SYMPOSIUM T
Materials for Magnetic Devices–Magneto-Electronics and Recording
April 16 – 19, 2001

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*Invited paper
it is shifted ~300 Oe from zero field by synthetic AF CoRu/Co and the exchange bias of the IrMn. Using Co in a NOL we find that in its field reaches ~1 mT, there is a sudden drop from ~300 Oe to single digits. It appears that for Co<10 mT, pinhole coupling across the Co forces the two films to switch together, but as the last of the pinholes in the Co close up at ~1 mT the center Co film can switch separately. In contrast, when AlOx is the NOL there is no sudden drop in the coupling with thickness, instead it resembles a 1/k decay. Such observations constitute a new approach to the study of pinholes, and we have used it to investigate a variety of oxides and metal spacer layers to clarify the behavior of pinholes.

10:00 AM T1.3
MAGNETISM OF COBALT BASE ARTIFICIAL LATTICE FILM, Masahide Minoura, Shun Masumoto, Yutaka Hayashi, Ritsumeikan University, Dept of Engineering, Kusuka, JAPAN.

The Co base artificial lattice films have attracted much interest by their special magnetization properties. We discussed the effect of the Pt layer thickness on the magnetic anisotropy, and we showed the effect of the hydrogen ion implantation on the magnetic properties of Pt/Co multi-layered films. The Pt/Co multi-layered films used in this report are formed on Si(111) substrates with molecular beam epitaxy. We did structure analysis, magnetic domain analysis and magnetic characteristics evaluation with XRD, MFM and VSM, respectively. Among the series of films of 0.5nm Co layer, XRD showed that the film of 1 nm Pt layer had a highest periodicity and that they had complete [111] plane orientation. The magnetic domains of these films showed typical stripe structure. The magnetic domain size reduced with the increase of the thickness of the Pt layer. We found the coercivity increased linearly as a function of the length of magnetic domain wall of the unit area. By result of VSM, the multi-layered films of Pt thickness of less than 2nm had perpendicular magnetic anisotropy. The value of magnetic anisotropy energy changed by the Pt layer thickness and showed a maximum value with 1.0nm Pt/0.5nm Co multi-layered film. After hydrogen implantation to the films, XRD showed that the lattice distance was elongated with the hydrogen dose. Also, MFM observed that the magnetic domain size reduced with the increase of the hydrogen dose. The easy axis of magnetization changed from perpendicular to parallel in the plane with the increase of the hydrogen dose. After evacuation of hydrogen at 1000 C, the perpendicular anisotropy was recovered. This phenomenon suggested that the origin of magnetic anisotropy was mainly the lattice mismatch and distortion in the lattice interface. We would mention also about Pt/Co multi-layered films.

10:15 AM T1.4
TEMPERATURE DEPENDENCE OF THE MAGNETORESISTANCE OF Co/Re SUPERLATTICES, Timothy Clarkson, David Lederman, Dept of Physics, West Virginia University, Morgantown, WV.

11:00 AM T1.2
PINHOLES AND NANO-OXIDE SPECULAR LAYERS IN SPIN VALVES. WE Egelslief, Jr., R.D. McMichael, P.J. Chen, R.A. Fry and C.J. Powell, NIST, Gaithersburg, MD; G. Beach, D. Morten and A.E. Berkovich, UCSB, La Jolla, CA.

Recently, nano-oxide layers (NOL) grown in giant magnetoresistance (GMR) spin valves have attracted much interest as a method of achieving the increased GMR associated with specular reflection at Co oxide interfaces while still permitting the use of Mn-based antiferromagnets (AF) to pin the hard layer and Permalloy (Py) to make the free layer. A typical structure would be: IrMn/Co/NOL/Co/Cu/Co/NOL/Pt. In order for the switching characteristic of the spin valve to benefit from the AF and Py the NOL must be thin enough so that strong magnetic coupling across the NOL exists. Otherwise, the magnetic films separated by the NOL could switch separately. We have investigated pinholes in the NOL in the structure 10 nm IrMn/ 2.5 nm Co/Ru/2.5 nm Co/A/25 nm Co/NOL/2.5 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/Co/Co/NOL/Co/Co/NOL/Py. Without a NOL, the center Co film is 5 nm thick, and the GMR loop obtained by switching

400

TUTORIAL
ST T: THE SPINTRONICS REVOLUTION
Monday, April 16, 2001
8:00 p.m. - 5:00 p.m.
Nob Hill C/D (Marriott)

New material structures having new mechanisms for spin dependent transport are being applied to a wide range of electronic functions, including magnetic field sensors, read heads for hard drives, nonvolatile memory, and phononic isolators. The evolution of the material properties of giant magnetoresistive (GMR) materials from multilayers to sandwiches and spin valves, and of magnetic tunnel junctions (MTJs) is described. Materials trade-offs in magnetic sensors and isolators are described in some detail. Opportunities for further material improvements will be described. Integration of these new magnetic structures with integrated circuits is necessary in some applications and desirable in others, and leads to other materials challenges. The integration of magnetic materials with semiconductor devices has evolved considerably in the last several decades, and the trend suggests that some new forms of integrated semiconductor and magnetic materials are likely. The new DARPA program on Spins In Semiconductors (SPINS) may be one platform on which such devices are conceived.

Instructor:
Dr. James Daughton, Nonvolatile Electronics, Inc.

SESSION T1: NEW DIRECTIONS IN MATERIALS
Chairs: Bethanie J.H. Stadler and Luis J. Cruz
Tuesday Morning, April 17, 2001
Golden Gate C3 (Marriott)

8:30 AM T1.1
MATERIAL PROPERTIES OF SPIN VALVE STACKS FOR 1000G/THIN HEAD APPLICATIONS. Sining Ma, Advanced Head Concept, Seagate Recording Heads, Minneapolis, MN.

Ultra high density magnetic recording technology needs a solid understanding about the thin film magnetic materials such as spin valve or spin tunneling junctions. In this talk, a systematic study will be presented to evaluate the technical challenges of spin valve head in the data storage product for 1000G/in2 [1]. The spin valve process-microstructure-performances relationship was emphasized with a variety of examples including NiMn, PtMn, CrMnPt, and IrMn spin valve head. A comparison between Top, bottom, and Dual spin valve heads will be given. Transport properties at cryogenic temperatures provide information on the interface and interface scattering. Thermal stability is a very key issue for HDD head application and will be emphasized [2]. Sensitivity and stability shall be compromised in the ultra high density head designs. The evaluation of spin valve head from 50 to 500 was used to predict the 1000G spin valve head performance and the feasibility of a real application. The possible path for the 1000G/in2 recording head is also evaluated. [1] Ed Murdock et. al., "Practical issues for magnetic recording heads at 1000G/in2 and more", Invited talk at Intermag 1999, paper BA-02.

9:00 AM T1.2
PINHOLE AND NANO-OXIDE SPECULAR LAYERS IN SPIN VALVES. WE Egelslief, Jr., R.D. McMichael, P.J. Chen, R.A. Fry and C.J. Powell, NIST, Gaithersburg, MD; G. Beach, D. Morten and A.E. Berkovich, UCSB, La Jolla, CA.

Recently, nano-oxide layers (NOL) grown in giant magnetoresistance (GMR) spin valves have attracted much interest as a method of achieving the increased GMR associated with specular reflection at Co oxide interfaces while still permitting the use of Mn-based antiferromagnets (AF) to pin the hard layer and Permalloy (Py) to make the free layer. A typical structure would be: IrMn/Co/NOL/Co/Cu/Co/NOL/Py. In order for the switching characteristic of the spin valve to benefit from the AF and Py the NOL must be thin enough so that strong magnetic coupling across the NOL exists. Otherwise, the magnetic films separated by the NOL could switch separately. We have investigated pinholes in the NOL in the structure 10 nm IrMn/2.5 nm Co/Ru/2.5 nm Co/A/25 nm Co/NOL/2.5 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/25 nm Co/NOL/Co/Co/NOL/Co/Co/NOL/Py. Without a NOL the center Co film is 5 nm thick, and the GMR loop obtained by switching
magnetoresistance properties, but film grown with pure Cu as the conducting layer exhibit no GMR effect. To provide insight into this phenomenon, atomic force microscopy (AFM) height images were obtained on the film surface and CuO/Cu layers. The Co layers have also been deposited and their surface morphology and roughness have been experimentally obtained. Atomic force microscopy (AFM) results reveal that the Cu film is not oxidized (in contrast to pure Cu), indicating that the roughness of the Cu film may be due to the magnetostrictive effect of the Cu film itself. The Co layers were investigated by magneto-optical Kerr effect from 10K to room temperature. The Cu layers are dominated by strong shape-induced uniaxial anisotropy and exchange coupling with the antiferromagnetic underlayer. Magnetization loops recorded along the easy axis exhibit a perfect squareness and switch in less than 10 Oe. Transverse measurements indicate that the switching occurs by domain nucleation and/or domain wall propagation. On the contrary, close to the [110] hard axis, magnetic switching occurs by coherent rotation that we fitted using a Stoner-Wohlfarth model including strong uniaxial anisotropy and exchange coupling terms. The bistable Co magnetization state along its easy axis has been used for ordering the NiOln configuration from room temperature to 10K. Sign and value of exchange bias induced by such a thermal treatment can be modulated thanks to a wide magnetostructural effect of local spin energies distributions.

11:30 AM T1.9
Abstract Withdrawn.

11:45 AM T1.10
EXCHANGE COUPLING AND SPIN-FLIP TRANSITION OF CoFeO2/α-Fe2O3 BILAYERED FILMS. Tetsu Fujii, Takuji Yano, Mutsuo Nakanishi and Jun Takada, Dept. of Applied Chemistry, Okayama Univ., Okayama, JAPAN.

(102)-oriented α-Fe2O3 epitaxial films deposited on α-Al2O3(102) are known to have a unique spin-flip transition at about 400 K [1]. The spin axis lying in the (102) plane above 400 K changes almost normal to the plane at room temperature. The magnetic properties of CoFeO2/α-Fe2O3 bilayered films. The spin-flip transition of α-Fe2O3 could influence the magnetic properties of CoFeO2, and vice versa. CoFeO2/α-Fe2O3 (ferromagnetic/antiferromagnetic) bilayered films on α-Al2O3(102) were prepared by helicon plasma sputtering method. The CoFeO2 layer grown on α-Fe2O3(102) had an [100] preferred orientation. Magnetization and microwave measurements of bilayered films suggested that the CoFeO2 layer had an in-plane magnetic anisotropy while the α-Fe2O3(102) had the spin aligned perpendicular to the film plane. The bilayered films did not show the spin-flip transition. The ferrimagnetic spins of the CoFeO2 layer were coupled perpendicularly to the antiferromagnetic spins of the α-Fe2O3 layer due to the exchange coupling between CoFeO2 and α-Fe2O3. The large in-plane anisotropy of the CoFeO2 layer could suppress the spin-flip transition of the α-Fe2O3 layer.

1:30 PM T2.1

Many magnetoelectronic devices, such as read heads and magnetic random access memories, are based on small magnetic elements whose resistance in a function of their magnetization state. These elements usually consist of a millimeter wide magnetostrictive film, non-magnetic spacer, and pinning layers such as antiferromagnets. As the elements become smaller, the magnetoelastic coupling between the magnetic layers dominates the behavior, leading to a magnetic anisotropy of the magnetic layers and raising their switching fields. In this work, we used magnetic techniques to characterize magnetic elements with diameters of 50 nm and lengths of 1 mm and above, to examine how the magnetoelastic coupling between the magnetic layers changes with element size. Films such as Co/Cu/NiFe pseudo-spin valves are sputtered then patterned into arrays of elements using interference lithography combined with ion milling. The magnetic hysteresis of the arrays is measured using magnetochemistry and magnetic force microscopy, and the magnetoresistance is measured by connecting the arrays with conductor lines in a self-aligned lithography process. As an example, in an unpinned Co-Ni/Co-NiFe/6 nm film, the magnetic...
layers are magnetized parallel at remanence and the two layers switch at 4.0 Oe and 1.0 Oe respectively. After patterning into an array of 80 nm wide 130 nm long hexagonal islands the two layers were measured. The magnetic layers in each element are now magnetized antiparallel at remanence, and the particles are single-domain. Distinct switching of the two layers can still be observed, and occurs at 600 Oe using Co for the Co and NiFe respectively. We will discuss the magnetic behavior of such elements as a function of size, characterize the distribution of switching fields and its origin in the film microstructure, and discuss methods for controlling the switching fields of nanoscale elements.

2000 PM T2.2
HIGH RESOLUTION MEM FOR MICROMAGNETICS. George D. Skidmore, Andrew Kurz, C. E. Campbell, and E. Dan Dahlberg, School of Physics and Astronomy, Minneapolis, MN.

We have previously developed electron beam deposited spacers for use in magnetic force microscopy [1] with a spatial resolution on the order of 30 nm [2]. These high resolution tips have been used to determine the magnetic microstructure of nanofabricated cylindrical nickel dots or cylinders with a perpendicular anisotropy. The dots have diameters in the range from 80 to 1000 nm, and thicknesses range between 48 and 140 nm. Also, the micromagnetic structure has been determined by Lundin-Lifshtiz-Gilbert (LLG) micromagnetic simulations. There is excellent agreement between the experiments and the simulations with no adjustable parameters in the simulations [3]. It is found the ratio of the dot diameter to the stripe period of an unpainted nickel film of the same thickness predicts which magnetic states are energetically favorable. The smallest particles (ratio equal to or less than 12) have simple magnetic structure consisting of one to three domains which can be characterized as either a stripe or a bullseye domain pattern. At larger diameters there emerge many different metastable states characterized by a stripe structure with random patterns, but with a stripe period the same as in nickel films of the same thickness.


2300 PM T2.3
OBSERVATION OF MAGNETIC STATES AND NUCLEATION FREE SWITCHING IN MICROSCOPIC RING MAGNETS. Mathias Klink, Johan Rothman, Luis Lopez-Diaz, Carlos A. V. J.A.C. Bland, University of Cambridge, Cavendish Laboratory, Cambridge, UNITED KINGDOM; Zheng Cai, Rutherford Appleton Laboratory, Chilton, UNITED KINGDOM.

Presynopsis Si(100) substrates have been used to grow free-standing epitaxial ring magnets of Cu(100)/Co(100)/Cu(100)/Si(100). TEM and EELS images into the growth direction have shown that the magnetic material on the substrates is physically disconnected from the magnetic material in the trenches thus preventing any exchange interaction between the structures and the trenches. Since the magnetic coreparticle is deposited not only on the ring structure but over the entire sample, magneto-optical measurements are difficult. Accordingly, the samples were magnetically characterized using specially adapted magneto-optic Kerr effect and Transport Force Microscopy techniques. Magnetic measurements and magneto-optical simulations of the rings with diameters between 0.7 μm and 1.8 μm show that a two step switching process occurs at high fields, indicating the presence of two different stable states. In addition to the vortex state, we find an intermediate field state which we believe to be a superposition of two peaks in the magnetic moment of the ring.

3:30 PM T2.5
HIGH FREQUENCY BEHAVIOR OF Fe-Co-Cu FILMS. N. X. Sun and S. X. Wang, Center for Research on Information Storage Materials, Stanford University, Stanford, CA; T. J. Silva, National Institute of Standards and Technology, Boulder, CO.

High frequency behavior of soft magnetic Fe-Co-Cu films with different dispersion angles and a Permalloy film were studied with a pulsed inductive microwave magnetometer at different bias fields along both hard axis and easy axis. The inductive two-domain data were analyzed to obtain the fundamental and superharmonic magnon frequencies. Frequency domain analysis was used to obtain the permeability spectrum. Ferromagnetic resonance (FMR) frequencies were determined as both the zero-crossing frequencies of the real permeability spectrum, f0, and the peak frequency of the imaginary permeability spectrum f2. The Fe-Co-Cu films with low dispersion angle show a peak in the damping parameter when the transverse bias field is close to the anisotropy field Hk. In addition, f0 is enhanced relative to f2. The Fe-Co-N films with larger dispersion angles, however, do not exhibit enhanced damping or f0. As a control study, we found that f0 and f2 are virtually identical for the Permalloy film.

3:45 PM T2.6
SUBMICRON-SCALE PERIODIC MAGNETIC ARRAYS. V. Meksukha, Department of Electrical Engineering and Computer Science, University of Illinois at Chicago, Chicago, IL, B. Iri, School of Applied and Engineering Physics, Cornell University, Ithaca, NY; M. Grinbard, N. Zaluzec, J. Johnson, Materials Science Division, Argonne National Laboratory, Argonne, IL, H. H. Koo, R. D. Greene, University of Maryland, College Park, MD, R. L. Needell, R. Kumar, Institute of Microelectronics, SINGAPORE.

The magnetic behavior of nano-magnetic arrays is determined by the magnetic properties of the individual elements, their spacing and the symmetry of the array. The properties of individual magnetic nano-dot are governed by the interplay between the crystalline anisotropy and shape anisotropy. For polycrystalline dots of Co, NiFe, permalloy containing a large number of grains of different orientation, the net magnetocrystalline anisotropy is expected to be small compared to the shape anisotropy. The shape anisotropy will therefore dominate the net anisotropy. Using the Magnetic Force Microscopy (MFM) we investigated the magnetic properties of periodic arrays of polycrystalline submicron magnetic dots and multilayer dots of Co, Fe (in plane magnetization), and Co/Pt10 (out of plane magnetization) with characteristic sizes ~100-400 nm and periods of ~200 nm, defined by e-beam liftoff or etching. To avoid complications due to
changes in growth-induced anisotropy and or thickness, elliptical elements of various sizes and shapes were deposited simultaneously on a single substrate. Magnetization measured inside the same substrate dramatically when the axis aspect ratio were reduced. In addition, we demonstrated that not only the shape of the dot but the array period and symmetry controlled the remanent state of densely spaced arrays. The example of the domain wall engineering in negative arrays will be shown.

4:00 PM T2.7
SHAPE TUNING OF MAGNETIC STABILITY IN NANO-PARTICLES: THE ROLE OF DIPOLAR INSTABILITY POCKETS.
M. Grimseich, A. Berger, J. Johnson, Materials Science Division, Argonne National Laboratory, Argonne, IL, V. Meshchko, Electrical Engineering Department, University of Illinois at Chicago, Chicago, IL, B. He, School of Applied Phys., Cornell Univ., Ithaca, NY; P. Neuzil and R. Kumar, Inst. of Microelectronics, Singapore, SINGAPORE.

Magnetization reversal onset fields have been measured in a series of nano-arrays of 30 nm thick Co and 20 and 30 nm thick permalloy elements. Elliptical elements with differing aspect ratios and with rounded or pointed ends have been investigated. The experimental results are compared with theoretical calculations, which are based on the concept of spin wave softening. These calculations enable us to identify regions near the particle ends, in which the tendency toward dipolar driven instability is substantially enhanced. These dipolar instability pockets are found to be responsible for the onset of magnetization reversal and allow for a calculation of the switching onset field without the need for full micromagnetic calculations. The calculated values, which depend only on the exchange constant and saturation moment and the shape of the elements, are in excellent agreement with the measured switching fields an as function of shape (rounded or pointed), material (Co or permalloy), and aspect ratio (1.2 to 7). The model even reproduces the actual switching fields to within less than 10% confirming the fact that the concept of dipolar instability pockets describes the essential physics of the magnetization reversal onset in nano-particles. Due to the tremendous technological significance of magnetic stability in nano-particles, the concept of dipolar instability pocket should also prove to be an indispensable tool for material design.

Work at ANL supported by US Department of Energy.

4:15 PM T2.8
MICROMAGNETIC INVESTIGATIONS OF THE EXCHANGE PINNING IN NiFe/Cu/ NiO TRILAYERS.

The phenomenon of exchange pinning, i.e., a unidirectional anisotropy arising from a ferromagnet (FM) being in close contact to an antiferromagnet (AFM), is often used to define a reference magnetic direction in spin valve systems. The fundamental physical mechanisms associated with this unidirectional anisotropy are not yet fully understood. Of particular technological relevance is the temperature behavior of the exchange pinning which determines the limits of application of the strength of the coupling between AFM and FM and is varied by a non-magnetic layer or of fundamental interest. We therefore investigated NiFe/Cu/NiO trilayers as a model system. The magnetic domain structures of the Permalloy layer were imaged for various Cu layer thicknesses and temperatures by means of Kerr microscopy. The temperature-dependent studies show that a domain pattern formed above the blocking temperature $T_B$ of the NiO film is completely frozen in after the system has been cooled down below $T_B$. Close to $T_B$, however, the system passes through various states of stability against magnetization reversal. In the most stable state ("strong pinning") at low temperature and large Cu spacer thickness the initial domain structure is only restored after applying magnetic fields up to 0.7 T in various directions. For higher temperatures (below $T_B$) intermediate spacer thicknesses the pinning appears to be weakened. As a consequence, the frozen-in domain state is only preserved, if the external field is applied along the hard magnetic axis. Applying the field along any other direction causes the domain pattern to change irreversibly. In this case the change of the magnetization in the uppermost physical plane follows the domain wall motion. The new domain pattern is again restored after applying the field along the hard axis. These results are discussed with respect to the application of exchange-biasing layers in magnetic sensors.

4:30 PM T2.9
MAGNETIZATION RESISTANCE AND INDUCED DOMAIN STRUCTURE IN TUNNEL JUNCTIONS.
M. Hehn, O. Lenclo, D. Lacour, A. Schulz, Laboratoire de Physique des Mag& #232;netiques, Nancy, FRANCE; D. Hrabovsky, J.F. Bobo, A.R. Pert, Laboratoire de Physique de la M& #233;canique Condens& #232;e, Toulouse, FRANCE.

Magnetization reversals in sputtered Co layers used in a magnetic tunnel junction are studied using in situ measurements with magneto-optic Kerr magnetometry and microscopy. The magnetization reversals of the hard and the soft Co layer have been studied separately and their ferromagnetic coupling is shown when combined in the tunnel junction. Using the tunnel junction as a probe for microscopic studies, we first evidence the existence of an unexpected domain structure in the soft Co layer. This domain structure originates from the duplication of the domain structure of the hard Co layer into the soft layer by ferromagnetic inter-electrode coupling. By tailoring the magnetic properties of the hard Co layer, we have demonstrated that the appearance of the domain duplication is driven by the magnetic anisotropy of the hard layer. Reversing this anisotropy leads to domain duplication but with effects non discernible in the tunnel magnetoresistance signal. Indeed, the duplication of low density 360° domain walls are then only observed on the TAM signal. Finally, a brief theoretical description of the domain duplication process allows us to extract the main parameters governing the effect. With this, we shed light on the parameters to adjust in order to get or avoid this phenomenon.

4:45 PM T2.10
CONTROL OF MAGNETIC ANISOTROPY FIELD IN FeTaNanolayers FOR ULTRA-HIGH-FREQUENCY APPLICATION.
Sung-Ryong Ryu, Seok Bae, Jong-Han Jeong, Choong-Sik Kim, Seong-Eun Nam, Hyoung-June Kim, Hongik Univ. Dept. of Metallurgical Eng. & Materials Sci., Seoul, KOREA.

Recently, FeTaN films for high frequency electromagnetic devices have been widely investigated due to their high saturation magnetization, high anisotropy, and low coercivity. It is reported that Yamaguchi’s [Tohoku University] paper included the result for the patterned magnetic thin films followed by the fabrication of this thin film inductor. However, FeTaN thin films have an advantage in the higher initial permeability because of higher saturation magnetization than that of conventional soft magnetic materials. Anisotropy field of soft magnetic thin films such as FeTaN is an important factor for the thin film inductor in 1-2 GHz drives mobile communication handset application. In this paper, we consider the effect of shape anisotropy on the ultra-high-frequency magnetic characteristics of FeTaN films was investigated. Patterned FeTaN films which were to research the effect of shape anisotropy were prepared by lift-off process and SiO$_2$ was used for insulating materials which were to reduce eddy current losses between stripe lines. Patterned FeTaN films with stripe lines exhibits higher $H_{c2}$ about 4000e. Ferromagnetic resonance frequency was also enhanced. It resulted from the increased anisotropy field of patterned FeTaN films and low eddy current losses. We suggest that patterned FeTaN films should be used for the 1-2 GHz drive inductors.
structure of substance/Fe/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/FeMn/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/FeMn/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFeCo/CoFe}
commercial media. Corresponding investigations were carried out on magnetooptic cels, and variations were measured using a vibrating sample magnetometer (VSM). Using chromium ion implantation at 20 keV, both remanence and coercivity were reduced to zero, i.e., rendering the ferromagnetic thin film paramagnetic at low doses. For Cr+ implantation at 20 keV, remanence and coercivity were also reduced to very low levels at doses of 5 x 10^14 cm^-2 after which further irradiation had no effect. Small decreases in remanence and coercivity were observed for 20 keV Na2. XRD measurements indicate that the hexagonal cobalt alloy phase remains intact after ion implantation treatment. Details of the coating surface treatment by AFM. Further changes in microstructure, including the depth profile of implanted species, were assessed by TEM. Combined with the development of a suitable staking mask, such chromium ion implantation can be used to develop a visible patterned media consisting of locally defined ferromagnetic and paramagnetic regions. This work is in progress. Work supported by California State DiM program in partnership with Sega Technology. Work J in LBNL supported by DOE under contract number DE-AC03-76SF00098.

T3.7 IMPROVEMENT OF CRYSTALLOGRAPHIC CHARACTERISTICS OF COCHTA THIN FILM USING DOUBLE UNDERLAYER. K.H. Kim, Y.J. Kim, Kyungwon Univ, School of Electrical & Electronic Engineering, Kyungkido, KOREA; S.H. Kong, S. Nakagawa, M. Nnca, Tokyo Institute of Technology, Dep of Physical Electronics, Tokyo, JAPAN.

Highly c-axis oriented Co-Cr based thin films are expected for ultra-high density recording media in perpendicular magnetic recording system. In order to improve dispersion angle of c-axis of Co-Cr based thin film for perpendicular magnetic recording media, we prepared trilayer with double underlayer using Magnetron Sputtering apparatus. The thickness of magnetic layer CoCrTa and double underlayer, such as interlayer Pt, paramagnetic CoCr, underlayer Ti was fixed 50nm, 21nm, respectively. In order to prepare the thin film, we used argon pressure 2mTorr, substrate temperature 350°C and input current 0.5A. The crystallographic characteristics of CoCrTa layer with varying interlayer thickness(60nm) have been investigated. By the result, the CoCrTa trilayer with interlayer Pt and CoCr underlayer Pt showed 3.45°, 1.62° at thickness 60nm, 10nm, respectively. However, CoCrTa thin film using interlayer paramagnetic CoCr showed 8.28°, 8.62° at thickness 60nm, 10nm, respectively.

T3.8 TANTALUM OXIDE AS A LOW HEIGHT TUNNEL BARRIER FOR MAGNETIC JUNCTIONS. P. Rietmann, R. Heinrich, O. Lembcke, F. Maiti, A. Schuhl, Laboratoire de Physique des Membranes, Nancy, FRANCE.

Magnetic tunnel junctions with a thick barrier of low height consisting of TaOx, and thin ferromagnetic layers are prepared by plasma oxidation of tantalum and tantalum nitride sputter-deposited tantalum. We have studied their magnetotransport properties at different temperatures and under a magnetic field. As a consequence, we have studied the tunnel junctions using X-ray, x-ray diffraction, and neutron diffraction. The barrier height determined using the Brinkman formula shows a dependence on temperature and thickness, and this dependence is described by the power law for a tunneling layer of 1.4-nm Ta layer. For this high tunneling can be explained by calculating the bulk densities of metallic T and stoichiometric Ta2O5. This barrier height was independently confirmed by measuring current - voltage characteristics I(V) as a function of temperature T. Then, plotting [I(V, T) - I(V, 0)]/I(V, 0) as a function of V produces as voltages corresponding to the barrier height. Magnetoresistance (MR) ratios of 2.5% at room temperature and 4% at low temperatures could be observed. The MR ratio is reduced to half of its maximum value at bias voltages of about 0.2 - 0.5 V at room temperature (0.23 - 0.5 V at 800 K), which is much lower than for aluminum oxide. Over or under oxidation of the barrier reduces the TMR signal and gives rise to Curie temperatures of the junctions. However, over-oxidized junctions, the barrier asymmetry of the Brinkman fit depends on the voltage being varied from negative to positive or vice versa. It is attributed to weak bonds ions moving in a Ta2O5 matrix driven by the electric field across the barrier. This movement can be frozen at lower temperatures and so voltage induced barrier asymmetry can be studied. The low barrier heights of TaOx gives the possibility to substantially increase the barrier thickness, as compared to aluminum oxide, and to decrease the coupling between the ferromagnetic layers as we were able to demonstrate. Furthermore, the low barrier makes it possible to safely study the field emission regime with applied voltages up to two or three times the barrier height.

T3.9 CB/Pd MULTILAYER BASED RECORDING LAYERS FOR PERPENDICULAR MEDIA. D. Levine, J. He, J. Wang, W. Timothy Klemme, J. J. Hope and S. Schmidt, Caltech Research, Pennsylvania, PA.

As the storage industry ramps the areal bit densities at increasingly high areal bit densities in recording media, there is a need to manifest themselves. Perpendicular recording technology while being technically close to conventional longitudinal recording and the least difficult technology to make the transition to if necessary, addresses the issue of thermal stability. Recent studies indicate that the thermal stability is limited at about 1000bit/in^2. Co and Co alloy based multilayers [1, 2] are among the candidates for perpendicular recording media because they exhibit high remanent squareness and easily controlled magnetic anisotropy with both aspects being radiatively coupled to the thermal stability. The results of an experimental study of CoB/Pd multilayer based recording layers for perpendicular recording media are presented. CoB/Pd multilayers were deposited by magnetron sputtering from CoB and Pd targets which were coated with a barrier layer of ITO layer. The sputtering was done in Kr at 3mTorr. The films exhibited strong perpendicular anisotropies with the coercivities of as deposited films ranging from 3.8 to 7 kOe. Microstructural studies revealed that the film thickness (columns) of ~1.5mm diameter isolated by lower density regions potentially serving as an exchange de-coupling material. Cross-sectional TEM showed that the columns were not completely separated throughout the thickness of the film, but rather continuously coupled to about 1/4 of the column height. No measurable crystalline texture was observed using X-ray diffraction, which further supports the view that the anisotropy arises purely from interfacial effects in the multilayer films. Aging studies were conducted and showed that, under appropriate conditions, it is possible to reduce a exchange coupling between the magnetic columns. A comparison between microstructural and magnetic data for as-deposited and aged multilayer films is presented.


T3.10 TUNNELING MAGNETORESISTANCE IN Ni0.9Fe0.1B2/LaAlO3/La0.8Ca0.2MgO3 TUNNEL JUNCTIONS. Jaeyoung Choi, Srinivas V. Pivinambaram, Rajiv K. Singh, Department of MSE, University of Florida, Gainesville, FL, Hooyong Jeong, Kim, Department of Materials Science and Engineering, Hongik University, Seoul, KOREA.

One of the distinguished features of La0.8Ca0.2MgO3 (LCMO) is a ferromagnetic half-metallic state, where only the single spin band crosses the Fermi level. Such a half metallic state can lead to 100% spin polarization of conduction carriers, which is much higher than that of typical ferromagnetic metals such as Ni, Fe or their alloys. One way of taking advantage of this highly spin polarized nature of these magnetic oxides is a spin-dependent tunneling magnetoresistance (TMR) of a magnetic tunnel junction (MTJ), since the TMR ratio depends on the spin polarizations of the two electrodes. Recently, TMR ratios up to 40% have been reported in La0.8Ca0.2MgO3/La2/3Sr1/3MnO3 tunnel junctions at low temperature [10 K]. Despite of these large TMR values, the obstacle in these systems is that large TMR values are observed at temperatures below 100 K, rapidly vanishing at higher temperatures. Since this temperature is far below the Curie temperature of these manganites (Tc of LCMO and LSMO are approximately 270 K and 370 K, respectively), this premature decrease of TMR brings an important issue for understanding as well as practical applications of these systems. Even though the cause of the rapid TMR loss with temperature is not understood at this moment, the existence of surface dead layer with depressed magnetic order at elevated temperatures is suspected. Since the magnetic properties of these materials are highly sensitive to local crystal properties and strain field induced by lattice mismatch among the grown layers, combination of selected material species, their crystal integrity, and thickness of insulators will be crucial for improving the TMR levels as well as the temperature dependency. In this paper, we report our studies on the growth, and magnetotransport properties of Ni0.9Fe0.1B2/LaAlO3/LAO/La0.8Ca0.2MgO3 films grown on [100] LaAlO3 substrate as a function of deposition conditions and insulator layer thickness. LCMO and LAO films are grown using a pulsed laser deposition system while NiFe films by sputtering. The films were then lithographically patterned into a MTJ structure and the TMR was measured using superconducting quantum interference magnetometer (SQUID). The effect of deposition temperature, thickness of the barrier layer and post annealing treatments on the TMR values will be discussed in detail.

T3.11 Nb0.5Bi0.5O3/He0.8-x SrxMnO3 SUPERLATTICES FOR OXIDE
Colossal magnetoresistance (CMR) compounds gained the scientific interest over last decades as novel devices for future oxide electronics. The crystal structure of the CMR manganites is similar to that of the perovskite high-temperature superconductors. Therefore, the fabrication of ferromagnetic-superconductor (F/S) heterostructures is the key step of the CMR devices fabrication.

Ferromagnetic-superconductor heterostructures consist of stacks of alternating ferromagnetic and superconducting layers, which give rise to novel phenomena. Depending on the relative thickness of F and S layers, one can observe ferromagnetic superconducting ground state. Coexistence of ferromagnetism and superconductivity in such structures can be considered. Proximity effect at F/S boundary is the most interesting properties of F/S heterostructures. We report on the magnetic studies of YBa$_2$Cu$_3$O$_{y}$/RE$_{1-x}$Sr$_x$MnO$_3$ (RE = Nd, La, Pr) superlattices. The superlatites have been fabricated by high-pressure dc sputtering method. A series of superlatites with fixed YBa$_2$Cu$_3$O$_{7-δ}$ thickness and varying RE$_{1-x}$Sr$_x$MnO$_3$ thickness has been prepared. The presence of superstructure-related satellite peaks in the X-ray diffraction spectra indicate the good quality of the obtained superlatites. Magnetization measurements have been carried out for different magnetic field orientations. The superconducting critical temperature of the superlatites decreases on increasing the ferromagnetic layer thickness. Magnetization hysteresis curves measured above the superconducting transition temperature show that the easy axis orientation for the ferromagnetic thin film depends on the thickness of the RE$_{1-x}$Sr$_x$MnO$_3$ layer. The possibility of tailoring the magnetic anisotropy of YBa$_2$Cu$_3$O$_{y}$/RE$_{1-x}$Sr$_x$MnO$_3$ superlattices could be useful for applications as active elements of non-volatile memory or magnetic field sensors.

Work supported by the ARPA/ONR and the State of Illinois under HECA. Partial support from the Polish Committee for Scientific Research (KBN) under grant no. 2 P03B 107/4 is acknowledged.

T3.12

The success in fabrication of diluted magnetic semiconductor and injection of spin into electronics greatly extended the frontier towards spin-based devices. In order to take advantage of spin-related phenomena in semiconductors, creation and manipulation of the spin-polarization of carriers is critical for device application. One way to achieve this goal is discovery of novel magnetic semiconductor with high magnetism in a wide temperature range and good interface with semiconductor. In this paper, we will report the employment of combinatorial ion implantation to rapidly prepare material libraries in IIVL-based semiconductor, a combination of high-throughput magnetic characterization using conventional SQUID and scanning SQUID microscopy. Ion implantation is a non-equilibrium process, where the doping atoms get driven into the solid by a violent interaction of their excess kinetic energy. In this way, high concentration of magnetic element in semiconductor host or high oriented magnetic nanocrystals that is unattainable by more conventional methods may be formed. We perform an implantation of Fe and Mn with various doses into GaAs substrate in a combination of combinatorial approach, which increases the possibility of novel material discovery. Following different annealing processes, we gain an understanding of the material's structure-property relationship. We also report effect of UV light irradiation on magnetism of the libraries, which is an alternative way to manipulate spin production.

SESSION T4.3/Joint Session T4.3/1.3
MAGNETO-RESISTANCE MATERIALS

S30 AM T4.1/1.3
ATOMIC AND SIZED ENGINEERED FERRITE SYSTEMS: NEW HORIZONS IN LOW DIMENSIONS. Y. G. Harris, Naval Research Laboratory, Washington, DC

Spinel ferrites are attractive materials for high frequency (1 MHz ≤ f ≤ 500 MHz) applications where low core losses are essential. Further, these materials are the only low-loss magnetic materials available for microwave frequency (f ≥ 1 GHz) applications. An essential property of the ferrites is their insulating properties that limit eddy current losses and other forms of conduction losses. Other attractive properties are their high permeability, low microstrip fields, low FMR linewidths, and low magnetic hysteresis. However, their ferromagnetic nature limits their intrinsic magnetization. This has the effect of limiting the power losses and efforts to reduce component size at the MHz frequencies, and their broadband utility at the microwave. Recent research trends in ferrite research have involved working for future oxide electronics applications. The crystal structure of the CMR manganites is similar to that of the perovskite high-temperature superconductors. Therefore, the fabrication of ferromagnetic-superconductor (F/S) heterostructures is the key step of the CMR devices fabrication.

Ferromagnetic-superconductor heterostructures consist of stacks of alternating ferromagnetic and superconducting layers, which give rise to novel phenomena. Depending on the relative thickness of F and S layers, one can observe ferromagnetic superconducting ground state. Coexistence of ferromagnetism and superconductivity in such structures can be considered. Proximity effect at F/S boundary is the most interesting properties of F/S heterostructures. We report on the magnetic studies of YBa$_2$Cu$_3$O$_{y}$/RE$_{1-x}$Sr$_x$MnO$_3$ (RE = Nd, La, Pr) superlattices. The superlatites have been fabricated by high-pressure dc sputtering method. A series of superlatites with fixed YBa$_2$Cu$_3$O$_{7-δ}$ thickness and varying RE$_{1-x}$Sr$_x$MnO$_3$ thickness has been prepared. The presence of superstructure-related satellite peaks in the X-ray diffraction spectra indicate the good quality of the obtained superlatites. Magnetization measurements have been carried out for different magnetic field orientations. The superconducting critical temperature of the superlatites decreases on increasing the ferromagnetic layer thickness. Magnetization hysteresis curves measured above the superconducting transition temperature show that the easy axis orientation for the ferromagnetic thin film depends on the thickness of the RE$_{1-x}$Sr$_x$MnO$_3$ layer. The possibility of tailoring the magnetic anisotropy of YBa$_2$Cu$_3$O$_{y}$/RE$_{1-x}$Sr$_x$MnO$_3$ superlattices could be useful for applications as active elements of non-volatile memory or magnetic field sensors.

Work supported by the ARPA/ONR and the State of Illinois under HECA. Partial support from the Polish Committee for Scientific Research (KBN) under grant no. 2 P03B 107/4 is acknowledged.

10:00 AM T4.3/1.3
DIRECT AND REAL-TIME OBSERVATION OF SUB-MICRON DOMAINS IN MAGNETICALLY BIASED STRONTIUM FERROITE PERMANENT MAGNETS BY ROOM TEMPERATURE SCANNING MICRO-HALL PROBE MICROSCOPY. A. Samba, N. Iida, Tokai Univ., Dept. of Electrical Engineering, JAPAN; T. Matsuda, Toei Kagyo Ltd., Tokyo, JAPAN; A. Oral, Bilkent Univ., Dept. of Physics, TURKEY; S. J. Bending, Univ. of Bath, Dept. of Physics, UNITED KINGDOM

The development of ferromagnetic materials for high performance permanent magnets requires a fundamental understanding of the behavior of magnetic domains in external bias fields. We have developed a new room temperature scanning microHall probe microscope (RT-SHPM) system for such purposes and will report on the imaging of domains in Sr ferrite permanent magnets (SFM) in external bias fields. The RT-SHPM system enables the highly sensitive, extremely fast, non-invasive, and quantitative measurement of localized surface magnetic fields on the micron-scale. A 0.8–1.0 μm GaAs/AIGaAs micro-Hall probe (300K Hall coefficient = 0.31/G and field sensitivities=0.04 G/√Hz) with an integrated STM tip for precise vertical positioning was used as a magnetic field sensor. External bias fields (Hex) of up to 30000 Oe were applied in steps of 4000 Oe in parallel to the easy and hard axes of carefully polished 400 μm thick thermally demagnetized Sr ferrite permanent magnets (Hc=2200 Oe; Br=2870 G). 50×50 μm areas were imaged at a height of 0.3 μm above the SFM surface for each Hex, with scan speeds of ~1 frame/second enabling almost real-time imaging in synchronization with bias field changes. RT-SHPM imaging for Hex applied along the easy axis of SFM showed [1] the existence of 8–15 μm sized domains with a surface magnetic field of ~2200 G at Hex=0 (2 domains) to move only above a critical bias field of 4700 Oe; [2] the measured surface magnetic field to decrease with increasing bias fields to a value of 170 G at Hex=30000 Oe. The details and physical interpretation of these and related results for bias fields along the hard direction and inside domains during demagnetization of the SFM from the coercive field will be discussed. Our results demonstrate the RT-SHPM system to be a valuable tool for the quantitative study of micro-magnetic phenomena in ferromagnetic materials.

9:15 AM T4.3/1.3
ADVANCES IN THE LOW TEMPERATURE PREPARATION OF LANTHANUM STRONTIUM MANGANITE POWDERS. Sophie Guillemard-Braz, Horst Coradin, Patricia Baradat, Philippe Tallon, Abel Rouset, CHRAT/LCMIE, Universite Paul Sabatier, Toulouse, FRANCE.

In recent years, the doped perovskite lanthanum strontium manganites have received much attention due to the colossal magnetoresistance (CMR) properties. It has been shown that the microstructure, and especially the grain size, plays a significant role on the intrinsic CMR properties. So the synthesis methods are very important for obtaining polycrystalline materials with well-developed microstructure. In this present work perovskite-type compounds of general formula La$_{1-x}$Sr$_x$MnO$_3$ were prepared by the thermal decomposition of precursor powders. Two different kinds of precursors: carbonates and citrates have been prepared by low temperature, i.e. “Chimie douce” technique. The careful control of the chemical and the hydrodynamic parameters during the synthesis process allows to obtain small particles [30 nm for citrates] and narrow size distribution. A precursor is observed after a low temperature thermal treatment, starting from 550°C. The structure is a function of the strontium content and the temperature. Moreover it depends also on the nature of the precursors used. It has been suggested that the main results from the different atmospheres due to the release of CO$_2$, CO and H$_2$O species during the decomposition process. The “Chimie douce” technique is a powerful tool to control the particle size and the surface area but also to a certain extent the structure of such perovskite materials.
9:30 AM T4.4/ U3.4
Abstract Withdrawn.

9:45 AM T4.5/ U3.5
CRYSTAL STRUCTURE AND MAGNETIC PROPERTIES OF THE DOUBLE PEROVSKITE (Sr2Mn2Fe9O16; T.-Sh. Chen1, R.-J. Lin1, R.-J. Chang1, Y.-S. Chen2, W.-H. Chang3, W.-C. Liu4, W.-C. Lai5
1Department of Physics and Research Center for Condensed Matter Science, National Taiwan University, Taipei, TAIWAN
2Department of Physics, National Taiwan Normal University, Taipei, TAIWAN
3Center for Condensed Matter Sciences, Institute of Physics, Academia Sinica, Taipei, TAIWAN
4Synchrotron Radiation Research Center, Hsinchu, TAIWAN.

A new series of ordered double perovskite oxides (Sr2Mn2Fe9O16; T.-Sh. Chen1, R.-J. Lin1, R.-J. Chang1, Y.-S. Chen2, W.-H. Chang3, W.-C. Liu4, W.-C. Lai5
1Department of Physics and Research Center for Condensed Matter Science, National Taiwan University, Taipei, TAIWAN
2Department of Physics, National Taiwan Normal University, Taipei, TAIWAN
3Center for Condensed Matter Sciences, Institute of Physics, Academia Sinica, Taipei, TAIWAN
4Synchrotron Radiation Research Center, Hsinchu, TAIWAN.

We have systematically studied the magnetic entropy change, DSM (H, T) in the Fe8 molecular crystals in a wide temperature range. Since the Fe8 crystals are composed of a large number of identical, non-interacting, aligned, anisotropic magnetic clusters with spin 2μB, it is a model system for the study of the fundamental properties of the noninteracted magnetic materials. The isothermal magnetization curves have been measured at the different temperatures between the applied magnetic field and the magnetic easy axes of the clusters. From the isothermal magnetization data, the temperature and field dependence of the magnetic entropy change or magnetocaloric effect [MCE] has been observed found that the magnetic anisotropy plays a very important role in the determination of the magnetocaloric effect.

The maximum and minimum MCE are observed when the applied magnetic fields are parallel and perpendicular to the easy axis, respectively in the whole temperature range. The magnetic entropy change and other properties of a system composed of isotropic magnetic clusters have been obtained by the numerical methods in order to illustrate the magnetic anisotropy effect.

11:45 AM T4.9/ U3.9
NANOSCALE MAGNETIC DOMAIN STRUCTURE IN COLOSSAL MAGNETORESISTANCE MATERIALS. Yen Wei, Yuri Suzuki, Department of Materials Science and Engineering, Cornell University, Ithaca, NY.

The doped perovskite manganites have received an enormous amount of attention recently because they exhibit colossal magnetoresistance (CMR) and may be half metallic, with complete spin polarization at the Fermi level. The magnetic and magnetoresistive responses are extremely sensitive to lattice strain and thus to structural distortion. As a result, many groups have studied partially and fully strained CMR films. We have chosen to study the effects of strain in CMR islands where we can tune the strain state through variation of island aspect ratio. We have fabricated sub-micron sized islands of La0.6Sr0.4MnO3. Magnetization loops indicate a characteristic field that reflects shape anisotropy effects. We have used magnetoresistance microscopy to image the magnetic domain states of these individual islands in zero field after saturation in different directions. The stripe magnetic domain states that we observe are a result of the competition among stripe anisotropy, strain anisotropy, magnetoelastic and magnetostrictive energies. The evolution of domains in a magnetic field reveals the importance of shape anisotropy as well as magnetostriction in determining the micromagnetic states of such small CMR structures. Our understanding of the magnetoresistance provides a foundation for the analysis and implementation of thin film magnetic devices made of this class of materials.

SESSION T5: DEVICES
Chair: William C. Black
Wednesday Afternoon, April 18, 2001
Glickenhouse C3 (Marriott)

1:30 PM T5.1
ELECTRON SPIN RESONANCE TRANSISTORS, FOR QUANTUM COMMUNICATION AND COMPUTING. Eli Yablonovich, UCLA, Los Angeles, CA.

We apply the full power of modern electronic band structure engineering and epitaxial heterostructures to design a transistor that can sense and control a confined electron spin. Spin resonance transistors may form the technological basis for quantum information processing in the near future. This new type of transistor will be similar in size to the transistors on the SIA Roadmap, but their design will emphasize the manipulation of the electron spin on a single donor ion as the core ingredient. The SPIN TRANSISTOR is expected to serve as the enabling device for quantum information processing, and quantum communication. One and two qubit operations are performed by applying a gate bias. The bias electric field pulls the electron wave function between layers of different alloy composition. Owing to the variation of the g-factor (Si<sub>1</sub>g=1.955, Ge<sub>1</sub>g=5.56), this displacement changes the spin Zeeman energy, allowing single-qubit operation. By displacing the electron even further, the overlap with neighboring qubits is affected, which allows two-qubit operation. Certain silicon-Germanium and III-V alloys allow a qubit spacing as large as 200 nm, which is well within the capabilities of current lithographic techniques. We discuss the possible extension of these concepts to semiconductor quantum communication based on spin-dependent selection rules in spin-dependent opto-electronic transceivers.

2:00 PM T5.2
INHOMOGENEOUS CURRENT DISTRIBUTION IN MAGNETORESISTIVE TUNNEL JUNCTIONS. Yun Li, Stanford University, Department of Materials Science and Engineering, Stanford, CA.

We studied the current distribution in NiFe tunnel junctions with single-magnetic-layer electrodes. The NiFe film was deposited on a SiO<sub>2</sub> substrate at different temperatures to control its magnetic anisotropy. The current-voltage characteristics and the output voltage characteristics of the device were measured. The magnetic anisotropy of the NiFe film was found to significantly affect the current distribution in the tunnel junction. The current distribution was found to be homogeneous in the case of a film with a low magnetic anisotropy, while it was found to be inhomogeneous in the case of a film with a high magnetic anisotropy. The inhomogeneous current distribution was found to be due to the magnetic anisotropy of the NiFe film. The magnetic anisotropy of the NiFe film was found to significantly affect the current distribution in the tunnel junction.
The combination of signal-to-noise requirements, write field limitations, and thermal activation of small particles is thought to limit the potential areal density of the longitudinal media and is commonly referred to as the areal density limit (ARD). Recording media composed of antiferromagnetically coupled (AFC) magnetic recording layers is a promising approach to extend areal densities of longitudinal media beyond these permitted limits. The recording medium is made up of two ferromagnetic recording layers separated by a nonmagnetic layer whose thickness is tuned to couple the layers antiferromagnetically. For such a structure, the effective areal moment density (\(M_{e}\)) of the composite structure is given by the difference between the ferromagnetic layers, allowing the effective layer thickness to scale independently of the physical thickness of the media. This allows AFC media to maintain thermal stability even for low \(M_{e}\) values. Experimental realization of this concept using Co/PtCB alloy layers that demonstrates thermally stable low-\(M_{e}\) media suitable for high-density recording will be discussed.

3:45 PM T5.6

Tunnel magnetoresistance (TMR) is of increasing technological importance for applications in spintronics and has been the subject of considerable research. (*) However, it is based on the presence of magnetic layers which may be affected by any type of interlayer coupling. Of particular importance in this context is the effect of dipolar magnetic coupling (also known as Néel-coupling or "orange-peel" coupling) induced by the interfacial and surface roughness of the layers. We therefore studied the influence of this dipolar coupling in Co/Au/NiFe(20) TMR layers and contacts. The roughness of the individual layers was determined from in-situ STM investigations. We also confirm an increase of the dipole coupling between the magnetic layers with decreasing barrier thickness as predicted by the model. Deviations from the theoretical prediction occur for the case of thinner soft magnetic layers. This can be understood by a reduced magnetization in very thin films. We demonstrate the importance of the dipolar coupling for the understanding of the magnetic behaviour of TMR elements by comparing TMR curves for morphologically optimised and non-optimised structures.

4:00 PM T5.7
REALIZATION OF HIGH SENSITIVE SENSORS BASED ON SPIN-DEPENDENT TUNNELING. Henri Jaffres, D. Lacour, F. Nguyen Van Dau, F. Petroff, J. Pavare, J. Thibaud, CNRS/THOMSON-CIL, Orsay Cedex, FRANCE.

Recent advances in the physics of spin-dependent tunneling across a thin insulating barrier pave the way for a new technology of magneto-electronics devices such as sensors, read head or memories. This is made possible by the development of aluminium tunnel junctions that offer large magnetic resistance at room temperature associated with a large resistance per unit area. This large resistance per unit area has enabled the realization of high sensitive sensors requires a perpendicular arrangement of the two magnetizations which is only possible by a perfect and independent control of each nanomagnet. Ideally, the so-called hard layer is pinned along a fixed direction by means of the unidirectional exchange bias (UEB) that exists at the interface with an antiferromagnet (AF). Under the external field, the signal modulation is then produced by a slight rotation of the soft layer from its easy axis direction perpendicular to the exchange bias. Following this argument, we have developed a concept of sensors working at room temperature and based on crossed exchange bias and step-bunching anisotropy originating from an artificial modulation of the substrate topography. The soft layer is played by a sputtered Co (NiFe) film grown on microsized Si(111) substrate. The top Co layer is hardened after deposition of an AF material (CoO, IrMn and others) and annealing in the presence of a strong magnetic field along the perpendicular to the substrate. The sensors can be used to present magneto-transport results of these sensors. Their response and thermal behavior will be analyzed and correlated to the magnetic properties of each electrode. Discussions will be led in sight to optimize either the sensitivity or the precision of the angular detection.
4:15 PM T5.8

The direct effect of high current density on magnetization states is studied on various electrodeposited magnetic nanowires of controlled morphology. Three kinds of samples have been studied: (1) homogeneous oxide-free nanowires made by sputtering on Co (10 nm)/Cu (10 nm) bilayers, (2) Co-Cu nanowires containing 10% Co, and (3) nanowires composed of a homogeneous Ni part and a multi-layered Co/Cu part. Three different experimental protocols were adopted for this study: (a) A DC current is injected. Giant magnetoresistance hysteresis loops are performed with current density up to about 10^7 A/cm^2. A modification of the hysteresis has been observed. A ramp of the current density at fixed external field was also performed showing a hysteretic behavior linked to the magnetization states. (b) Pulsed current is injected (0.5 μs) close to unstable states of the magnetization. The effect of the current is to force the magnetization to reach a more stable state. The states reached after the current injection are studied as a function of the magnetic configurations and are shown to depend on the direction of the spin polarization of the incident current. (c) A pulsed current is injected (10 μs up to some tens μs), and time resolved measurements are performed. Deviation from the thermal activation law (at fixed potential barrier height) was evidenced and quantified at high current density. In the case of the quasistatic measurements (a), the modification of the hysteresis could be described in terms of exchange torque produced by the spin-polarized current in a magnetic layer. In contrast, the measurement of irreversible magnetic transition (b) and (c) are more likely described in terms of spin transfer between the current and the magnetization due to spin-flip scattering.

4:30 PM T5.9
IN SITU CHARACTERIZATION OF ULTRA SMALL MAGNETIC JUNCTIONS MADE BY ELECTROCHEMICAL TECHNIQUES. A. Sidorov, J.R. Jennings, G.S. Yang, J. Redenbrning, D. Dadin. Dept. of Physics and Astronomy, Dept. of Chemistry, University of Nebraska Lincoln, Lincoln, NE.

We use template synthesis to make magnetic wires of diameters down to 30 nm. Using a plating/oxidation/plating sequence, we are able to synthesize ultra-small insulating junctions. They are of interest for magnetoresistance effects, in particular when investigating spin-dependent blockade effects due to impurities in the barrier. We use electrochemical impedance spectroscopy to characterize in-situ the growth of the oxide barrier. We are able to deduce the thickness and its evolution with oxidation time. For NiO barrier, we can also estimate the density of impurities from the bias dependence of the impedance spectrum, and adopt the oxidation process to maximize the impurity concentration. A reduction of two orders of magnitude has been obtained. The critical current density in the plating of the top layer. Nonaqueous electrochemistry is necessary to avoid the dissolution of the oxide barrier. Impedance spectroscopy is used for investigating how the insulating junction has been modified by the top layer deposition.

4:45 PM T5.10
REVERSAL PROCESSES IN ION IRRADIATION PATTERED Co/Pt MULTILAYERS. T. D. Dunning, M. Kostiuk, N. P. Cho, G. Thomas, Gregory Tenenbaum, Dept. of MSE, University of California, Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA; Bruce D. Terris, IBM Almaden Research Center, San Jose, CA; Dieter Weiser, Seagate Technology, Pittsburgh, PA.

[111] textured (Co,10-x)/Pt(10 nm) multilayers with perpendicular anisotropy were grown on an electron transparent SiN windows using electron beam evaporation. These multilayers were patterned into magnetic submicron arrays by ion beam irradiation through a stencil mask and by a direct Ga Focused Ion Beam writing. Two complementary techniques of scanning and transmission x-ray microscopy were employed to study the reversal processes of the patterned magnetic arrays. Lorentz transmission electron microscopy, sensitive to the in-plane magnetization, revealed magnetically soft ion-irradiated areas. X-ray transmission microscopy of the Advanced Light Source, utilizing element specificity (Co L absorption edge) and magnetic contrast due to magnetic circular dichroism (MCD), was used to image the reversal of perpendicular magnetization with a 25 μm resolution. Switching at a remanent field in a polar direction, showed significant decrease in intensity for irradiized regions as a result of the change of the easy axis of magnetization from out-of-plane to in-plane. The same area imaged at 750 kV, (off the Co edge), showing no topographical features or changes due to the patterning. Reversing the applied field direction resulted in partial switching of the un-irradiated areas at fields below the sample coercivity (Hc, eff = 6 kOe). The reversal originated at the edges of the un-irradiated and the non-irradiated regions. Details of the magnetizing experiment including the reversal mechanism for the samples exposed to different irradiation doses are being discussed in the paper. These results are correlated with the microstructure, which was investigated using high resolution and energy filtered transmission electron microscopy (TEM).

SESSION T6 SPINS IN SEMICONDUCTORS
Chair: Konrad Bassmann
Thursday, April 19, 2001
Golden Gate C3 (Marriott)

8:30 AM T6.1
Ni2MnIn FOR SEMICONDUCTOR SPIN INJECTION. R.H. Victora and K.A. Khiz, University of Minnesota, Dept. of Electrical and Computer Engineering, Minneapolis, MN.

The emerging field of 'spintronics' would benefit greatly from the discovery of a practical material system which permits the successful injection of spins from a ferromagnet into a semiconductor. Requirements include properly positioned bands near the Fermi level of the bulk material and a substantially non-scattering interface. We use a first-principles electronic structure method that employs the linearized augmented Slater-type orbital (LATO) formalism to examine these issues. Based on our calculation of the bulk band structures, we find that the first criterion is well satisfied for the combination of Ni2MnIn and InAs where the minority spin electron transmission near the zone center is nearly 1.0 and the corresponding spin injection efficiency will be strongly reflected. The second criterion requires the calculation of the magnetic and electronic structure for a complete interface. We find, for a 20 nm Ni2MnIn superlattice based on the [100] interface that the distortion of the Ni2MnIn magnetic structure by the semiconductor is minimal. For example, the maximum decrease in polarization is 0.20 cm at Mn atom, which is only a six percent decrease from the bulk value of 3.5. Charge transfer from the metal to the InAs is more significant, with the largest amount (approximately 0.6 e per formula unit) occurring for an In terminated semiconductor. Examination of the density of states projected near the 2-dimensional Brillouin zone center suggests that the overall scattering produced by interface states may be tolerable.

9:00 AM T6.2

Magnetoelectronic devices rely upon an imbalance in the number of minority and majority carriers to add additional degree of freedom to traditional logic devices. The ideal magnetoelectronic device consists of ferromagnetic materials that exhibit complete spin polarization at the Fermi surface (i.e. half-metallic ferromagnets). One promising class of materials is the Hessler alloys, some of which have been predicted by first principles band theory to be halfmetallic. Here we report on the magnetic, structural and spin polarization properties of two such Hessler alloys, Co2MnSi and Co2MnGe. We have studied single crystals, grown by a tri-arc Czochralski method, and thin films grown by d.c. magnetron sputter deposition. Single crystal boules, typically 5 mm in diameter and 3-4 mm in length, are grown by line backscattering diffusion and XRD. Thin films have been characterized for long-range and short-range chemical ordering by XRD and x-ray absorption fine structure (XAFS), respectively. All samples have been studied using SQUID magnetometry, digital scanning calorimetry, electron microscopy, energy dispersive x-ray spectroscopy, and point contact Andreau reflection (PCAR). Pure phase (space group: La) films have been found in the temperature range of 570K to 770K in a pressure range of 30 to 60 mTorr. The Curie temperatures were determined by DTA as 1000K and 900K for the Si and Ge alloys, respectively. The saturation magnetization per formula unit (at T = 10K) were measured by SQUID as 5.8 μB/μ < 5.15μB/μ for both alloys whereas theoretical predictions indicate 5.8μB/μ. Spin polarization (P) of single crystalline and thin films measured by PCAR at 4K have values ranging from 50-60% depending upon the processing histories. These results suggest that the Hessler alloy may not be halfmetallic. Alternatively, the P may be limited by antiferro effects. However, their measured P is enhanced compared with Fe, Co and permalloy and therefore may be of use in magnetoelectronic devices.
9:45 AM *TE.3

Electrical spin injection into a semiconductor is a prerequisite for realizing the potential of semiconductor-based spintronic devices. This has been an elusive goal, however, and only modest effects [< 1%] have been observed in the past. We report highly efficient electrical spin injection from a magnetic contact into a GaAs-based light emitting diode (LED) heterostructure spin-LED [1] in which the spin injection efficiency exceeds 50%. The samples are grown by MBE, and the semi-insulating GaAs barrier for MnSe serves as a source of spin-polarized electrons which are injected into an applied bias voltage into a GaAs quantum well. Raditive recombination of spin polarized carriers results in the emission of circularly polarized light. The carriers are generated via the capture of a polarized carrier spin carrier polarization, enabling a quantitative measure of spin injection efficiency. The measured circular polarization of the electroluminescence (EL) exceeds 50%, demonstrating that highly efficient spin transport occurs across the MnSe/AIGaAs interface despite the large 0.5% lattice mismatch. The EL line shape consists of multiple components whose relative polarization provides insight into spin relaxation mechanisms. We compare results from ex situ and in situ contacts, and with those obtained for carefully lattice matched systems and for hole injection.


10:15 AM *TE.4
AB INITIO CALCULATIONS FOR STRUCTURAL AND ELECTRICAL PROPERTIES OF MnGaAs Layers. Leonard Kozack, Meinhard Jain, and James R. Chelikowsky, Dep. of Chemical Engineering and Materials Science, Minneapolis, MN; Vitaly V. Godlevsky, Dep. of Physics, Rutgers University, Piscataway, NJ.

Fermi-vacuum semiconductors, especially III-V semiconductors with a magnetic ion impurity center, have recently attracted much attention due to their potential in making use of both charge and spin densities on the same chip. In order to realize this potential, one must understand the consequences of the impurity center on the electronic structure. Here, we present an ab initio calculation, based on a pseudopotential approach within a spin-polarized density functional theory framework, for the electronic structure of MnGaAs. Our simulations assume a realistic Mn content of several percent and allow for atomic relaxation effects. Therefore, they allow a direct comparison to experimental data. We find the MnAs bond to be stretched with respect to the GaAs bond, in agreement with experiment. We observe no Jahn-Teller distortion effects and find the structural relaxation to have little effect on the electronic properties. We find a significant distribution of Mn-related acceptor states in the lower part of the conduction band. The thermal stability of Mn dopants is found to be high, and the emission of the half-filled Mn-related states is found to be a promising candidate for spin injection into GaAs quantum well LED's.

10:30 AM *TE.5

Dilute magnetic semiconductors (DMS) offer the use of the spin degree of freedom of the electron in addition to its charge in device applications. Controlling the phase of the spin wavefunction within these devices would potentially enable the development of high speed logic and memory, quantum communication, and electro-optic switches and modulators. To date, current work in this "spintronics" arena has focused upon (Ga,Mn)As, (In,Mn)As, and (Ga,Mn)Sb. The drawbacks for these materials are Curie temperatures below room temperature, limiting their potential application. However, recent theoretical calculations have predicted a Curie temperature for GaMnN of roughly 400 K [1]. The potential for spin related phenomena coupled with the application potential of nitrides to high temperature power devices with a GaN channel make the GaMnN spin-FET highly desirable. In this paper, we will report for the first time on the growth of both GaMnN and GaMnP thin films by gas source molecular beam epitaxy (GSMBE). Me levels up to 41%, as determined by electron spectroscopic ellipsometry (ESE) have been obtained in GaMnN X-ray diffraction (XRD) shows no evidence of second phase formation in either GaN, (Mn)As, or GaN, (Mn)Sb. Addition of Mn to the GaN changes the conductivity from highly conductive n-type to a highly resistive p-type semiconductor, behaving as a deep acceptor. Nominal semi-insulating GaMnN with a Mn concentration of 4.5% shows paramagnetic behavior with a saturation moment per Mn of 3.9 Bohr magnets, suggesting that much of the Mn is substitutional. The addition of GaMnN makes the material n-type and produces what appears to be a ferromagnetic phase, but with a low Curie temperature. Similar studies on GaMnP will be discussed in this talk as will the effect of adding Mg to both materials to stabilize the ferromagnetic phase.


11:15 AM *TE.7

Spintronic devices will require both spin injection from a ferromagnetic (FM) to a semiconductor (SC) and spin detection from a SC to a FM [1]. We previously reported highly efficient spin detection associated with spin filtering of ballistic electrons across single layer FM/SC Schottky interfaces. We also observed no attenuation of the photocurrent at high temperature [2]. Here we extend the earlier study to test our model of the spin filtering mechanism with a spin-valve structure, in which the FM layers can be switched independently. We fabricated samples of Alx/Co/Cu/Fe in the range of 100 and measured the photocurrent into the Au layer and one ohmic contact to the bottom of the substrate. The samples were characterized by magnetotransport measurements which confirm the magnetization reversal for the applied bias. A helicity-dependent photocurrent, dependent upon the relative magnetization configuration in plane between the two FM layers (parallel or anti-parallel) was measured for the angle range of 0 ≤ θ ≤ 45°. In the case of θ = 0, the photon helicity is orthogonal to the FM magnetization and no spin dependence is expected, while the spin dependence of the transmission is expected to increase at 90°. For the case of θ = 90°, the spin is parallel to the photon helicity and no spin dependence is expected. The photocurrent shows no variation in transmission at θ = 90°, as expected. The photocurrent also shows no variation for θ = 45°, as expected. We also compare these results with those of samples with a single FM layer. These results demonstrate the importance of ballistic spin filtering in the spin-dependent transport and hold promise for the development of spintronic devices.


11:30 AM *TE.8
FERROMAGNETIC AND STRUCTURAL PROPERTIES OF Mn-IMPLANTED p-GaN. N. Theodoropoulou*, A.F. Hebard*.
Direct implantation of Mn ions into p-GaN epi layers was performed at temperatures of 350°C (to avoid amorphization) and doses designed to produce 0.1-5 at.
% Mn. The samples were annealed at 700°C-1000°C. For doses ≥ 3 at.
% large (10nm) precipitates and platelet structures were observed in addition to the implant damage induced dislocation loops. These structures are suggested to be either GaMn or MnN2 phases. When these are present, there is a hysteresis in the magnetization of the film which disappears at around 250K. A rough calculation from the saturation magnetization yields approximately 0.2 Bohr magnetons per Mn. At lower doses the material does not show any ferromagnetism. The direct implantation approach may be attractive for some spin-injection structures based on GaN.

11:45 AM T6.9
CHALCOGENITE MAGNETIC SEMICONDUCTORS: AN AB-INITIO STUDY OF THEIR STRUCTURAL, ELECTRONIC AND MAGNETIC PROPERTIES. S. Picardi, A. Continenza, Dip. Fisica, Univ. L’Aquila, L’Aquila, ITALY; W.T. Gem, Y.J. Zhao and A.J. Freeman, Materials Research Center (Supported by the U.S. National Science Foundation) and Dept. of Phys. and Astron., Northwestern Univ., Evanston, IL.

A great effort is being devoted to explore new advanced magnetic semiconductors based on crystal structures that transcend the limitations (such as defect formation, and too low operating temperatures for spin injection and ferromagnetic properties) of the magnetic zinc-blende systems explored so far (e.g. Ga0.8Mn0.2As). Within this context, we performed ab-initio full-potential linearized augmented plane wave (FLAPW) simulations for several Mn-doped chalcopyrite systems like ZnGe0.95Mn0.05S, CdGe0.95Mn0.05S and CdGe0.95Mn0.05S. We present results obtained for structural, electronic and magnetic properties as a function of Mn concentration, and we discuss the effect of cation (i.e. Zn vs Cd) and anion substitutions (i.e. As vs P) on the magnetic properties of these systems. Our studies are particularly timely in view of the report by Medvedkin et al. G.A. Medvedkin et al, Jpn. J. Appl. Phys. 39, L949 (2000) of room temperature ferromagnetism in highly concentrated CdGe0.95Mn0.05S.