rules the direction of the current is determined by the helicity of the light and can be reversed by switching the helicity from right- to left- handed. An existence of CPGE requires a sufficiently low symmetry lacking a center of inversion (gyrotropic point group). Both bulk Si and Ge have the inversion symmetry. However, Si/Ge quantum wells grown in (001) and (113) crystallographic orientation can be prepared without inversion symmetry. The observation of CPGE demonstrates that the spin degeneracy of subbands in k-space is lifted due to k-linear terms in the Hamiltonian [1]. We show that, as in the case of zinc-blend type materials, the CPGE can be used as a tool to investigate spin orientation and spin relaxation in Si/Ge structures.
[1] S.D. Ganichev, S.N. Danilov, J. Eroms, W. Wegscheider, D. Weiss, W. Prettl, E.L. Ivchenko, Phys. Rev. Lett. **86**, 4358 (2001).
[2] S.D. Ganichev, H. Ketterl, W. Prettl, E.L Ivchenko, L.E. Vorobjev, Appl. Phys. Lett. **77**, 3146 (2000).

F3.12

ANTI-WEAK-LOCALIZATION STUDY OF RASHBA SPIN-SPLITTING ENERGY AS A FUNCTION OF WELL ASYMMETRY IN InAlAs/InGaAs/InAlAs QUANTUM WELLS.
T. Koga, J. Nitta, T. Akazaki and H. Takayanagi, NTT Basic Research Laboratories, NTT Corporation, Atsugi-city, Kanagawa, JAPAN.

The use of spin-orbit interaction is a key strategy for the controlled manipulation of spins of the conduction carriers in semiconducting heterostructures, which is needed for realizing future spin devices. These future spin devices will utilize not only the properties of electron charges (as with conventional electronic devices) but also those of electron spin to achieve new device functionalities that have never been realized with conventional devices. In the present work, we use anti-weak-localization analysis to quantitatively analyze the zero-field spin-splitting energies (denoted by Δ_0) that are observed in InAlAs/InGaAs/InAlAs quantum wells. We found that the value of Δ_0 becomes larger as the degree of structural inversion asymmetry (SIA) for the InGaAs quantum well becomes larger. This observation is consistent with the fact that the Rashba mechanism is the dominant spin-orbit interaction for these samples. Experimentally, we varied the degree of SIA of the InGaAs quantum wells by growing a series of four different samples (by MOCVD) with different impurity densities in the carrier supplying layer (denoted by n^+), which is located below the quantum well, while keeping all the other structural parameters constant among these samples. Here, the values of n^+ are varied from $4\times10^{18}cm^{-3}$ (the most asymmetric quantum well) to $1\times10^{18}cm^{-3}$ (the least asymmetric quantum well). In addition, the

carrier concentrations of these samples are controlled by the applied gate voltage in order to study the carrier density dependence of the Δ_0 value. Finally, the experimental values of Δ_0 thus obtained are compared with the theoretically predicted values of Δ_R, the zero-field spin-splitting energy due to the Rashba spin-orbit interaction, in order to understand the observed Δ_0 values quantitatively for future device applications.
This research work is supported by the NEDO International Joint Research Grant Program.

SESSION F4: HALF-METALLIC MATERIALS
Chair: Jonathan Z. Sun
Tuesday Morning, November 27, 2001
Room 207 (Hynes)

8:30 AM *F4.1
PHASE SEPARATION AT INTERFACES IN $La_{2/3}Ca_{1/3}MnO_3$ THIN FILMS. J. Fontcuberta, M. Bibes, Ll. Balcells, B. Martinez, Institut de Ciencia de Materials de Barcelona, SPAIN; M. Wojcik, E. Jedryka, S. Nadolski, Institute of Physics, Polish Academy of Sciences, POLAND.

Spin devices and particularly tunnel junctions based on manganites, face to the difficulty that the tunnel magnetoresistance (MR) decreases much faster than the bulk magnetization upon heating. As a result, well below the Curie temperature, the MR becomes negligible and these tunnel devices can not be easily operated at high temperature. Although it has been shown that the magnetic properties of film(ferromagnetic)/vacuum differ from those of bulk, no much information is available to the nature of the insulator/film(ferromagnetic) interfaces and what is their role on the magnetotransport properties. In this paper we shall provide evidence that close to interfaces with the substrate, the manganite films, here illustrated by the particular case of $La_{2/3}Ca_{1/3}MnO_3$, are not longer homogeneous: ferromagnetic and metallic but a nanoscopic phase segregation takes place. The magnetotransport data here reported, for thin films grown on a variety of single crystalline substrates ($SrTiO_3$, $LaAlO_3$, $NdGaO_3$), conclusively show the presence of a conducting and magnetic dead layer close to the substrate/film interface, whose thickness (t_d) depends on the nature of substrate. Even more, we shall show that the properties of films can be severely perturbed much deeper ($t>t_d$) into the film. Detailed analysis of the magnetotransport properties as well as information gained from a microscopic magnetic probe (^{55}Mn-NMR) unambiguously reveals the presence of complex phase segregation triggered by interface effects. We shall argue that these effects could be at the origin of the discouragingly poor magnetoresistance in manganite based tunnel devices and strategies to overcome it shall be discussed.

9:00 AM F4.2
EPITAXIAL ELECTRODEPOSITION OF MAGNETITE THIN FILMS ON THE LOW INDEX PLANES OF GOLD.
Thomas A. Sorenson, Maxim P. Nikiforov, Jay A. Switzer, Graduate Center for Materials Research and Department of Chemistry, University of Missouri-Rolla, Rolla, MO; Simon A. Morton, G. Dan Waddill, Graduate Center for Materials Research and Department of Physics, University of Missouri-Rolla, Rolla, MO.

Epitaxial Fe_3O_4 thin films have been deposited on single crystal gold substrates using electrodeposition. Magnetite is a promising material for spin dependent transport devices, due to reported 100% spin polarization at the Fermi level. The magnetite films are formed using a bath consisting of 0.04 M potassium acetate and 0.01 M ferrous ammonium sulfate by applying an anodic current density of 0.05 mA/cm^2 at 90°C in an O_2 free environment. On Au(110), Fe_3O_4 grows with a [110] out-of-plane orientation, with the in-plane orientation aligned with the Au(110) substrate. On Au(111), the Fe_3O_4 grows with a [111] out-of-plane orientation, but the in-plane orientation is twinned, with both parallel and antiparallel oriented domains. On Au(100), both a [100] and a [111] out-of-plane orientation is observed. The Fe_3O_4 (100) is aligned with the Au(100) substrate, but 3 equivalent in-plane orientations of Fe_3O_4 (111) are observed. Both x-ray absorption spectra of the Fe $L_{2,3}$ and O K edge and magnetic x-ray circular dichroism measurements are consistent with spectra for bulk Fe_3O_4 previously reported in the literature.

9:15 AM F4.3
THE USE OF NiMnSb HEUSLER ALLOY IN MBE GROWN TUNNEL JUNCTIONS. Stéphane Andrieu, Pascal Turban, Bertrand Kierren, Lab. de Physique des Matériaux, CNRS / Univ H. Poincaré, Nancy, FRANCE; Alberto Tagliaferri, Céline De Nadai, Nike Brookes, ESRF, Grenoble, FRANCE.

NiMnSb is a material of significant interest for magnetotransport and spin-polarized transport applications due to its predicted half-metallic behavior. Up to now, the transport measurement performed on spin valves and magnetic tunnel junctions including the NiMnSb alloy demonstrate only poor spin polarization. This behavior was attributed to an insufficient crystalline or interfacial quality. In order to clarify the situation, we have studied high quality single-crystalline NiMnSb thin films grown by molecular beam epitaxy. The influence of growth conditions on crystalline quality was studied by RHEED and STM. The structural quality of the films was investigated by X-ray diffraction, EXAFS and HRTEM. For the optimized growth conditions, the expected NiMnSb C1b structure was observed. Moreover, the most stable and smooth surface was found to be 4x4 reconstructed. The magnetic properties were studied by SQUID, AC-susceptometer and X-ray magnetic circular dichroism. The magnetization is observed to be equal to 3.9 and 0.2 Bohr magnetons per Mn and Ni atoms respectively, in agreement with the theoretical calculated values. Moreover, spin-resolved x-ray photoemission spectroscopy experiments were performed at ESRF on the ID8 beamline. A polarization of at least 50% at room temperature was observed on an uncovered 4x4 reconstructed surface. Finally, we show that fully epitaxial NiMnSb/MgO/NiMnSb(001) and NiMnSb/MgO/Fe(001) trilayers can be prepared. Magnetoresistance experiments performed on both systems will be presented.

9:30 AM F4.4
ELECTRIC FIELD EFFECTS IN MIXED-VALENT MANGANITE FILMS: EVIDENCE OF ELECTRONIC PHASE SEPARATION.
T. Wu, S.B. Ogale, J.E. Garrison, B. Nagaraj, Amlan Biswas, Z. Chen, R.L. Greene, R. Ramesh, and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD; A.J. Millis, Center for Materials Theory, Department of Physics and Astronomy, Rutgers University, Piscataway, NJ.

A systematic study of electroresistance (ER) effects is conducted for the case of mixed-valent Manganite channels, using an inverted field effect geometry with ferroelectric or dielectric gates. A polarity-dependent large ER of ~76% at $4X10^5$V/cm is observed for the thin $La_{0.7}Ca_{0.3}MnO_3$ channel with PZT gate. The CMR (ER) effect is found to be comparable for the case of the unbiased and the electrically (magnetically) biased channel, reflecting the complimentary nature of the electric and magnetic field effects. In $Nd_{0.7}Sr_{0.3}MnO_3$, the effect is only a few percent and polarity independent. However, in this case, the magnetic field boosts the polarity dependent fraction in the ER effect. For $La_{0.7}Ba_{0.3}MnO_3$ and $La_{0.5}Ca_{0.5}MnO_3$ systems the magnitude of the effect is much lower. Analysis of these data strongly favor an electronic phase separation picture for mixed-valent manganites. This work is supported under NSF-MRSEC grant no. DMR-00-80008.

10:15 AM *F4.5
GROWTH AND PROPERTIES OF HALF-METALLIC CHROMIUM DIOXIDE THIN FILMS AND HETROSTRUCTURES. A. Gupta, IBM T.J. Watson Research Center, Yorktown Heights, NY; A. Anguelouch, G. Xiao, Dept of Physics, Brown University, Providence, RI.

Band structure calculations have shown that the well-known magnetic oxide material chromium dioxide (CrO_2) is a half-metallic system, i.e., it contain a gap in one spin band at the Fermi level and no gap in the other spin band. Recent superconducting point contact measurements have confirmed the half-metallicity of CrO_2, providing a spin polarization value as high as 98% at low temperatures. Since CrO_2 is a metastable phase, it has been difficult to grow thin films of this material using conventional techniques under normal growth conditions. We have utilized a simple atmospheric pressure chemical vapor deposition (CVD) technique to grow high-quality epitaxial thin films of CrO_2. They are grown at 400°C on (100)-oriented single crystal TiO_2 substrates using either CrO_3 or CrO_2Cl_2 as a precursor, and oxygen as a carrier gas. Films grown using CrO_2Cl_2 are atomically smooth with a rms roughness of less than 5 $\AA$ for a 1000 $\AA$-thick film. The CrO_2 films exhibit a metallic behavior, and the resistivity is anisotropic in the plane with a small change in slope around the Curie temperature. A sharp magnetic transition is observed for the films, with a Curie temperature of 390-395 K. The value of the saturation magnetization at low temperatures is ~650 emu/cm^3, corresponding closely to the full theoretical moment of 2 μ_B per Cr ion observed in the bulk. The resistivity and magnetic hysteresis loops are significantly influenced by the strain in the films. We have fabricated tunnel junctions using epitaxial CrO_2 grown as one of the ferromagnetic electrode and polycrystalline Co as the counter electrode material. In situ growth of heteroepitaxial tunnel junction structures of CrO_2 with barrier layers such as TiO_2 is being investigated.

10:45 AM F4.6
MORPHOLOGY OF MANGANITE PLD THIN FILMS DESCRIBED BY THE THORNTON'S ZONE MODEL. Anne-Marie Haghiri-Gosnet, Mohamed Koubaa, IEF, Univ Paris Sud, Orsay, FRANCE;

Rachel Desfeux, LPCIA, Univ d'Artois, Lens, FRANCE; Philippe Lecoeur, Wilfrid Prellier, Bernard Mercey, CRISMAT, ISMRA, Caen, FRANCE.

The morphology and the microstructure of pulsed laser deposited (PLD) $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) films are shown to follow the "morphology zone model" proposed by Thornton [1] for the sputtering technique. At a micrometer scale, the evolution of the LSMO film's morphology has been studied using both scanning electron microscopy (SEM) and atomic force microscopy (AFM), for the prominent PLD parameters, i.e. the target-to-substrate distance D, the oxygen pressure P_{O2} and the deposition temperature T. At large D values (D $\sim$65 mm) and high pressures (P_{O2} = 0.53 mbars) and for a fixed temperature of 670°C, the film exhibits a fine typical Zone I columnar porous morphology. The fine columns are the consequence of the self-shadowing effect of the impinging particules on the growth surface. The presence of embbeded noddles is a further proof of this shadowing effect. At reduced D values (D $\sim$45mm) and low pressures (P_{O2} = 0.15 mbars), the film exhibits a dense Zone II structure, which is associated with an exceptional surface flatness (Rms=0.1nm). The surface is very clean and free of any defects (noddles, inclusions and droplets). An increase of T of about 30°C shifts the ZoneI/ZoneII transition towards high pressures (Δ P_{O2} = 0.1 mbar) in agreement with Thornton's model. Finally, the role of each PLD parameter (T, D and P_{O2}) on the magnetic properties of the ablated LSMO films will be discussed in correlation with the morphology. [1] J.A.Thornton, JVST 11, 666 (1974)

11:00 AM F4.7
FLIP CHIP MAGNETIC TUNNEL JUNCTIONS. J.C. Read, Z.Y. Chen, R. Ramesh, T. Venkatesan, I. Takeuchi, Center For Superconductivity Research, University of Maryland.

We have developed a flip chip magnetic tunnel junction (FCMTJ) technique that provides a quick and flexible means to study the tunneling magnetoresistance between ferromagnetic thin films that are difficult to incorporate in in-situ grown muiltilayer structures. The FCMTJ structures consist of two individual electrode chips, patterned using conventional photolithography and etching techniques, which are pressed together to make cross-geometry junctions. Each electrode chip is a thin film bilayer composed of a lower ferromagnetic electrode layer capped with an ultra thin insulating layer. The junction resistance is tunable as a function of pressure. This technique precludes the necessity to fabricate all epitaxial trilayers, and therefore increases the number of possible insulator and ferromagnetic material combinations to be studied quickly. We have fabricated FCMTJ devices using Fe_3O_4 as the electrodes with SiO, Au/SiO, and native oxide as the barriers. The typical junction overlap area for these devices is 200 μm x 200 μm, and the junction resistance is tunable between kΩ and MΩ. The I-V curves are nonlinear and show parabolic conductivity, characteristic of tunneling junctions. Junction magnetoresistance of about 1% has been observed at room temperature in one Fe_3O_4 / native oxide / Fe_3O_4 FCMTJ. We are also making junctions incorporating other ferromagnetic half metallic materials such as CrO_2.

11:15 AM F4.8
LOCAL MAGNETISM AT BOUNDARIES IN $La_{2/3}Ca_{1/3}MnO_3$ THIN FILMS. D.J. Miller, V. Vlasko-Vlasov, U. Welp, Y.K. Lin, Materials Science Division, Argonne National Laboratory, Argonne, IL.

As with many other oxide-based compounds that exhibit electronic behavior, structural defects will have an influence on electronic properties of the CMR manganites. In this work, we have studied the local magnetic structure in $La_{2/3}Ca_{1/3}MnO_3$ thin films using magneto-optical imaging (MOI). Grain boundaries in this compound exhibit enhanced magnetoresistance, and we have used MOI to measure the local orientation of spins at grain boundaries in bicrystal thin films. We find a coordinated reorientation of spins near the boundary, the magnitude of which can be correlated to magneto-resistance across the boundary. A model describing this behavior will be presented. We have also used heavy ion irradiation to induce changes in magnetization. Using a masking process, we have produced samples that have a sharp interface between irradiated and unirradiated regions. At this interface we observe behavior similar to that across grain boundaries – a local reorientation of spins. Details of these studies and discussion of potential applications will be presented. This work was supported by the U.S. Department of Energy, Basic Energy Sciences-Materials Sciences, under contract #W-31-109-ENG-38.

11:30 AM F4.9
OPTIMIZING THE TRANSITION TEMPERATURE OF DOUBLE PEROVKITES. Amit Chattopadhyay, IBM Almaden Research Center, San Jose, CA; Andrew Millis, Kevin Phillips, Dept of Physics, Rutgers University, Piscataway, NJ.

Double perovskites have attracted a fair amount of attention due to the high values of transition temperature, which make them interesting for possible spintronic applications. By combining dynamical mean field theory (DMFT) with a tight binding parametrization of the underlying band structure, we have calculated T_c and optical conductivity and determined the conditions for optimizing the transition temperature.

SESSION F5: CURRENT-INDUCED MAGNETIC SWITCHING
Chair: Jack Bass
Tuesday Afternoon, November 27, 2001
Room 207 (Hynes)

1:30 PM *F5.1
BEAM AND SPIN-TRANSFER EFFECTS IN MAGNETIC MULTILAYER NANOSTRUCTURES. F.J. Albert, N.C. Emley, J.A. Katine, R.A. Buhrman, School of Applied and Engineering Physics, Cornell University, Ithaca, NY; E.B. Myers, D.C. Ralph, Phys. Dept., Cornell University, Ithaca, NY.

We will first describe some recent STM experiments that examine spin-dependent transport in electronic systems. This technique uses the spin-filtering properties of magnetic layers to produce polarized ballistic electron beams, and then spatially images the transmission of such beams into underlying layers. In this way we can obtain microscopic information regarding the ballistic propagation of spin-polarized electron currents across metal semiconductor interfaces. we will then discuss the spin-transfer effect where a spin-polarized current, that flows between two ferromagnetic nanostructures separated by a normal metal spacer layer, can, at sufficiently high current densities in an applied field, excite spin waves in one or both of the ferromagnets. At zero or low H the polarized current can reversibly switch the magnetic orientation of a free nanomagnet relative to that of a fixed ferromagnet, with the resultant orientation dependent upon whether the spin-polarized electrons flow to or from the free layer. The excitation and switching arises from the transfer of spin angular momentum from the conduction electrons to the ferromagnetic moment. This spin-transfer phenomenon has the potential of enabling a new type of direct-current-addressable magnetic memory and new high frequency nanoscale devices. We will discuss key aspects of current theoretical models that have been developed to describe and predict spin-transfer phenomena, as well as present recent results from experiments designed to test these models and to further examine and enhance the effects.

2:00 PM *F5.2
MAGNETIZATION REVERSAL INDUCED BY A SPIN POLARIZED CURRENT. V. Cros, J. Grollier, H. Jaffres, A. Hamzic, J.M. George, A. Fert, Unité Mixte de Physique CNRS-THALES, Orsay, FRANCE; G. Faini, LPN-CNRS, Bagneux, FRANCE; J. Ben Youssef, H. Le Gall, LMB, Brest, FRANCE.

The magnetic moment of a ferromagnetic layer can be reversed by spin transfer from a spin-polarized current (i.e. without applying a magnetic field), as predicted first by Slonczewski in 1996[1] and then in other contexts[2]. This effect has been confirmed by recent experiments on nano-pillars at Cornell's University[3] and at Orsay[4]. We will present our latest experiments obtained on Co/Cu/Co nano-pillars in which we find that a positive current switches the magnetic configuration from AP to P whereas a negative one switches from P to AP. This asymmetry is the signature of reversal by spin injection. The required current density is about 10^7 A/cm^2. We will also show the variation of the critical current with the applied magnetic field. In fact, this study is of interest to decide between the different theoretical approaches as they predict quite different field dependence of the switching current. Our interpretation is based on the dynamical approach of Slonczewski with a calculation of the current spin polarization in a standard model of the CPP-GMR. We show how the spin asymmetry involved in Slonczewski's equations is influenced by the thickness of the layer and the spin diffusion lengths in the magnetic and the nonmagnetic layers. Optimizing the parameters of the samples, the critical currents can certainly be reduced and be of interest for application to the switching of submicronic magnetic devices. [1] J. Slonczewski, J. Magn. Magn. Mat., 159, 1 (1996) [2] L. Berger, Phys. Rev. B54, 9353 (1996); Y. Bazaliy et al. Phys. Rev. B57, 3213 (1998); J.E. Wegrowe, Phys. Rev. B, 62, 1067, 2000; C. Heide et al, Phys. Rev. B, 63, 64424, 2001 [3] J.A. Katine et al, Phys. Rev. Lett., 84, 3149 (2000) [4] J. Grollier et al, Appl. Phys. Lett., 78, 3663 (2001).

3:00 PM *F5.3
THERMAL ACTIVATION-INDUCED SWEEP-RATE DEPENDANCE OF MAGNETIC SWITCHING ASTROID. R.H. Koch, J.Z. Sun, J.C. Slonczewski, P.L. Trouilloud, D. Abraham, Ian Bacchus, W.J. Gallagher, J. Hummel, Yu Lu, G. Wright, and

S.S.P. Parkin, IBM Research, Yorktown Heights, NY and IBM Almaden, San Jose, CA.

We examine the sweep-rate dependence of the magnetic switching field, Hs, in submicron magnetic tunnel junctions where shape-anisotropy is dominant. Experimental data support the use of a single-domain thermal activation model for description of activated magnetic reversal in junctions 0.2 by 0.5 μm or less in size. A scaling law is obtained for the thermal activation energy which varies as the cube of junction size. It is useful for understanding the scalability of shape anisotropy-based magnetic memory elements.

3:30 PM *F5.4

SPIN INJECTION IN POINT-CONTACT MAGNETIC MULTILAYERS. Maxim Tsoi, Dept of Physics and Astronomy, Michigan State Univ, East Lansing, MI and Grenoble High Magnetic Field Laboratory, MPI-FKF & CNRS, Grenoble, FRANCE.

We report the detection of electromagnetic waves radiated by current-driven magnons in a Co/Cu magnetic multilayer. The magnons were excited by means of a high current density $\approx 10^8$ A/cm^2 injected into the multilayer through a point contact. The point contact itself was used as a high frequency mixer to mix electromagnetic waves radiated by the current-driven magnons with externally generated microwave radiation. Here the external microwaves are used as a direct probe of the high-frequency behavior and partial phase coherence of the current-induced excitations. When the external frequency equaled the frequency of the magnons generated in the multilayer a dc voltage was found to develop across the contact. Investigation of how this voltage varies with exciting current, magnetic field, and microwave frequency provides detailed information on the spectrum of the current-driven magnons. Our observations support the feasibility of a spin-wave maser, or SWASER (spin-wave amplification by stimulated emission of radiation).

SESSION F6: IN-ROOM POSTER SESSION
Chair: Robert A. Buhrman
Tuesday Afternoon, November 27, 2001
4:00 PM
Room 207 (Hynes)

F6.1

GROWTH AND PROPERTIES OF ORIENTED HEUSLER ALLOY FILMS/MULTILAYERS BY PULSED LASER DEPOSITION. L.V. Saraf, V. Craicunescu, M. Vornbrock, R.P. Sharma, M. Wuttig and R. Ramesh, Department of Materials Science and Engineering, University of Maryland, College Park, MD.

We report epitaxial growth of new ferromagnetic Heusler alloys, Co_2NiGa and the half-metallic Co_2MnGe on (001) GaAs and $MgAl_2O_4$ substrates by pulsed laser deposition (PLD). Structural measurements reveal the films to be highly [001] oriented with a considerable degree of in-plane cube-on-cube orientational locking. The epitaxial nature of these samples was also confirmed by Rutherford Backscattering Spectroscopy (RBS) ion channeling experiments. Temperature and field dependent magnetic measurements reveal a strong thickness dependence of the martensitic structural phase transition, which is strongly suppressed below thicknesses $\sim$1000 Å. Also, a process has been optimized for the deposition of ferromagnet/non-ferromagnet/ferromagnet trilayer structures grown on GaAs to study their properties for use in spin valves and tunnel junctions. We will report results of structure, magnetic properties and spin polarization measurements (in collaboration with R. Soulen, NRL). This work is supported by Office of the Naval Research.

F6.2

MECHANISMS OF ELECTRONIC TRANSPORT IN ARTIFICIAL GRAIN BOUNDARY DEVICES MADE FROM CMR FILMS. A.K. Raychaudhuri, Mandar Paranjape, Department of Physics, Indian Institute of Science, Bangalore, INDIA; N. Khare, National Physical Laboratory, New Delhi, INDIA.

Magnetic field sensors based on artificial grain boundary junctions of Colossal Magnetoresistive Materials a viable device in the field of spintronics. The mechanism of grain boundary conduction in zero field as well as applied magnetic field is a subject of current research. In this work we report study of artificial grin boundary junctions fabricated on bicrystal substrate depositing epitaxial film of CMR material (primarily LBMO). The study consists of non-linear transport characteristics for 4.2K-400Kin a field of 0-6T. In addition we have studied the junction using STM technique and Scanning Tunneling Potentiometry (STP). The STP technique allows us to study potential drops in nanometer scale and it shows the extent of inhomogenity in the electrical transport in the film as well as the grain boundary. The grain boundary transport changes drastically on application of field, and the mechanism of transport also depends on the temperature. It is tunneling at low temperature, changing to spin-flip scattering at higher temperatures. These mechanisms can be active simultaneously and provide parallel conduction path for the grain boundary device. It appears that the physical quality of the grain boundary and its physical size determine the mechanisms that will be dominant.

F6.3

PROCESS PARAMETER OPTIMIZATION FOR PULSED LASER DEPOSITION OF Sr_2FeMoO_6 FILMS AND STUDY OF THE FILM PROPERTIES. S.R. Shinde, S.B. Ogale, R.L. Greene, and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD; Y.S. Hor, K. Tsoi and B.G. Kim, S.-W. Cheong and A.J. Millis, Department of Physics and Astronomy, Rutgers University, Piscataway, NJ.

Thin films of Sr_2FeMoO_6 have been deposited by pulsed laser deposition technique, using a high quality, polycrystalline, and stoichiometric Sr_2FeMoO_6 target. The substrates used were (100) and (111) oriented $SrTiO_3$. The depositions were performed under various conditions with a view to optimize the process parameters. It is observed that the growth process is highly sensitive to the deposition parameters viz., the substrate temperature, the laser energy density, and the background gas pressure. The films deposited below about 980 C show a semiconducting behavior at all temperatures below 300 K, while the films deposited between 980-1050 C exhibit a metallic behavior between 300-100 K and a semiconducting behaviour below 100 K. It is observed that a laser energy density higher than 2.5 J/cm^2 yields better quality films. The structural properties of these films are studied by x-ray diffractometry and Rutherford back-scattering channeling techniques. The film morphology is studied by atomic force microscopy. The magneto-transport measurements are also performed and will be analyzed vis a vis other film properties. This work is supported under NSF-MRSEC grant no. DMR-00-80008.

F6.4

MAGNETIC AND MAGNETO-OPTICAL PROPERTIES of Sr_2FeMoO_6 THIN FILMS. H. Asano, M. Osugi, Y. Kohara, D. Higashida, and M. Matsui, Dept. of Crystalline Materials Science, Nagoya University, Nagoya, JAPAN.

Epitaxial thin films of a half-metallic ferromagnet Sr_2FeMoO_6 have been grown on (001) $SrTiO_3$, and MgO substrates by magnetron sputtering. Their structural, magnetic, magneto-optical and transport properties at room temperature were investigated and compared. Large differences were observed especially in the magnetic and magneto-optical properties between thin films on $SrTiO_3$ and MgO. The films on $SrTiO_3$ exhibited larger saturation magnetic moment and larger complex polar Kerr effect with a rotation θ up to -0.32° at 1.6 eV and RT than those on MgO. The observed differences in properties of the films on the two substrates could be interpreted in terms of the strain effect and the structural disorder.

F6.5

DILUTE MAGNETIC OXIDES BASED ON ANATASE TiO_2 AND C-RARE EARTH In_2O_3: ANALYSIS OF PROSPECTS FOR ROOM TEMPERATURE FERROMAGNETISM AND TRANSPARENCY. Oleg Mryasov, Mark van Schilfgaarde, Sandia National Laboratories, Livermore.

We report results of the modeling of magnetic, optical properties and energetics of TiO_2 and In_2O_3:oxides doped with 3d transition metals. We employ LMTO method within the local spin density approximation to calculate magnetic moments, exchange interaction parameters, Curie temperature (within the mean-field approximation) and energetics of substitution in TiO_2 and In_2O_3 with V, Cr, Mn, Fe, and Co. We find that for a homogeneous distribution of Co in TiO_2, the magnetic exchange is too small to provide RT ferromagnetism. But the calculated energies of Co pairs indicate the possibility for the strong short range ordering which may account for discrepancies in the predictions with observations [1]. In contrast with TiO_2, results for In_2O_3 favor more homogeneous substitution into the In sub-lattice and ferromagnetism which is mediated not by Op states (like in TiO_2) but the free electron like s-type conduction band. The later feature of In_2O_3 also provide better transmittance of the visible light, as indicated by calculations of the imaginary part of the complex dielectric constant. The calculated exchange interaction parameters for lowest energy Mn: In_2O_3 substitution configuration with 6% concentration suggest possibility for RT FM. Thus, while Co doped TiO_2 has been reported to be a room temperature (RT) transparent ferromagnet [1], Mn doped In_2O_3: is predicted to have a good prospects for RT ferromagnetism also with distinct from Co: TiO_2 features of electronic structure, mechanism of FM ordering and light absorption and substitution properties. 1. Matsumoto Y., et. al, Science; 2 Feb. 2001; vol.291, no.5505, p.854-6.

F6.6
STUDIES OF $Ti_{1-x}Co_xO_2$ THIN FILMS FOR SPINTRONIC DEVICES. A. Hidalgo, M.S. Tomar, R. Melgarejo, Univ. Puerto Rico, Phys. Dept., Mayaguez, PR; A. Dixit, and R.S. Katiyar, Univ. Puerto Rico, Phys. Dept., San Juan, PR.

Oxide-based $Ti_{1-x}Co_xO_2$ material has attracted attention because of reported room temperature ferromgnetism with potential applications in spintronics. We synthesized this material using a simple solution method and thin films were deposited by spin coating. The results on their structural, electrical, optical, and magnetic properties are presented.

F6.7
HETEROSTRUCTURES FOR SPINTRONICS: A COMPARISON OF (100) AND (110) ORIENTATIONS. J.J. Zinck, W.B. Barvosa-Carter, S.L. Skeith, HRL Laboratories LLC, Malibu, CA; T.F. Boggess, Physics and Astronomy, Univ. of Iowa, Iowa City, IA.

Most molecular beam epitaxial growth on III-V substrates has been optimized for (100) oriented growth. However, spintronic devices may benefit from growth of quantum structures on (110) oriented substrates because the Dyakanov-Perel spin relaxation mechanism is suppressed or absent in this orientation for 2-D systems. We are currently engaged in the growth of 6.1 heterostructures on InAs (110) oriented substrates and have noted interesting differences in the growth behavior between the (100) and (110) orientations with respect to group V dependence and antimonide on arsenide terminated interfaces. We will discuss the results of in situ RHEED, photoemission, and scanning tunneling microscopy studies of InAs/GaSb heterostructures grown on both (100) and (110) InAs substrates as well as ex situ measurements of spin lifetimes for the two orientations.

F6.8
ELECTRONIC STRUCTURE AND MAGNETIC PROPERTIES OF TRANSITION METAL DOPED SILICON CARBIDE. Maosheng Miao and Walter R.L. Lambrecht, Department of Physics, Case Western Reserve University, Cleveland, OH.

It has been argued that wide band gap semiconductors have possibly an advantage to produce room temperature dilute magnetic semiconductors. Here we present a study of transition metal (TM) doped silicon carbide. The linear muffin-tin orbital method is used to calculate the electronic structure of 64-atom supercells of 3C-SiC with either a Si or a C substituted by a 3d transition metal: Sc–Zn. Only the neutral charge state is investigated. Spin-polarized and non-spin-polarized total energies are compared. For the systems with a non-zero magnetic moment, we also investigate supercells containing two adjacent TM atoms in either the ferro or antiferromagnetic alignment. We find that the late transition metals starting with Fe prefer a low spin configuration. The most promising candidate for ferromagnetic behavior is found to be Cr, while Mn is found to exhibit antiferromagnetic interaction between neighboring impurities. Electronic densities of states are used to analyze the results. Supported by ONR under grant No. N000-99-1-1073.

F6.9
KINETIC EXCHANGE VS ROOM TEMPERATURE FERRO-MAGNETISM IN DILUTED MAGNETIC SEMICONDUCTORS. J. Blinowski[1], P. Kacman[2] and T. Dietl[2]; [1]Institute of Theoretical Physics, Warsaw University, Warszawa, POLAND; [2]Institute of Physics, Polish Academy of Sciences, Warszawa, POLAND.

The pursuit for room-temperature ferromagnetism in semiconductors was recently boosted by theoretical predictions of high Curie temperatures for p-type (Ga,Mn)N and (Zn,Mn)O, resulting from a strong kinetic p-d exchange. These predictions were made under the assumption that the magnetic ions have the d^5 electronic configuration, as inferred from photoemission data for Mn-based II-VI compounds and (Ga,Mn)As. However, in general, electronic configurations different from d^5 are possible, for which a non-standard orbital-dependent kinetic exchange can be expected.
Guided by the internal-reference rule and the known band offsets, we first discuss the feasibility of obtaining III-V and II-VI DMS with p-type conductivity, required for the carrier induced ferromagnetism. Then, we consider the dependence of kinetic exchange on the p-d hybridization, on the electronic configurations of the magnetic ions, and on the energies of the charge transfer between the valence band of host materials and the magnetic ions.
The results of this analysis indicate that in the II-VI host compounds only the Mn ions seem to allow for the p-type, but with the co-doping. In some III-V compounds this is possible, either with or without co-doping, also for Fe and Co ions. We show that the prospects of room temperature ferromagnetism in III-V DMS with Mn ions depend on the charge state of these ions and that Fe- or Co-based III-V DMS with strong p-d hybridization look very promising.

F6.10
STRESS EVOLUTION DURING Fe(001) EPITAXY ON GaAs(001). Reinhold Koch, Paul-Drude-Institut für Festkörperelektronik, Berlin, GERMANY; D. Richard Nötzel, Semiconductor Physics, University of Technology, Eindhoven, THE NETHERLANDS; Bernhard Wassermann, Gerd Wedler, Institut für Experimentalphysik, Freie Universität Berlin, Berlin, GERMANY.

Thin Fe films on GaAs substrates have evolved as a model system for the integration of magnetic materials with semiconductors. We report on in situ stress measurements of Fe/GaAs(001), which enlighten the dynamics of the interface formation of this important magnetic metal/semiconductor system. At deposition temperatures of 300 K and 450 K, the stress evolution during growth is very similar. In Fe films thicker than 6–7 nm, the stress is compressive owing to the misfit between the lattices of Fe and GaAs. Thinner films surprisingly are dominated by a tensile stress contribution due to considerable As (and Ga) interdiffusion even at 300 K.

F6.11
EFFECTS OF ANNEALING ON THE MAGNETIC, ELECTRONIC, AND STRUCTURAL PROPERTIES OF (Ga,Mn)As EPILAYERS. Stephen J. Potashnik, Keh-Chiang Ku, Seung-Hyun Chun, Joseph J. Berry, Nitin Samarth, Peter Schiffer, The Pennsylvania State University, Department of Physics and Materials Research Institute, University Park, PA.

Ferromagnetic semiconductors hold the promise of creating novel devices by combining control of the spin as well as the charge of the carriers. MBE-grown films of ferromagnetic (Ga,Mn)As have recently emerged as an important testbed for the physical properties of such systems and how they can be integrated with conventional semiconductors. We have studied the evolution of the magnetic, electronic, and structural properties of annealed (Ga,Mn)As epilayers grown by low temperature molecular beam epitaxy. Annealing at 250°C for less than 2 hours significantly enhances the conductivity and ferromagnetism, reproducibly producing the maximum curie temperature observed for this system of about 110K; however annealing for longer periods suppresses both. These data indicate that such annealing induces the defects in (Ga,Mn)As to evolve through at least two processes, and they point to a complex interplay between the different defects and ferromagnetism in this material.

F6.12
A DFT-LAPW STUDY OF THE InAs/GaSb HETERO-STRUCTURE: STRUCTURAL AND ELECTRONIC PROPERTIES. Richard S. Ross, HRL Laboratories, LLC, Malibu, CA; Max Petersen, Dept of Mathematics, UCLA, Los Angeles, CA.

Exploiting spin phenomena in semiconductor heterostructures requires highly detailed knowledge of the electronic band-structures of these materials. The spin splitting of sub-bands in these systems is due to a combination of the Dresselhaus effect (Bulk Inversion Asymmetry) and the Rashba effect (Structural Inversion Asymmetry). Additionally, the Rashba effect can have contributions arising from pure interface effects, such as in the No Common Atom heterostructures, as well as structural asymmetries due to variations in barrier heights and composition. In this paper we present the results of ab-initio calculations of short period superlattices in the 6.1 Angstrom materials system, particularly the (001) InAs/GaSb heterostructure. We use the full potential linear augmented plane wave (FP-LAPW) method combined with density functional theory in the local density approximation (LDA). The spin-orbit interaction is explicitely included. With this approach we can simulate different interface bonding types and periods of the InAs/GaSb superlattice, studying the resulting effect on the spin-splittings of the conduction and valence bands. Since InAs and GaSb are known within the LDA to have a negative band gap and an incorrect ordering of states at the Γ point, we apply "false Darwin shifts" as discussed by Cardona *et.al.*[1]. As a result, we obtain a better electronic band structure and a correct ordering of states close to the fundamental gap, all without sacrificing the accuracy of structural parameters. [1] M. Cardona, N.E. Christensen, and G. Fasol, Phys. Rev. B **38, 1806 (1988).**

SESSION F7: NEW TECHNOLOGIES, NEW EFFECTS, SILICON INTEGRATION
Chair: Timothy J. Klemmer
Wednesday Morning, November 28, 2001
Room 207 (Hynes)

8:30 AM *F7.1
THERMAL LIMITS IN MAGNETIC RECORDING. Dieter Weller, Seagate Technology, LLC, Pittsburgh, PA.

Media noise suppression is a key element in approaches to extremely high-density magnetic recording media, requiring continued reduction in the media grain size and improvement in grain uniformity and magnetic grain isolation. Continued grain size reduction, however, will eventually cause thermal destabilization of the media grains, thereby limiting the attainable areal density. To postpone the onset of superparamagetic decay in recording media and to push out areal density, one generally seeks to enhance the media anisotropy. However, smaller magnetically harder grains also require enhanced write fields and the thermal stability problem essentially becomes a write field problem. A technologically important route to enhancing the write field is perpendicular recording, in which a single pole write head is combined with a double layer hard/soft magnetic medium. The presence of the soft magnetic layer permits flux closure directly through the recording layer enabling enhanced fields and sharper cross track gradients. Such media have been developed recently and record areal densities in the 60 Gbpsi range have been reported [1]. Of particular interest are granular media with large perpendicular magnetic anisotropy, large remanence ratio near 1, and a magnetization reversal onset at negative fields > 1000 Oe. Another important approach is hybrid recording, where the write field is temporally reduced via thermal heating [2]. Finally, patterned media are considered as a means to lower media noise by lithographic definition of the recording transitions, hence enabling recording with fewer grains per bit. Ultimate recording densities in the 20-50 Tbpsi are conceivable in self-organized magnetic array patterned media [3].
[1] H. Takano et al. "A practical approach for realizing high-recording density hard disk drives", paper CA-01, MMM/Intermag 2001, San Antonio, TX, January 7-11 [2] M. Alex et al., paper HC-01 and H. Sukeda et al., paper AA-05, MMM/Intermag 2001, San Antonio, TX, January 7-11 [3] S. Sun et al., Science 287, March 2000, pp. 1989-1992.

9:00 AM F7.2

PROPOSAL OF A NOVEL SPIN FILTER REALIZED IN A TRIPLE BARRIER RESONANT TUNNEL DIODE USING RASHBA SPIN-ORBIT INTERACTION. T. Koga, J. Nitta, NTT Corporation, NTT Basic Research Laboratories, Atsugi-city, Kanagawa, JAPAN; S. Datta, Purdue University, School of Electrical and Computer Engineering, West Lafayette, IN; H. Takayanagi. NTT Corporation, NTT Basic Research Laboratories, Atsugi-city, Kanagawa, JAPAN.

The central themes in the recently growing field of "spintronics" are (1) to explore novel spin-dependent phenomena that are predicted to occur in various form of solid state materials and (2) to use these new phenomena to design future electronic devices with completely new functionalities which have never realized in conventional electronic devices. Here, it should be noted that conventional electronic devices utilize only the properties of electron charges, and not those of the spins. In the present work, we propose a novel spin filter that utilizes the Rashba spin-orbit interaction in an InAlAs-InGaAs-InAlAs-InGaAs-InAlAs triple barrier resonant tunnel diode (RTD). This spin filter makes use of spin-dependent resonant states that are formed in the triple barrier structures. We find that, for a certain source-drain voltage, it is possible to engineer the device structure in such a way that a resonant level formed between the first and second barriers in the RTD matches that formed between the second and third barriers only for a selected spin state, thus realizing an electronic spin filter. The calculated polarization of the transmitted current through the device, as defined by $|I_{-}I_{-}|/(I_{I-})$, where I and I_{-} are the spin-up and spin-down currents, respectively, is found to exceed 99%. We also discuss possible applications for this unique device and propose some experiments to be performed to confirm the predicted theoretical results.
This research work is supported by the NEDO International Joint Research Grant Program.

9:15 AM F7.3

ULTRATHIN $(Ga,Gd)_2O_{3-x}$ TUNNEL BARRIERS FOR SPIN TRANSPORT IN SEMICONDUCTOR SYSTEMS. N.C. Oldham, C.J. Hill, R.P. Strittmatter, T.C. McGill, Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA.

The properties of the $(Ga,Gd)_2O_{3-x}$ system have been examined for ultrathin spin-dependent tunnel barrier applications. Structures of type FM/T/SC and FM/T/FM/SC have been fabricated, where FM denotes a ferromagnetic material, T an insulator, and SC a semiconductor. Semiconductors include GaAs, InAs, and GaN. Ultrahigh vacuum fabrication techniques allow nearly contamination-free interfaces to be formed. Effective band offsets and layer chemistry have been investigated using x-ray photoelectron spectroscopy (XPS). $x \leq 0.3$ has been observed. TEM imaging has allowed us to observe lattice imperfections and crystal structure. I-V characteristics were measures and spin transport properties determined by Stokes-parameter analysis of optical emission. It is found that these films are amorphous and suitable for use as tunnel junctions.

9:30 AM F7.4

SPIN VALVE EFFECT IN MAGNETIC RESONANT TUNNELING DEVICES. D.O. Demchenko, A.N. Chantis, and A.G. Petukhov, Dept of Physics, South Dakota School of Mines and Technology, Rapid City, SD.

We propose a new electronic device utilizing resonant tunneling between two magnetic materials. The device is comprised of a semiconductor quantum well sandwiched between two insulating barriers and ferromagnetic leads. At certain geometries and material parameters this structure may exhibit a strong spin valve effect leading to a great enhancement of magnetoresistance. New ferromagntic semiconductors such as GaMnAs or its analogs are suitable materials that can be used to fabricate the device in question. As an example, we consider resonant tunneling of holes in GaMnAs/AlAs/GaAs/AlAs/GaMnAs double-barrier heterostructures. Our calculations of tunneling conductance for parllel and anti-parallel alignment of magnetizations in the leads demonstrate that at certain thickness of the quantum well and the barriers this system can significantly outperform conventional tunneling junctions comprised of one insulating barrier sandwiched between two ferromagnetic electrodes. We also investigate the bias dependence of magneto-resistance. Another interesting feature of the proposed device is a possibility of a bias-controlled coupling between two magnetic electrodes.

10:15 AM F7.5

CONDUCTION ELECTRON SPIN RESONANCE IN SiGe QUANTUM WELLS: A POTENTIAL ROUTE TOWARD QUANTUM COMPUTING. N. Sandersfeld, M. Mühlberger, Z. Wilamowski, W. Jantsch, F. Schäffler, Inst Halbleiter- und Festkörperphysik, Univ Linz, AUSTRIA; S. Lyon, Electr. Eng. Dept, Princeton Univ, NJ.

We report on spin properties of 2D electron gases (2DEG) in the strained Si and SiGe quantum wells of modulation-doped Si/SiGe heterostructures. In a standard electron spin resonance (ESR) set-up conduction electron spin resonance of the 2DEGs leads to sharp absorption lines with line widths as narrow as 30 mG at a g-factor close to 2. Both microwave saturation and spin echo experiments were conducted to extract the spin coherence and spin life times. In the best samples we found spin coherence times of several micro seconds, which is 3 - 4 orders of magnitude larger than in most III-V semiconductors. Thus, electrons in Si, which are known to experience extremely weak spin-orbit interaction, appear to be well suited for the investigation of quantum computing concepts. A possible scheme employs ESR to induce controlled spin flip operations. By utilizing a quantum well structure consisting of two materials with different g-factor, ESR spin flips can be switched on and off by moving the electron wave functions from one layer to the other by, e.g., applying a gate voltage. Since the g-factors in Si (2.00) and Ge (1.54) differ significantly, g-factor tuning will become possible by changing the composition. To test the feasibility of this concept we performed CESR experiments on strained, n-type modulation-doped Si(1-x)Ge(x) quantum wells with $x \leq 10\%$. The experiments show a systematic decrease of the g-factor with composition. Given the narrow line width of the ESR signal a change of x from 0 to as little as 5% would be sufficient to shift the 2DEG out of resonance. Such a structure can easily be implemented with standard Si technologies, which is a further strong motivation for considering Si-based heterostructures for spin devices.

10:30 AM F7.6

MAGNETIC-SPIN PROPERTIES OF SPUTTER-DEPOSITED CO FILMS INVESTIGATED USING DIFFUSE-SOFT-X-RAY HYSTERESIS. B.M. Barnes, Mark Friesen, J.J. Kelly IV, D.E. Savage, and M.G. Lagally, University of Wisconsin-Madison, Dept. of Physics, Madison, WI.

Development of spintronics devices requires detailed knowledge of the surface and interfacial magnetic properties of ultra-thin sputter-deposited films. With soft-x-ray scattering using a tuneable source of x-rays, one can probe element-specific magnetic properties. Measuring the diffuse component of the scattered intensity provides depth-limited (i.e., interfacial) information on the selected material. Previous work[1] reported slight changes (relative to the specular component, which measures bulk film effects) in coercivity and hysteresis loop shape in the diffuse intensity as a function of both chemical and magnetic roughness, and of grain size. The coercivity increase was attributed to a loss of coordination, which would allow fluctuating spins; however, it was also conjectured that disorder affects the local anisotropy and thus changes the shape of the hysteresis loops. We report on Co-based film systems for which the diffuse hysteresis and loop shape remain unchanged from the specular throughout the diffuse scattering. To investigate the interrelations between morphology and magnetic anisotropy, we vary parameters of this base system to produce changes in the nature of interfacial magnetic properties. These changes include additions of capping layers, increases in sputter pressure, and ion-etching of Cu buffer layers. Behavior of magnetic spins at the interface will be analyzed by comparing our results in light of competing models, that magnetic spins are most affected with increasing roughness by either a loss of coordination or by local anisotropy. Supported by Seagate and ONR. Support for the SRC is provided under NSF Grant #DMR 00-84402. [1] J.W. Freeland, K. Bussmann, P. Lubitz, Y.U. Idzerda, and C.-C. Kao, Appl. Phys. Lett. 73, 2206-2208 (1998).

10:45 AM F7.7
REAL-TIME OBSERVATION OF REMAGNETIZATION PROCESS IN Fe_3O_4 FILMS. M. Turchinskaya, National Institute of Standard & Technology, Ceramic Division, Gaithersburg, MD; A. Roytburd, Department of Chemical and Nuclear Engineering, University of Maryland, College Park, MD; A. Orozco, S.R. Shinde, S.B. Ogale, and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD.

The remagnetization process of (001) Fe_3O_4 films deposited on (001) $SrTiO_3$ substrates was studied using a magneto-optical imaging technique. The films were deposited by pulsed laser deposition technique. They were characterized by different techniques to ensure their high epitaxial quality and the expected electrical properties including the Verwey transition. The films having thicknesses 400 and 800 nm were examined. It was found that remagnetization in 400 nm (thinner) films proceeds continuously without observation of domain structure. On the other hand, in 800 nm (thicker) films, the continuous evolution of remagnetization is interrupted by the discontinuous formation of the domain structure when the field approaches the coercive field (Hc). Once the domains are nucleated, they spread throughout the sample with a slight change in applied field. At a field slightly higher than Hc, the magnetization again becomes uniform. This discontinuous change of the magnetization with the field results in the appearance of a steep change of magnetization in the hysteresis loop near the Hc. For thinner films, when the field is applied along $< 110 >$ direction, i.e. along the easy direction of magnetization for Fe3O4 film, the magnetization proceeds uniformly through gradually changing the magnitude without changing its direction. When the field is applied along $< 100 >$ direction, the magnetization proceeds through the gradual rotation of its direction. Similar behavior is observed for thicker films, the only difference being the formation of domain structure at field values close to Hc. The creep phenomenon is also observed once the domains are nucleated in thicker films. When the field was applied along $< 110 >$ direction, the nucleated domains grow in size for about 30 s even though the applied field is kept steady. For field applied along $< 100 >$ direction, the domain movement was much faster. This work is supported under NSF-MRSEC grant no. DMR-00-80008.

11:00 AM *F7.8
MATERIALS AND PROCESSING CHALLENGES IN MAGNETIC NANOFABRICATION. J.A. Katine, IBM Almaden Research Center, San Jose, CA.

Devices exploiting giant magnetoresistance or tunneling magneto-resistance typically contain magnetic layers no more than 2 or 3 nm thick; hence, these devices are often called magnetic nanostructures. Although we are now capable of controlling these multilayer interfaces to sub-Angstrom precision, controlling the lateral dimensions of magnetic devices is more challenging. In this talk, I will show examples which illustrate the techniques being used today to fabricate magnetic devices with lateral dimensions below 100 nm. Such techniques can broadly be classified into two categories: additive and subtractive. In additive techniques, material is deposited into a previously fabricated stencil. Examples of such additive techniques are electrodeposition and collimated deposition/lift-off processing. Though extremely useful for certain applications, these additive techniques are ill-suited for fabricating complex multilayer structures. In such structures, the precision requirements for the magnetic layers forces the multilayer deposition to be done first, with the film subsequently patterned via subtractive processing such as focused ion beam milling, reactive ion etching, or Ar ion milling with a lithographically-defined mask. It is important that this subtractive processing does no significant damage to the resulting magnetic nanostructure. The various techniques to be presented in this talk have made it possible to probe the behavior of laterally constrained magnetic nanostructures. Understanding this behavior is becoming increasingly important to the magnetic storage industry, in which, within five years, the physical dimensions of multilayered sensors is anticipated to be less than 100 nm.

11:30 AM *F7.9
INTEGRATION OF MAGNETIC DEVICES WITH SEMI-CONDUCTOR CIRCUITS: PROMISES AND CHALLENGES. Dexin Wang, James M. Daughton, NVE Corporation, Eden Prairie, MN.

Magnetoresistive materials are under intensive research and development driven mainly by their high potential and initial commercialization successes in read heads for data storage, magnetic field sensing, and a variety of derivative devices. These demonstrated devices exploit the superior properties of magnetoresistive materials, such as high signal level and high sensitivity. The devices can also be integrated with semiconductor circuitry for signal conditioning and supply modulations. Therefore many applications demand certain level of integration of the magnetic components with IC electronics in order to achieve the desired performance. Although it is a more complex design and fabrication process and there are associated yield losses in integrating magnetoresistive materials with IC electronics, there are far more significant advantages, including small size, high speed, low power, and better overall performance. Recently announced transistors with feature sizes of 20 nm for chip speed of 20 GHz typify the continued progress in semiconductor IC technologies. On the magnetics side, GMR materials are being applied to commercial use in discrete as well as integrated forms, as soon SDT materials will be. MRAM arrays of different types with feature sizes of 200 to 600 nm have been demonstrated. Much smaller devices enabled by Curie point writing and other ingenious inventions suggest speedy increase in MRAM density. The spin degree of freedom, in addition to the charge degree of freedom, for electrons seems to promise great potential for more advanced devices where integration is anticipated. In this presentation, magnetoresistive materials applied to magnetic field sensors, galvanic isolators, and several types of MRAM devices integrated with underlayering IC electronics are used to illustrate the achievements, promises, and the challenges in design, fabrication, and performance in this fascinating frontier.

SESSION F8: ADVANCED TECHNOLOGIES FOR MAGNETIC CHARCTERIZATION AND IMAGING
Chair: Bruce M. Clemens
Wednesday Afternoon, November 28, 2001
Room 207 (Hynes)

1:30 PM *F8.1
SEMPA STUDIES OF THIN FILM MAGNETIC STRUCTURES. John Unguris, National Institute of Standards and Technology, Gaithersburg, MD.

Scanning Electron Microscopy with Polarization Analysis (SEMPA) provides a direct image of a sample's magnetization by measuring the spin polarization of secondary electrons emitted in a scanning electron microscope. With submonolayer magnetic sensitivity and probe sizes as small as 10 nm, SEMPA is sensitive to extremely small amounts of magnetic material; as small as 1000 Fe atoms or 10^{-7} emu. In particular, SEMPA's surface sensitivity makes it especially well suited for the direct, quantitative mapping of the magnetization direction in thin film structures used in spintronic devices. Correlations between magnetic and physical structures in these systems can be determined, since SEMPA provides separate, yet simultaneous, images of the magnetic and topographic structure. When combined with other compatible surface analytical techniques such a Auger, RHEED and STM, SEMPA can also provide information about the relationship between the magnetic structure, the chemical structure, and the atomic scale order. SEMPA can also be used for in situ imaging of magnetic structure during thin film growth and depth profiling. This talk will describe the SEMPA technique and present examples of measurement applications from thin film and multilayer magnetism. These measurements have provided a better understanding of domain structures in patterned thin film structures, multilayer exchange coupling, magnetic ordering in antiferromagnetic films, and the relationship between magnetic domain structure and magnetoresistance in multilayers.

2:00 PM *F8.2
PEEM STUDIES OF THIN FILM MICROMAGNETICS. Andreas Scholl, Lawrence Berkeley National Laboratory, CA; Christian Stamm, Hendrik Ohldag, Joachim Stöhr, Hans-Christoph Siegmann, Stanford Sychrotron Radiation Laboratory, CA; Scott Andrews, Stanford University, CA; Frithjof Nolting, Swiss Light Source, SWITZERLAND.

The magnetic microstructure and the magnetic coupling to adjacent layers govern the magnetic properties of a magnetic thin film. Of particular importance in many technical applications is the interface between two magnetic layers or between a magnetic and a non-magnetic layer. Phenomena such as exchange bias, giant magneto resistance and spin injection are interface phenomena and precise knowledge of the interface spin structure and chemistry are essential for the understanding of these effects. We will show that X-ray Photoelectron Emission Microscopy (X-PEEM) offers sub-monolayer magnetic sensitivity which is sufficient to detect very small spin concentrations at surfaces and interfaces. High spatial resolution of currently down to 50 nm and theoretically down to 1 nm, elemental and chemical specificity, and sensitivity to ferromagnetic and antiferromagnetic order make PEEM an ideal tool for the study of magnetic interface phenomena. Here we will present results on the magnetic exchange coupling in ferromagnet-antiferromagnet structures, and we will show initial experiments on spin injection in all-metallic devices. In ferromagnet/antiferromagnet samples such as $Co/LaFeO_3$ and Co/NiO we were able to separate the contributions to the sample magnetism of the antiferromagnetic bulk, of its interface to the ferromagnet and of the ferromagnetic layer itself. The relative alignment of the magnetization and its response to external magnetic fields provides important information on the origin of the exchange coupling between the layers, as we will show. Spin polarized currents provide a new method of efficiently manipulating nanoscale magnetic domains. We will present initial experiments on current induced switching, where we directly image the magnetization reversal in response to a localized current. We are currently designing a new experiment setup which will allow stroboscopic measurements using a synchronized sychrotron-laser setup. We expect to achieve 50 ps time resolution at the full spatial resolution of the microscope, opening new ways of studying dynamic magnetic processes. This work was supported by the Director, Office of Basic Energy Sciences, of the US Department of Energy.

3:00 PM F8.3

SYNCHROTRON-RADIATION-BASED INVESTIGATIONS OF POTENTIAL HALF-METALLIC-FERROMAGNETS. J.G. Tobin, M. Hochstrasser, D.A. Arena, LLNL, CA; S.A. Morton, G.D. Waddill, U. Missouri-Rolla, MO; S. Kim, I.K. Schuller, Univ of California-San Diego, CA; S.A. Chambers, PNNL, WA; A. Holm, S. Kauzlarich, W. Pickett, Univ of California-Davis, CA.

Many materials have been predicted to be half metallic ferromagnets, yet despite extensive study, remarkably little truly compelling evidence for half metallic behavior has emerged. One technique that can potentially yield a definitive answer to the question of half metallic character is spin polarized photoemission and it is from this technique that the strongest evidence to date has emerged [1]. Using the spin-resolving photoelectron spectrometer at the Spectro-microscopy Facility (Beamline 7) at the Advanced Light Source [2], we have found evidence for half-metallic behavior in thin films of magnetite. Thin films of magnetite hold out the possibility of use in devices as pure spin sources. Because our spin resolving experiments are performed at higher photon energies, we were able to monitor the spin polarization of the near Fermi energy electrons without resorting to destructive surface cleaning techniques, using the samples "as is". Furthermore, we have demonstrated that harsh sample cleaning procedures such as ion etching causes the loss of the desired spin polarization, which may help explain the failure of other previous experiments to observe half metallic behavior. By measuring the polarization as a function of emission angle and photon energy, and combining these measurements with a substrate overlayer model, we have gained substantial insight into the nature of magnetite. Furthermore, our spin resolved spectra demonstrate close agreement with simulated spectra derived from theoretical one electron density of states calculations [3]. In the case of the Zintl compound, Yb14Mn Sb11, X-ray Magnetic Circular Dichroism was used to demonstrate that the Mn was the dominant contributor to the magnetic moment, possessing a magnetic moment on the scale of 5 Bohr-Magnetons. This work was performed under the auspices of the U.S Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48. Most of the experiments were carried out at the Spectromicroscopy Facility (Beamline 7.0) at the Advanced Light Source, built and supported by the U.S. Department of Energy. 1. Park et al, Nature 392, 794 (1998); Phys. Rev. Lett. 81, 1953 (1998). 2. J.G. Tobin et al, MRS Symp. Proc. 524, 185 (1998). 3. Z. Zhang and S. Satpathy, Phys. Rev. B. 44, 13319 (1991).

3:15 PM F8.4

INFLUENCE OF ROUGHNESS ON MAGNETIC INTERFACIAL PROPERTIES. J.J. Kelly, IV, B.M. Barnes, D.E. Savage, M. Friesen, M.G. Lagally, Dept. of Materials Science, University of Wisconsin-Madison, Madison, WI.

New applications in magneto-electronics and thin magnetic films require detailed knowledge about the nature of magnetism at surfaces and interfaces at the subnanometer level. The influence of surface and interface morphology, both chemical and magnetic, on spin-dependent electron scattering, and thus on the performance of spintronics devices, is a critical question. Diffuse x-ray resonant magnetic scattering (DXRMS), a unique element-specific method that provides information on both the chemical and magnetic morphology at surfaces and interfaces, shows evidence for a disordered magnetic layer at the interface between a magnetic / non-magnetic material. [1-3] In this disordered layer, the magnetic spins do not follow the applied magnetic field perfectly. We present DXRMS data for a series of samples with deliberately roughened Cu buffer layers (via ion etching) of the form 7 nm Co / 10 nm Cu / $< 100 >$ Si. The Co and Cu films are sputter deposited, and are smooth to < 0.5 nm without the deliberate roughening. We discuss trends in the nature of the disordered layer and in the chemical and magnetic roughness and describe a model for the magnetic interface consistent with all data. Supported by Seagate Technology Co. and ONR Support for the SRC is provided by NSF under grant number DMR-0084402 [1] J.F. Mackay, C. Teichert, D.E. Savage, and M.G. Lagally, Phys. Rev. Lett. 77, 3925 (1996). [2] C.S. Nelson, G. Srajer, J.C. Lang, C.T. Venkataraman, S.K. Sinha, H. Hashizume, N. Ishimatsu, and N. Hoshito, Phys. Rev. B 60 (17), 12234 (1999). [3] J.J. Kelly IV, B.M. Barnes, D.E. Savage, Mark Friesen, M.G. Lagally, in preparation (2001).

3:30 PM F8.5

OCCUPIED AND UNOCCUPIED METALLIC QUANTUM WELL (MQW) STATES IN THE Cu/fccM/Cu(100) [M=Ni, Fe] SYSTEMS. Anthony G. Danese, Robert A. Bartynski, Rutgers University, Dept. of Physics, Piscataway, NJ; Dario A. Arena, Michael Hochstrasser, James Tobin, Lawrence Livermore National Lab, Lawrence Berkeley Lab, Berkeley, CA.

Multilayer structures composed of alternating ferromagnetic (FM) and nonmagnetic (NM) layers are known to exhibit Giant Magneto Resistance (GMR), an effect whereby a large change in the multilayer resistance occurs as a function of magnetic field. These multilayers have been applied to magnetic storage and sensing technologies, and this has sparked a great deal of interest in understanding these systems at a fundamental level. We have studied the Metallic Quantum Well (MQW) electronic structure of the prototypical NM/FM/NM systems, Cu/fccM/Cu(100) [M=Ni,Fe], using angle resolved photoemission (PE) and inverse photoemission (IPE) along the $\overline{\Gamma X}$ direction. We have also used a phase accumulation model (PAM) to calculate the dispersions of MQW electronic states along this axis. The PAM predicts that MQW states will have high a effective mass when they lie in the energy and momentum region of the projected spin polarized band gap of the underlying magnetic material. Two states of high effective mass were observed using PE on the Cu/fccNi/Cu(100) system, one inside the Ni band gap and one near the gap edge, and another state was seen just above the gap using IPE in good qualitative agreement with the PAM. Numerous MQW states were seen using IPE on Cu/fccFe/Cu(100) but no pronounced high-effective-mass state was seen in the Fe band gap. Additionally, the PAM predicts that MQW states will increase in energy as a function of increasing Cu thickness. Although we observed this in our IPE results for MQW states in Cu/fccFe/Cu(100) and PE of Cu/fccNi/Cu(100), our IPE data for Cu/fccNi/Cu(100) show MQW states decreasing in energy as a function of increasing Cu thickness. In general, however, the PAM gives a good qualitative fit to our experimental results. We will discuss our results in the context of the PAM and address the origins of discrepancies between the PAM's predictions and our measurements

3:45 PM F8.6

IMAGING SELF-ORGANIZED DOMAINS AT THE MICRON SCALE IN ANTIFERROMAGNETIC ELEMENTAL Cr USING MAGNETIC X-RAY MICROSCOPY. P.G. Evans, E.D. Isaacs, Bell Laboratories, Lucent Technologies, Murray Hill, NJ; G. Aeppli, NEC Research Institute, Princeton, NJ; Z. Cai, B. Lai, Advanced Photon Source, Argonne National Laboratory, Argonne, IL.

The domains of antiferromagnetic order in a Cr single crystal can be observed with spatial resolution that is improved by orders of magnitude in comparison with previous techniques using the diffraction of x-rays focused to a submicron spot. The incommensurate spin-density wave of the Cr antiferromagnetic state allows magnetic x-ray scattering to be easily distinguished from diffraction due to non-magnetic order. Using the spin-polarization dependence of the magnetic x-ray scattering cross section we have imaged the first order spin-flip transition near 120 K directly and found that it is broadened in temperature by several degrees even at the micron scale. This inherently quantitative technique connects the phenomena occurring at the single domain scale near this transition to anomalies in transport and magnetization measurements.

SESSION F9: IN-ROOM POSTER SESSION

Chair: William P. Pratt, Jr.
Wednesday Afternoon, November 28, 2001
4:00 PM
Room 207 (Hynes)

F9.1

OPTICAL AND TRANSPORT STUDIES OF IMPURITY STATES IN Mn-DOPED GaAs EPILAYERS. M. Furis, G. Itskos, C. Ruester,

G. Comanescu, X. Chen, A. Petrou, B.D. McCombe, H. Luo, Department of Physics and Center for Advanced Photonic and Electronic Materials, University at Buffalo, State University of New York, Buffalo, NY; Y. Sasaki, X. Liu, and J.K. Furdyna, Department of Physics, University of Notre Dame, IN.

We have carried out optical and transport studies of Mn-doped GaAs epilayers. The Mn concentration was kept below 0.005% and all samples are paramagnetic. The low Mn concentration used in this study allows high temperature growth at 580°C, instead of the low temperatures used for GaMnAs alloys to avoid the formation of MnAs precipitates (usually below 300°C). In this study, we have focused on the behavior of Mn-related acceptor states as a function of Mn concentration. As the Mn concentration increases, the samples become metallic, with the highest hole concentration up to 2.5 x 10^{18}/cm^3. As the Mn concentration increases, the conduction band to acceptor state transition at 11,400 cm^{-1} (as observed in the photoluminescence spectra from low concentration samples) evolves into a broad band that extends above the GaAs band gap. This observation suggests that isolated Mn acceptor states evolve into an impurity band, extending into the valence band. This is supported by the results of photoconductivity measurements, which exhibit a broadening of the absorption edge of GaAs with increasing Mn-concentration. The transport measurements show a slight decrease of sheet resistance with increasing temperature for all metallic samples that also exhibit a negative magnetoresistance at low magnetic field. At higher magnetic fields, the magnetoresistance becomes positive. The negative magnetoresistance decreases with increasing temperature and vanishes around 100 K.

F9.2
IMPLANTATION OF Mn, Fe AND Ni INTO GaN, SiC AND GaP FOR CREATION OF DILUTE MAGNETIC SEMICONDUCTORS. S.J. Pearton, Univ of Florida, Dept of MS&E, Gainesville, FL; N. Theodoropoulou, Univ of Florida, Dept of Physics, Gainesville, FL; M.E. Overberg, Univ of Florida, Dept of MS&E, Gainesville, FL; S.N.G. Chu, Agere Systems, Murray Hill, NJ; A.F. Hebard, Univ of Florida, Dept of Physics, Gainesville, FL; C.R. Abernathy, Univ of Florida, Dept of MS&E, Gainesville, FL; R.G. Wilson, Consultant, Stevenson Ranch, CA; J.M. Zavada, ARO, Research Triangle Park, NC.

The magnetic and structural properties of p-GaN, SiC and GaP implanted with Mn, Fe or Ni at doses of 10^{15}-5x10^{16} cm^{-2} and subsequently annealed have been investigated. At implanted element concentrations of 3-5at.% we observe signatures of ferromagnetic (hysteresis, difference between field-cooled and zero field-cooled magnetization) for some combinations of elements and semi-conductors. For example Ni in all these materials produces T_C values of < 50 K, varying up to ~250 K for Mn in GaP. Under most conditions, no secondary phases could be detected by TEM, XRD or SADP. The results correlate well with results from epitaxially grown materials containing some of the same dopants. A strong effect of hole density on TC was observed.

F9.3
CHARACTERISTICS OF MOLECULAR BEAM EPITAXY-GROWN GaFeAs. Y.J. Park, H.T. Oh, E.K. Kim, Semiconductor Lab. Korea Institute of Science and Technology, Seoul, KOREA; C.J. Park, H.Y. Cho, Dept of Physics, Dongguk Univ. KOREA; R. Moriya, H. Munekata, Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, JAPAN.

Diluted magnetic semiconductors $Ga_{1-x}Fe_xAs$ were grown by molecular beam epitaxy and characterized. $Ga_{1-x}Fe_xAs$ ternary alloys were obtained at the growth temperature T_s=260°C ranging from x=0.005 to 0.03. In order to investigate the magnetic properties of the sample, electron paramagnetic resonance, magnetic force microscope and super-conducting quantum interference device magnetometer were employed. The effects of thermal treatment on behaviors of defects, affecting to the magnetic properties of GaFeAs layer were particularly elucidated. As-grown samples were treated at temperatures varying from 100°C to 600°C. From the measurement of double crystal X-ray diffraction, we observed Fe-related peak which shifted to a higher diffraction angle as the Fe content increased, indicating that the lattice constant decreases with increasing Fe content. In contrast, above the annealing temperature 500°C, the lattice constant becomes smaller than that of GaAs. Using the optical deep level transient spectroscopy, various defects in GaFeAs layer were observed and identified in conjunction with the changes of magnetic properties.

F9.4
FERROMAGNETISM IN GaN- AND AlN-BASED DILUTED MAGNETIC SEMICONDUCTORS. Kazunori Sato, Hiroshi Katayama-Yoshida, Inst of Scientific and Industrial Research, Osaka Univ., Ibaraki, JAPAN.

Since the discovery of the carrier induced ferromagnetism in (In, Mn)As and (Ga, Mn)As, diluted magnetic semiconductors (DMSs) have been of much interest from the industrial viewpoint because of their potentiality as a new functional material which will open a way to introduce the freedom of spin into semiconductor devices. In this paper, the magnetism in GaN- and AlN-based DMSs is investigated based on the first principles calculations and material design of ferromagnetic DMSs is proposed. GaN and AlN have wide band gap energy of 3.39 and 6.2 eV, respectively, and have been the most promising materials for information processing with short wavelength optics, therefore, detailed investigation on the feasibility of GaN- and AlN-based ferromagnetic DMSs is of great importance. The electronic structure is calculated by the Korringa-Kohn-Rostoker method combined with the coherent potential approximation (KKR-CPA) based on the local spin density approximation. The KKR-CPA is one of the most sophisticated methods to treat substitutional disordered systems with taking disorder into account. We calculate the electronic structure of ferromagnetic and spin-glass GaN-based DMSs, and total energy difference between them is calculated to estimate whether the ferromagnetic state is stable or not. It is shown that the ferromagnetic states are stable in V- and Cr-doped GaN, but Fe-, Co- and Ni-doped GaN show the spin-glass states. In Mn-doped GaN, the magnetic state depends on the concentration of Mn. A similar trend is obtained for AlN-based DMSs. This chemical trend in the magnetic states of GaN-based DMSs is well understood based on the double exchange mechanism by a simple empirical rule in which the symmetry of impurity orbital are taken into account[1]. [1] K. Sato and H. Katayama-Yoshida, Jpn. J. Appl. Phys. 39 (2000) L555, ibid. 40 (2001) L334, ibid. 40 (2001) L485.

F9.5
Abstract Withdrawn.

F9.6
Abstract Withdrawn.

F9.7
PREDICTIONS OF CURIE-TEMPERATURE ENHANCEMENTS IN FERROMAGNETIC SEMICONDUCTOR SUPERLATTICES BASED ON MEAN-FIELD THEORY. I. Vurgaftman, J.R. Meyer, Naval Research Laboratory, Washington, DC; L.R. Ram-Mohan, Worcester Polytechnic Institute, Worcester, MA.

A previous 6-band $\mathbf{k}\cdot\mathbf{p}$ description of the valence band dispersion relations, in conjunction with mean-field theory (MFT), successfully accounted for the Curie temperatures (T_c) observed in bulk III-Mn-V semiconductor alloys. Also ferromagnetism was recently reported for digital superlattices (SLs), in which the Mn ions are confined to at most a few monolayers (MLs). These quantum structures with a large local Mn fraction are interesting for their intrinsic properties, and also provide a testing ground for determining the limitations of MFT treatments of the exchange interaction in ferromagnetic semi-conductors. Whereas the $\mathbf{k}\cdot\mathbf{p}$ method is a quasi-continuum approach, in dealing with digital SLs it is important to have a band structure model that treats single atomic layers. The effective-bond orbital method (EBOM), in which the full symmetry of the zinc-blende lattice is reduced to that of an fcc lattice, is more attractive than other atomistic approaches for reasons of straightforward reduction to an 8-band $\mathbf{k}\cdot\mathbf{p}$ model, efficiency, and simplicity. We have verified that in bulk alloys, T_c predicted by EBOM nearly coincide with $\mathbf{k}\cdot\mathbf{p}$ values. Including self-consistent exchange and electrostatic potentials, we find that the SL T_c is always enhanced over that in a bulk alloy with the same average Mn fraction and hole density, owing to the localization of the wavefunction in the magnetic layer. For the example of a GaAs/GaMnAs SL with a 10-ML period with hole density $P = 10^{20}$ cm^{-3}, the enhancement is to $T_c = 120$ K, which compares with 53 K in bulk. As the thickness of the non-magnetic spacer layer increases, the degree of hole localization saturates, reproducing the experimentally observed saturation of T_c. Room-temperature ferromagnetism is predicted by MFT for a digital SL with AlAs spacers to provide a high valence-band offset with respect to GaMnAs, assuming the same high $P = 10^{20}$ cm^{-3}.

F9.8
INTERFACE RESISTANCE AND ELECTRICAL SPIN INJECTION INTO SEMICONDUCTORS. D.L. Smith, A. Saxena, R.N. Silver, Los Alamos National Laboratory; F.X. Bronold, Institut für Theoretische Physik, Magdeburg, GERMANY.

We discuss the role of interface resistance on electrical spin injection from a spin-polarized contact into a nonmagnetic semiconductor. Without interface resistance, spin injection is typically weak for contacts with metallic resistivities. For high bulk resistivity contacts, such as doped semiconductors, or for completely spin-polarized contacts significant spin injection is possible without interface resistance. A tunnel barrier with spin dependent interface resistance can greatly enhance spin injection from spin-polarized metallic contacts. To achieve spin injection, the system must be driven out of local equilibrium by an electric current so that the electrons injected into the semiconductor are spin-polarized. It is difficult to drive the electron population in a metallic contact far from local quasi-thermal equilibrium because of the metals high electrical conductivity. Without interface resistance, the electrons in the contact and in the semiconductor remain in good thermal contact; therefore, the electrons in the semiconductor also stay in local quasi-thermal equilibrium and spin injection is weak. A tunnel barrier with spin dependent resistance provides a mechanism for the applied current density to drive electrons out of quasi-thermal equilibrium at the contact/semiconductor interface and can significantly enhance spin injection. An insulating tunnel barrier with a spin-polarized contact has spin dependent interface resistance because of the difference in Fermi wave vectors for the two spin types in the contact material. A ferromagnetic insulator tunnel barrier can also have spin dependent interface resistance. We describe calculations of spin injection for a variety of contact, barrier and semiconductor structures and investigate the properties that are required for significant spin injection.

F9.9

MAGNETIC ANISOTROPY OF STRAINED $La_{0.7}Sr_{0.3}MnO_3$ THIN FILMS STUDIED BY MOKE. Mohamed Koubaa, Anne-Marie Haghiri-Gosnet, Univ Paris Sud, Orsay, FRANCE; Wilfrid Prellier, Philippe Lecoeur, Bernard Mercey, CRISMAT, ISMRA, Caen, FRANCE.

Magnetic anisotropy of (001) strained $La_{0.7}Sr_{0.3}MnO_3$ films has been studied using Magneto Optical Kerr Effect (MOKE) as a function of pulsed laser deposition (PLD) parameters, i.e. the temperature T, the target-to-substrate distance D and the oxygen pressure P_{O2}. On $SrTiO_3$ substrate, the tensile stress is known to induce in-plane magnetic anisotropy, but the orientation of the easy axis is seen along the [100] or the [110] direction of the pseudocubic unit cell, depending on the authors [1,2]. The value of D is relevant for magnetic anisotropy: at a small distance D, [110] axis is found to be clearly easier than the [100] one, although, at large distance D values, both [100] and [110] directions are equivalent. The optimal D value (D = 45 mm for P_{O2} = 300 mTorr) produces films with very low roughness (Rms = 0.1 nm), associated to a maximum value of the saturated magnetization [3]. It is also shown that remanent magnetisation increases with pressure: for the optimal value (P_{O2} = 300 mTorr), hysteresis loops are perfectly square along the [100] direction (HC = 36 G, K= 1.6 10^4 erg/cm^3). In compressive films grown on $LaAlO_3$, for optimal PLD conditions, the perpendicular [001] direction is a hard axis and, in the plane, the easy direction lies along the [100] axis (HC = 70G, K= 7.2 10^4 erg/cm^3). The presence of an in-plane anisotropy [2] at RT will be discussed from PLD parameters.

[1] L.M. Berndt et al, APL 77, 2903 (2000)
[2] F. Tsui et al, APL 76, 2421 (2000)
[3] A.M. Haghiri-Gosnet et al, JAP 88, 4257 (2000).

F9.10

OXYGEN-ISOTOPE EFFECTS ON THE LOCAL STRUCTURE DISTORTIONS AND TRANSPORT PROPERTIES OF THE EPITAXIAL THIN FILMS OF $Nd_{0.67}Sr_{0.33}MnO_3$. R.P. Sharma, D.J. Kang, R. Marcia, M. Rajeswari, S.B. Ogale, H.D. Drew, R.L. Greene and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD; Guo-meng Zhao, and H. Keller, Physik-Institut, Universitat Zurich-Irchel, Zurich, SWITZERLAND.

Detailed investigation of incoherent lattice fluctuations and electrical transport are made in oxygen isotope substituted $Nd_{0.67}Sr_{0.33}MnO_3$ thin films. Ion channeling measurements have clearly shown an increase in the rms displacement of the Mn atoms as the sample goes from the feromagnetic to the paramagnetic state. This incoherent displacement is much larger than the phonon background over the same temperature range around 200 K. The observed anomaly is about 10% larger for ^{18}O than for ^{16}O samples. The peak in resistivity, which is close to the magnetic phase transition, is shifted to lower temperature by about 20 K in the former case as compared to the later one. Similar shift is seen in the ion channeling measurements The transport measurements have also shown that in the paramagnetic state the transport activation energy of the ^{18}O samples is higher than the ^{16}O samples by about 10%. Also the ^{18}O samples have a sharper resistivity drop below T_c than the ^{16}O samples. These features will be discussed in terms of the development of Jahn-Teller small polorons as the system approaches the paramagnetc state.

F9.11

CRITICAL MAGNETISM OF THE CMR RUDDLESDEN-POPPER MANGANITE $La_{1.2}Sr_{1.8}Mn_2O_7$. Matias Velazquez, Alexandre Revcolevschi, Laboratoire de Physico-Chimie de l'tat Solide, Université de Paris-Sud, Orsay, FRANCE; Jean-Pierre Renard, Claire Dupas, Institut d'lectronique Fondamentale, Département MMS, Université Paris-Sud, Orsay, FRANCE.

Ruddlesden-Popper layered compounds, of formula $(La,Sr,Ca)_3Mn_2O_7$, offer the opportunity to explore bidimensional magnetism in the manganites family. In order to investigate the intrinsic and anisotropic character of their physical properties, we have carried out careful and systematic single crystal growth experiments. High-quality centimeter size single crystals of $La_{1.2}(Sr,Ca)_{1.8}Mn_2O_7$ were successfully grown using a floating zone method associated with an image furnace [1]. These single crystals were characterized by means of X-ray and neutron diffraction, as well as high-resolution transmission electron microscopy. In our presentation, we shall bring up a thorough investigation [2] of the critical behaviour of $La_{1.2}Sr_{1.8}Mn_2O_7$, through static magnetization and susceptibility measurements, including the determination of the fundamental characteristics of a magnetic system: magnetic anisotropy, critical exponents and crossovers in the vicinity of the Curie temperature, Tc 108K. $La_{1.2}Sr_{1.8}Mn_2O_7$ can be viewed as a two-dimensional Heisenberg ferromagnet with notable deviations from this ideal model: firstly, the XY anisotropy stemming from the competition between spin-orbit coupling and dipolar interactions (anisotropy field of about 132 mT at low temperature), secondly, the three-dimensional couplings between perovskite bilayer blocks. These deviations successively induce a spin dimensionality crossover at Ts 157K, and a lattice one at Tl 117K. The slow development of the two-dimensional ferromagnetic correlations above Tc, and our quantitative measurements (critical exponents delta=(4.3±1.1) and gamma 1.4 in the vicinity of Tc), lead us to believe that the ferromagnetic transition in $La_{1.2}Sr_{1.8}Mn_2O_7$ is essentially of three-dimensional nature. Intrically related with ferromagnetism are an insulator-metal transition at Ti-m 128K, and a negative magnetoresistance maximum effect (δR/R(8T))[001] 1000 2*(δR/R(8T))[110], typical of $La_{1.2}Sr_{1.8}Mn_2O_7$ three-dimensional homologs, as one can expect from its critical behaviour. [1] M. Velazquez, C. Haut, B. Hennion and A. Revcolevschi, J. Cryst. Growth, 220 (2000) 487. [2] M. Velazquez, A. Revcolevschi, J.P. Renard and C. Dupas, submitted to Eur. Phys. J. B, (2001).

F9.12

ION BEAM DEPOSITED GMR MATERIALS. J.M. Lannon Jr., D. Temple, G.E McGuire, C.C. Pace, MCNC, Materials and Electronic Technologies Division, Research Triangle Park, NC; A.F. Hebard, University of Florida, Department of Physics, Gainesville, FL.

The development of ion beam sputter deposition (IBSD) techniques for deposition of giant magnetoresistance (GMR) films has been studied using an automated IBSD system designed and built in-house. We have studied the properties of Fe/Cr multilayers deposited using either Ar or Xe ions with the primary ion beam energy varying from 500 eV to 1100 eV. The films were characterized using transmission electron microscopy (TEM), atomic force microscopy (AFM), Auger electron spectroscopy (AES), magnetization measurements, and magnetoresistance measurements. The maximum value of GMR obtained was 29% (measured at 10K). For the Cr spacer thickness layer chosen, this GMR ratio is better than the best values reported for polycrystalline Fe/Cr multilayers deposited by magnetron sputtering. We have found that GMR ratios for the Fe/Cr multilayers increase with decreasing primary ion beam energy, and are greater for films deposited using Xe ions than for films deposited using Ar ions. We explain the observed effects on the basis of energy distributions of sputtered atoms and backscattered working gas atoms (neutrals). The energy distributions were calculated using TRIM (Transport of Ions in Matter) software based on the Monte Carlo method.

SESSION F10: STRUCTURES WITH SUPERCONDUCTORS AND NANOSTRUCTURED SYSTEMS

Chair: Jagadeesh S. Moodera
Thursday Morning, November 29, 2001
Room 207 (Hynes)

8:30 AM F10.1

TOWARDS A SUPERCONDUCTING SPIN SWITCH. A. Rusanov, R. Boogaard, M. Hesselberth and J. Aarts, Kamerlingh Onnes Laboratory, Leiden University, THE NETHERLANDS.

It was recently demonstrated that junctions of two superconducting banks (S) with a weak ferromagnet (F) in between can sustain a supercurrent; the behavior of the critical currents of such junctions suggest that for a certain temperature and F-layer thickness interval the phase difference between the banks can be π instead of 0 (*). The π-state is a manifestation of an inhomogeneous order parameter in, and induced by, the ferromagnet, the so-called Larkin-Ovchinnikov-Fulde-Ferrel (LOFF) state. Using this state it should be possible to fabricate a 'superconducting spin switch', consisting of an F/S/F structure with both F-layers thickness-tuned to sustain a LOFF-state. Rotating the direction of the magnetization of the layers with respect to each other should then influence the superconducting transition temperature of the S-layer. We have investigated the proximity effects in multilayers of $Nb/Cu_{1-x}Ni_x$, with x between 0.5 and 0.7. We show that for the lowest Ni-concentrations the conditions for such a device with respect to interface transparency and S-layer critical thickness are met. (*)V.V. Ryazanov et al., Phys. Rev. Lett. 86, 2427 (2001).

8:45 AM F10.2
THE TRANSMISSION POLARIZATION OF FERROMAGNET/ SUPERCONDUCTOR INTERFACES. K. Xia and P.J. Kelly, University of Twente, THE NETHERLANDS; G.E.W. Bauer, Delft University of Technology, THE NETHERLANDS; I. Turek, Institute of Physics of Materials, Brno, CZECH REPUBLIC.

Andreev reflection at an interface between a ferromagnet (FM) and a superconductor (S) has become an attractive technique to measure the spin polarization of magnetic materials. The results of these measurements are interpreted using the so-called BTK model introduced almost twenty years ago which is based on a free-electron model of the conduction electrons and an interface modelled by a delta function with strength Z. In neglecting the complex *d*-bands of transition metal elements, such models are known to neglect important aspects of the physics of electron transport through interfaces; the spin-dependence of the interface transmission plays an essential role in Giant MagnetoResistance. An additional complication is that most FM/S interfaces (such as Co/Pb or Co/Nb) are not epitaxial and difficult to model realistically on an atomic scale. Using a newly developed method based on the TB-LMTO method[1], we model FM/S interfaces using large lateral supercells, calculate entirely from first-principles the spin polarization of the transmission through Pb/Co and Pb/Cu interfaces and use the results to calculate the conductance above and below the superconducting transition temperature (thus, taking into account the Andreev reflection). This allows us to make a detailed comparison with experiment and discuss the conclusions which can be drawn about the spin-polarization of the ferromagnet.
[1]K. Xia, P.J. Kelly, G.E.W. Bauer, I. Turek, J. Kudrnovský, and V. Drchal, Phys. Rev. B **63**, 64407 (2001).

9:00 AM F10.3
TRANSPORT STUDY ACROSS A CrO_2/Ag/YBCO JUNCTION USING FLIP-CHIP CONFIGURATION. Z.Y. Chen, Amlan Biswas, S.B. Ogale, I. Takeuchi, J. Read, T. Venkatesan and R.L. Greene, Univ. of Maryland, Center for Superconductivity Research, College Park, MD; A. Anguelouch, G. Xiao, Dept. of Physics, Brown University, Providence, RI; A. Gupta, IBM T.J. Watson Research Ctr., Yorktown Heights, NY.

In our recent work[1] on the transport across a LSMO/YBCO hetero-interface, we demonstrated the suppression of the zero-bias conductance peak (ZBCP) associated with the Andreev bound states at the ab-plane of the interface due to the spin polarization of LSMO carriers. However, the temperature dependence of the shape of the ZBCP indicated that the decay of the surface spin polarization of LSMO occurs far below the Curie temperature raising questions about the applicability of LSMO in spintronics applications. CrO_2 is another transition metal oxide, which has suggested to be highly spin polarized. In this work we report the results of a transport study applied to a CrO_2/Ag/YBCO junction, employing the flip-chip mechanism. The junction is formed by pressing a CrO_2 film against a Ag/YBCO junction. The Ag/YBCO junction in the same flip-chip configuration clearly shows the zero-bias conductance peak (ZBCP), proving the validity of the flip-chip mechanism employed in the study. The transport characteristics of the CrO_2/Ag/YBCO junction do not reveal any ZBCP all the way up to the T_c of YBCO, 80 K. The strong suppression of ZBCP is an evidence of the high spin-polariztion (near 100%) of the CrO_2 surface, its persistence up to the T_c of YBCO indicates a good temperature stability of the spin polarization. A comparison of the results obtained for different CrO_2 film thickness is also carried out. This work was supported by ONR grant No. N00140010028 (Deborah Van Vechten) and NSF-MRSEC grant No. DMR-00-80008. [1] Z.Y. Chen *et al.* Phys. Rev. B **63**, 212508 (2001).

9:15 AM *F10.4
THERMAL RELAXATION IN SOFT, PATTERNED MAGNETIC ELEMENTS. H.Q. Yin, W.D. Doyle, The Center for Materials for Information Technology, The University of Alabama, Tuscaloosa, AL.

The methodology for characterizing thermal relaxation in magnetic systems exhibiting single domain behavior is now well established, in contrast to systems dominated by domain wall motion. However, as film thicknesses and element sizes in practical devices are reduced, thermal relaxation becomes a critical issue [Ref. 1]. Here we report on a study of arrays of nominally rectangular bars patterned with conventional lithography in sputtered uniaxial permalloy films with thicknesses of 7.9, 18.3 and 43.5 nm. The design dimensions [wxl] were 1x5, 1x10, 1x15, and 2x10 μm^2 with 2μm spacings but the final bar dimensions measured using AFM were smaller. Time-dependent remanent coercivity measurements on the arrays [$>10^5$ elements] were used to extract the intrinsic switching field H_o and the average thermal sensitivity factors equal to U/kT in Sharrock's model and correlated with direct MFM observations of time decay and domain structures in individual elements. Here U is the effective energy barrier, k is Boltzmann's constant and T is the temperature. The decay of the remanent moment in the arrays was logarithmic with time, characteristic of a distribution of energy barriers. Equivalent measurements made by counting individually switched elements using MFM were also logarithmic. However, individual elements with $w = 1$ μm always switched spontaneously between two equivalent remanent states. The ratio of H_o/H_k where H_k is the anisotropy field obtained from FMR measurements decreased with increasing film thickness from ∼0.5 to ∼0.1. The values of U/kT varied from 110-240 in the 7.9 nm thick samples, increased to 170-690 in the 18.3 nm thick samples, but decreased precipitously to 70-90 in the 43.5 nm thick samples. No clear correlation with sample dimensions was observed. However, the remanent domain configurations were primarily single domains with simple end curling [Ref. 2, Fig. 4a] in the thinnest samples, single domains with simple end curling and end vortices [Ref 2, Fig. 4a] in the intermediate samples and single domains with only end vortices in the thickest samples. Although the 2 μm wide elements showed intermediate closure structures during reversal, nothing unusual was seen in the U/kT values. It is tempting to equate U to an effective KV_s where K is an anisotropy density and V_s is a switching volume. Using the values of K obtained from FMR measurements on the arrays, then V_s is found to be orders of magnitude smaller than the element volume. However if K is taken to be the induced uniaxial anisotropy, V_s is increased to approximately the volume of the domain configurations at the ends of the elements in the two thinnest samples but still an order of magnitude smaller in the 43.5 nm sample. The probability of switching between symmetric and anti-symmetric end structures will also be quantified. [1] R.H. Koch et al, Phys. Rev. Lett., 84, 5419 (2000) [2] J. Shi et al, Appl. Phys. Lett., 74, 2525 (1999).

10:15 AM *F10.5
MAGNETIZATION REVERSAL PHENOMENA IN NANO-STRUCTURED MAGNETIC SYSTEMS. T. Shinjo, Institute for Chemical Research, Kyoto University, Kyoto-fu, JAPAN.

Investigations on magnetic properties of nanoscale systems have been of significant importance from fundamental and also technical viewpoints. Using electron-beam lithography, the author's group has prepared wires and dots of nanoscale magnetic systems and studied the magnetic properties systematically.
In the present talk, mainly two experiments are introduced. One is a study on magnetization reversal in wire samples from resistivity measurements. The wire sample is consisting of trilayer structure, NiFe/Cu/NiFe or NiFe/Cu/Co. Due to the GMR principle, the magnetization reversal at one magnetic layer causes a great resistance change. Therefore the magnetization reversal, or domain wall propagation, has been studied from the change of resistance. The temperature dependence of the switching field is argued.
The subject of the other study is the behavior of vortex magnetization in circular NiFe dots. Using MFM observation, the existence of perpendicularly magnetized spot at the center of each dot has been confirmed. The switching field for the core magnetization is estimated from MFM observation after applying and removing an external field, and the difference of magnetization reversal process regarding to in-plane and perpendicular external field is distinguished.

10:45 AM F10.6
PARAMAGNETIC ION DOPED NANOCRYSTAL AS A VOLTAGE CONTROLLED SPIN FILTER. Al. L. Efros, M. Rosen, Naval Research Laboratory, Washington, DC; E.I. Rashba, SUNY Buffalo, Buffalo, NY.

We have developed a theory of spin injection through a device consisting of a paramagnetic ion doped nanocrystal (quantum dot) as a connector between a ferromagnetic metal and a semiconductor. This system (i) controls the spin injection in a way quite similar to a tunnel contact, (ii) is completely controlled by the voltage (or the current through the dot) and does not require an external magnetic field, (iii) results in the enhancement of the spin injection coefficient with increasing current, and (iv) is a nearly monochromatic source of spin polarized electrons. Spin polarized current injected from the ferromagnetic source polarizes the ion; the polarization of the ion, in turn, controls the spin polarization of the current flowing through the nanocrystal. Depending on the voltage, the ion can either enhance the injection coefficient by several times or suppress it. A larger enhancement of the spin injection is obtained with ions having a larger spin.

11:00 AM F10.7
VARIABLE-RANGE HOPPING IN ARRAY OF MAGNETIC QUANTUM DOTS. M. Foygel and A.G. Petukhov, South Dakota School of Mines and Technology, Rapid City, SD.

We analyzed spin-dependent conductivity in a system of paramagnetic quantum dots embedded a semi-insulating matrix. We assume that the conductivity is due to bound magnetic polaron (BMP) inter-dot hopping controlled by magnetic fluctuations. If the system in question is characterized by wide distributions of the non-magnetic and magnetic parts of electron energies, variable-range and variable-polaron-barrier hopping can be observed at low temperatures T. It results in giant magnetoresistance, $\rho(B,T)$ governed by a non-activational law, $\ln \rho \propto [T_0(B)/T]^p$, where $T_0(B)$ is a decreasing function of the magnetic field B. Depending on the conditions, parameters of the material, and the dimensionality of the system, the value of the exponent p lies between 0.25 and 1. Sush dependencies have been observed in some of the $GaAs : Mn$ and $GaAs/ErAs$ nanostructures.

11:15 AM F10.8
INFLUENCE OF GATE VOLTAGE SEQUENCES AND CHARGED IMPURITIES ON BOUND SPINS IN SMALL QUANTUM DOTS. Mark Friesen, P. Rugheimer, D.E. Savage, M.G. Lagally, D.W. van der Weide, Robert Joynt, and M.A. Eriksson, University of Wisconsin-Madison, Madison, WI.

Individual electrons confined in quantum dots provide unique opportunities. On the one hand, such isolated spins are the basis for quantum bits. More fundamentally, isolated electron spins in Si are thought to have extremely long coherence times. However, measurements on individual spins are very challenging. To address these issues, we have designed and are fabricating a novel back-gated quantum dot to trap and manipulate single electrons in a coupled dot array. Here we present numerical simulations of two coupled dots. The simulations are performed on the actual device geometry, and implemented using a self-consistent Poisson and Hartree Fock/ Configuration Interaction method. The low-lying two-particle modes are determined, and the exchange coupling, J, between the two electrons is extracted. By varying gate voltages, J is tunable from 0 to well over 2 μeV, an energy that enables spin evolution on nanosecond time scales. Our calculations follow the evolution of the electron spins through a series of gate voltage manipulations. The simulations also investigate errors introduced by charged defects near the quantum dots. Work supported by NSF-MRSEC Program, ARO, and NSA.

11:30 AM F10.9
SIZE DEPENDENCE OF ELECTRON G-FACTOR IN SEMICONDUCTOR NANOCRYSTALS. A.V. Rodina, I. Physics Institute, Justus Liebig University of Giessen, GERMANY and Ioffe Physico-Technical Institute, St. Petersburg, RUSSIA; Al. L. Efros, M. Rosen, Naval Research Laboratory, Washington, DC; B.K. Meyer, I. Physics Institute, Justus Liebig University of Giessen, GERMANY.

The size–tunable optical properties of semiconductor quantum dots (QDs) in an external magnetic field open wide possibilities for controlled manipulation of the spins of confined carriers for spintronics and magneto–electronics applications. Recent experimental studies on the time-resolved Faraday rotation in bare and core–shell semiconductor nanocrystals [1] have indicated the need for a detailed understanding of quantum size effects and the influence of QD surfaces on the spin dynamics and carrier effective g factors in these systems. In the present work we develop a theory of the linear Zeeman effect for conduction electron states confined in spherical semiconductor nanocrystals and spherical layered semiconductor heterostructures. We use appropriate eight band and fourteen band effective mass Hamiltonians to describe the properties of the bulk–like semiconductor layers and model all material parameters as functions of the spatial radial coordinate with abrupt jumps at the interfaces. The interface and surface properties are modeled by different choices of the boundary conditions imposed on the envelope functions. We study quantum confinement and surface effects on the splitting of the electron quantum size energy levels and show that heterostructure interfaces and nanocrystal surfaces directly affect the values of the electron effective g–factors. We calculate the size dependence of the electron effective g–factors in the ground and excited states in bare semiconductor nanocrystals. A comparison with experimental data provides direct evidence of the effect of the surface on the electron effective g values in small nanocrystals. [1] J.A. Gupta, D.D. Awschalom, X. Peng, and A.P. Alivisatos, Phys. Rev. B **59**, R10421 (1999).

11:45 AM F10.10
ELECTRICAL TRANSPORT AND MAGNETIC PROPERTIES OF FERROMAGNETIC GaAs/Mn DIGITAL ALLOYS. M.H. Na, K. Mooney, F. Lehmann, X. Chen, M. Cheon, and S.M. Wang, H. Luo, B.D. McCombe, Department of Physics and Center for Advanced Photonic and Electronic Materials, University at Buffalo, The State University of New York, Buffalo, NY; Y. Sasaki, X. Liu, and J.K. Furdyna, Department of Physics, University of Notre Dame, Notre Dame, IN.

Magnetic and transport properties of Mn layers in GaAs/Mn digital alloys were studied as a function of Mn layer coverage. All samples were grown at 275°C to avoid the formation of MnAs precipitates. Ferromagnetism appears in samples having more than 0.1 Mn in each Mn-containing layer. The Curie temperature showed a strong dependence on the Mn fraction. A correlation between the effective spin density (obtained from saturation magnetization) and the Curie temperature is observed for all samples studied so far. This also includes other structurally similar samples grown under different growth conditions with different Curie temperatures. The electrical conductivity exhibits variable range hopping behavior of holes, indicating that the ferromagnetic exchange interaction in GaAs/Mn digital alloys is mediated by localized holes. Both positive and negative magnetoresistance are observed in the ferromagnetic phase, qualitatively similar to metallic and ferromagnetic GaMnAs random alloys, but quantitatively different. On the other hand, the temperature dependence of the negative magnetoresistance resembles that in insulating and ferromagnetic GaMnAs random alloys.

SESSION F11: METALLIC STRUCTURES
Chair: Teruya Shinjo
Thursday Afternoon, November 29, 2001
Room 207 (Hynes)

1:30 PM *F11.1
SPIN-MEMORY LOSS IN METALLIC SUPERLATTICES. William P. Pratt, Jr., Department of Physics, Center for Fundamental Materials Research, and Center for Sensor Materials, Michigan State University, East Lansing, MI.

Interest in the field of spin-polarized transport exploded after the discovery of giant magnetoresistance (MR) in multilayers consisting of alternating layers of ferromagnetic (F) and nonmagnetic (N) metals. There are two orientations of current flow for measurements of this MR: in plane (CIP) and perpendicular to the plane (CPP). The CPP-MR is generally larger than the CIP-MR and usually gives more direct access to the fundamental parameters of spin-polarized transport in multilayers [1]. Recently, interest has begun to focus on the length scales for 'spin-flipping' (spin-memory loss) in the bulk of the F and N layers and at F/N interfaces. Spin-memory loss usually reduces the CPP-MR, but under certain circumstances it can *enhance* it. We will describe versatile CPP-MR techniques for measuring spin-memory loss in multilayers, and present measurements of such losses in F and N layers and at interfaces between different N metals. We will also present preliminary results suggesting the possibility of significant spin-memory loss at F/N interfaces. Lastly, we will explain how a counterintuitive increase in CPP-MR with increasing spin-memory loss can occur. Work supported in part by the MSU CFMR, MSU CSM, and the US NSF under DMR Grants 98-20135 and 98-09688. [1] J. Bass and W.P. Pratt, Jr., J. Magn. Magn. Mater. **200**, 274 (1999) and references therein.

2:00 PM *F11.2
SPIN INJECTION AND SPIN ACCUMULATION IN MESOSCOPIC TWO-DIMENSIONAL ELECTRON GAS AND METAL SPIN VALVES. B.J. van Wees, Department of Applied Physics and Materials Science Centre, University of Groningen, THE NETHERLANDS.

An exciting new direction in the field of spintronics is the possibility to generate, control and apply spin polarized currents and the associated phenomenon of spin accumulation. I will discuss our results on mesoscopic spin valve structures, where two ferromagnetic electrodes are coupled to either a two-dimensional electron gas present in an InAs quantum well, or to a non-magnetic metal. In the semiconductor devices we have sofar not been able to observe indications of spin polarized tranport. An explanation for this can be given in terms of "conductivity mismatch". However, in the full metal devices we have observed clear evidence for spin injection and spin accumulation, both at 4.2K and at room temperature. We have systematically measured the spin signal in devices with electrode spacing ranging from 250 nm to 2μm. From the analysis we obtain a spin flip length in Cu of 1 μm at 4.2K and 350 nm at room temperature. Recent measurements on Al indicate that the spin flip length can be even longer. This opens up new possibilities to control the spin e.g. by means of controlled precession in an applied magnetic field. Furthermore I will show how the "conductivity mismatch" problem might be avoided, using magnetic tunnel junctions for injection and detection of spin polarized currents.

2:30 PM F11.3
PERPENDICULAR TRANSPORT IN METALLIC MULTILAYERS WITH BOTH SPECULAR AND DIFFUSE SCATTERING AT INTERFACES. Asya Shpiro, Peter M. Levy, Department of Physics, New York University, New York, NY; Shufeng Zhang, Department of Physics and Astronomy, University of Missouri, Columbia, MO.

By using a rather simple model potential we calculate the influence of specular and diffuse scattering at interfaces on the resistance for currents perpendicular to the plane of the layers (CPP) in multilayered metallic structures. We find that if one maintains the same interfaces between layers, their contribution to the total resistance of the system depends on the thickness of the intervening layers. Their contribution is constant only if the distance between interfaces is larger then the electron mean free path in the bulk of the layers. The error incurred by neglecting the dependence of the interface resistance on layer thickness depends on the amount of diffuse scattering at interfaces and the height of the potential step at the interface. For a multilayer consisting of three layers this error does not exceed 5% for completely diffuse interfaces, but for interfaces where there is a 50% probability that the electrons are scattered specularly the error reaches about 20%; this exceeds the experimental error and merits further study.

3:15 PM *F11.4
SPIN HALL EFFECT. S. Zhang, University of Missouri-Columbia, Dept of Physics, Columbia, MO.

Scattering of unpolarized electrons by an unpolarized impurity results in spatial separation of electrons with different spins due to spin-orbit interaction. For this reason, an electrical current in a semiconductor is accompanied by a spin flow perpendicular to the current; this is known as the "spin Hall effect". For a steady-state current, a non-equilibrium spin accumulation is established in the transverse direction of the current. If one is able to inject a spin polarized current into a semiconductor, a Hall voltage should be generated due to this spin Hall effect. By using macroscopic equations for the spin current and spin accumulation, we derive the transverse spin accumulation and the Hall voltage in nanowires, thin films and multilayers. In particular, we show that the measurement of the Hall voltage should yield information of spin polarization of the optically or electrically injected current. Therefore, the spin Hall effect can be used as a tool to probe the spin polarization of the current. Based on spin orbital parameters of several semiconductors, we estimate the magnitude of the spin Hall effect.

3:45 PM *F11.5
THEORY OF SPIN TRANSPORT ACROSS HETERO-INTERFACES. G.E.W. Bauer, Yu. V. Nazarov, D. Huertas-Hernando, TU Delft, NETHERLANDS; K. Xia, and P.J. Kelly, Univ of Twente, NETHERLANDS; A. Brataas, Harvard University, Cambridge, MA.

Interfaces between ferromagnetic and non-magnetic metals are essential functional elements of magnetoelectronics because of the high spin-selectivity of the electron transmission probabilities. In order to understand and control the spin-injection process, qualitative and quantitative understanding of the electronic structure is important. Interesting novel physics like the spin-current induced torque on the mangetization is also strongly localized to the interface. Within a semiclassical approximation scheme, the characteristics of magnetoelectronic circuits and devices can be expressed in terms of four interface parameters, viz. the conventional spin-up and spin-down conductances and the real and imaginary part of the mixing conductance or spin-torque. The former ones are experimentally accessible by transport experiments on magnetic multilayers in the current perpendicular to the plane (CPP) configuration as pioneered by the MSU collaboration. The latter can at least in principle be measured via the angular magnetoresistance of CPP spin valves. We present results for the interface conductances as computed by first principles for specular and disordered interfaces. The results will be compared with available experimental data and the consequences for the physical properties of mesoscopic circuits and devices will be discussed.

4:15 PM F11.6
SPIN-INJECTION EFFECTS IN THREE TERMINAL MAGNETIC TUNNELLING JUNCTIONS. Simon Stein, Hermann Kohlstedt, Rainer Waser, Research Centre Juelich, Institute of Solid State Research, Juelich, GERMANY.

A magnetic tunnelling spin injection device (MAGTID)[1] consisting of a stack of two ferromagnetic tunnelling junctions with access to the intermediate electrode has been developed. The layer structure is $Co/Al_2O_3/NiFe/Al_2O_3/Co$. The layers were deposited by dc-magnetron sputtering and the barriers were formed by ultraviolet-light assisted thermal oxidation. The performance of the upper and lower junctions within a stack were determined by current-voltage characteristics, the first derivatives (dV/dI vs. V) and the individual tunnelling magnetoresistances (TMR). In-situ secondary ion beam spectroscopy (SIMS) has been used during argon ion beam etching to achieve precise etch stops. Therefore, even a potential contact to an only 5 nm thick NiFe middle layer was successful. Using one junction in a stack as a spin injector and the second junction as a detector various magnetoresistance measurements were performed. The resistance of the detector junction was dependent on the magnetization of the common NiFe layer (parallel or antiparallel to the Co layers) and the injector current. The normalized TMR of the detector varied by up to 30%. This result will be discussed in the framework of non-equilibrium spin accumulation in the in the intermediate NiFe layer. For further improvement of the MAGTID we have studied $Ta/NiFe/FeMn/CoFe/Al_2O_3/CoFe/NiFe$ single barrier junctions using FeMn as an antiferromagnetic pinning layer. First results of these junctions will be presented. [1]Solid state communications 117, 599 (2001).

4:30 PM F11.7
ROLE OF INTERFACE ROUGHNESS IN THE PERPENDICULAR GIANT MAGNETORESISTANCE OF Fe/Cr SUPERLATTICES. J. Santamaria[a,c], M-E Gomez[a,d], M.-C. Cyrille[a,e], C. Leighton[a], Kannan M. Krishnan[b] and Ivan K. Schuller[a]. [a]Department of Physics, University of California-San Diego, La Jolla, CA; [b]Materials Sciences Division, National Center for Electron Microscopy, Lawrence Berkeley Laboratory, University of California-Berkeley, CA; [c]On leave from U. Complutense, Madrid, SPAIN; [d]On leave from Universidad del Valle, Cali, COLUMBIA; [e]Present address IBM Almaden.

Studies of Giant Magnetoresistance (GMR) in metallic superlattices have produced much new physics. However, important open questions remain regarding the role played by interface roughness and the relative importance of bulk and interfacial scattering in the GMR mechanism. To address this issue, we have performed an extensive comparative study of growth, structure, magnetization, and magnetotransport in Fe/Cr superlattices. We have correlated magnetization and transport using the geometry in which the current flows perpendicular to the interfaces (Current Perpendicular to the Plane-CPP) with structural information about the interfaces obtained from energy filtered transmission electron microscopy (EFTEM) and X-ray diffraction. Both structural probes supply quantitative information about the interface structure not only in the growth direction (interface width) but also in the lateral direction (lateral roughness correlation length). We have found a clear correlation between transport data and roughness parameters which shows that in Fe/Cr superlattices, the resistivity is mostly dominated by the lateral roughness correlation length, whereas the magnetoresistance is determined by the interface width. These results provide the quantitative connection between structural measurements and transport for the development of a quantitative theory of GMR. Work supported by the US-DOE.

4:45 PM F11.8
DIPOLAR INTERACTION IN PATTERNED SPIN VALVES AND THEIR NUMERICAL MODELLING. Kai-Uwe Barholz, Marco Diegel, Roland Mattheis, Sergeui Dachkowski, Inst. Phys. High Technol. Jena, GERMANY; Dima Berkov, Innovent Jena, GERMANY; Jens Hauch, Gotthard Rieger, Michael Vieth, Siemens Erlangen, GERMANY.

The response of spin valve systems, used in magnetoresistive sensors or GMR read heads, depends not only on the intrinsic layer properties, like anisotropy of the sensing layer, but also on the magnetic interaction between the sensing layer and the pinned layer. Depending on strip geometry and direction of pinning, additional anisotropies due to the interlayer interaction modify the sensor characteristics. To determine the influence of these parameters strips of a Py/Co/Cu/Co/FeMn-stack, 500 μm in length with a width ranging from 5μm to 15μm, were studied. The unidirectional and the uniaxial part of the anisotropy was determined from MOKE and magnetoresistance measurements. These measurements were repeated for different orientations of the exchange bias with respect to the long axis of the strip. For comparison micromagnetic simulations [1] were performed. To ensure the simulation quality the cell sizes in the calculations were chosen smaller than the characteristic magnetic length. In return the model sizes were reduced to strips ranging from 8 μm x 1 μm to 4 μm x 0.2 μm, since the overall cell number is restricted by calculation time. Experimental data are presented and compared with the simulation results. The good agreement between experimental behaviour und theory gives the base for better understanding of the relevant interactions in such systems. Support by BMBF Grant (13N 7910) is gratefully acknowledged.
[1] MicroMagus program package, developed by D. Berkov and N. Gorn, further information available from db@innovent-jena.de.