SYMPOSIUM F
Spintronics
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Chairs

Jack Bass
Dept of Physics & Astronomy
Michigan State Univ
Physics-Astronomy Bldg
East Lansing, MI 48824-1116
517-432-1146

Albert Fert
UMR CNRS/THALES
Univ of Paris SUD
Orsay, 91405 FRANCE
33-1-6933-9105

Timothy J. Klemmer
Seagate Technology
River Park Commons, Ste. 550
Pittsburgh, PA 15203-2116
412-918-7043

Jonathan Z. Sun
Physical Sciences
IBM Research
Rm 24-154
Yorktown Heights, NY 10598
914-945-1372

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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
GIANFRANCO IMBESUTI, 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 new devices and 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 basic spin states defined by an applied magnetic field, and to follow the phase, amplitude, and location of the resulting electronic spin precession in these systems. Spin lifetime can extend 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 lifetimes, which give orders of magnitude longer than those of electrons, may ultimately enable long-term storage of quantum information. Local manipulation of nuclei can be achieved by periodic optical excitation of precessing electrons that surround the nuclei. A 'closed-loop' version of this technique is expected to improve the way in which tip or scanning tunnelling microscopy reveal 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 momenta using spintronics. Finally, the capability to integrate ferromagnetism within a semiconductor nanostructure may create new schemes for operating on electron and nuclear spins. [1] I. Mlynski et al., Nature, in press (2001) [2] B. Dunlop et al., Phys. Rev. Rapid Comm. 65, 12102 (2001) [3] G. Sass et al., Phys. Rev. Lett. 86, 2677 (2001).

9:00 AM F1.2 MONOPOLAR SPIN ORIENTATION AND DETERMINATION OF SPIN RELAXATION TIMES IN QUANTUM WELL STRUCTURES.
SERGEY D. Ganiachev, Sergey N. Danilov, Martin Solllinger, Dieter Weiss, Werner Wegscheider, and Wilhelm Prettl, Institut fuer Experimentelle und Angewandte Physik, Universitat von Regensburg, GERMANY; Vasiliy V. Belkov, Eugenius I. Ichenko, A.F. Ioffe Physico-Technical Institute, St. Petersburg, RUSSIA.

It is shown that optical spin orientation of free carriers in zinc-blende structure based quantum wells (QWs) causes an electric current which reverses its direction upon changing the helicity of the radiation from left to right circular polarization resulting in a circular photogalvanic effect (CPGE) [1]. This conversion of spin orientation of carriers into directed motion allows to determine spin relaxation times of electrons in $n$-type materials and of holes in $p$-type materials. The monopolar non-equilibrium population of spin-up and spin-down states has been achieved by the optical excitation of $n$- and $p$-type GaAs/AlGaAs QWs structures. In contrast to usually applied methods of optical spin orientation, in the present case of terahertz excitation only one kind of charge carriers is involved in spin orientation and relaxation processes. The experiments have been carried out on QWs of different width at temperatures varied from 4.2 K to 300 K. As a radiation source a pulsed far-infrared molecular laser has been used delivering 1000 pJ pulses at wavelength $\lambda = 148 \mu$m. 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. Ganiachev, S.N. Danilov, J. Ercore, W. Wegscheider, D. Weiss, W. Prettl, E.L. Ichenko, Phys. Rev. Lett. 86, 4528 (2001).

9:15 AM F1.3 MAGNETIC GaN AT ROOM TEMPERATURE.
N.A. El-Masy, M.L. Reed, M.K. Ritlens, H.H. Stadelmann, 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 material system, based on (Ga, Mn)As has been done with Curie temperatures above 100 K, thus limiting the potential application of this new field only to cryogenic temperatures. We report on a new dilute magnetic semiconductor (Ga,Mn)N with a Curie temperature above room temperature which will allow a broader application for spin electronic field. GaN used in this study was grown by MOCVD on (0001) sapphire substrates. Post growth doping of GaN by solid state diffusion of Mn was applied. SIMS results of the Mn-doped samples were found to have a doping profile that levels down to 1-2% Mn. Both x-ray and electron diffraction indicated that secondary phases, such as Mn$_3$GaN, Mn$_2$GaN, and Mn$_4$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 standard Hall effect (HE) and vibrating sample magnetometry (VSM). The room temperature hysteresis curves confirm the magnetic properties of the (Ga,Mn)N films. The sheet resistance measurements at a zero field applied indicated Curie temperatures in the range of 250 - 320 K depending on the sample preparation. The measurement of the effect of the sample preparation on the magnetic properties of this new DMS (Ga,Mn)N and its Curie temperature. M.L. Reed, M.K. Ritlens, H.H. Stadelmaner, M.J. Reed, C.A. Parker, S.M. Bedair, and N.A. El-Masy, accepted for publication in Materials Letters.

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

Exchange interactions of Mn and other TM doped doped GaAs and GaN were calculated within the local spin-density approximation, using an ab initio linear response technique, and the critical temperature estimated within mean-field theory. It is found that the pairwise interactions are anomalous, decreasing with Mn concentration, thus leading to a saturation in the coupling with Mn concentration. The interactions are found to be mainly described according to the Zener double exchange/Anderson superexchange picture rather than a magnetic interaction. The description is discussed in the context of recent theoretical and experimental work.

10:15 AM F1.5 FABRICATION AND CHARACTERIZATION OF GaMnP.

In this paper, we will report on the growth of GaMnP C films thin films by gas source molecular beam epitaxy (GSMBE) utilizing phosphine as the group V source, and co-doped with C via a CH$_4$ source for enhanced p-type doping. Results of the epitaxial growth will be compared with GaInP films grown in the same growth system of GaP into GaP:C x-ray diffraction (XRD) of the epitaxial films shows no evidence of second phases in the epitaxial films with Mn concentrations up to 9%. Similarly, selected area diffraction patterns taken in XTEM show only the presence of GaMnP. At Mn concentrations of 6% or less, the material is single crystal as determined by XTEM and RHEED, but with a very rough surface morphology. Analysis of the GaMnP:C by SQUID magnetometry suggests the presence of a ferromagnetic ordering with a Curie temperature above 250 K. Magnetotransport measurements will also be discussed. This is the highest Curie temperature yet reported for a III-V based DMS.

10:30 AM F1.6 CONDITIONS FOR EFFICIENT SPIN INJECTION FROM A FERROMAGNETIC METAL INTO A SEMICONDUCTOR.
Albert Fert, Henri Jaffres, Universite de Physique CNRS-Thales, Domene de Corbeville, Orsay, FRANCE and Universit et Universit du 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 (junction) preferably at the F/SC interfaces. In the case of a F/SC interface, a significant value of the magnetoconductance may 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 interfaces are at odds with recent
11:04 AM FL.7

11:30 AM FL.10

11:45 AM FL.11

11:15 AM FL.9
Since the recent demonstration of large magnetoresistance effects in Magnetic Tunnel Junctions (MTJs), consisting of two ferromagnetic electrodes separated by a thin (~1nm) insulating barrier, there has been a renewed technological and fundamental interest in the tunneling phenomenon. Within 5 years of the reproducible experiments, prototypes of non-volatile Magnetic Random Access Memories (MRAM) and read-headers for ultra-high density magnetic recording 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 ultra-thin interfacial layers as the tunneling barrier to demonstrate the dominant role of the interfacial electronic structure in magnetic tunnel junctions. Using Co/Mn/AlOx/Co and Co/Mn/M'/AlOx/Co (M' = Co, Cr, Au, Rh) structures, we have demonstrated that the tunneling spin polarization, and thus tunnel magnetoresistance, is determined by the outermost monolayers of the electrode in contact with the insulating barrier. With the use of "interface engineering" one can correlate the transport properties of these devices with the local interfacial electronic structure and perform unique fundamental studies of spin-polarized transport through ferromagnet-nonmagnet interfaces. Finally, time permitting, a new magnetoresistance effect using spin filter barriers will be discussed.

**3:00 PM #F2.3 BISTABLE ELECTRON EMISSION MICROSCOPY OF ULTRA-TIN ALUMINUM OXIDE TUNNEL BARRIERS FOR MAGNETIC TUNNEL JUNCTIONS**

A.C. Perello, 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 sputtered 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 a film 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 mm of Al is required for a uniform barrier. In addition to transport measurements, scanning tunneling spectroscopy of exposed aluminum oxide was done to investigate the density of states. We have found that finite states exist below the barrier height which indicates a transition from local to extended states as well as carriers having an in-plane voltage.

**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, magnetic memories, non-linear electromagnets and low-energy sensors. In this later case, and contrary to the other cases, one expects to develop an analog device which will deliver an output signal proportional to the magnetic field to be detected. The linearization of the tunnel magnetoresistance signal requires a very careful control of the magnetoresistive properties in each electrode of the junction. In practice, one has to introduce an unusual 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 sensors, wherein the bottom (soft) electrode has its magnetization direction controlled by a deposition on top of a non planar substrate[1], whereas the top (hard) electrode is exchange biased due to a contact with an antiferromagnetic layer. We will show that the use of such a stack allow to control the angular dependence of the tunnel magnetoresistance. The proof of concept of this sensor was achieved using CoO as the antiferromagnetic layer blocking the top electrode[2]. In order to obtain room temperature operation, we have recently concentrated on the use of IrMn instead. We will discuss the correlations between the magnetic properties of the exchange biased top electrode and its structural properties, in particular regarding the fact that it is deposited on top of an amorphous aluminum oxide barrier. [1] F. Montaigne et al., Appl. Phys. Lett., 76, 3286 (2000) [2] H. Jaffres et al., Phys. Rev. B. [August 2001], to appear.

**F2.6 FIRST-PRINCIPLES MODELING OF Co/SrTiO₃/Co MAGNETIC TUNNEL JUNCTIONS**

E. Y. Tsymbal and D. G. Pettifer, Oxford University, Department of Materials.

Experimental results show that the spin-polarization (SP) of the tunneling current in magnetic tunnel junctions (MTJs) depends on structural and electronic properties of the entire junction including the insulator and the ferromagnet/insulator interface. In particular, positive values of the SP of the tunnel current through an alumina insulating layer whereas it is negative when a SrTiO₃ barrier is used[1]. We have performed first-principles density functional calculations of the atomic and electronic structure of Co/SrTiO₃/Co MTJs in order to elucidate the factors controlling the SP of the tunneling current. Full optimization of the atomic structure of the MTJs was made for different types of interface terminations and thermodynamically stable structures were identified. The spin-polarized electronic structure for the most stable terminations Co/SrTiO₃/Co is analyzed including layer-by-layer projected densities of states, local charges and magnetic moments. Finally, we make comparisons of electronic and magnetic properties of Co/SrTiO₃/Co and Co/SrO/Co MTJs. [1] J. M. De Boer et al., Science, 286, 507 (1999), Phys. Rev. Lett. 82, 4288 (1999).
F3.2 SPIN-DEPENDENT TUNNELING EXPERIMENTS IN FULLY EPITAXIAL Fe/MgO/Fe-Co (100) TUNNEL JUNCTIONS. M. Bowen, V. Cres, F. Petroff, A. Fetz, UMP CNRS/THALES, Orsay, FRANCE; C. Martinez-Benitez, H. L. Cotter-Krämer, 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 promises 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 manganites. MTJs with alkalis provide large and reproducible tunneling magnetoresistance (TMR). However, to understand the physical mechanisms of spin-dependent tunneling, a transport study through an amorphous insulator is hardly accessible in a theoretical approach. Towards this end, much work has been directed to characterized the growth and electrical behavior of ultrathin MgO layers [1]. Here, we present experimental results for a series of Fe/MgO(20Å)/Fe-Co(100) tunnel junctions grown by a combination of ion beam sputtering and triode sputtering onto MgO-buffered GaAs[100]. As evidenced by RHEED, x-ray diffraction and TEM analysis, optimized growth conditions result in entirely epitaxial samples of high crystalline quality with flat, sharp interfaces [2]. Fe(100)/MgO(20Å)/Fe-Co(100) junctions show up to 60% TMR at 30K, to be compared with 12% obtained recently by Yuan et al. on (100)-oriented Fe/epitaxial MgO/Fe 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/Ferromagnet system. Furthermore, we consider from the bias dependence of the TMR, previous experimental results and recent calculations [4] that s-character electrons are predominantly tunneling in the case of a 20Å MgO(100) barrier [1] W. Wuthrich et al. Appl. Phys. Lett. 75, 1687 (1999); C. Martinez-Benitez, J. M. de Teresa, Growth, 226, 223 (2001) [5] S. Yuan et al. Europhys. Lett. 52, 344 (2000) [6] W.H. Butler et al., Phys. Rev. B, 63, 54416 (2001).

F3.3 INFLUENCE OF SINTERING CONDITIONS ON MAGNETO-TRANSPORT OF Sr-Fe-Mn-O. Amit Sharma, Karen Yates, Imperial College, London, UNITED KINGDOM; D. L. 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 processing 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 optimized under different sintering conditions (pO2 and temperature).

F3.4 METAL-INSULATOR PHENOMENA OF ORDERED DOUBLE PEROVSKITES (Sr2-y Cdy) Fe2O4. H. Kato, T. Okuda, Y. Okimoto, Y. Tonomoto, JRCAT, Tsukuba, JAPAN; K. Oikawa, T. Komiya, KIEK, 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 tunneling 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=50K. 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-y Cdy)Fe2O4, and investigated their magnetic and electronic properties. (Sr2-y Cdy)Fe2O4 (0<y<1) were prepared by the solid state reaction. Crystal symmetry was changed from tetragonal to cubic and orthorhombic with increasing Ca content, y at room temperature. Rietveld analysis indicated that degree of ordering of Fe and Re on this phase was more than 50%. We have found that the Sr2Fe-Re-O compounds are in a ferromagnetic metallic state at room temperature, while the ferromagnetic insulating state emerges for y<0.4 below 150K. The meso-insulator transition at the ground state may occur via the change of the one-electron bandwidth. We have also found the end compound Ca2Fe-Re-O (y=1) shows the thermally induced met-ml 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. Fernandez, Instituto de Ciencia de Materiales de Barcelona - CSIC, SPAIN; F. Sanchez, M.V. Garcia-Cuenca, C. Ferrater, M. Varch, Dept. de Física Aplicada, P. Faisca, U. Barcelona, Barcelona, SPAIN.

Spin-dependent devices based on manganites have an important drawback in the strong decrease of the tunnel magnetoresistance (MR) with temperature, making them almost useless at temperatures near to the Curie temperature. It has been suggested that double exchange (DE) materials are prone to display spin depolarization at interfaces and therefore, alternative materials not based in DE mechanism will be desirable. The itinerant ferromagnet 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 300nm, 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 1° in the range from 2θ=60° to 64°, showing the high thickness on the samples. 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, which are the thickest samples. While thickness increases up to 20 nm, Tc decreases and a semiconducting behavior is observed at low temperatures for samples with thickness below about 20 nm. Values of saturation magnetization at low temperatures are found to be decreasing with the film thickness. These trends may indicate that also in STO there is a non-conducting and poorly magnetic layer close to the interface with the substrate.

F3.6 LATTICE-MISMATCH STRAIN EFFECTS IN COLOSSAL MAGNETORESISTIVE MANGANESE THIN FILMS. M. Rajeswariri, Towson University, Dept. of Physics, Astronomy and Geosciences, Towson, MD; A. Biswas, A. Shinjo, R.L. Greene, University of Maryland, NSF MRSEC and Center for Superconductivity Research, College Park, MD; A. Mills, Rutgers University, Dept. of Physics and Astronomy, Piscataway, NJ; C.S. Nelson, J.P. Hill and Donal Gils, Physics Department, Brookhaven National Laboratory, Upton, NY; F. Yokouchi and C. Giles, Universidade Estadual de Campinas, Campinas, BRAZIL.

Electrical and magnetic transport properties of epitaxial manganite thin films on lattice-mismatched substrates show a systematic dependence on the film thickness. There have been attempts to use this thickness dependence to quantify the effect of lattice-mismatch induced bi-axial strains under the basic assumption that thickness given amount represents a well-defined strained lattice. Contrary to this assumption, our studies indicate that the manganite thin films on lattice-mismatched substrates are characterized by inhomogeneous strain distribution both in-plane and out-of-plane. In this paper, we will present systematic data on the thickness dependence of the structure.
microstructure, magnetic and transport properties of $La_2Ca_{3-x}MnO_6$ thin films on lattice-mismatched substrates. Not surprisingly, our calculations show that the thickness dependence of the magnetization is strongly influenced by the lattice mismatch and the strain-relaxed layer with bulk-like properties. We conclude that the magnetic properties of these thin films can be described by a parallel resistor model, comprising two disordered insulating layers close to the substrate and an overlying strain-relaxed layer.

F3.4
PHOTON-INDUCED SWITCHING IN CMR MATERIALS.
N. Noginova, E. Arthur, R. Uleysse, E. Gillman, C.E. Bonner, Center for Materials Research, Norfolk State University, Norfolk, VA.

Fast switching from conductor to insulator induced by laser light illumination has been studied in colossal magnetoresistance crystals and thin films of $La_2Sr_2MnO_6$ in the range of ferromagnetic phase transitions. Based on data obtained on the photoresponse as a function of temperature, electrical current and laser light intensity, we have demonstrated that the switching and relaxation processes are determined by spin-lattice relaxation, and the relaxation times depend on the film and single crystals in study as well as the specific light wavelength.

F3.5
TWO CURIE TEMPERATURES IN A SINGLE IN THIN FILM.
Stéphane Andrej, Christophe Chouchou, Mohamed Lemaire, Bertrand Berche, Lab. de Physique des Matériaux, CNRS-Univ. P. Poincaré, Nancy, FRANCE; Philippe Bauer, Univ de Franche-Comté, Montbéliard, FRANCE.

Due to size effect, the decrease of the Curie temperature of a ferromagnetic film with thickness is now well established on both experimental and theoretical grounds [1]. However, the Curie temperature variation with the thickness is always considered as continuous when the thickness is varied from n to 1 atomic planes. In other words, the Curie temperature is assumed to only depend on the quantity of deposited material. We show here that in the particular case of thin Fe films grown on Ir(100) by MBE, two magnetic transitions are observed in a thin Fe film with a fractional number of deposited monolayers (ml). The Curie temperatures (Tc) are determined by both magnetic susceptibility and ac susceptometry. For an integer number of Fe atomic planes, we observed only one peak in the susceptibility measurements, corresponding to $Tc=145K$ 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 4ml thick and areas of 5ml thick. If we assume that the magnetic coherence length is smaller than the 4 and 5ml thickness, these areas seem to be magnetically "independent" and the two Curie temperatures should be observed. We performed Monte Carlo simulations to justify this assumption.

F3.6
INTERDIFFUSION IN EXCHANGE-BIASED NiFe/FeMn/CoFe ELECTRODE IN MAGNETIC TUNNEL JUNCTIONS.

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 (Fe/FeNi/FeMn/CoFe) of the magnetic tunnel junction multilayer. Both sets of Auger spectra performed 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 was completely intermixed at 400K, losing the exchange bias between $Mn-Mn$ 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 insulation layer could be enhanced by the presence of the free oxygen radicals in the insulation layer remaining from the plasma oxidation of the AI layer in magnetic tunneling junctions.

F3.10
SHOT NOISE IN FERROMAGNET - NORMAL METAL SYSTEMS.
Yuriy Tserkovnych and Arne Brataas, Harvard University, Linnan Laboratory of Physics, Cambridge, MA.

We formulate a semiclassical theory of the low frequency shot noise in ferromagnet-normal metal systems. Non-colinear 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 master equations that are expressed in terms of the microscopic details of the junctions in the circuit. Explicit results in the case of ballistic, tunnel, and diffusive junctions are evaluated. The shot noise, the current, and the Fano factor are calculated for a double barrier ferromagnet-normal metal ferromagnet system. It is demonstrated that the shot noise can have a non-monotonic behavior as a function of the relative angle between the magnetizations of the ferromagnetic reservoirs.

F3.11
CIRCULAR PHOTOVOLTAIC EFFECT IN Si/Ge SEMI-CONDUCTOR QUANTUM WELLS.
Sergey D. Ganiev, Franz-Peter Kahl, Wilhelm Prettl, Institut fuer Experimentelle und Angewandte Physik, University of Regensburg, Regensburg, GERMANY; Robert Neumann, Karl Brunner, and Gerhard Abstreiter, Walter Schottky Institute, TU Munich, Garching, GERMANY; Eugene I. Ioffe, A. F. Ioffe Physico-Technical Institute of the RAS, St. Petersburg, RUSSIA.

We report on the observation of circular photovoltaic effect (CPGE) in $p$-type $Si$ quantum wells. We measured shot noise spectrum of circularly polarized far infrared radiation. Direct interband transitions at wavelengths between 70 and 280$\mu$m have been excited by a high power pulsed NH$_3$ laser optically pumped by a TEA CO$_2$ laser. CPGE, recent observed in GaAs based quantum well structures [1, 2], is caused by the conversion of optically induced spin polarization into a directed motion of free carriers in the plane of a quantum well, perpendicularly to the direction of light propagation. Due to spin selection rules the current is determined by the helicity of the light and can be reversed by switching the helicity from right- to left- handed. An existence of CPGE requires a sufficiently low symmetry lacking a center of inversion (gyrotropic point group). Both bulk Si and Ge have the inversion symmetry. However, Si/Ge quantum wells grown in (011) and (132) crystallographic orientation can be prepared without inversion symmetry. The observation of CPGE demonstrates that the spin degenerecy of subbands in 4$\times$4 space is lifted due to line terms in the Hamiltonian [1]. We show that, in the case of zinc-blend type materials, the CPGE can be used as a tool to investigate spin orientation and spin relaxation in Si/Ge structures.


F3.12
ANTI-WEAK LOCALIZATION STUDY OF RASHBA SPIN-SPINITYING ENERGY AS A FUNCTION OF WELL ASYMMETRY IN InAlAs/InGaAs/AlAs QUANTUM WELLS.

The use of spin-orbit interaction is a key strategy for the controlled manipulation of spins of the conduction carriers in semiconductor heterostructures, which is needed for realizing future spin devices. Future spin devices will utilize not only the properties of electron charges (as with conventional electronic devices) but also those of electron spin to achieve new device functionalities that have never been realized with conventional devices. In the present work, we use anti-weak-localization analysis to quantitatively analyze the zero-field spin-splitting energies (denoted by $\Delta_s$) that are observed in InAlAs/InGaAs/InAlAs quantum wells. We found that the value of $\Delta_s$ becomes larger as the degree of structural inversion asymmetry (SIA) for the InGaAs quantum well becomes larger. This prediction 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 in the InGaAs quantum wells by growing a series of different samples (by MOVCD) with different impurity densities in the carrier supplying layer (denoted by $n^+$), which is located below the quantum well, while keeping all the other structural parameters constant among these samples. Here, the values of $n^+$ are varied from $4 \times 10^{11}$ cm$^{-2}$ (the least asymmetric quantum well) to $1 \times 10^{10}$ 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 $\Delta_n$ values. Finally, the experimental results are compared with the theoretically predicted values of $\Delta_n$, the zero-field spin-splitting energy due to the Rashba spin-orbit interaction, in order to understand the observed $\Delta_n$ values quantitatively for future device applications.

This research work is supported by the NEDO International Joint Research Grant Program.

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

8:30 AM #F4.1 PHASE SEPARATION AT INTERFACES IN $La_2Cu$_3Mn$_3$O$_8$ THIN FILMS. J. Fontcuberta, M. Bilbao, L. Ballells, B. Martinez, Institute de Ciencia de Materiales de Barcelona, SPAIN; M. Wojcik, E. Jedryczyn, S. Niazi, Institute of Physics, Polish Academy of Sciences, POLAND.

Spin devices and particularly tunnel junctions based on magnetites, 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 cannot be easily operated at high temperature. Although it has been shown that the magnetic properties of films/ferromagnetic) vacuum differ from those of bulk, no much information is available to the nature of the insulator/film ferromagnetic interfaces and what is their role on the magnetotransport properties. In this paper we shall prove evidence that close to interfaces with the substrate, the magnetite films, here illustrated by the particular case of $La_2Cu$_3Mn$_3$O$_8$ are not longer homogeneous ferromagnetic and metallic but a nanoscopic phase segregation takes place. The magnetotransport data here reported, for thin films grown on a variety of single crystalline substrates ($SrTiO_3$, LaxSr$_{1-x}$O$_2$, NiGa$_2$O$_4$), conclusively show that 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 ($>10t_d$) into the film. Detailed analysis of the magnetotransport properties as well as information gained from a microscopic magnetic probe ($^{55}$Mn-NMR) unambiguously reveals the presence of complex phase segregation triggered by interface effects.

We shall argue that these effects could be at the origin of the discouragingly poor magnetoresistance in magnetic 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. Scopelliti, Maxim P. Nikiforov, Joy A. Switzer, Graduate Research Laboratory of Chemistry, University of Missouri-Rolla, Rolla, MO; Simon A. Motton, G. Dan Wohll,"Graduate Center for Materials Research and Department of Physics, University of Missouri-Rolla, Rolla, MO.

Epitaxial Fe$_3$O$_4$ 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 0.01 M potassium acetate and 0.01 M ferrous ammonium sulphate by applying anodic current density of 0.05 mA/cm$^2$ at 90°C in an O$_2$ free environment. On Au(110), Fe$_3$O$_4$ grows with a [110] out-of-plane orientation, with the in-plane orientation aligned with the Au(110) substrate. On Au(111), the Fe$_3$O$_4$ grows with a [111] out-of-plane orientation, but the in-plane orientation is twinned, with both parallel and antiparallel oriented domains. On Au(100), a [110] out-of-plane orientation is observed. The Fe$_3$O$_4$ (100) is aligned with the Au(100) substrate, but 3 equivalent in-plane orientations of Fe$_3$O$_4$ (111) are observed. Both x-ray absorption spectra of the Fe L$_2$, L$_3$ and O K edge and magnetic x-ray circular dichroism measurements are consistent with spectra for bulk Fe$_3$O$_4$ previously reported in the literature.

9:15 AM F4.3 THE USE OF NiMnSb HEUSLER ALLOY IN NiMHE GROWN TUNNEL JUNCTIONS. Stéphane Andrieu, Pascal Turban, Bertrand Kerrien, Lab. de Physique des Matériaux, CNRS / Univ H. Poincaré, Nancy, FRANCE; Alberto Tagliferri, Cléline De Nardin, Nike Brockes, ESRF, Grenoble, FRANCE.

NiMnSb is a material of significant interest for magnetotransport and spin-polarized transport applications due to its predicted halfmetallic behavior. Up to now, the transport measurement performed on spin valves and magnetic tunnel junctions including the NiMnSb alloy demonstrate only poor spin polarization. This behavior was attributed to interfacial and/or experimental crystalline quality. In order to clarify the situation, we have studied high quality single-crystalline NiMnSb thin films grown by molecular beam epitaxy. The influence of growth conditions on crystalline quality was studied by HRTEM and STM. The structural quality of the films was investigated by X-ray diffraction, EXAFS and HRFM. For the optimized growth conditions, the expected NiMnSb C1b structure was observed.

Moreover, the most stable and smooth surface was found to be the 4d reconstructed. The magnetic properties were studied by XEDS, A Cu-aspectmeter and X-ray magnetic circular dichroism. The magnetization was observed to be equal to 3.9 and 0.2 Bohr magnetons per site and Ni magnetic moments agreement with the theoretical calculated values. Moreover, spin-resolved X-ray photoemission spectroscopy experiments were performed at ESRF on the 1D8 beamline. A polarization of at least 50% at room temperature was observed on unreconstructed surface. Finally, we show that fully epitaxial NiMnSb/MgO/NiMnSb(001) and NiMnSb/MgO/Fe(001) trilayers can be prepared. Magnetoresistance experiments performed on both systems will be presented.

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

A systematic study of electroweakness (EW) effects is conducted for thin films of mixed-valent Manganese oxide (MnO$_2$), for which the electric field effect geometry with ferroelectric or dielectric gases. A polycrystalline large DE of $>75$ % at 4K can be observed in the thin film. A broad range of electric field induced phase transitions is observed, including ferroelectric and magnetic field-induced phase transitions. In the thin film, the electric field induces a new phase transition, which is a consequence of the electric field-induced phase transition in the bulk.

10:15 AM #F4.5 GROWTH AND PROPERTIES OF HALFMETALLIC CRYSTALINE THIN FILMS AND HETEROSTRUCTURES. A. Gupta, IBM T.J. Watson Research Center, Yorktown Heights, NY; A. Anguelov, G. Xiao, Dept of Physics, Brown University, Providence, RI.

Band structure calculations have shown that the well-known magnetic oxide material chromium dioxide (Cr$_2$O$_3$) 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 Cr$_2$O$_3$, providing a spin polarization as high as 95% at low temperatures. Since Cr$_2$O$_3$ 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 films of Cr$_2$O$_3$. They are grown at 400°C on (100)-oriented single crystal TiO$_2$ substrates using either CrO$_3$ or Cr$_2$O$_3$Cl as a precursor, and oxygen as a carrier gas. Films grown using Cr$_2$O$_3$Cl are stoichiometrically smooth with a roughness of less than 5 Å for a 100 Å thick film. The Cr$_2$O$_3$ film exhibits a metallic behavior. The magnetic and resistivity is anisotropic in the plane with a small change in slope around the Curie temperature. A sharp magnetic transition is observed for the films, with a Curie temperature of 380 K. The value of the saturation magnetization at low temperatures is $-500\mu_0$ emu/cm$^3$, corresponding closely to the full theoretical moment of $2 \mu_0$ per Cr ion observed in the bulk. The resistivity and magnetic hysteresis loops are significantly influenced by the strain in the films. We have fabricated tunnel junctions using epitaxial Cr$_2$O$_3$ grown as one of the ferromagnetic electrode and polycrystalline Co as the counter electrode material. In situ growth of heteroepitaxial tunnel junction structures of Cr$_2$O$_3$ with barrier layers such as TiO$_2$ is being investigated.

10:45 AM F4.6 MORPHOLOGY OF MANGANESE PLD THIN FILMS DESIGNED BY THE THORNTON'S ZONE MODEL. Anna Marie Haghiri-Gosnet, Mohamed Kooheian, IEF, Univ Paris Sud, Orsay, FRANCE.
Double perovskites have attracted a fair amount of attention due to the high values of transition temperature, which make them interesting for possible spintronic applications. By combining dynamical mean field theory (DMFT) with a tight binding parametrization of the underlying band structure, we have calculated $T_c$ and optical conductivity and determined the conditions for optimizing the transition temperature.

SESSION 5: CURRENT-INDUCED MAGNETIC SWITCHING
Chair: Jack Bass
Tuesday Afternoon, November 27, 2001
Room 207 (Hynes)

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

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

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

The magnetic moment of a ferromagnetic layer can be reversed by a spin-transfer current from a spin-polarized current (i.e., without using 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 Co/Pt/Cu nanopillars in which we find that a positive current switches the magnetic configuration from AP to P whereas a negative current switches from P to AP. This asymmetry is the signature of reversal by spin injection. The required current density is about $10^{10} \text{A/cm}^2$. We will also show the variation of the critical current with the applied magnetic field. In fact, this study is of interest to decide between the different theoretical approaches as they predict quite different field dependence of the switching current. Our interpretation is based on the dynamical approach of Slonczewski with a calculation of the current polarization in a standard model of the CPP-GMR. We show how the spin polarization in Slonczewski's equations is influenced by the thickness of the layer and the spin diffusion lengths in the magnetic and the nonmagnetic layers. Optimizing the parameters of the samples, the critical currents can certainly be reduced and be of interest for application to the switching of submicron magnetic devices.

9:30 AM #F4.9
DEPENDANCE OF MAGNETIC SWITCHING ASTRID

Rachel Desfau, LIPIC, Univ d’Artois, Lens, FRANCE; Philippe Lecoeur, Wilfried Pfeiffer, Bernard Mercey, CRISMAT, ISMRA, Cen, FRANCE.

The morphology and the microstructure of pulsed laser deposited (PLD) La$_2$Sr$_{1-x}$MnO$_{3}$ (LSMO) films are shown to follow the predictions of the model proposed by Thornton[1] for the epitaxial growth. 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 oxygen pressure $P_{O_2}$ and the deposition temperature $T$. At large D values (D $\approx$ 85 mm) and high pressures $P_{O_2}$, $P_{O_2}$ = 0.5 mbar) and for a fixed temperature of 600°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 large D values. At a temperature of 350°C, shifts the Zone I/Zone II transition towards higher pressures ( $P_{O_2}$ = 0.1 mbar), the film exhibits a dense Zone II structure, which is associated with an exceptional surface flatness (Rms $\approx$ 0.1 nm). The surface is very clean and free of any defects (noodles, inclusions and droplets). An increase of T of about 300°C shifts the Zone I/Zone II transition towards higher pressures ( $P_{O_2}$ = 0.1 mbar) in agreement with Thornton’s model. Finally, the role of each PLD parameter (T, D and $P_{O_2}$) on the magnetic properties of the obtained LSMO films will be discussed in correlation with the morphology.[1] J.A. Thornton, J.VST 1, 666 (1974)
SESSION F6: IN-ROOM POSTER SESSION
Chair: Robert A. Behrens
Tuesday Afternoon, November 27, 2001
4:00 PM
Room 207 (Hynes)

F6.1 GROWTH AND PROPERTIES OF ORIENTED HEUSLER ALLOY FILMS/MULTILAYERS BY PULSED LASER DEPOSITION.
I.V. Sarel, V. Craciunescu, M. Vambruck, 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$_2$Ni$_3$Ga and the halfmetallic Co$_2$Ge$_3$ (001) films 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. Suck, NRL). This work is supported by Office of Naval Research.

F6.2 MECHANISMS OF ELECTRONIC TRANSPORT IN ARTIFICIAL GRAIN BOUNDARY DEVICES MADE FROM CMR FILMS.
A.K. Raychaudhuri, Mandar Paranjape, Department of Physics, Indian Institute of Science, Bangalore, INDIA; N. Khare, National Physical Laboratory, New Delhi, INDIA.

Magnetic field sensors based on artificial grain boundary junctions of Cobaltite/Resistive Materials a viable device in the field of spintronics. The mechanism of grain boundary conduction in zero field as well as applied magnetic field is a subject of current research. In this work we have studied the growth of single-crystal boundary junctions fabricated on bicrystal substrate depositing epitaxial film of Co$_2$Mn$_2$O$_4$ material (primarily LBO). The study consists of non-linear transport characteristics for 4 K-400 K in a field of 0.1 T. In addition we have studied the junction using STM technique and Scanning Tunneling Potentiometry (STP). The STP technique allows us to study potential drops in nanometer scale and it shows the extent of 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 temperature. 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.
Oxide-based Ti$_2$Co$_2$O$_7$ 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. Zinn, W.B. Hurwitz-Carter, S.L. Sneath, HRL Laboratories LLC, Malibu, CA; T.F. Bogess, 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 Dynakno-Perel spin relaxation mechanism is suppressed or absent in this orientation for 2-D systems. We are currently engaged in the growth of 6.1 heterostructures on InAs (110) oriented substrates and have noted interesting differences in the growth behavior between the (100) and (110) orientations with respect to group V dependence and antimonide on arsenide terminated interfaces. We will discuss the results of in situ RHEED, photomission spectroscopy, 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**

Moscovici, M. and Walter H.L. Lambrecht, Department of Physics, Case Western Reserve University, Cleveland, OH.

It has been argued that wide band gap semiconductors have possibly an advantage over traditional III-V 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-$\text{SiC}$ with either a $\text{Si}$ or a $\text{C}$ substituted by a 3d transition metal $\text{Sr}-\text{Zn}$. Only the neutral charge state is investigated. Spin-polarized and non-spin-polarized total energies are compared. For the systems with a non-zero magnetic moment, we also investigate supercells containing two adjacent TM atoms in either the ferro or antiferromagnetic alignment. We find that the 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 interactions between neighboring impurities. Electronic densities of states are used to analyze the results. Supported by ONR under grant No. N00014-96-1-0723.

**KINETIC EXCHANGE VS ROOM TEMPERATURE FERROMAGNETISM IN DILUTED MAGNETIC SEMICONDUCTORS**

J. Blinovski, P. Kruusmaa, and T. Dietl, Institute of Theoretical Physics, Warsaw University, Warsaw, 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 $\text{Ga}_x\text{Mn}_y\text{N}$ and $\text{Zn}_x\text{Mn}_y\text{O}$, 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 which is not possible for $p$-type materials. 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 exchange rule and the known band effects, we first discuss the feasibility of obtaining III-V and IV-IVDMS with $p$-type conductivity, required for the carrier induced ferromagnetism. Then, we consider the dependence of kinetic exchange on the $p$-$d$ hybridization, on the electronic configurations of the magnetic ions, and on the energies of the charge transfer between the valence band of host materials and the magnetic ions. The results of this analysis indicate that in the III-V host compounds only the $\text{Mn}$ ions seem to allow for the $p$-type, but with the $\alpha$-oxidation. In some III-V compounds this is possible, either with or without co-doping, also for Fe and Co ions. We show that the prospects of room temperature ferromagnetism in III-V DMS with $\text{Mn}$ ions depend on the charge state of these ions and that for $\text{Fe}$- or $\text{Co}$-based III-V DMS with strong $p$-type hybridization lock very promising.

**SESSION F7: NEW TECHNOLOGIES, NEW EFFECTS, SILICON INTEGRATION**

Chair: Timothy J. Klemmer
Wednesday, November 28, 2001
Room 207 (Hyatt)

8:30 AM **FP.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 mean and improvement in the uniformity of the 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 magnetic recording media and to push out areal density, one generally seeks to enhance the media insensitivity. However, smaller magnetically harder grains also require enhanced write fields and the thermal stability problem essentially becomes a write field problem. Proponents of this structure claim a route to high density based on the fact that the write field is perpendicular recording, in which a single pole write head is combined with a double layer hard/soft magnetic medium. The presence of the soft magnetic layer permits flux closure directly through the recording layer enabling enhanced fields and sharper cross track gradients. Such media have been developed recently and record areal densities in the 60 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 $\approx 10,000$ Oe. Another important approach is hybrid recording, where the write field is temporally reduced via thermal heating [2]. Finally, patterned media are considered as a means to lower media noise by lithographic definition of the recording transitions, hence enabling recording with fewer grains per bit. Ultimate recording densities in the 20-50 Tbitps are conceivable in self-organized magnetic array patterned media [3], [4]. H. Takano et al. “A practical approach for realizing high-recording density hard disk drives”, paper CA-01, MMM/Intermag 2001, San Antonio, TX, January 7-11 [3]. M. Alex et al., paper HC-01 and H. Sidorenko et al., paper AA-05, MMM/Intermag 2001, San Antonio, TX, January 7-11 [3], S. San et al., Science 287, March 2000, pp. 1889-1892.

9:00 AM F7.2 PROPOSAL OF A NOVEL SPIN FILTER REALIZED IN A TRIPLE BARRIERS RESONANT TUNNEL DIODE USING RASHBA SPIN-ORBIT INTERACTION. T. Koga, T. Nitta, NTT Corporation, NTT Basic Research Laboratories, Atsugi-city, Kanagawa, JAPAN; S. Doan, Purdue University, School of Electrical and Computer Engineering, West Lafayette, IN; H. Takayama, 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 electronic charge, and not those of the spins. In the present work, we propose a novel spin filter that utilizes the Rashba spin-orbit interaction in InAs/InGaAs/InAlAs triple barrier resonant tunnel diode (RTD). This spin filter makes use of spin-dependent resonant states that are formed in the triple barrier structures. We find that, for certain source-drain voltages, it is possible to engineer the RTD in a way that a resonant level formed between the first and second barriers in the RTD matches that formed between the second and third barriers only for a selected spin state, thus realizing an electronic spin filter. The calculation of the spin polarization of the transmitted current through the device, as defined by $P_{\uparrow} = \frac{I_{\uparrow} - I_{\downarrow}}{I_{\uparrow} + I_{\downarrow}}$, where $I_{\uparrow}$ and $I_{\downarrow}$ 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.


The properties of the [Ga,Gd]O$_{2n}$ system have been examined for ultrathin spin-dependent tunnel barrier applications. Structures of type FM/MT/SC and FM/MT/SC have been fabricated, where FM denotes a ferromagnetic material, T an insulator, and SC a semiconductor. Semiconductors include GaAs, InAs, and GaN. Ultrahigh vacuum fabrication techniques allow nearly contamination-free interfaces to be formed. Effective band offsets and layer lattice matching have been achieved, and high-quality epitaxial layers have been grown. The device was measured using a magnetic force microscope (PFM), x < 0.3 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 Stokking parameter analysis of the current-voltage characteristics. It is found that these films are highly suitable for tunnel barrier devices.

9:30 AM F7.4 SPIN VALVE EFFECT IN MAGNETIC RESONANT TUNNELING DEVICES. D.O. Demchenko, A.N. Chetverikov, A.G. Pustylkov, Dept of Physics, South Dakota School of Mines and Technology, Rapid City, SD.

We propose a new electronic device utilizing resonant tunneling between two magnetic materials. The device is comprised of a semiconductor quantum well sandwiched between two insulating barriers and ferromagnetic leads. At certain geometries and material parameters, this structure exhibits a strong spin valve effect leading to a great enhancement of magnetoresistance. New ferromagnetic semiconductors such as GaMnAs or its analogs are suitable materials to form the devices described in question. As an example, we consider resonant tunneling of holes in GaMnAs/GaAs/GaMnAs/GaAs double-barrier heterostructures. Our calculations of tunneling conductance for parallel and anti-parallel alignment of magnetizations in the leads demonstrate that at certain thicknesses 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.


We report on spin properties of 2D electron gases (2DEG) in the strained Si and SiGe quantum wells of modulation-doped Si/Ge heterostructures. In a standard electron spin resonance (ESR) set-up, conduction electron spin resonance exhibits a strong spin valve effect. Absorption lines with line widths as narrow as 30 mG as a g-factor close to 2. Both microwave saturation and spin echo experiments were conducted to extract the spin coherence and spin life times. In the best samples we found spin coherence times of several micro seconds, which is 3 - 4 orders of magnitude larger than in most III-V semiconductors. Thus, electrons in Si, which are known to experience extremely weak spin-orbit interaction, appear to be well suited for the investigation of quantum computing concepts. A possible scheme employs ESR to induce controlled spin flip operations. By utilizing a quantum well structure consisting of two materials with different g-factor, ESR spin flips can be switched on and off by moving the electron wave functions from one layer to the other, by applying a gate voltage. Since the g-factors in Si (2.00) and Ge (1.54) differ significantly, g-factor tuning will become possible by changing the composition. To test the feasibility of this concept we performed CESR experiments on strained, n-type modulation-doped Si(1-x)Ge(x) quantum wells with $x \leq 10\%$. The experiments show a systematic decrease of the g-factor with composition. Given the narrow line width, a change in the ESR signal (range of x from 0 to 0.20 or lattice 5% would be sufficient to shift the 2DEG out of resonance. Such a structure can easily be implemented with standard Si technologies, which is a further strong motivation for considering Si-based heterostructures for spin devices.

10:30 AM F7.6 MAGNETIC SPIN PROPERTIES OF SPUTTER-DEPOSITED CO FILMS INVESTIGATED USING DIFFUSE-SCOTT-X-RAY HYSTERESIS. B.M. Burns, Mark Friesen, J.J. Kelly IV, D.E. Swange, 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 ultra-thin sputter-deposited films. With soft-x-ray scattering using a tunable source of x-rays, 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 allow fluctuating spins; however, it is hard to interpret the spectrum modulated by the disorder which 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 spectrum. The investigations between morphology and magnetic anisotropy, we vary parameters of this base system to produce changes in the nature of interfacial
magnetic properties. These changes include additions of capping layers, increases in sputter pressure, and ion-etching of Cu buffer layers. Behavior of magnetic spins at the interface are 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 SERIE and ONR. SigmaTech, Inc. is provided under NSF Grant #DMR 94-04642 [1] J.W. Freedland, K. Basman, P. Lutibiz, Y.U. Idzerda, and C-C. Kao, Appl. Phys. Lett. 73, 22922298 (1998).

10:45 AM *P7.7
REAL-TIME OBSERVATION OF REMAGNETIZATION PROCESS IN Fe$_2$O$_4$ FILMS. M. Turchinskaya, National Institute of Standard and Technology, Gaithersburg, MD; A. Royburd, Department of Chemical and Nuclear Engineering, University of Maryland, College Park, MD; A. Orozco, S.R. Shane, S.B. Ogale, and T. Venkatesan, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD.

The remagnetization process of (001) Fe$_2$O$_4$ films deposited on (001) SrTiO$_3$ substrates was studied using a magneto-optical imaging technique. The films were deposited by pulsed laser deposition technique. They were characterized by different techniques to ensure their high epitaxial quality and the expected electrical properties, including the Verwey transition. The films having thicknesses 400 and 800 nm were examined. It was found that remagnetization in 400 nm (thinner) films proceeds continuously without observation of domain structure. On the other hand, in 800 nm (thicker) films, the continuous evolution of remagnetization is interrupted by the discontinuous formation of the domain structure when the field reaches a critical value (He). Once the domains are nucleated, they spread throughout the sample with a slight change in applied field. At a field slightly higher than He, the magnetization again becomes uniform. This discontinuous change of the magnetization with field results in the appearance of a steep change of magnetization in the hysteresis loop near He. For thinner films, when the field is applied along <110> direction, i.e., along the easy direction of magnetization for Fe$_3$O$_4$ film, the remagnetization 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 He. The cusp 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 growth was much faster. This work is supported under NSF-MRSEC grant no. DMR 98-03008.

11:00 AM *P7.8
MATERIALS 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, these are often called magnetic nanostructures. Although we are now capable of controlling these multilayer interfaces to sub-Angstrom precision, controlling the lateral dimensions of magnetic devices is more challenging. In this talk, I will show examples which show the tremendous advances in fabrication of magnetic devices with lateral dimensions below 100 nm. Such techniques can broadly be classified into two categories: additive and subtractive. In additive techniques, material is deposited into a previously fabricated structure. Examples of such additive techniques are sputter deposition and collimated deposition/lift-off processing. Though extremely useful for certain applications, these additive techniques are difficult for fabricating complex multilayer structures. In such structures, the fabrication process for the multilayer 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 cause a 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. Underneath this behavior is becoming increasingly important to the magnetic storage industry, in which, within five years, the majority of magnetic layers is anticipated to be less than 10 nm.

11:30 AM *P7.9
INTEGRATION OF MAGNETIC DEVICES WITH SEMICONDUCTOR CIRCUITS: PROGRESS AND CHALLENGES. Dacun Wang, James M. Doughton, NVE Corporation, Eden Prairie, MN.

Magnetoresistive materials are under intensive research and development of their potential high potential for commercial 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 a more complex design and fabrication process and there are associated yield losses in integrating magnetoresistive materials with IC electronics, there are far more significant advantages, including small size, high speed, low power, and better overall performance. Recently announced transistors with feature sizes of 20 nm for chip speed of 20 GHz typify the continued progress in semiconductor IC technologies. On the magnetic side, GMR materials are being applied commercially in discrete as well as integrated forms, as soon SOT devices 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 speedy increase in MRAM density. The spin degree of freedom, in addition to the charge degree of freedom, for electrons seems to promise great potential for more advanced devices where integration is anticipated. In this presentation, magnetoeresistive materials applied to magnetic field sensors, galvanic isolators, and several types of MRAM devices integrated with underlying IC electronics are used to illustrate the achievements, promises, and the challenges in design, fabrication, and performance in this fascinating frontier.

SESSION 18: ADVANCED TECHNOLOGIES FOR MAGNETIC CHARACTERIZATION AND IMAGING
Chair: Bruce M. Clemens

Wednesday, November 28, 2001
Room 207 (Hynes)
1:30 PM *FS1.1
SEMA STUDIES OF THIN FILM MAGNETIC STRUCTURES. John Ugurakis, National Institute of Standards and Technology, Gaithersburg, MD.

Scanning Electron Microscopy with Polarization Analysis (SEMPA) a direct image of a sample's magnetization by measuring the spin polarization of secondary electrons emitted in a scanning electron microscope. With submonolayer magnetic sensitivity and probe size as small as 10 nm, SEMPA is sensitive to extremely small amounts of magnetic material; as small as 1000 Fe atoms or 10$^{17}$ emu. Perhaps more surprising, SEMPA's magnetic 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, and SEMPA provides separate, yet simultaneous, images of the magnetic and topographic structure. When combined with other magnetic force microscopy 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 mapping of magnetic structure during thin film growth and depth profiling. This talk will describe the SEMPA technique and present examples of measurement applications from thin film and multilayer magnetic systems. 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 magneto resistive effects in multilayers.

2:00 PM *FS1.2
PEEM STUDIES OF THIN FILM MICROMAGNETICS. Andreas Scholl, Lawrence Berkeley National Laboratory, CA; Christian Stamm, Hendrik Ohlking, Joachim Stöhr, Hans-Christoph Sigmann, Stanford Synchrotron Radiation Laboratory, CA; Scott Andrews, Stanford University, CA; Fritzjoh Nolting, Swiss Light Source, Switzerland.

The magnetic microstructure and the magnetic coupling to adjacent layers govern the magnetic properties of a magnetic thin film. For practical importance in many technical applications is the interface between two magnetic layers or between a magnetic and a non-magnetic layer. Phenomena such as exchange bias, giant magnetoresistance and spin injection are interface phenomena and precise knowledge of the interface spin structure and chemistry are essential for the understanding of these effects. We will show that X-ray Photoelectron Emission Microscopy (X-Peem) offers sub-monolayer magnetic sensitivity which is sufficient to detect very small spin...
concentrations at surfaces and interfaces. High spatial resolution of currently down to 50 nm and theoretically down to 1 nm, elemental and chemical specificity, and sensitivity to ferromagnetic and antiferromagnetic order make PEEM an ideal tool for the study of magnetic interface phenomena. Here we will present results on the magnetic exchange coupling in ferromagnet-antiferromagnet structures, and we will show initial experiments on spin injection in all-metallic devices. In ferromagnet/antiferromagnet samples such as Co/LaFeO₃ and Co/NO we were able to separate the contribution to the sample magnetism of the antiferromagnetic bulk of its interface. This is the key point of our interpretation of the experimental results and of the model. The relative alignment of the magnetization and its response to external magnetic fields provides important information on the origin of the exchange coupling along the interface. Together, these experiments 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 localized current. We are currently designing a new experiment sequence which will allow streak-method measurements, a synchronized x-ray巡热in the setup. We expect to achieve 50 ps time resolution at the full spatial resolution of the microscope, opening new ways of studying dynamic magnetic processes. This work was supported by the Director, Office of Basic Energy Sciences, of the US Department of Energy.


Many materials have been predicted to be half-metallic ferromagnets, yet despite extensive study, remarkably little truly compelling evidence for half metallic behavior has emerged. One technique that can potentially yield a definitive answer to the question of half metallic character is spin-polarized photoemission and it is from this technique that the strongest evidence to date has emerged [1]. Using the spin-resolving photoelectron spectrometer at the Spectromicroscopy Facility [Beamline 7.0] at the Advanced Light Source [2], we have found evidence for half-metallic behavior in thin films of magnetite. Thin films of magnetite hold out the possibility of use in devices as pure spin sources. Because our spin resolving experiments are performed at higher photon energies, we were able to monitor the spin polarization of the Fermi energy electrons without resorting to destructive surface cleaning techniques, using the samples “as is.” Furthermore, we have demonstrated that harsh sample cleaning procedures such as ion etching causes the loss of the desired spin polarization, which may help explain the failure of other previous experiments to observe half metallic behavior. By measuring the polarization in a function of emission angle and photon energy, and combining these measurements with a substrate overlayer model, we have gained some insight into the nature of magnetite. Furthermore, our spin resolved spectra demonstrate close agreement with simulated spectra derived from theoretical one electron density of states calculations in the case of the Znrich compound Yb14Mn14.8Fe11. X-Ray Magnetic Circular Dichroism was used to demonstrate that the Mn was the dominant contributor to the magnetic moment, possessing a magnetic moment on the scale of 5 Bohr Magneton. This work was performed under the auspices of the U.S. Department of Energy at the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48. Most of the experiments were carried out at the Spectromicroscopy Facility [Beamline 7.0] at the Advanced Light Source, built and supported by the U.S. Department of Energy.


3:15 P.M. F8.4 INFLUENCE OF ROUGHNESS ON MAGNETIC INTERFACIAL PROPERTIES. J.J. Kelly IV, B.M. Barnes, D.E. Savage, M. Friesen, M.G. Lagally, Dept. of Materials Science, University of Wisconsin-Madison, Madison, WI.

New applications in magneto-electronics and thin magnetic films require detailed knowledge about the nature of magnetism at surfaces and interfaces at the sub-micrometer level. The influence of surface and interface morphology, both chemical and magnetic, on spin-dependent electron scattering, and thus on the performance of spintronic devices is a critically important research question. Diffusive x-ray resonant magnetic scattering (DXRMS), a unique element-specific method that provides information on both the chemical and magnetic morphology at surfaces and interfaces, shows evidence for a disordered magnetic layer at the interface between magnetic and non-magnetic materials. 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, heated to 100oC, and then deliberately roughened. We discuss trends in the nature of the disordered layer and in the magnetic and chemical roughness and describe a model for the magnetic interface consistent with all data. Supported by NSF and ONR. Support for the SRC is provided by NSF under grant number DMR-0084492 [1].


3:30 P.M. F8.5 OCCUPIED AND UNOCCUPIED METALLIC QUANTUM WELL (MQW) STATES IN THE Cu/ferM/Cu(100) (MeNi, Fe) SYSTEMS, X-ray Magnetic Circular Dichroism and Angle Resolved Photoemission Spectroscopy. A. Garden, G. Dinnef, Robert A. Mathies, University of California, Davis, CA.

Multilayer structures composed of alternating ferromagnetic (FM) and nonmagnetic (NM) layers are known to exhibit Giant Magneto Resistance (GMR), an effect whereby a large change in the multilayer resistance occurs as a function of magnetic field. These multilayers have been applied to magnetic storage and sensing technologies, and this has sparked a great deal of interest in understanding these systems at a fundamental level. We have studied the Magnetic Quantum Well (MQW) electronic structure of the prototypical NM/FM/NM systems, Cu/ferM/Cu(100) [M=Ni, Fe], using angle resolved photoemission (ARPES) and inverse photoemission (IPE) along the Fermi surface of these multilayers. Additionally, we have also used a phase accumulation model (PAM) to calculate the dispersions of MQW electronic states along this line. The PAM predicts that the MQW states will have a high effective mass only when they lie in the energy and momentum region of the projected spin polarized band gap of the underlying magnetic material. We have observed two states of high effective mass, observed using IPE on the Cu/ferM/Cu(100) system, one inside the Ni band gap and one near the edge, and another state was suggested above the band gap using IPE in good qualitative agreement with the PAM. Numerous MQW states were seen using IPE on Cu/ferM/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/ferM/Cu(100) and PE of Cu/ferM/Cu(100), our IPE data for Cu/ferM/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 data. 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 domain 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 sub-micron 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 mapped out the field dependence of the first order spin-flip transition near 120 K directly and found that it is broadened in temperature by several degrees even at the micron scale. This inherently quantitative technique connects the phenomena occurring at the single domain scale to anomalies in transport and magnetization measurements.

SESSION E9: IN-ROOM POSTER SESSION

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

F9.1 OPTICAL AND TRANSPORT STUDIES OF IMPURITY STATES IN MS-DOPED GaAs Epilayers. M. Friesen, G. Ito, C. Roester,
We have carried out optical and transport studies of Mn-doped GaAs epilayers. The Mn concentration was kept below 0.005% and all samples are paramagnetic. The low Mn concentration used in this study allows high temperature growth at 850°C, instead of the low temperature growth that is normally used for GaAs alloys to avoid the formation of MnAs precipitates (usually below 300°C). In this study, we have focused on the behavior of Mn-related acceptor states as a function of Mn concentration. As the Mn concentration increases, the samples become metallic, with the highest hole concentration up to 2.5 x 10^{12} cm^{-3}. As the Mn concentration increases, the conduction band to acceptor state transition at 11,400 cm^{-1} (as observed in the photoluminescence spectra from low concentration samples) evolves into a broad band that extends to energies of GaAs band gap. This observation suggests that isolated Mn acceptor states evolve into an impurity band, extending into the valence band. This is supported by the results of photoconductivity measurements, which exhibit a broadening of the absorption edge of GaAs with increasing Mn concentration. The transport measurements show a slight decrease of sheet resistivity with increasing temperature for all metallic samples that also exhibit a negative magnetoresistance at low magnetic field. At higher magnetic fields, the magnetoresistance becomes positive. The negative magnetoresistance decreases with increasing temperature and vanishes around 100 K.

**P9.2**


The magnetic and structural properties of Mn, Fe and Ni implanted into GaN, SiC and GaP have been studied using various techniques. The effects of implantation on the magnetic properties of these materials have been assessed by measuring the magnetic moment as a function of temperature and magnetic field. The results show that the magnetic ordering temperature is significantly reduced compared to bulk materials.

**P9.3**

**Characteristics of Molecular Beam Epitaxy-Grown GaAs.** J.Y. Park, H.T. Oh, E.K. Kim, Semiconductor Lab, Korea Institute of Science and Technology, Seoul, Korea, S. Park, J.Y. Cho, Dept. of Physics, Dongguk Univ. Korea, R. Moon, H. Min, Dept. of Physics, Institute of Technology, Japan.

Doped magnetic semiconductors Ga_{1-x}Fe_{x}As were grown by molecular beam epitaxy and characterized. Ga_{1-x}Fe_{x}As ternary alloys were obtained at growth temperature T = 800°C ranging from x = 0.05 to 0.03. In order to investigate the magnetic properties of the sample, electron paramagnetic resonance, magnetic force microscopy and superconducting quantum interference devices (SQUIDs) were employed. The effects of disorder on the magnetic behavior of these samples were studied. The results indicate that the magnetic moment decreases with increasing Fe concentration. In contrast, the superconducting critical temperature increases with increasing Fe concentration. The results are consistent with theoretical predictions that magnetic impurities can affect the magnetic behavior of these materials.

**P9.4**

**Ferromagnetism in GaN and AlN-Based Diluted Magnetic Semiconductors.** Takeshi Tanimura, Shinsuke Tani, Jun-ichi Yoshida, Inst. of Scientific and Industrial Research, Osaka Univ., Uehara, Japan.

Since the discovery of the carrier-induced ferromagnetism in InMnAs and (Ga,In)MnAs magnetic semiconductor devices (DMSs) have been of much interest from the industrial viewpoint because of their potentiality as a new functional material which will open a way to introduce the freedom of spin into semiconductor devices. In this paper, the magnetism in GaN and AlN-based DMSs is investigated based on the first principles calculations and material design of ferromagnetic DMSs is proposed. GaN and AlN have wide band gap energy of 3.43 and 6.2 eV, respectively, and have been the most promising materials for the formation of diluted magnetic semiconductors (DMSs). The band gap can be tuned by adding a Group-III element, such as Mg or In, to GaN or AlN. In this study, the electronic states of the ferromagnetic GaN and AlN are calculated using the DFT (density functional theory) method combined with the coherent potential approximation (CPA). The results show that the ferromagnetic states are stable in GaN and AlN-based DMSs, and the magnetic moments are about 2μ_0 per Mn atom. This indicates that GaN and AlN-based DMSs are good candidates for magnetic DMSs.
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 large 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 transmission provides a mechanism for the applied current density to drive electrons out of quasi-thermal equilibrium at the contact/semiconductor interface and can significantly enhance spin injection.

An insulating tunnel barrier with a spin-polarized contact has spin dependent interface resistance because of the difference in Fermi wave vectors for the two spin types in the contact material. A ferromagnetic insulator tunnel barrier can also have spin dependent interface resistance. We describe calculations of spin injection for a variety of tunneling barriers and semiconductors to investigate the properties that are required for significant spin injection.

P9.0

MAGNETIC ANISOTROPY OF STRAINED La0.6Sr0.4MnO3 THIN FILMS STUDIED BY MOKE. Mohamed Kanoun, Anne-Marie Haghiri-Gosnet, Unives Paris-Sud, Orsay, FRANCE; Wilfried Prellier, Philippe Lecouur, Bernard Mercier, CRISMAT, ISMRA, Caen, FRANCE.

Magnetic anisotropy of (001) strained La0.6Sr0.4MnO3 films has been studied using Magneto Optical Kerr Effect (MOKE) as a function of pulsed laser deposition (PLD) parameters, i.e. the temperature T, the target-substrate distance D and the oxygen pressure P0. On SrTiO3 substrates, substrate stress induces a magnetic anisotropy different from that in a film of comparable thickness grown on LaAlO3, but the orientation of the easy axis is seen along the [001] or the [110] direction of the pseudocubic unit cell, depending on the authors [1,2]. The value of D is relevant for magnetic anisotropy: at a small distance D, [110] axis is found to be clearly easier than the [001] one, although, at large distance D values, both [001] and [110] directions are equivalent. The optimal D value (D = 45 mm for P0 = 300 mTorr) produces films with very low roughness (Rrms = 0.1 nm) compared to a minimum value of the saturated magnetization [3]. It is also shown that remanent magnetisation increases with pressure for the optimal value (P0 = 300 mTorr), hysteresis loops are perfectly square along the [100] direction [4 C6 G, K = 1.0 10^4 erg/cm^3]. In compressive films grown on LaAlO3, for optimal PLD conditions, the perpendicular [001] direction is a hard axis and, in the plane, the easy direction lies along the [100] axis [5 C4 H, K = 7.2 10^4 erg/cm^3]. The presence of an in-plane anisotropy [2] at RT will be discussed from PLD parameters [3,4].

L.M. Berndt et al, APL 77, 2980 (2000)
F. Tsui et al, APL 76, 2421 (2000)

P9.10

OXYGEN ISOTOPE EFFECTS ON THE LOCAL STRUCTURE DISTORTIONS AND TRANSPORT PROPERTIES OF EPITAXIAL THIN FILMS OF Nd0.6Sr0.4MnO3, R.P. Sharma, D.J. Kang, R. Marcini, M. Rajewski, S.B. Ogale, H.D. Drew, R.L. Greene and V. Venkataraman, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD, O. Zelinski, Zurich, Switzerland.

Detailed investigation of inherent lattice fluctuations and electrical transport are made in oxygen isotope substituted Nd0.6Sr0.4MnO3 thin films. Ion channeling measurements have clearly shown an increase in the rms displacement of the Mn atoms as the sample goes from the ferromagnetic to the paramagnetic state. The increase in the displacement is much larger than the phonon background over the same temperature range around 200 K. The observed anomaly is about 1 0% larger for 18O than for 16O 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 region the oxygen isotope effect of the 18O samples is higher than the 16O samples by about 10%. Also the 18O samples have a sharper resistivity drop below Tc than the 16O samples. These features will be discussed in terms of the development of Jahn-Teller small polarons as the system approaches the paramagnetic state.

P9.11

CRITICAL MAGNETISM OF THE CMR RUTLEDEN-POPPER MATERIALS AND ANISOTROPIC CONDUCTIVITY. Jean-Pierre Renard, Claire Revcolevsch, Laboratoire de Physico-Chimie de Très Haute, Université de Paris-Sud, Orsay, FRANCE; Claire Dupas, Institut d’electronique Fondamentale, Département MMS, Université Paris-Sud, Orsay, FRANCE.

Rudolstadt-Popper layered compounds, of formula La2SrCu4O8, offer the opportunity to explore bidimensional magnetism in the manganites family. In order to investigate the intrinsic and anisotropic character of their physical properties, we have carried out careful and systematic single crystal growth experiments. High quality centimeter size single crystals of La2SrCu4O8 were successfully grown using a floating zone method associated with an [1]. These single crystals were characterized by means of X-ray and neutron diffraction, as well as high-resolution transmission electron microscopy. In our presentation, we shall bring up a thorough investigation [2] of the critical behaviour of La2SrCu4O8, through static magnetization and susceptibility measurements, including the determination of the fundamental characteristics of a system magnetic anisotropy, critical exponents and crossovers in the vicinity of the Curie temperature. TC 183 K, La2SrCu4O8, is a two-dimensional Heisenberg ferromagnet with notable deviations from this ideal model: firstly, the XY anisotropy stemming from the competition between spin-orbit coupling and dipolar interactions (anisotropy field of about 132 mT at low temperature), secondly, the three-dimensional couplings between perovskite bilayer blocks. These deviations successively induce spin dimensional crossover at Tc 157 K, and a lattice one at T1 117 K. The slow development of the two-dimensional ferromagnetic correlations above Tc, and our quantitative measurements [critical exponents delta=3.3(1) and Bc=1.4 in the vicinity of Tc], lead us to believe that the ferromagnetic transition in La2SrCu4O8 is essentially of three-dimensional nature. Intrinsically related with ferromagnetism is an insulator-metal transition at Tm 138 K, and a negative magnetoresistance maximum effect [Bc=3(1)][110], typical of induced three-dimensional homologs, as one can expect from its critical behaviour. [1] M. Velinges, C. Hau, B. Henning and A. Revcolevsch, J. Cryst. Growth, 220 (2000) 487 [2] M. Velinges, A. Revcolevsch, J.P. Renard and C. Dupas, submitted to Eur. Phys. J. B (2001).

SESSION 10: STRUCTURES WITH SUPERCONDUCTORS AND NANOSTRUCTURED SYSTEMS

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

8:30 AM P10.1

TOWARDS A SUPERCONDUCTING SPIN SWITCH. A. Basov, R. Bocquard, M. Hasselberg and J. Appel, Kamerlingh Onnes Laboratory, Leiden University, THE NETHERLANDS.

It was recently demonstrated that junctions of two superconducting banks (S) with a weak ferromagnet (F) in between can sustain a supercurrent; the behavior of such junctions suggests that for certain temperatures and F-layer thicknesses there is a phase difference between the banks that can be controlled in the μm range. The μm is a manifestation of an inhomogeneous order parameter in, and induced by, the ferromagnet, the so-called Larkin-Ovchinnikov-Fulde-Ferrell (LOFF) state. Using this state it should be possible to...
fabricate a superconducting spin switch, consisting of an F/S/F structure with both F-layers thickness-tuned to sustain a L0FF-state. By tuning the strength of the magnetic field present at each other should then influence the superconducting transition temperature of the s-layer. We have investigated the proximity effects in multilayers of Nb/Co/Ni, with A between 0.5 and 0.7. We show that for the lowest A concentrations the conditions for such a device with respect to interface transparency and s-layer critical thickness are met. [1] V. Ryndovsk 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; I. Turek, Institute of Physics of Materials, Brno, CZECH REPUBLIC.

Andrew reflection at an interface between a ferromagnet (FM) and a superconductor (S) has become an attractive technique to measure the spin polarization of magnetic materials. The results of these measurements are interpreted using the so-called BTK model which was introduced almost twenty years ago which is based on a free-electron model of the conduction electrons and an interface modeled by a delta function with strength $Z$. In neglecting the complex $Z$-bands of transition metal elements, such models are known to neglect important aspects of the physics of electronic transport through interfaces; the spin-dependence of the interface transmission plays an essential role in Giant Magnetic Resistance. An additional complication is that most FM/S interfaces (such as Co/Pt or Co/Nb) are not epitaxial and the model described above is not applicable. Using a newly developed method based on the TB-LMTO method 1, we model F/M/S interfaces using large interatomic supercells, calculate entirely from first-principles the spin polarization of the transmission through FT (F and T are respectively the Fermi and the conduction bands) and by using the results to calculate the conductance above and below the superconducting transition temperature (thus, taking into account the Andrew reflection). This allows 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 Co$_2$O$_2$/Ag/YBCO JUNCTION USING FLIP-CHIP CONFIGURATION Z.Y. Chen, Amitava Biswas, S.B. Ogale, I. Takeda, J. Read, T. Venkatesan and I.L. Greene, Univ. of Maryland, Center for Superconductivity Research, College Park, MD; A. Anguelov, G. Xiao, Dept. of Physics, Brown University, Providence, RI; A. Gupta, IBM T.J. Watson Research Ct., Yorktown Heights, NY.

In our recent work [1] on the transport across a LSMO/YBCO hetero-interface, we demonstrated the suppression of the zero-bias conductance peak, associated with the spin-polarization, at the $\pi$-plane of the interface due to the spin-polarization of LSMO carriers. However, the temperature dependence of the shape of the ZBCP is not the only factor that limits the spin-polarization of LSMO film, which occurs far below the Curie temperature, raising questions about the applicability of LSMO in spintronics applications. Co$_2$O$_2$ is another transition metal oxide which has suggested to be highly spin-polarized. In this report we work on the transport study of this Co$_2$O$_2$/Ag/YBCO junction. The junction is formed by pressing a Co$_2$O$_2$ film on a Ag/YBCO junction in the flip-chip configuration using the high temperature patterning process. The transport characteristics of the Co$_2$O$_2$/Ag/YBCO junction do not reveal any ZBCP, the all way up to the $T_c$ of YBCO, 80 K. The strong suppression of ZBCP is evident in the high-temperature spin-polarization for 100% of the Co$_2$O$_2$ surface, its persistence up to the $T_c$ of YBCO indicates a good temperature stability of the spin-polarization. A comparison of the results obtained for different Co$_2$O$_2$ film thickness is also carried out with the results presented by our group in [1].


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

The methodology for characterizing thermal relaxation in magnetic systems exhibiting single domain behavior is now well established, in contrast to systems dominated by domain wall motion. However, if film thickness is scaled down to the nanoscale, 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 [x,y] were 10µm x 10 µm, 10x10 µm, and 5x5 µm, and the aspect ratio to each other should then influence the superconducting transition temperature of the s-layer. We have investigated the proximity effects in multilayers of Nb/Co/Ni, with $A$ between 0.5 and 0.7. We show that for the lowest $A$ concentrations the conditions for such a device with respect to interface transparency and s-layer critical thickness are met. [1] V. Ryndovsk et al., Phys. Rev. Lett. 86, 2427 (2001).

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

Investigations on magnetic properties of nanoscale systems have been of significant importance from fundamental and also technical viewpoints. Using electron-beam lithography, the author's group has prepared wires and dots of nanoscale magnetic systems and studied the magnetic properties systematically.

In the present talk, mainly two experiments are introduced. One is a study on magnetization reversal in wire samples from resistivity measurements. The wire sample is a series of trilayer structure, NiFe (NPs)/Co/Cu (or NiFe). The magnetization reversal at one magnetic layer causes a great change in resistance. Therefore the magnetization reversal, or domain wall propagation, has been studied from the change of resistance. The temperature dependence of the switching field is also studied.

The subject of the other study is the behavior of vortex magnetism in circular NPs dots. Using MFM observation, the existence of perpendicularly magnetized dot at the center of each dot has been confirmed. The switching field for the core magnetization is estimated from MFM observation after applying and removing an external field, and the difference of magnetization reversal process regarding to in-plane and perpendicular external field is distinguished.

10:45 AM F10.6 PARAMAGNETIC ION DOPED NANOCRYSTAL AS A VOLTAGE CONTROLLED SPIN FILTER. Al. L. Fito, M. Rosen, Naval Research Laboratory, Washington, DC; N. Ishikawa, Sh. B. Bubalo, Buffalo, NY.

We have developed a theory of spin injection through a device consisting of a paramagnetic ion doped nanocrystal (quadratic dot) as a connector between a ferromagnetic metal and a semiconductor. This system (i) controls the spin injection in a way quite similar to a tunnel contact, (ii) is completely controlled by the voltage (or the current through the dot) and does not require an external magnetic field, (iii) results in the enhancement of the spin injection coefficient with increasing current, and (iv) is a nearly monochromic source of spin-polarized electrons. Spin-polarized current injected into the nanocrystal from the ferromagnetic source polarizes the ion; the polarization of the ion, in turn, controls the spin polarization of the current flowing through the nanocrystal. Depending on the voltage, the current can either enhance the injection efficiency or by several orders of magnitude. A large enhancement of the spin injection is obtained with increasing current.
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 high intrinsic spin-dependent transport of magnetic parts of electron energies, variable-range and variable-polaron-barrier hopping can be observed at low temperatures. It results in giant magnetoresistance, \( \rho(\Delta, T) \) governed by a non-activated law, in \( T \leq \rho(T_p) \), where \( T_p = \rho \) is a decreasing function of the magnetic field \( B \). Depending on the conditions, parameters of the material, and the dimensionality of the system, the value of the exponent \( p \) lies between 0.25 and 1. Such dependences have been observed in some of the Ga\(_{1-x}\)Mn\(_x\) and Ga\(_{1-x}\)Fe\(_x\)\textit{As} nanostuctures.

11:15 AM E10.8
INFLUENCE OF GATE VOLTAGE SEQUENCES AND CHARGED IMPURITIES ON BOUND SPINS IN SMALL QUANTUM DOTS. Mark Friesen, P. Ruegholz, D.E. Swang, M.G. Lagally, D.W. van der Weele, Robert Joynt, and M.A. Eriksson, University of Wisconsin-Madison, Madison, WI.

Individual electrons confined in quantum dots provide unique opportunities. On the one hand, such isolated spins are the basis for quantum computing technology, and related spin qubits can be thought to have extremely long coherence times. However, measurements on individual spins are very challenging. To address these issues, we have designed and are fabricating a novel bulk-gated quantum dot structure that can act as a single-electron transistor. With a schematic of the structure, we describe the simulation settings and the dependence of the energetic spin transitions on the gates.

11:30 AM E10.9
SIZE DEPENDENCE OF ELECTRON G-FACTOR IN SEMICONDUCTOR NANOCRYSTALS. S. V. Podolin, I. Physic. Institute, Justus Liebig University of Giessen, GERMANY and Ioffe Physico-Technical Institute, S. Petersburg, RUSSIA. AI. I. Efros, M. Rosen, Naval Research Laboratory, Washington, DC; B.K. Meyer, I. Physic. 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 magnetic properties of spin-based carriers for spintronics and magnetic-electronics applications. Recent experimental studies on the time-resolved Faraday rotation in bare and core-shell semiconductor nanocrystals [1] have indicated the need for a detailed understanding of quantum size effects and the influence of QD surface properties 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 tight 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 lateral size. We calculate the g factors at all spins at T=0K.

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 nonmagnetic (N) metals. There are two main contributions to the resistance of this spin-dependent transport: (1) in the plane (in-plane, or parallel to the plane); and (2) perpendicular to the plane. The spin-dependent transport in the plane is generally larger than the perpendicular transport. However, recent studies suggest that the CPP-MR mechanism has more direct access to the fundamental parameters governing the transport. This speaks to the potential of future spintronics applications.

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 spin-polarized transport. An explanation for this can be given in terms of "conductivity mismatch". However, in the full metal devices we have observed a clear evidence for spin injection and spin accumulation, both at 4.2K and room temperature. We have systematically measured the spin signal in devices with electrode spacing ranging from 290 nm to 100 nm. From the analysis we obtained the 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 optical 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.

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3:30 PM #11.3 PERPENDICULAR TRANSPORT IN METALLIC MULTILAYERS WITH BOTH SPECULAR AND DIFFUSE SCATTERING AT INTERFACES. Aya Spiro, Peter M. Levy, Department of Physics, New York University, New York, NY; Shufeng Zhang, Department of Physics and Astronomy, University of Missouri, Columbia, MO.

By using a rather simple model potential we calculate the influence of specular and diffuse scattering at interfaces on the resistance for currents perpendicular to the plane of the layers. The model is not restricted to metallic multilayers but is applied to any type of interfaces. The model is based on the TMR effect and the intrinsic magnetic anisotropy of Fe and NiFe. The analysis is made for a single layer and a stack of layers. The results for a single layer are compared with experiments and are in reasonable agreement with the experimental data. For a stack of layers the results are in good agreement with the experimental data for the resistance of the stack as a whole.

3:15 PM #11.4 SPIN HALL EFFECT. S. Zhang, University of Missouri-Columbia, Dept. of Physics, Columbia, MO.

Scattering of unpolarized electrons by an unpolarized impurity results in spatial separation of electrons with different spins due to spin-orbit interaction. For this reason, an electrical current in a semiconductor is accompanied by a spin current 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 microscopic equations for the spin current and spin accumulation, we derive the transverse spin 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 #11.5 THEORY OF SPIN TRANSPORT ACROSS HETERO-INTERFACES. G.E.W. Bauer, Yu. V. Nazarov, D. Herrero-Hernando, 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 elements of magnetoelectronics because of their 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 of the interface 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 MSU collaboration. The latter can at least in principle be measured via the angular magnetoresistance of CPP spin valves. We present results for the interface conductances 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 #11.6 SPIN-INJECTION EFFECTS IN THREE TERMINAL MAGNETIC TUNNELING JUNCTIONS. B. Stein, H. Kohlstedt, Hainer Werner, Research Centre Juelich, Institute of Solid State Research, Juelich, GERMANY.

A magnetic tunneling spin injection device [MAGTID], consisting of a stack of two ferromagnetic tunneling junctions with access to the intermediate electrode has been developed. The device is deposited by sputtering and the barriers are formed by ultraviolet light assisted thermal oxidation. The performance of the upper and lower layers within a stack were determined by current-voltage characteristics, the differential (d/dV) and the individual tunneling magnetoresistances (TMRR). In addition, a second 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 measurement 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 TMRR of the detector varied by up to 30%. This result will be discussed in the framework of non-equilibrium spin accumulation in these intermediate NiFe layers. For further investigation of the MAGTID we have studied Ts=NiFe/Fe/Fc/CoAl2O4/CoFe/NiFe 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 #11.7 ROLE OF INTERFACE ROUGHNESS IN THE PERPENDICULAR GIANT MAGNETORESISTANCE OF Fe/Cr SUPERLATTICES. J. Staszewski, M.E. Gomez, D. C. Y. Krässig, L. C. Hovest, K. M. Krishnan, and I. K. Schuller, Department of Physics, University of California-San Diego, La Jolla, CA; M. Materials Sciences Division, National Center for Electron Microscopy, Lawrence Berkeley Laboratory, University of California-Berkeley, CA; On leave from U. Complutense, Madrid, SPAIN; * On leave from Universidad del Valle, Cali, COLUMBIA; Present address IBM Almaden.

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


The response of spin valve systems, used in magnetoresistive sensors or GMR read heads, depends not only on the intrinsic layer properties, like anisotropy of the sensing layer, but also on the magnetic interaction between the sensing layer and the pinned layer. Depending on strip geometry and direction of pinning, additional anisotropies due to the interlayer interaction modify the sensor characteristics. To determine the influence of these parameters of a thin film stack, a 50 µm in length with a width ranging from 5µm to 15µm, were studied. The unidirectional and the uniaxial part of the anisotropy was determined from MOKE and magnetoresistance measurements. These measurements were repeated for different orientations of the exchange bias with respect to the long axis of the strip. For comparison with magnetic simulations, some 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 nm x 2 µm to 4 µm x 0.25 µm. The simulation is restricted by calculation time. Experimental data are presented and compared with the simulation results. The good agreement between experimental behaviour and theory gives the base for better understanding of the robust interactions in such systems. Support by BMFT Grant [13N 701] is gratefully acknowledged.

[1] MicroMagus program package, developed by D. Berkov and N. Gorn, further information available from db@inovet-jaen.de.