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 SEMICONDUCTORS by Jürgen Schmiedmayer, 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 semiconductors as a means 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 spin states defined by an applied magnetic field, 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]. Spin 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 processing electrons that surround the nuclei, and the relaxation of the resulting tickled 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. Finally, the capability to integrate ferromagnetism within a semiconductor or a nanomaterial may create new schemes for operating on electron and nuclear spins. [1] I. Mihailovic et. al., Nature, in press (2001); [2] B. Bernstorff et. al., Phys. Rev. Rapid Comm. B65, 121601.R (2001); [3] G. Suh 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 by 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; Vasiliy V. Belkov, Eugenius I. Ishchenko, 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 monopol non-equilibrium population of spin-up and spin-down states has been achieved by the injection of n-type and p-type GaAs/AlGaAs QWs structures. In contrast to usual 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 2.4 K to 300 K. As a radiation source a pulsed far-infrared molecular laser has been used delivering 1010 pulses at wavelength λ = 148 mm. Spin relaxation times in the range between 2 ps to 1 ns have been derived depending on QW width, mobility and temperature. [1] S.D. Ganichev, S.N. Danilov, J. Ercom, W. Wegscheider, D. Weiss, W. Prettl, E.I. Ishchenko, Phys. Rev. Lett. 86, 4538 (2001).

9:15 AM F1.3 MAGNETIC GaN AT ROOM TEMPERATURE by N.A. El-Masy, M.L. Reed, M.K. Ritums, H.H. Stadelmeier, 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 focused on GaN/AlGaN on GaN substrates with Curie temperatures above 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. SI MS results of the Mn-doped samples were found to have a doping profile that levels down to 1-2%. Both x-ray and electron diffraction indicated that secondary phases, such as Mn,GaN, Mn,N, and Mn,N, are not present and (Ga,Mn)N is achieved as a solid solution. The magnetic properties of (Ga,Mn)N films were studied by low-field EPR 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 dependent on the sample preparation. VSM measurement revealed the effect of the sample preparation on the magnetic properties of this new (Ga,Mn)N and its Curie temperature. M.L. Reed, M.K. Ritums, H.H. Stadelmeier, M.J. Reed, C.A. Parker, J.S. Bedair, and N.A. El-Masy, accepted for publication in Materials Letters.

9:30 AM F1.4 INITIATIVE MAGNETIC EXCHANGE INTERACTIONS IN Mn DOPED GaAs And GaN by 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 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 interlayer interaction was found to be metallic described according to the Zener double exchange/Anderson superexchange picture as an RKXY description. The reason for this description in terms of electronic structure. Using a rigid band model, the counterdecoupling dependence of the exchange and Tc are estimated. It is found to quickly fall from a ferromagnetic interaction to antiferro with increasing electron concentration. With increasing hole content the interactions increase to a maximum at about 1/2 hole per Mn, in agreement with a simple double exchange Auerbach picture.


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 CH4 source for enhanced n-type doping. Results of the epitaxial growth films will be compared to GaInP:C films grown from the same growth run of Mn into GaP:C. X-ray diffraction (XRD) of the epitaxial films shows no evidence of secondary 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:C. 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 by Albert Feri, Henri Joffres, and Marie-Noelle Chalvet, CNRS-INRH, 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 (and junction) preferably at the F/SC interfaces. In the case of a F/SC 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 structures are at odds with recent
We present recent results from a detailed study of spin polarization and spin injection in III-VI semiconductor heterostructures consisting of diluted magnetic semiconductor (DMS) barriers and a non-magnetic quantum well (QW), by magneto-optical spectroscopy (MOS). The spin polarization in the QW is largely determined by the spin injection from the DMS barriers leading to a reverse sign in the circular polarization of the QW exciton emission. Up to 30% spin polarization can be achieved at ST. One type 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 photon bottleneck effect has also been observed in the experiment when spin relaxation can be significantly affected.

11:00 AM FL8
CaMo₃: A new semiconductor material for spin electronics.
"Faculty of Applied Physics and MEESA Research Institute, University of Twente.
Faculty of Sciences and Research Institute for Materials, University of Nijmegen; Department of Applied Physics and CORBA Research School, Eindhoven University of Technology, THE NETHERLANDS.

Ferromagnetism was recently observed at unexpectedly high temperatures in La-doped CaMo₃ 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 hexagonal as a semi-metal with a very small overlap between the lowest two conduction bands, 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 CaMo₃ is a non-metallic but a semiconductor with a band gap of 0.04 eV. This finding has far-reaching consequences for understanding the basic properties of the doped, ferromagnetic phase and for applications. The magnetism in La₄Ca₂Mo₃ has occurred on the metallic side of a Mott transition in the La-induced impurity band. As a ferromagnetic semiconductor, CaMo₃ is a promising material for spintronics.

11:15 AM FL9
INTERFERENCE STATES IN INVERTED MAGNETIC QUANTUM WELLs, TYPE A/1/2-MO/1/2/A/1/2-MO/1/2/A/1/2-MO/1/2
Natalia Milenkovic, Materials Research Laboratory, University Park, PA.
Ulf Ebbesen, 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 well has been studied using magnetic semiconductors with mutually inverted band arrangement is strucuted with the envelope-function formalism. Interface states are shown to appear in these structures in the case of overlapping bulk bands of the conduction and valence bands. The hybridization between these bands and the states of the Mn atoms leads to spin splitting. The spin-diffusion effect of the interface states as a function of external magnetic field, well width, and field offsets and fraction of the magnetic barrier, is studied. The results give evidence of the potential perspective for using the magnetic semiconductor structures in spin electronics.

11:30 AM FL10
FIRST PRINCIPLES STUDIES OF RASHBA EFFECT IN SUPERLATTICES.
Jacek A Majewski, Peter Vogl, Walter Schotky Institute, Technical University of Munich, Garching, GERMANY.

We present first-principles calculations of k-linear zero-field spin splittings in 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 caused by spin-orbit coupling in the valence band of InAs/GaAs and InAs/GaSb. However, its magnitude, physical origin, the role of interfaces, and dependence on microscopic 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 wurzitine GaN/AlGaN superlattices. In zincblende superlattices with a common anion or cation, the Rashba effect vanishes and the k-linear zero-field spin splitting is entirely caused by the bulk inversion asymmetry (BIA) term that originates from the bulk Dresselhaus term. The corresponding BIA constants \( a_{BIA} < \) 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 fields to induce Rashba constants \( a_{R} > \) that are typically smaller than \( a_{BIA} > \). In the wurzitine structure, the Rashba effect is a bulk effect, in contrast to the situation in zincblende crystals. The calculations for wurzitine 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. Pfeiffer, Phys. Rev. B 59, 15902 (1999), and references therein.

11:45 AM FL11
GROWTH AND PROPERTIES OF FERROMAGNETIC Gd₃Mn₅As₂/ZnSe HETEROSTRUCTURES (Gd₃Mn₅As₂)/ZnSe HETEROSTRUCTURES, S.H. Chan, K.C. Ku, S.J. Potashnik, P. Schiffer, and N. Samarth, Deparment 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 interest on Gd₃Mn₅As₂, 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 Ga₃Mn₅As₂ as a spin filter. Other spin dependent devices using this material are expected to be useful for demonstrating proof-of-concept semiconductor "spintronics" applications. However, the growth of homogeneous Ga₃Mn₅As₂ 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 Ga₃Mn₅As₂/ZnSe heterostructures in either sequence along the growth axis. Since the optimal growth temperatures of both materials are compatible with each other, it is possible to fabricate the fabrication of complex heterostructures that include both semiconductor and ferromagnetic components. While the growth of ZnSe on top of a Ga₃Mn₅As₂ 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 recrystallized GaAs template prior to Ga₃Mn₅As₂ deposition. We find that under the same flux conditions the ferromagnetic transition of Ga₃Mn₅As₂ is lower than that of Ga₃Mn₅As₂/GaAs. We discuss the effect of Mn concentration, ZnSe surface termination, and low temperature post-annealing on the physical origin of Ga₃Mn₅As₂ on ZnSe, as well as the effects of n-doping on the ZnSe layer. Supported by grants from ONR, DARPA and NSF.
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 (~1 nm) 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 MTJs have already been demonstrated. Although the basic principles behind the large magnetoresistance effects are understood, considerable progress has been made in utilizing these effects, and the 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 ultrathin (interfering) tunnel barrier materials to demonstrate the dominant role of the electronic interface structure in magnetic tunnel junctions. Using Co/M/AlOx/Co and Co/Mi/M’/AlOx/Co (MM’ = Co/Mn, Cr, Au, Rh) structures, we have demonstrated that the tunnelling 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 “interferential engineering” one can correlate the transport properties of these devices with the local interface electronic structure and perform unique, fundamental studies of spin polarised transport through ferromagnet-nonmagnet interfaces. Finally, time permitting, a new magnetoresistance effect using spin filter barriers will be discussed.

2:00 PM **F2.5**

**ELECTRONIC PROPERTIES OF MAGNETIC TUNNEL JUNCTIONS**

E.Y. Tytymbal, I.I. Olenik, 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 barrier and the partially filled conduction bands. 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 localised 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].


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 100 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 indicate a transition from local to extended states as well as having non-vanishing voltage.

3:15 PM **F2.4**

**INVERSE MAGNETORESISTANCE EFFECT IN Co,Fe,Mn,FeCo TUNNEL JUNCTIONS**

M. Sugiyama, H. Asano, M. Misui, Dept. of Crystalline Materials, Nagoya University, Nagoya, JAPAN; H. Hayakawa, M. Ichimura, S. Kondo, K. Itou, H. Toki, Tokyo, JAPAN; and A. Nakama, H. Nishi, Metals Soc., Nagoya, JAPAN

Magnetic tunnel junctions have been fabricated with halfmetallic L10, Sr2MnO3 and Co,Fe,Mn,FeCo electrodes. The junctions have a spin valve structure with an antiferromagnetic Mn,Fe,Mn,FeCo layer. The measurements have shown that the inverse magnetoresistance effect in this spin valve structure is of the type R-H loops with inverse TMR effect. The TMR ratio is 22% at 4.2 K, and its bias dependence is highly symmetric with respect to the bias direction. A negative spin polarization for Co,Fe,Mn,FeCo, 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**


The rapid development of spin dependent tunneling technology is associated with needs for at least three types of related devices, namely magnetic memories, non-volatile high density memory cells, and low power sensors. In this latter case, and contrary to the other cases, one expects to develop a signal processing device which will deliver an output signal proportional to the magnetic field to be detected. The incorporation 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 axes 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 plano substrate [1], whereas the top (hard) electrode is exchange biased due to a contact with an antiferromagnetic layer. We will show 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 a room temperature operation, we have recently concentrated on the use of FeMn. 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.


**SESSION F3: IN-ROOM POSTER SESSION**

Chair: Evgeny Y. Tytymbal

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. Ichiguchi, J. Inoue, Nagoya University, Dept. of Applied Physics, Nagoya, JAPAN; A. Umemori, J. Mutoh, M. Villiet, Cergy Uni, 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 coupled LSMO and NiO layers. 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-bond 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 of the spin-polarized electron 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 for the oscillation of the exchange coupling, a period given by the height of the quantum well is found in it. In the absence of disorder 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/Fe-Co [100] TUNNEL JUNCTIONS. M. Bowen, V. Cres F. Petroff, A. Ferr, UMP CNRS/THALES, Orsay, FRANCE; C. Martinez-Broto, I.L. Cost-Ringer, J.V. Anguita, A. Cebollada, F. Briones, 1MM, 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 aluminum. MTJs with aluminum provide large and reproducible tunnel 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/MgO/Fe(100) junctions grown by a combination of laser ablation and triode sputtering onto MgO-doped GaAs[100]. As evidenced by RHED, x-ray diffraction and TEM analysis, optimized growth conditions result in entirely epitaxial samples of high crystalline quality with flat, sharp interfaces [2]. Fe/MgO/Fe-Co 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/insulator system. Furthermore, we can confirm the bias dependence of the TMR, previous experimental results and recent calculations [4] that the spin character of electrons is predominantly tunneling in the case of a 20 Å MgO barrier [1]. W. Wulfhekel et al. Appl. Phys. Lett. 75, 1324 (1999) [2]. J. Mathew, J. Appl. Phys. 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 MAGNETIC TRANSPORT OF Sr-Fe-Mn-O. Atsui Sharma, Karen Yates, Imperial College, Dept of Physics, London, UNITED KINGDOM; L.P. Cohen, Imperial College, Dept of Physics, London, UNITED KINGDOM; J.L. MacManus-Driscoll, Imperial College, Dept of Materials, London, UNITED KINGDOM.

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

F3.4 METAL-INSULATOR PHENOMENA OF ORDERED DOUBLE PEROVSKITES (Sr2-x-Cu1-x)Fe2O4. H. Kato, T. Okuda, Y. Okimoto, Y. Tomioka, JRCAT, Tsukuba, JAPAN; K. Okawa, T. Koniymann, KIK, Tsukuba, JAPAN; Y. Tokura, University of Tokyo, Department of Applied Physics, Tokyo, JAPAN.

Recently, ordered double perovskites Sr2Fe-Mn-O and Sr2Fe-Re-O have been reported as a new class of prospective magnetoelectronic compounds, which show tunnel magnetoresistance at room temperature in polycrystalline form due to the half-metallic nature with high magnetic Curie temperature TC. Among these materials, Sr2Fe-Re-O has been known as a ferromagnetic oxide with high TC≈280K. Although the insulating nature of this compound was reported recently, the magnetic and electronic properties of Sr2Fe-Re-O have not been clearly understood as yet. In this study, we have prepared the 4-site solid solution [Sr2-x-Cu1-x]Fe2O4, and investigated their magnetic and electronic properties by polycrystalline [Sr2-x-Cu1-x]Fe2O4 ([0<y<1]) prepared by the solid state reaction. Crystal symmetry was changed from tetragonal to cubic and orthorhombic with increasing Cu content, y at room temperature. Rietveld analysis indicated that degree of ordering of Fe and Re on this lattice was more than 70% and 90% at room temperature. It was also confirmed that the 4-site 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 Sr2Cu2Fe-O, y=1 shows the thermally induced met-al-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 SrRuO3 FILMS. G. Herranz, B. Martinez, J. Ruestaher, Instituto de Ciencia de Materiales de Barcelona - CSC, SPAIN; F. Sanchez, M.V. Guerra-Cuenco, C. Ferrater, M. Varez, Depto. de Fisica Aplicada, F. Fisica, U. Barcelona, Barcelona, SPAIN.

Spin-dependent devices based on manganites have an important drawback in the strong decrease of the tunnel magnetoresistance (TMR) with temperature, making them almost useless at temperatures near to the Curie temperature. It has been suggested that double exchange (DE) mechanism is prone to explain spin polarization at interfaces and therefore, alternative materials based on DE mechanism will be desirable. The itinerant ferromagnet SrRuO3 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 SrRuO3, 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 0.8° to 1.1° 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 film 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 μΩ cm at room temperature are found for the thickest samples, but as the film thickness is raised up, Tc increases 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 with thickness.

These results indicate that also in STO there is a non-conducting and poorly magnetic layer close to the interface with the substrate.
microstructure, magnetic and transport properties of NaN$_2$, Ca$_2$Mn$_2$O$_5$ thin films on lattice-mismatched substrates. Not surprisingly, our attempt to analyze the thickness dependence of 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 a 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 vibration, quantification of this strain-induced correlation with transport properties is rendered complicated by the inhomogeneous distribution of strain in partially strain-relaxed films. We will also discuss our ongoing work on the influence of lattice mismatch strain on charge and orbital ordering in thin films of Pr$_{1-x}$Ca$_x$MnO$_3$. Acknowledgement: Work at the University of Maryland was supported by the NSF MRSEC (DMR-1004818). Work at Brookhaven National Laboratory was supported by the U.S. DOE, Division of Materials Sciences and Engineering, Contract DE-AC02-86CH13177 (886). F.Y. and C.G. acknowledge support for this work from LNSL (Brazil) financed by CNPq and FAPESP (Contract 06/55863/6).

F.3.7 PHOTOINDUCED SWITCHING IN CMR MATERIALS.
N. Nogina, 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 NaN$_2$, Ca$_2$Mn$_2$O$_5$ in the range of ferromagnetic phase transition. Based on recent 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 mechanisms in the T = T$_{c}$ regime. Relaxation times for the films and single crystals in study as well as the specific heat of the phase transition have been determined.

F.3.8 TWO CURIE TEMPERATURES IN A SINGLE IRON THIN FILM.
Stéphane Andrieu, Christophe Chatelain, Mohamed Lemine, Bertrand Berche, Lab. de Physique des Matériaux, CNRS-Univ. P. Painlevé, 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 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 depend on the amount of deposited material. We show here that in the particular case of thin Fe films grown on [0 1 0] 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 magnetic measurements and ac susceptibility. For an integer number of Fe atomic planes, we observed only one peak in the susceptibility measurements 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 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 5 ML 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.


Auger Electron Spectroscopy (AES) and Rutherford Backscattering Spectroscopy (RBS) analysis were carried out to elucidate the extent of interdiffusion during thermal treatment of the pinned electrode (Ta/NilFe/FeMn/CoFe) of the magnetic tunnel junction multi-layer. For comparison purposes, results from RBS and AES, a significant amount of Mn-CoFe interdiffusion was observed when the sample was annealed at 200-400K under vacuum. The multi-layer we completely intermixed at 480K, losing the exchange bias between FeMn and CoFe layers. It was shown 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 electrode, the Mn diffusion was minimized up to 300K. Our experiment suggests that the Mn diffusion to the insulating layer could be enhanced by the presence of the free oxygen radicals in the insulation layer remaining from the plasma oxidation of the Al layer in magnetic tunneling junctions.

F.3.10 SHOT NOISE IN FERROMAGNET - NORMAL METAL SYSTEMS.
Yaroslav Tserkovnyak and Arne Bratnag, Harvard University, Lurman 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 stochastic parameters that are expressed in terms of the microscopic detail 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 shown that the shot noise can have a non-monotonic behavior as a function of the relative angle between the magnetizations of the ferromagnetic reservoirs.

F.3.11 CIRCULAR PHOTOVOLTAIC EFFECT IN Si/Ge SEMICONDUCTOR QUANTUM WELLS.

We report on the observation of circular photovoltaic effect (CPVE) in p-type Si and SiGe quantum well structures by the illumination with circularly polarized far infrared radiation. Direct interband transitions at wavelengths between 76µm and 280µm have been excited by a high power pulsed NH$_3$ laser optically pumped by a TEA CO$_2$ laser. CPVE, recent observed in GaAs-based quantum well structures [1], 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 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 CPVE requires a sufficiently low symmetry breaking of 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] crystalllographic orientation can be prepared without inversion symmetry. The observation of CPVE demonstrates that the spin degeneracy of subbands in 4-space is lifted due to linear terms in the Hamiltonian [1]. We show that, in the case of zinc-blend type materials, the CPVE can be used as a tool to investigate spin orientation and spin relaxation in Si/Ge structures.


F.3.12 ANTI-WEEK-LAW LOCALIZATION STUDY OF RASHBA SPIN-SPLITTING ENERGY AS A FUNCTION OF WELL ASYMMETRY IN InAlAs/InGaAs/InAlAs QUANTUM WELLS. T. Koga, J. Nitta, T. Akuzuki and H. Tokuyama, NTT Basic Research Laboratories, NTT Corporation, Atsugi-shi, Kanagawa, JAPAN.

The use of spin-orbit interaction is a key strategy for the controlled manipulation of spins in the conduction bands in semiconducting heterostructures, which is needed for realizing future spin devices. Realization of spin devices will utilize not only the properties of electron charge (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 microwave localization analysis to quantitatively analyze the zero-field spin-splitting energies (denoted by $\Delta_s$) that are observed in InAlAs/InGaAs/InAlAs quantum wells. We found that the value of $\Delta_s$ becomes larger in the degree of structural inversion asymmetry (SIA) for the InGaAs quantum well becomes larger. This deviation 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 sequence of four different samples (MOVCD) with different impurity densities in the carrier supplying layer (denoted by $n_s$), which is located below the quantum well, while keeping all the other structural parameters constant among these samples. Here, the values of $n_s$ are varied from $1 \times 10^{-5}$ cm$^{-2}$ (the most asymmetric quantum well) to $1 \times 10^{-6}$ cm$^{-2}$ (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 $\Delta_0$ value. Finally, the experimental data are compared with the theoretically predicted values of $\Delta_0$, the zero-field spin-splitting energy due to the Rashba spin-orbit interaction, in order to understand the observed $\Delta_0$ 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 $\text{La}_2/3 \text{Ca}_2/3 \text{MnO}_3$ THIN FILMS. J. Fontcuberta, M. Bills, L. Balcells, B. Martínez, Institute de Ciencia de Materiales de Barcelona, SPAIN; M. Wojcik, E. Jedryśka, Institute of Physics, Polish Academy of Sciences, POLAND.

Spin devices and particularly tunnel junctions based on magnets, 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/semiconductor from those of bulk, no much information is available to the nature of the insulator/ferromagnetic/semiconductor interfaces and what is their role on the magnetotransport properties. In this paper we shall provide evidence that close to the interfaces with the substrate, the magnetic films, here illustrated by the particular case of $\text{La}_2/3 \text{Ca}_2/3 \text{MnO}_3$, are not longer homogeneous, ferromagnetic and metallic but a monoclinic phase segregation takes place. The magnetotransport data here reported, for thin films grown on a variety of single crystalline substrates ($\text{SrTiO}_3$, $\text{LaAlO}_3$, $\text{NdGaO}_3$), 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 ($\sim t_D$) into the film. Detailed analysis of the magnetotransport measurements as well as information gained from a microscopic magnetic probe ($\mu$-MNR) 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 magnetoelectric 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. Sorensen, Maxim P. Nikiforov, Joy A. Switzer, Graduate Research and Development Center, University of Missouri-Rolla, Rolla, MO; Simon A. Merton, G. Dan Wadhilli, Graduate Center for Materials Research and Department of Physics, University of Missouri-Rolla, Rolla, MO.

Epitaxial $\text{Fe}_3\text{O}_4$ 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 magnetic films are formed using a bath consisting of $0.04 \text{ M KMnO}_4$ and $0.01 \text{ M Fe}_{2}\text{(SO}_4)_3$. The bath is covered by a magnetic field to induce the reaction. The magnetic films grow on a single crystal $\text{Fe}_3\text{O}_4$ substrate, under a magnetic field of $500 \text{ Oe}$ on $[100]$ oriented single crystal $\text{TiO}_2$ substrates using either $\text{Co}$ or $\text{CoO}_2$ as a precursor, and oxygen as a carrier gas. Films grown using $\text{CoO}_2$ are stoichiometrically smooth with a rms roughness of less than $5 \text{ Å}$ for a $1000 \text{ Å}$ thick film. The $\text{CoO}_2$ films exhibit a metallic behavior at room temperature, whereas the $\text{Co}$ films are insulating. The magnetic films were characterized by electron microscopy, X-ray diffraction, EXAFS and HITEMP. For the optimized growth conditions, the expected $\text{NiMnSb}$ C1b structure was observed. Moreover, the most stable and smooth surface was obtained on undoped substrates. 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 element and Ni magnetic moment 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 undoped surface. Finally, we show that fully epitaxial $\text{NiMnSb}/\text{MgO}/\text{NiMnSb}(001)$ and $\text{NiMnSb}/\text{MgO}/\text{Fe}(001)$ trilayers can be prepared. Magnetoresistance experiments performed on both systems will be presented.

9:30 AM F4.3 ELECTRIC FIELD EFFECTS IN MIXED-VALENT MANGANITE FILMS: EVIDENCE OF ELECTRONIC PHASE SEPARATION. T. We, S.B. Ogale, J.E. Gerhard, B. Nagaraj, Ambike Bavas, Z. Chen, R.L. Greene, R. Ramasesh, and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD; A. Mills, Center for Materials Theory, Department of Physics and Astronomy, Rutgers University, Piscataway, NJ.

A systematic study of electretsistance (ER) effects is conducted for thin films of mixed-valent $\text{La}_{x}\text{Sr}_{1-x}\text{MnO}_3$ manganite buffer, using both an electric field effect geometry with ferroelectric or dielectric gases. A polycrystalline, large effect of $\approx70%$ at $4\times10^3 \text{ V/cm}$ is observed for the thin $\text{La}_{0.6}\text{Sr}_{0.4}\text{MnO}_3$ film with $\text{PO}_{4}$ crystals. The CMR (ER) effect is found to be comparable for the case of the undoped and the electrically (magnetically) biased film, reflecting the complimentary nature of the electric and magnetic field effects. In $\text{Nd}_{x}\text{Sr}_{1-x}\text{MnO}_3$, the effect is only a few percent and polarity independent. However, in this case, the magnetic field increases the polarity dependent fraction in the ER effect. For $\text{La}_{0.8}\text{Sr}_{0.2}\text{MnO}_3$ and $\text{La}_{0.8}\text{Ce}_{0.2}\text{MnO}_3$, the effect is shown to be much stronger, with a maximum of $70\%$.

Analysis of these data strongly favors an electronic phase separation picture for mixed-valent manganites. This work is supported under NSF-MRSEC grant no. DMR-0088008.

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

Bond structure calculations have shown that the well-known magnetic oxide chromium trichloride ($\text{CrO}_3$) is a half-metallic system, i.e. it contains 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 $\text{CrO}_3$, providing a spin polarization value as high as $98\%$ at low temperatures. Since $\text{CrO}_3$ is a metallic 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 $\text{CrO}_3$ films on $\text{TiO}_2$ substrates using either $\text{CrO}_3$ or $\text{CrO}_2\text{Cl}_2$ as a precursor, and oxygen as a carrier gas. Films grown using $\text{CrO}_2\text{Cl}_2$ are stoichiometrically smooth with a rms roughness of less than $5 \text{ Å}$ for a $1000 \text{ Å}$ thick film. The $\text{CrO}_3$ films exhibit a metallic behavior at room temperature, whereas the $\text{CrO}_3$ films are insulating. The magnetic films were characterized by electron microscopy, X-ray diffraction, EXAFS and HITEMP. For the optimized growth conditions, the expected $\text{NiMnSb}$ C1b structure was observed. Moreover, the most stable and smooth surface was obtained on undoped substrates. 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 element and Ni magnetic moment 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 undoped surface. Finally, we show that fully epitaxial $\text{NiMnSb}/\text{MgO}/\text{NiMnSb}(001)$ and $\text{NiMnSb}/\text{MgO}/\text{Fe}(001)$ trilayers can be prepared. Magnetoresistance experiments performed on both systems will be presented.

10:45 AM F4.6 MORPHOLOGY OF MANGANITE PLD THIN FILMS DESCRIBED BY THE THORNTON'S ZONE MODEL. Anna-Marie Haghiiri-Goonet, Mohamed Koohan, IEF, Univ Paris Sud, Orsay, FRANCE;...
Rachel Desfous, LPCIA, Univ d’Artois, Lens, FRANCE; Philippe Lecoeur, Wilfried Prellier, Bernard Mecary, CRISMAT, ISMRA, Caen, FRANCE.

The morphology and the microstructure of pulsed laser deposited (PLD) La2Sr2CuMo6O19 (LSMO) films are shown to follow the "morphology model" proposed by Thornton [1] for the spattering 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., target-substrate distance D, the cryopump pressure P02, and the deposition temperature T. At large D values (D = 60 mm) and high pressures [P02 = 0.5 mbar] and for a fixed temperature of 60°C, the film exhibits a fine typical Zone I porous morphology. The fine columns are the consequence of the self-shadowing effect of the impinging particles on the growth surface. The presence of embedded nodules is a further proof of this shadowing effect. At smaller D values and lower pressures [P02 = 0.15 mbar], the film exhibits a dense Zone II structure, which is associated with an exceptional surface flatness [Rms = 0.1 nm]. The surface is very clean and free of any defects (noddles, inclusions and droplets). An increase of T of about 30°C shifts the Zone I/Zone II transition towards higher pressures (ΔP02 = 0.1 mbar) in agreement with the Thornton’s model. Finally, the role of each PLD parameter (D, T, and P02) on the magnetic properties of the ablated LSMO films will be discussed in correlation with the morphology, [1] J. A. Thornton, J. Phys. D: Appl. Phys. 36, 1666 (1994).

11:00 AM P4.5
FLIP CHIP MAGNETIC TUNNEL JUNCTIONS J.C. Read, Z.V. 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-a-tub grown multilayer structures. The FCMTJ structures consist of two individual electrode chips, patterned using conventional photolithography and etching techniques, which are pressed together to make 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 Fe3O4 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 10 MΩ and 1 GΩ. The IV curves are nonlinear and show parabolic conductivity, characteristic of tunneling junctions. Magnetoresistance of about 1% has been observed at room temperature in one Fe3O4/native oxide/Fe3O4 FCMTJ. We are also making junctions incorporating other ferromagnetic half-metallic materials such as Cr2O3.

11:15 AM P4.8
LOCAL MAGNETISM AT BOUNDARIES IN La2/3Sr1/3CuO3 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 materials. In this work, we have studied the local magnetic structure in La2/3Sr1/3CuO3 thin films using magnetic-optical imaging (MOI). Grain boundaries in this compound exhibit enhanced magnetoresistivity, 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 magnetoresistance across the boundary. A model describing this behavior will be presented. This model is based on the use of Heisenberg exchange to induce changes in magnetization. Using a mapping 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 in bicrystals - a local spin flip. 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 P4.9
OPTIMIZING THE TRANSITION TEMPERATURE OF DOUBLE PEROVSKITE MgCu2O4. I. Altmann Research Center, San Jose, CA, Andrew Mills, 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 parameterization of the underlying band structure, we have calculated Tc and optical conductivity and determined the conditions for optimizing the transition temperature.

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

1:30 PM F5.1

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 channels across metal semiconductor interfaces. We will then discuss the beam-transfer effect where a spin-polarized current, that flows between two ferromagnetic nanolayers 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 nanolayer fixed to that of a fixed ferromagnetic layer, 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 a new high frequency nanoscale device. 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. Hansez, J.M. George, A. Pert, Unité Mixte de Physique CNRS-TALES, Orsay, FRANCE; G. Faini, LIP-CNRS, Bagnues, FRANCE; J.-B. Youssef, H. Le Gall, LBMB, Brest, FRANCE.

The magnetic moment of a ferromagnetic layer can be reversed by a spin-polarized current (i.e. without moving 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 nanopillars at Cornell University[3] and at Orsay[4]. We will present our latest experiments obtained on Cu/CoFeB/MgO nanopillars 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 107 A/cm². 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 symmetry implied in Slonczewski’s equations is influenced by the layer thickness of 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 submicron magnetic devices.

3:00 PM F5.3
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, $H_s$, in submicron magnetic tunnel junctions where shape-anisotropy is dominant. Experimental data support the use of a single-domain thermal activation model for the 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 P.M.**

**F6.5**

**SPIN-INJECTION IN POINT-CONTACT MAGNETIC MULTILAYERS.**

M. Tauc, Dept. of Physics and Astronomy, Michigan State U., East Lansing, MI and Grenoble High Magnetic Field Laboratory, MPRK-CNRS, Grenoble, FRANCE.

We report the detection of electromagnetic waves radiated by current-driven magnons in a Co$_x$/MgO magnetic multilayer. The magnons were excited by means of a high current density $\approx 10^7$ A/cm$^2$ injected into the multilayer through a point contact. The point contact itself was used as a high frequency mixer to mix electro-magnetic waves radiated by the current-driven magnons with externally generated microwave radiation. Here the external microwave is used as a direct probe of the high-frequency and low-frequency behavior and partial coherence of the current-induced excitations. When the external frequency equals the frequency of the magnons generated in the multilayer a dc voltage was found to develop across the device with a frequency of half of the injected current frequency. The same experiment was repeated with a current magnet field, and microwave frequency provided detailed information on the spectrum of the current-driven magnons. Our observations support the feasibility of a spin-wave maser, or SWATER (spin-wave amplification by stimulated emission of radiation).

**SESSION F6: IN-ROOM POSTER SESSION**

Chair: Robert A. Behmami

**Tuesday Afternoon, November 27, 2001**

**4:00 P.M.**

**Room 207 (Hynes)**

**F6.1**

**GROWTH AND PROPERTIES OF ORIENTED HEUSLER ALLOY FILMS/MULTILAYERS BY PULSED LASER DEPOSITION.**

I.V. Sard, V. Cretescu, M. V thorough, R.P. Sharma, M. Wettig 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$_2$NiAl and the half-metallic Co$_2$MnGe on (001) GaAs and Mg$_x$AlO$_y$ 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 orientation locking. The epitaxial nature of these samples was confirmed by Rutherford Backscattering Spectroscopy (RBS) ion channeling experiments. Temperature and field dependent magnetic measurements reveal a striking thickness dependence of the magnetocrystalline structural phase transition, which is strongly suppressed below thicknesses of 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. Sulem, NRL). This work is supported by the Office of Naval Research.

**F6.2**

**MECHANISMS OF ELECTRONIC TRANSPORT IN ARTIFICIAL GRAIN BOUNDARY DEVICES MADE FROM CMR FILMS.**

A.K. Raychaudhuri, Murshid Parainnab, 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 Co$_x$Mn$_{1-x}$Ga$_2$ have been fabricated in the device field of spintronics. The spintronics of magnetic boundary junctions in zero field as well as applied magnetic field is a subject of current research. In this work we report a study of the behavior of artificial grain boundary junctions fabricated on bcc crystal substrate depositing epitaxial film of CoMn material (primarily LMMO). The study consists of non-linear transport characteristics for 4K-10K in a field of 0.5 T. In addition to this 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 inhomogeneity 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 field direction. It is tunneling at low temperature, charge 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$_2$Fe$_2$Mo$_2$O$_9$ FILMS AND STUDY OF THE FILM PROPERTIES.**

S. 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. Tauc and B.G. Kim, S.-W. Cheong and A.J. Millis, Department of Physics and Astronomy, Rutgers University, Piscataway, NJ.

Thin films of Sr$_2$Fe$_2$Mo$_2$O$_9$ have been deposited by pulsed laser deposition technique, using a high quality, polycrystalline, and stoichiometric Sr$_2$Fe$_2$Mo$_2$O$_9$ 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 was 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 300K, while the films deposited between 980-1050°C exhibit a metallic behavior between 300K-100K and a semiconducting behavior below 100K. It is observed that the energy density higher than 0.5 J/cm$^2$ yields better quality films. The structural properties of these films are studied by X-ray diffractometry and Rutherford backscattering channeling techniques. The film morphology is studied by atomic force microscopy. The magneto-transport measurements are also performed and will be analyzed via a vis other film properties. This work is supported under NSF-MRSEC grant no. DMR-00-80018.

**F6.4**

**MAGNETIC AND MAGNETO-OPTICAL PROPERTIES OF Sr$_2$Fe$_2$Mo$_2$O$_9$ THIN FILMS.**

H. Aso, M Osugi, Y. Kohara, D. Higashida, and M. Shima, Dept. of Crystaline Materials Science, Nagoya University, Nagoya, JAPAN.

Epitaxial thin films of a halfmetallic ferromagnet Sr$_2$Fe$_2$Mo$_2$O$_9$ 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 $\theta$ up to 0.32° at 1.6 eV and $\gamma$ 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**

**DIFFERENT MAGNETIC OXIDES BASED ON ANATASE TiO$_2$ AND C-RARE EARTH In$_2$O$_3$. ANALYSIS OF PROSPECTS FOR ROOM TEMPERATURE TERMOELECTRICITY AND TRANSPARENCY.**

Oleg Myasoeev, Mark van Schilfgaarde, Sandia National Laboratories, Livermore.

We report results of the modeling of magnetic, optical properties and energetics of TiO$_2$ and In$_2$O$_3$ oxides doped with 3d transition metals. We employ LAPT 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$_2$O$_3$ 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 short range ordering which may account for discrepancies in the predictions with observations [1]. In contrast with TiO$_2$, results for In$_2$O$_3$ favor more homogeneous substitution into the In-sublattice and ferromagnetism which is mediated not by O states (like in TiO$_2$) but the free electron like conduction band. The latter feature of In$_2$O$_3$ also provide better transmissibility 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$_2$O$_3$ substitution configuration with 6% concentration suggest possibilities for RT ferromagnetism. But starting from 0.1% Co-doped TiO$_2$ has been reported to be a room temperature (RT) transparent ferromagnet [1]. Mn doped In$_2$O$_3$ is predicted to have a good prospect for RT ferromagnetism also with distinct from Co: TiO$_2$ features of electronic structure, maximum of $\rho$ ordering and light absorption and substitution properties. 1. Masumoto, Y., et al, Science; 2 Feb. 2001; vol.291, no.5505, p.854-6.
Oxide-biased Ti$_{2}$Co$_{2}$O$_{7}$ thin film material has attracted attention because of reported room temperature ferromagnetism 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.

Heterostructures for Spintronics: A Comparison of (100) and (110) Orientations. J.J. Zuck, W.B. Harvieux-Carter, S.L. Sheith, HRL Laboratories LLC, Malibu, CA, T.F. Bogges, 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 Dzyaloshinskii-Moriya spin relaxation mechanism is suppressed or absent in this orientation for 2D systems. We are currently engaged in the growth of 6L 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 terminated interfaces. We will discuss the results of in situ RHEED, photoluminescence, and 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.

Electronic Structure and Magnetic Properties of Transition Metal Doped Silicon Carbide. Michael McClymonds, Max and Walter H. Lambrecht, Department of Physics, Case Western Reserve University, Cleveland, OH.

It has been argued that wide band gap semiconductors have possibly an advantage for room temperature ferromagnetic 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 Si-Zr. 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 line 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 magnetic interaction between neighboring impurities. Electronic densities of states are used to analyze the results. Supported by ONR under grant No. N00014-99-1-0703.

Kinetic Exchange vs Room Temperature Ferromagnetism in Diluted Magnetic Semiconductors. J. Blinowski, P. Kim, and T. Dietl, Institute of Theoretical Physics, Warsaw University, Warsaw, POLAND, Poland Institute of Physics, Polish Academy of Sciences, Warsaw, POLAND.

The pursuit for room-temperature ferromagnetism in semiconductors was recently located by theoretical predictions of high Curie temperatures for p-type (Ga,Mn)$_2$N and (Zn,Mn)$_2$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, derived from photoluminescence data for Mn-based III-V compounds and (Ga,Mn)$_2$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 interband reference rule and the known band offsets, we first discuss the feasibility of obtaining III-V and IV-IV DM 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 configuration 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 III-V host compounds only the Mn ions seem to allow for the p-type, but with the p-doping. In some III-V compounds this is possible, either with or without codoping, also for Fe and Co ions. We show that the prospects of room temperature ferromagnetism in III-IV DM with Mn ions depend on the charge state of these ions and that Fe- or Co-based III-IV DM with strong p-type hybridization look very promising.

SESSION F7: NEW TECHNOLOGIES, NEW EFFECTS, SILICON INTEGRATION

Chair: Timothy J. Klemmer

Wednesday, November 28, 2001
Room 207 (Hynes)

8:30 AM-9:30 AM Session 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 noise level and improvement in recording uniformity in magnetic grain isolation. Continued grain size reduction, however, will eventually cause thermal destabilization of the magnetic grains, thereby limiting the attainable areal density. To postpone the onset of superparamagnetic 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. As this singularity is not a limited route to enhanced media performance, the drive field is a natural approach to magnetic 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 recently developed and record areal densities in the 60 Gbitps 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 temporarily 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 Tbitps are conceivable in self-organized magnetic array patterned media [3].


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. Date, 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 forms 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 charge, and not those of the spin. In the present work, we propose a novel spin filter that utilizes the Rashba spin-orbit interaction in InAlAs-InGaAs-InAlAs triple barrier resonant tunnel diodes (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, the Rashba spin-orbit coupling effect leads to a resonant level that is split into two levels in the RTD which matched between the second and third barriers only for a selected spin state, thus realizing an electronic spin filter. The calculation of the spin polarization of the transmitted current through the device, defined by \( P = (I_L - I_R) / (I_L + I_R) \), where \( I_L \) and \( I_R \) 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]O\(_2\) TUNNEL BARRIERS FOR SPIN TRANSPORT IN SEMICONDUCTOR SYSTEMS

N. Oehlem, C.J. Hell, T.P. Frey, T.C. Maimone, J. Wassen, Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA.

The properties of the [Ga,Gd]O\(_2\) system have been examined for ultrathin spin-dependent tunnel barrier applications. Structures of type FM/MT/SC and FM/MT/FM/SC have been fabricated, where FM denotes a ferromagnetic material, T an insulator, and SC a semiconductor. Semiconductors include GaAs, InAs, and Si. Ultra-thin vacuum fabrication techniques allow nearly contamination-free interfaces to be formed. Effective band offsets and layer exchange have been investigated using a tunnelling photo-emission spectrometer (XPS) x < 0.1 has been observed. TEM imaging has allowed us to observe lattice imperfections and crystal structure. LV characteristics were measured and spin transport properties determined by the Stokowski-parameter analysis of current-voltage data. It is found that these films are magnetic and suitable for use as tunnel junctions.

9:30 AM F7.4 SPIN VALVE EFFECT IN MAGNETIC RESONANT TUNNELING DEVICES

D.O. Destenako, A.N. Chetverikov, A.G. Pustovoy, 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 of the device these structures exhibit a clear spin valve effect leading to a great enhancement of magnetoresistance. New ferromagnetic semiconductor devices such as GaMnAs or its analogs are suitable materials for fabricating the devices in question. As an example, we consider resonant tunneling of holes in GaMnAs/AlAs/GaMnAs/AlAs/GaMnAs double-barrier heterostructures. Our calculations of tunneling conductance for parallel and anti-parallel alignment of magnetizations in the leads demonstrate that at certain thickness of the quantum well the barriers this system can significantly outperform conventional tunneling junctions comprised of an insulating barrier sandwiched between two ferromagnetic electrodes. We also investigate the bias dependence of magnetoresistance. 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


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 exhibits a strong spin valve effect with absorption lines with line widths as narrow as 30 mG as a 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 be possible by changing the composition. To test the feasibility of this concept we performed ESR experiments on strained, type modulation-doped Si(1-x)Ge(x) quantum wells with x < 10%. The experiments show a systematic decrease of the g-factor with composition. Given the small size, one can change the ESR signal at x = 0 to x = 0.05 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. Burns, Mark Friesen, J.J. Kelly IV, D.E. Swango, and M.G. Legally, University of Wisconsin-Madison, Dept. of Physics, Madison, WI.

Development of spintronics devices requires detailed knowledge of the surface and interfacial magnetic properties of ultrathin sputter-deposited films. With soft-x-ray scattering using a tunable source of x-ray, one can probe elements 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 make a spin more labile. In the present study we find that x-ray scattering can be used to allow observation of the magnetic 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. The changes 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 layer. 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, this research is provided under NSF Grant #DMR-88-14402 [1]. J.W. Freedland, K. Bassmann, P. Lubitz, Y.U. Idzerda, and C.-C. Kao, Appl. Phys. Lett. 73, 2262-2268 (1998).

10:45 AM *F7.7*
REAL-TIME OBSERVATION OF REFRIGERATION PROGRESSIVE IN Fe3O4 FILMS M. Turchinskaya, National Institute of Standardization and Technology, Gaithersburg, MD; A. Royburd, Department of Chemical and Nuclear Engineering, University of Maryland, College Park, MD; A. Orszho, S.R. Shinde, S.B. Ogale, and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD.

The magnetization process of (001) Fe3O4 films deposited on (001) SrTiO3 substrates was studied using a magnetooptical 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 magnetization 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 magnetization 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 Hc. For thinner films, when the field is applied along <110> direction, i.e., along the easy direction of magnetization for Fe3O4 films, 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 expansion was much faster. This work is supported under NSF-MRSEC grant no. DMR 98-080008.

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

Devices exploiting giant magnetoresistance or tunneling magnetoresistance typically contain magnetic layers no more than 2 or 3 nm thick, hence, they are often called magnetic nanostructures. Although we are now capable of controlling these multilayer interfaces to 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 patterned stencil. Examples of such additive techniques are electrodeposition and collimated deposition/lift-off processing. Though extremely useful for certain applications, these additive techniques are limited for fabricating complex multilayer structures. In such structures, the precision required 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 not 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 five-dimensional data capacity is anticipated to be less than 100 nm.

11:30 AM *F7.9*
INTEGRATION OF MAGNETIC DEVICES WITH SEMICONDUCTING CIRCUITS: CHALLENGES AND PROGRESS. Deka Wang, James M. Daughton, NVE Corporation, Eden Prairie, MN.

Magnetoresistive materials are under intensive research and development due to their high potential and initial commercialization success 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 modulation. Therefore, many applications demand certain level of integration of the magnetic components with IC electronics in order to achieve the desired performance. Although 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 magnetic side, GMR materials are being applied in commercial ICs in discrete form as well as integrated into arrays, so soon SMD form will be. MRAM arrays of different types with feature sizes of 200 to 800 nm have been demonstrated. Much smaller devices enabled by Curie point writing and other ingenious inventions suggest steady 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 CHARACTERIZATION AND IMAGING
Chair: Bruce C. Clemens
Wednesday Afternoon, November 28, 2001
Room 207 (Hynes)

1:30 PM *F8.1*
SEMAP 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 sub-monolayer 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 as 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 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.
Andrew Scholl, Lawrence Berkeley National Laboratory, CA; Christian Stamm, Hendrik Ohlking, Joachim Stöhr, Hans-Christoph Siegmann, Stanford Synchrotron 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 technological applications is the interface between two magnetic layers or between a magnetic and a non-magnetic layer. Phenomena such as exchange bias, giant magnetoresistance, and spin injection are interface phenomena and precise knowledge of the interface spin structure and chemistry is 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/LaFeO₃ and Co/NiO we were able to separate the contributions to the sample magnetism of the uniferromagnetic bulk of its interface and the exchange bias of the interface. The relative alignment of the magnetization and its response to external magnetic fields provides important information on the origin of the exchange coupling and the layer thickness. We will show that 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 longitudinal current. We are currently designing a new experiment setup which will allow strobo-photomicroscopy using a synchronized x-ray-tomography layout. We hope 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 P.M. FS.3 SYNCHROTRON-RADIATION-BASED INVESTIGATIONS OF POTENTIAL HALF-METALLIC-FERROMAGNETS. J.G. Tobin, M. Hochstrasser, D.A. Arena, L.L.N. CA; S.A. Morton, G.D. Widdow, U. Missouri Rolla, Rolla, MO; C. Klussmann, K.J. Schuller, University of California, San Diego, CA; S.A. Chambers, PNNL, WA; A. Holm, S. Kuzmic, W. Pickett, University of California, Davis, CA.

Many materials have been predicted to be half metallic ferromagnets, yet despite extensive study, remarkably few 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 x-ray 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 Spectroscopic Facility (Beamline 7.1) at the Advanced Light Source, we have found evidence for half-metallic behavior in thin films of magnetic. High films of magnetic 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 hard 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 new insight into the nature of magnetic. Furthermore, our spin resolved spectra demonstrate close agreement with simulated spectra derived from theoretical one electron density of states calculations in the case of the Znt compound, Y4Mn7Si11, X-ray Magnetic Circular Dichroism (XMCD) was used to demonstrate that the Mn was the dominant contributor to the magnetic moment, possessing a magnetic moment on the scale of five Bohr Magneton.


3:15 P.M. FS.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 submonolayer 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 issue. Diffuse x-ray 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 magnetic fets. 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 / c 100) Si. The Co and Cu films were sputter-deposited at 0.5 nm per minute, followed by 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 Shantag Technologies Co. and ONR. Support for the SRC is provided by NSF under grant number DMR-0884492 [1] J.P. Mosky, C. Teichert, D.E. Savage, and M.G. Lagally, Phys. Rev. Lett. 77, 3925 (1996). [2] C.J. Nelson, G. Strger, J.C. Long, C.T. Venkatarman, S.K. Sinha, H. Takayama-Muromachi, N. Ishimasa, and N. Hoshiho, 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 P.M. FS.5 OCCUPIED AND UNOCCUPIED METALLIC QUANTUM WELL (MQW) STATES IN THE Cu/Sm/Cu (Me=Ni, Fe) SYSTEMS. H. B. Beste, G. Droese, Robert A. Albers, University of Physics, Piscataway, NJ; Dario A. Arens, 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 Magnetoresistance (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 Magnetic Quantum Well (MQW) electron structure of the prototypical NM/NM/NM systems, Cu/fcm/Cu(100) [M=Ni,Fe], using angle resolved photoemission (ARP) and inverse photoemission (IPE) along the [100] direction. We have also used a phase accumulation model (PAM) to calculate the density of MQW electronic states along this axis. The PAM predicts that MQW states will have a high effective mass when they lie in the energy and momentum region of the projected spin polarized band gap of the underlying magnetic material. The two states of high effective mass were observed using PE on the Cu/fcm/Ni(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/fcm/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/fcm/Cu(100) and PE of Cu/fcm/Cu(100), our IPE data for Cu/fcm/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.


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 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 quantitave technique connects the phenomena occurring at the single domain scale with 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 (Hyres)

F9.1 OPTICAL AND TRANSPORT STUDIES OF IMPURITY STATES IN Mn-DOPED GaAs EPILAYERS. M. Feher, G. Isikoa, C. Roest et al.
Since the discovery of the carrier induced ferromagnetic in InMnAs and (Ga,Mn)As magnetic semiconductor (DMS) have been of much interest from the industrial viewpoint because of their potential 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 DMS 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 high-speed and high temperature optoelectronics, therefore, detailed investigation on the feasibility of GaN- and AlN-based ferromagnetic DMSs is of great importance. The electronic structure is calculated by KKR-CPA-Rostoker method combined with the coherent potential approximation (KKR-CPA) based on the spin density approximation. The KKR-CPA is one of the most sophisticated methods to treat substitutional disordered systems with taking disorder into account. We calculated the electronic structure of ferromagnetic GaN and AlN-based DMS 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. Kugimiya-Yoshida, Jpn. J. Appl. Phys. 39 (2000) L553, ibid. 40 (2001) L538, ibid. 41 (2001) L855.

P.0.5

Abstract Withdrawn.

P.0.6

Abstract Withdrawn.

P.0.7

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

A previous 6-band $k \cdot p$ 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-V-Mn 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 semiconductors. Whereas the $k \cdot p$ method is a quasicontinuum approach, in dealing with digital SLs it is important to have a band structure model that tends single atomic layers. The effective-mass orbital method (EOM), in which the full symmetry of the zinc-blende lattice is reduced to that of an $s$-orbital, is more attractive than other atomistic approaches for reasons of straightforward reduction to an $6band k \cdot p$ model, efficiency, and simplicity. We have verified that in bulk alloys, $T_c$ predicted by EOM nearly coincide with $k \cdot p$ values. Including self-consistent exchange and electron correlation 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/Ga$_{0.7}$Mn$_{0.3}$As SL with a 10 ML period with hole density $P = 10^{20}$ cm$^{-2}$, 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 the room-temperature ferromagnetism. Also for digital SLs, with AIsAAs superlattices to provide a high-valence-band offset with respect to GaMnAs, assuming the same high $P = 10^{20}$ cm$^{-2}$.

P.0.8

INTERFACE RESISTANCE AND ELECTRICAL SPIN INJECTION INTO SEMICONDUCTORS. D.L. Smith, A. Suen, R.N. Silver, Los Alamos National Laboratory; T.M. Brucholl, Institut für Theoretische Physik, Mgbldorf, 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, a significant spin injection will occur together with high sheet 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 metal's 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 tunnel barrier can also have spin dependent interface resistance. We describe calculations of spin injection for a variety of semiconductor/ferromagnetic layers, and investigate the properties that are required for significant spin injection.

P9.0 MAGNETIC ANISOTROPY OF STRAINED \( \text{La}_0.7\text{Sr}_0.3\text{MnO}_3 \) THIN FILMS STUDIED BY MORE, Mohamed Khnour, Anne-Marie Haghiri-Gosnet, Unv Paris Sud, Orsay, FRANCE, Wilfried Pfeiller, Philippe Leconte, Bernard Mercye, CRISMAT, ISMRA, CEA, FRANCE.

Magnetic anisotropy of \((001)\) strained \( \text{La}_0.7\text{Sr}_0.3\text{MnO}_3 \) films has been studied using Magnetic Optical Kerr Effect (MOKE) as a function of pulsed laser deposition (PLD) parameters, i.e., the temperature, the target-to-substrate distance and the oxygen pressure \( P_0 \). On \( \text{SrTiO}_3 \) substrates, sublimed target material has been used for magnetic anisotropy, but the orientation of the easy axis is seen along the \([1 0 0]\) or the \([1 1 0]\) direction of the pseudocubic unit cell, depending on the authors.[1] The value of \( D \) is relevant for magnetic anisotropy; at a small distance \( D \). \([1 1 0]\) axis is found to be clearly easier than the \([0 1 0]\) one, at least at large distance \( D \) values, both \([0 1 0]\) and \([1 1 0]\) directions are equivalent. The optimal \( D \) value \((D = 45 \text{ mm for } P_0 = 300 \text{ mTorr})\) produces films with very low roughness (Ra not 0.1 nm) and a maximum value of the saturated magnetization \( [1] \). It is also shown that remanent magnetisation increases with pressure: for the optimal \( P_0 = 300 \text{ mTorr} \), hysteresis loops are perfectly square along the \([1 0 0]\) direction \([H = 346 \text{ G}, K = 1.0 \times 10^4 \text{ erg/cm}^3]\). In compressive films grown on \( \text{LaAlO}_3 \), for optimal PLD conditions, the perpendicular \([0 0 1]\) direction is a hard axis and, in the plane, the easy direction lies along the \([1 0 0]\) axis \([H = 700 \text{ G}, K = 7.2 \times 10^4 \text{ erg/cm}^3]\). The presence of an in-plane anisotropy \([2]\) at RF will be discussed from PLD parameters.

F9.10 OXYGEN-ISOTOPE EFFECTS ON THE LOCAL STRUCTURE DISTORTIONS IN \( \text{Nd}_x\text{Sr}_{1-x}\text{MnO}_3 \) THIN FILMS OF EPIITAPY THIN FILMS OF \( \text{Nd}_x\text{Sr}_{1-x}\text{MnO}_3 \) R.P. Sharma, D.J. Kang, R. Marcini, M. Rajasekhar, B.S. Ogale, H.D. Drew, R.L. Greene and V. Vaitheesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD, Ginsburg, Department of Physics & Astronomy, University of Zurich, Zurich, Switzerland.

Detailed investigation of inherent lattice fluctuations and electrical transport are made in oxygen isotope substituted \( \text{Nd}_x\text{Sr}_{1-x}\text{MnO}_3 \) thin films. Ion channeling measurements have clearly showed an increase in the rms displacement of the \( \text{Mn}^2+ \) atoms as the sample goes from the ferromagnetic 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 1% larger for \( ^{18} \text{O} \) than for \( ^{16} \text{O} \) 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 latter one. Similar shift is seen in the ion channeling measurements. The transport measurements have also shown that in the paramagnetic state the oxygen isotope doping affects the energy of the \( ^{18} \text{O} \) samples is higher than the \( ^{16} \text{O} \) samples by about 1%. The \( ^{18} \text{O} \) samples show a sharper resistivity drop below T_c than the \( ^{16} \text{O} \) samples. These features will be discussed in terms of the development of John-Teller small polarons as the system approaches the paramagnetic state.
fabricate a 'superconducting spin switch', consisting of an F/S/F structure with both F-layers thickness-tuned to sustain a LLG-state. Rotating the magnetic moments of the superconducting, magnetic layers 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/Ni₃Al₃, with x between 0.5 and 0.7. We show that for the lowest X- concentrations the conditions for such a device with respect to interface transparency and S-layer critical thickness are met. [6]V. Ryzhov et al., Phys. Rev. Lett. 86, 2427 (2001).

8:45 AM F10.2 THE TRANSMISSION POLARIZATION OF FERROMAGNET/SUPERCONDUCTOR INTERFACES K. Xin and P.J. Kelly, University of Twente, the Netherlands E.M. Bakker, Delft University of Technology, THE NETHERLANDS. I. Turek, Institute of Physics of Materials, Brno, CZECH REPUBLIC.

Andrew reflection as 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 Ω-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/Pt or Co/Nb) are not epitaxial and the magnetic model used is at best a good approximation. Using a newly developed method based on the TB-LMTO method, we model FM/S interfaces using large lateral supercells, calculate entirely from first-principles the spin polarization of the transmission through Fe and Co/Pt/S 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.


9:00 AM F10.3 TRANSPORT STUDY ACROSS A Co3O4/Ag/YBCO JUNCTION USING FLIP-CHIP CONFIGURATION Z.Y. Chen, Anubis Biswas, S.H. Ogale, I. Takeuchi, J. Read, T. Venkatesh and R.I. Greene, Univ. of Maryland, Center for Superconductivity Research, College Park, MD. A. Angelopoulos, G. Xiao, Dept. of Physics, Brown University, Providence, RI. A. Gupta, IBM T.J. Watson Research, 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 due to the spin dependent scattering associated with the Andreev states at the n-plane of the interface due to the spin polarization of LSMO carriers. However, the temperature dependence of the shape of the ZBPC and the temperature decay of the surface spin polarization of LSMO occurs far below the Curie temperature raising questions about the applicability of LSMO in spintronics applications. Co3O4 is another transition metal oxide, which has been suggested to be highly spin polarized. In this work we report the results of a transport study carried out across a Ag/Co3O4/YBCO junction following the flip-chip mechanism. The junction is formed by pressing a Co3O4 film against a Ag/YBCO junction. The Ag/YBCO junction in the same flip-chip configuration clearly shows the zero-bias conductance peak (ZBPC), proving the validity of the flip-chip mechanism employed in the study. The transport characteristics of the Co3O4/Ag/YBCO junction do not reveal any ZBPC all the way up to the Tc of YBCO, 80 K. The strong suppression of ZBPC is in evident with the high Andreev states suggested at the n-plane of the Co3O4 surface, its persistence up to the Tc of YBCO indicates a good temperature stability of the spin polarization. A comparison of the results obtained for different Co3O4 film thickness is also carried out under high magnetic fields using the NSF-MRISEC grant No. DMR-00-08088 [1]. Z.Y. Chen et al., Phys. Rev. B 63, 212508 (2001).

9:15 AM F10.4 THERMAL RELAXATION IN SOFT, PATTERNCED 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 shrink down to the atomic scale, 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 [μm] were 100 x 10, 1x10, 1x10, and the height of the bar was fixed to 2 μm. The thermal conditions are independent of the bar thickness.

119
11:00 AM E10.7
VARIABLE-RANGE HOPPING IN ARRAY OF MAGNETIC QUANTUM DOTS. M. Fogel 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 in 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 a strong contribution of the inter-dot magnetic parts of electron energies, variable-range and variable-polaron-bARRIER hopping can be observed at low temperatures. It results in giant magnetoresistance, \( \rho( B, T) \) governed by a non-activation law, in the form of \( \rho( B, T) \sim T^{-\alpha} \), where \( T \) 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 \( \alpha \) lies between 0.25 and 1. Such dependences have been observed in some of the GaAs/AlGaAs and GaAs/FeGaAs nanowires.

11:15 AM E10.8
INFLUENCE OF GATE VOLTAGE SEQUENCES AND CHARGED IMPURITIES ON BOUND SPINS IN SMALL QUANTUM DOTS. Mark Friesen, P. Rugeheimer, D.E. Savage, M.G. Lagally, D.W. van der Welie, Robert Joynt, and M.A. Erikson, 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 computing devices. On the other hand, isolated 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 an novel bulk-gated quantum dot containing a single-electron transistor device. Here we present numerical simulations of two coupled dots. The simulations are performed on the actual device geometry, and implemented 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 3 \( \mu \text{eV} \), 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 effects introduced by charged defects near the quantum dots. Work supported by NSF-MSPSEC Program, ARO, and NSA.

11:30 AM E10.9
SIZE DEPENDENCE OF ELECTRON G-FACTOR IN SEMICONDUCTOR NANocrystallites. J. V. Bardarson, J. Phys. Institute, Justus Liebig University of Giessen, Germany and Ioffe Physico-Technical Institute, St. Petersburg, Russia; Al. I. Efros, M. Rosen, Naval Research Laboratory, Washington, DC; B. Meyer, J. Physics Institute, Justus Liebig University of Giessen, Germany.

The size-tunable optical properties of semiconductor quantum dot (QDs) in an external magnetic field open wide possibilities for controlled manipulation of the spin 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 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 size to calculate with arbitrary band at any QD.

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.

11:45 AM F10.10
ELECTRIC TRANSPORT AND MAGNETIC PROPERTIES OF FERROMAGNETIC GaAs/Mn DIGITAL ALLOYS. M. N. K. Money, 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; X. Liu, J.K. Furdy, 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 temperature dependence of the Mn fraction is a decreasing function of the magnetic field. A correlation between the effective Mn spin density (obtained from saturation magnetization) and the Curie temperature is observed for all Mn-stabilized samples. This correlation 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 (Hyres)
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 non-magnetic (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 direct access to the fundamental parameters of spin-polarized transport in multilayers [1]. Recently, interest has begun to focus on the transport lengths for spin-flipping (spin-memory) loss in the bulk of the F and N layers and on F/N interfaces. Spin-memory loss usually reduces the CPP-MR, but under certain circumstances it can enhance it. We will describe various 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 US DOE, NSF, and the US NSF under DMR Grants 98-20135 and 98-09988. [1] J. Biss 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 VAIVES. 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 so far not been able to observe indications of spin polarized transport. 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 291 nm to 81 nm. 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 so-called 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. Aya Shapiro, Peter M. Levy, Department of Physics, New York University, New York, NY; Shuqiang 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 current transport. At the current density of 50% mismatch between the plane layers, the calculated partial specularly scattered 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 those intervening layers. Their effect is constant only if the distance between interfaces is larger than the 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 and on the height of the potential steps encountered 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 50%; 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 a 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 nonequilibrium 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. C.W. Baus, Yu. V. Nazarov, D. Haerten-Hernandez, TU Delft, NETHERLANDS; K. Xin, 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 torques on the magnetization 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 are experimentally accessible by transport experiments on magnetic multilayers in the current perpendicular to the plane (CPP) configuration as pioneered by the MÜS collaboration. The later can at least in principle be measured via the angular magnetoresistance of CPP spin valves. We present results for the interface conductances computed from 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 Schiel, Henrik Kohlstedt, Rainer Waser, Research Centre Juelich, Institute of Solid State Research, Juelich, GERMANY.

A magnetic tunnelling spin injection device (MAGTID) consisting of a stack of two ferromagnetic tunnelling junctions with access to the intermediate electrode has been developed. The layered structure is Co/AlOx/NiFe/AlOx/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 tunneling magnetoresistances (TMR). In addition, the 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 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 the non-equilibrium spin accumulation in the intermediate NiFe layer. For further improvement of the MAGTID we have studied Fe/NiFe/Fe/Mn/Co/AlOx/CoFeNi single barrier junctions using FeMn as an antiferromagnetic pinning layer. First results of these junctions will be presented. Solid state communications 117, 590 (2001).

4:30 PM #F11.7 ROLE OF INTERFACE ROUGHNESS IN THE PERPENDICULAR GIANT MAGNETORESISTANCE OF Fe/Cr SUPERLATTICES. J. Samuelsen, E. M. Gomez, M. C. Cyrille, C. L. Houghton, Koenraad M. Kishnam and Iain K. Schuller, Department of Physics, University of California-San Diego, La Jolla, CA; Materials Sciences Division, National Center for Electron Microscopy, Lawrence Berkeley Laboratory, University of California-Berkeley, CA; On leave from Universidad del Valle, Cali, COLUMBIA; Present address IBM Almaden.

Studies of Giant magnetoresistance (GMR) in metal superlattices have proved 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 these issues, we have performed an extensive comparative study of growth, structure, magnetization, and magnetoresistance 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 (interface roughness length). We have found a close correlation between transport data and roughness parameters which shows that in Fe/Cr superlattices, the resistance 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. Kaa-Uwe Barholz, Marco Diegel, Roland Matthes, Sergiusz Duchkowski, Inst. Phys. High Temp. Jena, GERMANY; Dinni Berkov, Innocent Jen, GERMANY; Jens Haich, Goetzried 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 anisotropy due to the interlayer interaction may modify the sensor characteristics. To determine the influence of these parameters and of the field of the peak current on the behaviour of the system, we have performed an extended numerical study. 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, micro-magnetic simulations 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 2 μm to 4 μm x 1 μm. The range of the calculations was restricted by calculation time. Experimental data was presented and compared with the simulation results. The good agreement between experimental behaviour and theory gives the basis for better understanding of the robust interactions in such systems. Support by BMBF Grant (13N 7910) is gratefully acknowledged.

[1] MicroMagus program package, developed by D. Berkov and N. Gor, further information available from db@imowett.jfrena.de.