SYMPOSIUM F
Magnetic Materials, Structures, and Processing for Information Storage
April 24 – 27, 2000

Chairs

Michael A. Seigler
Seagate Technology
River Park Commons
Pittsburgh, PA 15203
412-918-7016

Christopher Murray
IBM T.J. Watson Research Ctr
PO Box 218
Yorktown Heights, NY 10598
914-945-3021

Tom P. Nolan
Mountainview, CA 94043
650-968-8010

Shan Wang
Dept of MS&E
Stanford Univ
McCullough Bldg Rm 351
Stanford, CA 94305-4045
650-723-8671

Brian J. Daniels
Wafer Process Development
Seagate Recording Heads
MS NRW 113
Minneapolis, MN 55435-5489
612-844-8377

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*Invited paper
SESSION F1: PATTERNED MAGNETIC RECORDING MEDIA I

Monday Morning, April 28, 2000
Goldman Gate B3 (Marriott)

10:00 AM #F1.1
PATTERNED MAGNETIC MEDIA FOR HIGH DENSITY DATA STORAGE
Bruce D. Terris, IBM Almaden Research Center, San Jose, CA.

The growth in density of magnetic disk drives has traditionally been accompanied by a reduction of the media grain size in order to maintain sufficient signal to noise levels by keeping a constant number of grains per writter bit. However, at some density, thought to be below 100 Gbit/in², scaling processes begin to grind to a halt, which is unacceptable to thermally excited reversals of the magnetization direction; they will become superparamagnetic. One approach to avoid this is to create single domain magnetic bits in a patterned magnetic film by exploring a number of routes to producing such patterned magnetic islands, with the goal of producing sub-100 nm magnetic islands covering a 1-2 inch diameter disk. I will discuss our progress in patterning using ion beam irradiation through a stencil mask, direct patterning using a Ga-irradiated ion beam, and a stamping and replication technique. MFM imaging as a function of applied magnetic field is used to study the magnetic properties of sub-100 nm islands patterned in multilayer and granular films.

10:30 AM #F1.2
NANOIMPRINT LITHOGRAPHY FOR QUANTIZED (PATTERNED) MAGNETIC DISKS
S.Y. Cho, L. Kong, M.T. Li, W. Wu, W. Yu, and B. Cui, NanoScience Laboratory, Department of Electrical Engineering, Princeton University, Princeton, NJ.

Since its proposal and initial demonstration [1], the advantages of nanoimprint lithography (NIL) for the fabrication of magnetic thin films [2] have been recognized. The recognition stems partially from two facts: (a) conventional magnetic recording media is approaching its limit; and (b) the technological advances in magnetic recording media are required. We believe the most promising manufacturing technology of all is nanoimprint lithography [NIL], which-patterns a material mainly by mechanical deformation (i.e. embossing) [2], rather than by radiation or chemical reaction. We will present the latest development of NIL and its application in patterning QMDs. QMDs with a density of 400 Gbits/in² have been fabricated. The reading and writing of QMDs with 65 Gbits/in² for perpendicular magnetization and 50 Gbits/in² for longitudinal magnetization will be shown. The imprint area over 4 inch wafer with excellent uniformity has been demonstrated.

11:00 AM #F1.3
TOPOLOGICAL AND MAGNETIC PATTERNING OF Co/Pt MULTILAYERS
V. Metha, S. Cho, C. Chu, J. Reihl, and D. J. DiPaola, School of Applied and Engineering Physics, Cornell University, Ithaca, NY; W. J. Choyke and J. R. Gomer, Center for Magnetic Recording, University of New Mexico, Albuquerque, NM; B. Terris, IBM Almaden Research Center, San Jose, CA.

Using magnetron sputtering for Pt and e-beam deposition for Co the [Co/Pt]n multilayers were prepared on a Si/SiO2 substrate. The patterning of submicron periodic arrays were done in two ways, using traditional interferrence or e-beam lithography and lift-off which modulates the material composition of the film, and using 310 KeV ion irradiation to create a mask which leaves the chemical composition and topography unchanged but reduces the magnetic anisotropy. The results of systematic characterization of arrays for different doses ranging from 10¹⁵ to 5 x 10¹⁷ ions/cm² with SQUID magnetization to determine the magnetic anisotropy and moment size, with atomic force microscopy (AFM) and magnetic force microscopy (MFM) to determine the topography and the magnetic order in the periodic arrays, and with magnetic optical imaging to visualize the moment reversal process during a magnetization cycle will be presented. This work was supported by the U.S. DOE, BES-Materials Sciences, under contract W-31-109-ENG-38 (U.W., V.M., G.C.) and by DARPA (W.F., S.R.J.B.)

11:15 AM #F1.4
FABRICATION AND 2.6GHZ 5/IN² RECORDING IN PERPENDICULAR PATTERNED MEDIA
Joyce Wong, Axel Scherer, California Institute of Technology, Dept of Electrical Engineering, Pasadena, CA; Mladen Baric, Sheldon Schalk, University of California, San Diego, Dept of Physics, La Jolla, CA.

Patterned media hold the prospect of delaying the onset of the superparamagnetic effect in current longitudinal thin film media to beyond 100Gbit/in². Using a combination of high current electron beam lithography, chemically assisted ion beam etching and electroplating, we have fabricated high aspect ratio Ni columns that are embedded in an (AlGa)0.2O0.8/ GaN substrate. The etching process takes advantage of the high etching rate of AlGaN's and GaNs, and the superb selectivity of GaNs over (AlGa)0.2O0.8 to create high aspect ratio holes in the GaN substrate. Besides using a robust ion etch mask, the (AlGa)0.2O0.8 layer also acts as an ideal surface for chemical mechanical polishing to remove all overlapped Ni mushroom. This results in a smooth surface that is suitable for subsequent slider contact during magnetic characterization. We have fabricated perpendicular patterned media samples in the form of tracks, with 0.25µm and 0.5µm spacing in the down-track and cross-track direction respectively. Magnetic Force Microscopy and Scanning Magneto-Resistance Microscopy are used to confirm that the embedded Ni magnets in the (AlGa)0.2O0.8 matrix are stable single domain magnets. Furthermore, we have demonstrated data storage in these embedded 150nm-diameter Ni columns, corresponding to an areal density of 2.6Gbits/in², using a commercial inductive write/in-line read sensor. This demonstration bridges the gap between the fabrication of such structures and their use in actual magnetic storage systems. Current work includes reducing the down-track spacing to 0.125µm and keeping the cross-track spacing at 1 µm, which corresponds to increased storage density of 5.2Gbits/in². In addition to embedding the magnets in the (AlGa)O0.2/GaN system, recent work on the fabrication of high aspect ratio Ni columns in an alternative SiO2/Si embedding material system will also be presented.

SESSION F2: PATTERNED MAGNETIC RECORDING MEDIA II

Monday Afternoon, April 28, 2000
Goldman Gate B3 (Marriott)

1:30 PM #F2.1
FABRICATION AND MAGNETIC PROPERTIES OF PATTERNED MAGNETIC MEDIA
C.A. Ross, Massachusetts Institute of Technology, Department of Materials Science and Engineering, Cambridge, MA.

Periodic arrays of magnetic nanoparticles are interesting, both as materials for the study of the fundamental behavior of magnetic switching and interactions, and for applications in data storage. New methods for data storage will become important in the next few years as data densities increase, because of the onset of thermal instability in conventional media. One approach is to use 'patterned media', in which each bit is stored in a lithographically defined magnetic element with two stable magnetization states. Data are read and written using an ultra-narrow magnetic head or a magnetic probe tip. Another application for magnetic structures is in the design of magnetic RAM, in which data are stored in tiny magnetoresistive elements. We have used interferometric lithography to pattern large-area arrays of magnetic nanostuctures with periods of 100 nm and above. Arrays of magnetic particles have been made using evaporation, etching, or planarization processes, allowing the particle microstructure, magnetic anisotropy, shape and array geometry to be controlled. We will describe the magnetic properties of arrays of particles, in particular their magnetoresistance, switching behavior, mutual interactions, and how closely they approximate to the coherent reversal model, and I will discuss their application in data storage devices.
2:00 PM F2.2
IN SITU TEM INVESTIGATION OF SWITCHING OF MAGNETIC PATTERNS PREPARED BY ION-BEAM IRRADIATION. Greg J. Kusinski, Dept of Materials Science and Engineering, Univ of California, Berkeley, CA; D. Weller, B.D. Terrin, L. Felks, C. Betterm, M.E. Best, A.J. Kellock, J.E.E. Baglin, IBM Research Division, Almaden Research Center, San Jose, CA; K.M. Thomas, Materials Science Division, Lawrence Berkeley National Laboratory; G. Thomas, Dept of Materials Science and Engineering, University of California, Berkeley, CA.

Co/Pt multilayers with perpendicular anisotropy were grown on an electron transparent Si$_3$N$_4$ membrane using electron beam evaporation. Regularly spaced 1 micron sized regions, with the easy axis of magnetic anisotropy directed into the silicon underlayer, were magnetically patterned via ion beam irradiation through a silicon stencil mask. Typical conditions were 700 keV nitrogen ions at doses of 5.1x10$^{14}$/cm$^2$. Transmission electron microscopy analysis revealed no microstructural or chemical differences between the irradiated and non-irradiated regions. A wide lognormal grain size distribution, with approximately a 50nm mean diameter, was observed. In-situ magnetizing experiments, in which magnetization reversal processes were viewed directly in the presence of varying magnetic fields, were staged in the transmission electron microscope operated in the Lorentz mode. In the remnant state, the in-plane axes were in a multidomain configuration. When the in-plane field component was increased to 200Oe, domain wall motion was observed, resulting in alignment of the patterns with the direction of the applied field. A significant softening of the in-plane regions as compared to the out of plane coercivity, (Hc || z-axis) = 5-6kOe was confirmed by Kerr measurements of larger, 1-2Km regions exposed to the same doses of ion irradiation.

2:15 PM F2.3

Nanowires with lateral dimensions as small as 20 nm have been fabricated by nucleate track etching in 5 micron thick, single-crystal muscovite mica wafers. The nanowires have a diamond shape cross section with their axes aligned with the crystal axes of mica as a result of anisotropic etching. Nickel nanowire arrays have been fabricated by electrodeposition into the nanowires. Strong shape anisotropy has been observed due to the high aspect ratio of the wires. Due to the diamond shape of the wire cross section, strong in-plane magnetic anisotropy has also been measured. Phase transformation in these quasi-one-dimensional entities have been studied by high temperature magnetization measurements. The Curie temperature shifts to lower temperatures with decreasing wire diameter and obeys finite size scaling theory.

3:00 PM #F2.4
TIME-DEPENDENT COERCIVITY IN MAGNETIC STORAGE MEDIA. W.D. Doyle and S. Srinivas, Center for Materials for Information Technology, Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, AL.

The natural precessional response of the magnetization in an applied field has always complicated the high frequency switching process in magnetic devices. Until recently, magnetic recording, which has dominated on-line and archival storage, could be treated quasi-statically. However, as linear densities approaching 400Kbits/in at disk rotation speeds exceeding 10,000 RPM, recording must occur in ~10-6s, the regime where precessional effects become important. At the same time, to achieve these extraordinary linear densities, grain size in recording media must be reduced to control nucleation and to reduce exchange coupling between grains. The result is significantly increased thermal instability, reducing the remanent coercivity which at 10°/s is ~400kA/m to values below 2500 Oe at long times (10%), thereby reducing readability. This requires that the time dependent properties be addressed over > 18 orders of magnitude! Here, the experimental data on the time-dependent remanent coercivity $H_{Cr}(t)$ in state-of-the-art media is presented and related to the loss of magnetic recording, particularly both the magnetic instability and anisotropy. Orientation is shown to have relatively little effect on $H_{Cr}(t)$. In all cases, $H_{Cr}(t)$ is well described by a generic form of Sherrack's Law, at least down to 10°/s. Below 10°/s, precessional effects increase $H_{Cr}(t)$ more rapidly but the product of the field increment relative to $H_{Cr}(t)$ at 10°/s and the field pulse width is only ~100 200 Oe as. Therefore, existing high moment record head and media materials should be adequate up to several GHz.

3:30 PM F2.5
MAGNETIZATION DECAY IN MAGNETIC THIN FILM MEDIA. Shiting Li, Daniel Brown, John Dykes, Jack vonofeld, Dean Palmer and Rick Drue, Advanced Recording Technology Laboratory, Seagate Technology, Bloomington, MN.

A systematic experimental study of the magnetization decay (M-decay) in various high recording density media with different grain sizes, chemical compositions and crystalline orientations has been carried out to study the effect of the microstructure, demagnetizing field and initial magnetization field on the stability of the magnetic recordings. The magnetization decay of those media was carefully measured via an alternating force magnetometer (AGM). It is found that the observed M-decay rates from AGM are quite comparable with the spin-flop and testing results. It is also found that the M-decay rates are very sensitive to both demagnetizing fields and in-plane crystal orientations. In addition, the magnitude of the initial magnetizing fields also shows certain influence on the decay rates, suggesting that some non-magnetization decay mechanisms might exist in the magnetization decay process of magnetic recording media.

3:45 PM F2.6
REVIEW OF RELAXATION MECHANISMS IN DYNAMIC MAGNETIZATION PROCESSES. H. Neal Bertram, Vladimir L. Safonov, Center for Magnetic Recording Research, University of California-San Diego, La Jolla, CA.

Very high frequency applications of magnetic materials require detailed understanding of magnetization relaxation processes. For example, for projected high density recording beyond 1 GHz, both the media and the heads must respond in less than 0.25 nsec. In this presentation we will review both fundamental and “dimensional” relaxation. For thin films whose plane dimensions exceed a domain wall width or an exchange length, the magnetization dynamics is initially governed by the thin film demagnetization factor. As the magnetization becomes almost completely reversed, the excitation of non-linear spin waves removes the Zeeman energy, allowing the magnetization to remain in almost the completely reversed state. We will discuss final relaxation by homogeneous magnetoelastic coupling to the lattice. For fine grains whose size is sufficiently small so that the grain magnetization is virtually uniform, nearly spin waves cannot exist and we will discuss a new analytic model of reversal that couples the coherent rotation to impurity ions by an anisotropic exchange mechanism. These impurity ions, whose ground state can be expressed in terms of an “effective” spin, are assumed to relax at very high rate to the lattice.

4:15 PM F2.7
SUPERPARAMAGNETIC BEHAVIOR OF GRANULAR COBALT-CARBON FILMS CONSISTING OF NANOCRYSTALLINE COBALT ENCAPSULATED IN CARBON COATINGS. Hao Wang, Shupeng Weng, Ning Ke, Wingyiu Cheng, Manfie Chinh, The Chinese Univ of Hong Kong, Dept of Electronic Engineering and Materials Science Technology Research Center, Hong Kong, CHINA; Gehui Wen, Xixiang Zhang, Hong Kong Univ of Science and Technology, Dept of Physics, Hong Kong, CHINA.

Co$_x$C$_{1-x}$, (x=49,60,65%,5%) composite thin films of about 20 nm thick were prepared by pulsed filtered vacuum arc deposition. Subsequent annealing was performed in vacuum (~10$^{-8}$ Pa) at 350°C for one hour. The films were characterized by X-Ray scattering, transmission electron microscopy, Raman spectroscopy, atomic force microscopy and magnetic force microscopy. The as-deposited films were found to be amorphous. After annealing, the films were found to consist of nanocrystalline Co grains encapsulated in carbon coatings. The superparamagnetic behavior of the annealed Co$_x$C$_{1-x}$ films was observed by the measurement of DC susceptibility and magnetic hysteresis using a SQUID magnetometer. The superparamagnetic relaxation blocking temperature was marked to be about 12 K by the narrow peak of the zero-field-cooled magnetization under an applied field of 100 Oe, and the irreversibility was found to start at 38 K in the field-cooled process. Higher Co concentration and further annealing at higher temperature led to the transformation from superparamagnetism to ferromagnetism. This work is partially supported by the Research Grants Council of Hong Kong (Ref. No.: CUHK 4192/89E).

4:30 PM F2.8
STATIC AND DYNAMIC MAGNETIC BEHAVIOR OF SUPERPARAMAGNETIC NANOPIERCES, Eugene L. Venturini, Jess P. Wilcoxson and Paolo N. Provenci, Sandia National Laboratories, Albuquerque, NM.

We discuss the DC and AC magnetic susceptibilities of monodisperse Fe and Co nanoparticles with diameters between 2 and 5 nm, giant spins of several hundred to several thousand Bohr magnetons, and
superparamagnetic blocking temperatures of 5 to 50 K. Synthesis in oil-free liquid-nitrogen-cooled equipment provides samples containing only iron, nickel, and cobalt-free ensembles of controlled size. Static susceptibilities exhibit irreversibility (temperature and field hysteresis) below the blocking temperature and fit a Langevin function at higher temperatures. At frequencies between 0.1 and 1000 Hz AC susceptibilities show no measurable temperature hysteresis but have substantial dispersion in peak temperature and in amplitude at temperatures below the peak. Fitting these data to a single model based on a two-level jump process for spin reorientation yields estimates for the spread in anisotropy energy barriers (determined by the product of the nanoparticle volume and magnetic anisotropy). The frequency dependence provides insight into the spin dynamics, including the influence of a static magnetic field. Due to the giant spin on individual nanoparticles, an applied field of a few hundred Oe introduces a Zeeman energy into the dynamics that is comparable to the energy barrier from magnetic anisotropy and is the peak in the AC susceptibility at higher temperatures. The sample provides an impossibly high estimate of the spin magnetic susceptibility and allows a consistency check with the value obtained from Langevin function fits to the static susceptibility. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. DE-AC09-08R43589. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy.

4.45 PM F2.9

SUPERPARAMAGNETISM AND SURFACE SPIN DISORDER IN GAS-PHASE PREPARED MAGNETIC NANO PARTICLE POWDERS. B. Bellinger, A. Kurz, E. F. Klemm, Experimentelle Tiefenphysik, Gerhard-Mercator University, Duisburg, GERMANY; Ch. Janzen, P. Roth, Institut für Verbrennung und Gasdynamik, Gerhard-Mercator University, Duisburg, GERMANY.

γ-Fe₂O₃ (magnetite) – formerly one of the most widely used materials for magnetic recording – has recently experienced a remarkable interest in basic research fields of magnetism such as superparamagnetism [1] or surface spin disorder effects [2]. In order to generate powders of iron oxide nanoparticles, we have employed a gas-phase preparation route utilizing a low pressure flame reactor setup [3], thereby offering the advantage of higher purity as compared to chemical methods. Magnets prepared in this manner are in the range 4nm≤d≤12nm and are controlled by varying the concentration of Fe(II), precursor material within the flame gas. Structural and spectroscopic measurements utilizing XRD, IRAS, and EELS show that the individual particles are single crystalline and single phase magnetite. Magnetic properties of the particle ensembles are studied by means of SQUID magnetometry. Besides the expected decrease of the saturation magnetization accompanied by the onset of superparamagnetism with decreasing particle size, the occurrence of a spin disorder phase becomes obvious from a remaining splitting between field cooled and zero field cooled magnetization curves in external fields of 500Oe corresponding to the observed temperature T₆, is observed to decrease logarithmically with the external field. Below a minimum field, H₆, T₆ remains constant, and within the simple model of a magnetic core surrounded by a non-magnetic entity, the absolute value of H₆ is in good quantitative agreement with the surface stray field of the particle core [1]. [1] J.L. Dähnemann, R. Cherkasov, I. Spivak, M. Nogues, F. Lucardi, F. D'Orano, D. Fiorani, A. Garcia, E. Tronc, and J.P. Jelivet, J. Magn. Magn. Mat., 187 (1998) 139. [2] B. Martínez, X. Obradors, L.I. Balcells, A. Roumet, and C. Monty, Phys. Rev. Lett. 80 (1998) 181, and references therein. [3] A. Janzen, B. Reilinghans, and P. Roth, J. Nanopart. Res. (1999), accepted.

SESSION F3/G1.1-JOINT SESSION: MAGNETIC RECORDING MEDIA

Tuesday Morning, April 25, 2000
Golden Gate B3 (Marriott)

8:30 AM #F3/G1.1

ADVANCED-LONGITUDINAL RECORDING MEDIA USING HCP COBALT ALLIES. Mary F. Doerner, Xingping Bian, Kai Shi, Mohammad Mirzamans, Adam Poluyk, IBM Storage Systems Division, San Jose, CA; Kurt Rubin, Ken Takano, Michael F. Toney, Andrew Moser, Dieter Welker, IBM Almaden Research Center, San Jose, CA.

It is well recognized that thermal stability may place a limit on longitudinal magnetic recording media with practical limits of a maximum data density limit ranging from 50 to 100 Gbit/in² depending on system assumptions such as bit aspect ratio and channel requirements for a given signal-to-noise ratio. Recently, IBM has demonstrated the capability to write and read data with excellent error rates at 35 Gbit/in² using magnetic media that are thermally stable. The very low signal decay rate of 0.05%/decade measured on a SQUID magnetometer at 150 K and 1000 Oe reverse field suggests that there is room for further increase in areal density using conventional Co-alloys. One of the key media improvements that contributed to achieving this good stability was an increase in the magnetocrystalline anisotropy (Ku) of the magnetic film. Although Ku as high as 3.7 × 10⁶ ergs/cm³ has been measured for polycrystalline HCP Co₅FePt₁₂Co₃13, Ku decreases significantly when higher concentrations of Cr and the addition of Ta are used to reduce intergranular exchange coupling. This paper will discuss the processing employed to achieve high anisotropy in Co-alloys including the role of defects, segregation and crystallographic orientation. It is also believed that the capability of the head to write high coercivity will ultimately limit the areal density of magnetic media. Therefore, it is important that the media microstructure be optimized to achieve a narrow grain size distribution and good in-plane c-axis orientation in the Co-HCP alloy. High coercive squareness (8) is necessary for good overwrite properties. The grain size distribution and spin polarization play a key role in determining the thermal decay rate and media signal-to-noise ratio. These aspects of the media microstructure will also be discussed.

9:00 AM F3.2/G1.2

EFFECT OF BORON ON CRYSTALLOGRAPHIC, MAGNETIC, AND RECORDING PROPERTIES OF COBALT ALLOY THIN FILM MEDIA. Dong-Won Park, Robert Sinclair, Department of Materials Science and Engineering, Stanford University, Stanford, CA; Mareike Schluter, Bijl B. Lai, Michael A. Rusnak, HMT Technology, Fremont, CA.

Increasing the storage density of longitudinal thin film media requires accurate control of cobalt alloy grain size without deteriorating magnetic properties including the signal to noise ratio (SNR), overwrite (OW), and thermal stability. In order to achieve precise control of these characteristics, high resolution transmission electron microscopy (HRTEM), vibrating sample magnetometer, and alternating gradient force magnetometer are required, which provide microstructure, magnetic characteristics, and thermal stability, respectively. Furthermore, a dual element head consisting of an inductive and a MR head reveals magnetic recording properties. These characterization tools have been applied to investigate a series of Co₅Fe₇Pt₃Co₅Fe₇Pt₉Co₅Fe₇Pt₁₃ thin film longitudinal media, prepared under environmentally identical sputtering conditions. HRTEM revealed that adding 5% or 8% boron to the magnetic layer resulted in significantly reduced average grain size compared to the media with a Co₅Fe₇Pt₅ magnetic layer. It was also found that by adding boron, SNR and media noise properties were improved, while coercivity and OW decreased. For the medium with 8% boron in the magnetic layer, the OW value was found to be smaller than 30 dB which is required not to cause errors while reading new recorded data. In addition to this characterization, magnetic switching volume and dynamic coercivity will be also presented, which are relevant to the thermal stability of cobalt alloy longitudinal thin film media with and without the presence of the medium.

9:15 AM F3.3/G1.3

TEM AND SUPPORT MAGNETIC MEDIA DEVELOPMENT IN YI2000 Warren J. McInery, Tom P. Nolan and Paul Dorney, Komag, Inc., San Jose, CA

In this 1 square inch space, hard drive media of 1999 stored 2 Gbytes. This requires reproducibly producing thin films with judicious control of >2,000,000 Gs/cm² magnetic grains. Further constraints include corrosion resistance in all environments, impact resistance involving GPa stresses, >300 lbs signal-to-noise, rapid information transfer, and wear resistance associated with heads flying at 20,000 rpm and at a signal density of 0.00075 mm²/byte of a hard disc. These requirements for a finished 3.5" disk of media at $8 in 1999. In the year 2000, storage density must increase >1000%, and price must drop. To solve this ongoing Y2K problem, statistical and efficient TEM techniques are necessary. This paper presents statistical and state-of-the-art TEM methods for the study & control of crystallization in all three directions in these media grains on metal or glass substrates. Electron diffraction, weakbeam dark field, and in situ tilting experiments provide structural analysis to advance these media. Refined thinning and statistical imaging enable the microscopist to see, study, and improve the spatial microheterogeneities that are necessary to isolate each bit of information. Computer processing now enhances the analysis of TEM data, enabling a synergistic relation among TEM, computers, and media processing that improves performance of all.

9:30 AM F3.4/G1.4

RELATIONSHIP BETWEEN THE GRAIN SIZE OF MAGNETIC LAYER AND THAT OF UNDERLAYER IN CO/Pt/C MEDIA. Gui Ma. Robert Sinclair, Stanford University,
High data density and low medium noise requirements make the grain size a critical constraint in the design and manufacture of magnetic media. It is known that the microstructures of the magnetic layer are strongly dependent on the microstructure of the underlayer. A great deal of effort has been expended on decreasing the underlayer grain size in order to decrease the magnetic layer grain size. But recent investigations have shown that the grain size of the magnetic layer might not always follow that of the underlayer, e.g., decreasing at the same time. When the underlayer grain size is too small, the magnetic grain size no longer decreases with underlayer grain size. Considering that the bi-crystal grain boundaries usually are not clearly revealed in normal bright field (BF) Transmission Electron Microscopy (TEM) images, high resolution TEM (HRTEM) images are used to accurately measure the magnetic layer grain size and the angles between the c-axes of adjacent grains. By carefully controlling the processing conditions, CoMo underlayer grain sizes were made to vary from 10nm to 15nm. However, the corresponding CoCrPtBi layer grain sizes became significantly improved. As the demand for higher bit density increases, the crystallographic orientation and microstructure of the magnetic thin film becomes increasingly important. Co-ally films with a small grain size and a highly oriented c-axis offer the possibility of achieving a high signal to noise ratio with fewer grains per bit for future perpendicular magnetic media. In order to produce films with the desired properties, the introduction of a buffer layer and a suitable seed layer is considered to be an important process. The purpose of this paper is to investigate the microstructure of the BiPt$\text{CoFeP}^\text{Bi}$Co-alloy films grown on substrate materials without an intermediate layer, and to compare with those in which an intermediate buffer and seed layer are employed. In the process of the comparison, the roles of the additional layers to enhance the crystalllographic properties of the Co-alloy films is characterized. Furthermore, the effect of substrate temperature during deposition and the sputtering conditions on the resulting microstructure of the films is also determined.

11:00 AM *F3.7/G1.7
CHEMICAL ORDERING AND MICROSTRUCTURE OF FePt THIN FILMS WITH PERPENDICULAR MAGNETIC ANISOTROPY. Bruno Gilles, LTPCM, CNRS Grenoble, FRANCE, Amin Maniy, Yves Simon, David Halley, DFRMC, CENG Grenoble, FRANCE.

The L1$_0$ ordered phases in FePt, FePt$_x$Co$_{1-x}$Pt and CoPt binary alloys in thin films might be promising materials for high density storage media, due to their high magnetocrystalline anisotropy. Depending on the deposition temperature, we have found that FePt alloys grown by MBE may be obtained with a long range order (LRO) varying from 0 to 1, i.e. from the disordered binary alloy to the well ordered L1$_0$ phase with the c-axis perpendicular to the surface. Therefore the ratio between the perpendicularly magnetized anisotropy and the shape anisotropy may be varied from 0 to nearly 2 and materials may be obtained with either in-plane magnetization or out-of-plane magnetization. In this talk we will focus on the growth process and show how the chemical order develops at the surface of the growing layer. Indeed, combining RHEED, STM and Auger or XPS spectroscopies we have found that a complicated segregation process occurs during growth, which may explain the development of the ordered structure with only one out of the 2 equivalent variants. This has been confirmed by experiments in which As or Te surfactants have been shown to inhibit the ordering process. TEM measurements as well as quantitative X-ray analysis have shown that the diffusion of anti-phase boundaries is decreased when the growth temperature is increased and STM images revealed larger atomic and bi-atomic terraces. This suggests that the diffusion length of the atoms on the growing surface may play an important role. Attention has been paid to the relaxation of strain which is in favor of the tetragonal ordered phase but it seems that it is not the effective driving force in the ordering process.

11:30 AM *F3.8/G1.8
MECHANISM FOR ION BEAM MODIFICATION OF MAGNETIC PROPERTIES OF THIN FILMS AND MULTILAYERS. J.E. Bliga, D. Weller, J. Bentley, Hong Kong University of Science and Technology, Hong Kong, KONG.

Co-alloy thin films are a popular choice for current magnetic media. As the demand for higher bit density increases, the crystallographic orientation and microstructure of the magnetic thin film becomes increasingly important. Co-alloy films with a small grain size and a highly oriented c-axis offer the possibility of achieving a high signal to noise ratio with fewer grains per bit for future perpendicular magnetic media. In order to produce films with the desired properties, the introduction of a buffer layer and a suitable seed layer is considered to be an important process. The purpose of this paper is to investigate the microstructure of the BiPt$\text{CoFeP}^\text{Bi}$Co-alloy films grown on substrate materials without an intermediate layer, and to compare with those in which an intermediate buffer and seed layer are employed. In the process of the comparison, the roles of the additional layers to enhance the crystalllographic properties of the Co-alloy films is characterized. Furthermore, the effect of substrate temperature during deposition and the sputtering conditions on the resulting microstructure of the films is also determined.

10:30 AM *F3.6/G1.6
TEMP CHARACTERIZATION OF CHEMICAL COMPOSITION INHOMOGENEITY IN MAGNETIC THIN FILM MEDIA. J.E. Wettig, J. Ma, J. Bentley*.

The structural requirements for low noise magnetic recording media (small grain size, separation of magnetic particles) increasingly conflict with those for magnetization (large uniform grain size, high uniform magnetic anisotropy). Magnetic Co-alloy grain size, grain separation and anisotropy in modern thin film media are all controlled in large part by chemical composition inhomogeneities. Thus, characterization of chemical composition within and between Co-alloy grains is becoming critical for micromagnetic modeling and future media development. Since the grain size of modern recording media is on the order of 1.0 to 15 nm, high resolution characterization methods such as transmission electron microscopy (TEM), nanogauge energy dispersive spectroscopy (EDS) and energy filtered imaging (EFTEM) are necessary to accurately describe the microstructure. This paper demonstrates the strengths and limitations of these characterization techniques using a series of longitudinal recording media prepared for the extreme high density recording (EHD) project of the National Storage Industry Consortium (NSIC). These EHD disks have NiP/A1 supermagnetic substrates with a 60 nm NiAl seed layer and a 7.5 nm CoMn intermediate layer. The magnetic media is a Co$_7$Cr$_3$Pt$_5$Ti$_2$Nb$_2$ alloy with seven different thicknesses resulting in Mrt values from 0.1 to 0.6 memu/cm$^2$. Both EDS and EFTEM have been used to characterize the composition in these longitudinal recording media. Under electron beam irradiation, decreasing magnetic film thickness on the quantification capability. Research is in the ORNL SHaRE User Faculty was supported by the Division of Materials Sciences, U.S. Department of Energy under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, and through the SHaRE Program under contract DE-AC05-76OR000033 with Oak Ridge Associated Universities.

SESSION F4/G2: JOINT SESSION: CHARACTERIZATION OF MAGNETIC THIN FILMS AND STRUCTURES
Tuesday Afternoon, April 25, 2000
Golden Gate B3 (Marriott)

1:30 PM *F4.1/G2.1
X-RAY PROFILES OF MAGNETIC MULTILAYER STRUCTURE. B.K. Tinne, T.P.A. Hase, B.D. Fulthorpe, J. Clarke and S.B. Wilkins, Department of Physics, University of Durham, Durham, UNITED KINGDOM.

We discuss the application of x-ray scattering and fluorescence to the problem of unravelling the relationship between structural and magnetic properties of magnetic multilayers. Particular attention is paid to the use of grazing incidence diffuse scatter to determine the compositional gradient, out-of-plane roughness amplitude, in-plane correlation length and fractal parameter of layered structures. We show how to determine the degree of conformality of the roughness in multiple layer structures from layer-to-layer variations. Measurements of the changes in the interface structure of permalloy-copper multilayers during heat treatment and the effects of cobalt doping at the interfaces are described. The power of combining high angle diffraction and scattering with grazing incidence scattering, surface diffraction and fluorescence is illustrated in studies of Au-Fe multilayers grown by molecular beam epitaxy. Careful correlation of the structural and magnetotransport measurements provides evidence
for a novel mechanism of the giant magnetoresistance in this system. Variable angle grazing incidence fluorescence studies of thin films enable the determination of impurities. For example, 1.0% Cr film, it is determined. We present evidence for surface and behaviour of Nb in the growth of Au-Fe multilayers. Soft x-ray scattering allows us to access larger areas of reciprocal space in comparison to grazing incidence scattering in film. We compare structural data taken from Co-Cu multilayers taken with 800eV and 8keV x-rays and show that it provides more directly a measure of interface structure with very short in-plane correlation length. By tuning to the absorption edges of transition metals, a very substantial resonant enhancement is observed in the magnetic x-ray scattering and we show how these measurements can be used to determine the amplitude and length-scale of the pure magnetic roughness independently of the structural roughness.

2:00 PM F4.2/G2.2
PHOTOLUMINESCENCE SPECTROSCOPY OF PSEUDOMORPHIC THIN FILMS OF THE INVARIALLY ALLOY Fe$_{80}$Ni$_{20}$ by Michael Hochstrasser, Roy F. Willis, The Pennsylvania State University, Physics Department, University Park, PA; Frank O. Schumacher, James G. Tobin, Lawrence Livermore National Laboratory, Material Science Division, Livermore, CA; Eli Rotenberg, Lawrence Berkeley National Laboratory, Advanced Light Source, Berkeley, CA.

In bulk, the magnetic moments of Fe$_{80}$Ni$_{20}$ alloys deviate strongly from an Fe concentration of 80%, dropping quickly to zero as does the Curie temperature, at which point, a structural phase transition from fcc to bcc is observed. Recently, it has been shown that Fe$_{80}$Ni$_{20}$ films can be stabilized in the fcc phase when grown on sapphire. The fcc to bcc structural transition is quenched, but the magnetic instability persists. We have investigated with angular resolved photoemission the k-space electronic structure of thin Fe$_{80}$Ni$_{20}$ alloy films pseudomorphically grown on Cu(100) over the whole energy and momentum range. We have observed a clear change in the Fermi surface which can be associated with hybridization effects of the d-bands with the sp-bands at particular positions in the k-space electronic structure. These hot-spots relate to specific spanning wave-vectors at the Fermi surface which are important in understanding quantum-well oscillations and giant magnetoresistance effects. Dispersion curve measurements of the sp-bands allow us to measure lifetime effects and exchange splitting. With spin-resolved photoemission we can probe the spin-resolved density of states and we have further investigated to get a better insight into the changing magnetic and electronic structure of Fe$_{80}$Ni$_{20}$ alloy films. We have observed changes in the Fermi surface which indicate magnetic disorder. To understand the magnetic instability x-ray magnetic linear dichroism measurements have been used to measure the magnetization behavior of these magnetic thin films.

2:15 PM F4.3/G2.3
ON THE STABILIZATION OF 2D SURFACE ORDERED ALLOYS BY MAGNETIC POLARIZATION, S. Mehta, A. Aguilera, C. Demangeot, H. Dreyssé, IPCMS, Strasbourg, FRANCE: A. Kukkola, University of Florida, Physics, Florida Atlantic University, Boca Raton, FL.

Choi et al. [Phys. Rev. B 58, 1998 5169 (1998)] have studied the magnetic properties of ultrathin Mn films on for Co/Cu(100) using the in situ magneto-optical Kerr effect (MOKE) and low energy electron diffraction. They found that a two-dimensional Mn-Co(100) surface alloy is stabilized in the range 0.3-0.8 monolayer of Mn. Also Antel et al. have tried to elucidate the origin of exchange biasing in FeMn/Cu(100) by MOKE and x-ray dichroism. Theoretical electronic and magnetic structure studies on Mn-Co and (Fe-Mn) Co systems have been carried out using the Tight-Binding Linear Muffin-Tin Orbital (TB-LMTO) method within the density-functional theory (DFT) and its local density approximation (LDA). We discuss the stability of a Mn monolayer on Co(100) versus the formation of 1 or 2ML thick Mn-Co(100) alloys, as well as the inverted Co/Mn(100) system case. The Mn-Co alloy is found to be more stable than the Mn overlay on Co(100) substrate, in qualitative agreement with the experimental predictions above. In the case of 2ML thick Mn-Co alloy the magnetic coupling between Mn and Co atoms at the surface and the substrate favors ferromagnetic coupling uniform ferromagnetic respectively. We discuss the stability of a 2D ordered Fe-Mn alloy on Co(100) versus the buried Co/Ti/Mn/Co(100) alloy. As previously we found that the buried configuration is the ground state. The Mn atoms in the buried alloy are always found with antiferromagnetic coupling with its nearest neighbors.

2:30 PM F4.4/G2.4
SHAPE EFFECTS ON THE MAGNETIZATION OF COBALT AND PERMALLOY NANO-SCALE ARRAYS, J. Johnson, V. Metelshko, P. Vavassori, M. Grimsheidt, Materials Science Division, Argonne National Laboratory, Argonne, IL; B. Hic, School of Applied and Engineering Physics, Cornell University, Ithaca, NY; F. Nuez, R. Kumar, Institute of Microelectronics, Singapore, SINGAPORE.

We have investigated the shape and thickness dependence of a series of Co and ferromagnetic nano-scale arrays using the Magneto Optical Kerr Effect (MOKE) technique and MFM. The patterns were produced by e-beam lithography combined with e-beam deposition and lift-off techniques. Fifteen 1.0 by 2.5 micron trapezoidal arrays with elliptical aspect ratios of 0.01, 0.05, 0.10, 0.15 and 0.20 were fabricated simultaneously, on a single substrate, to avoid complications due to changes in W/H and thickness. Identical patterns were fabricated for 30nm of Co and 30nm and 30nm of permalloy. The effect of the MOKE loops for the three samples will be presented. Domain structure as inferred from MOKE, observed with MFM and estimated based on shape anisotropies will be discussed. Work at Argonne National Laboratory was supported by the U.S. Department of Energy, Division of Material Sciences, Office of Basic Energy Sciences, under contract W-31-109-ENG-38. P.V. acknowledges support by a research grant from INFM Istituto Nazionale per la Fisica della Materia.

3:15 PM F4.5/G2.5
TEMPERATURE AND INDUSTRIAL RESEARCH, Philip M. Rice, Stuart P. Parkin, Robin P. Cowick, Mary Moore, IBM Almaden Research Center, San Jose, CA; William J. Gallagher, IBM T.J. Watson Research Center, Yorktown Heights, NY; Tsun Lin, IBM Storage Systems Division, San Jose, CA.

Competition in the storage industry has driven research toward ever increasing areal densities. These increases in areal densities are derived either from improving the technology used (such as switching from MR to GMR sensors) or simply decreasing the size of the elements involved. As the size of elements decreases, the magnetic multilayers become thinner and more complex. Transmission Electron Microscopy (TEM), with its high spatial resolution, plays an increasingly important role in the characterization of both the microstructure and microchemistry of magnetic multilayers. How TEM has been used to help in the research of GMR sensors and magnetic tunnel junction (MTJ) stacks will be discussed. The focused Ion beam (FIB) has also become an invaluable instrument due to its ability to make site specific TEM specimens from production wafers and heads. Examples from the Magnetic RAM project will be used to show how TEM can help in the development of wafer-based production. Results from analytical TEM studies of deformation migration between multilayers will also be discussed.

3:45 PM F4.6/G2.6

We investigated ultrathin alloy films in an element-specific manner by means of dichroism in photoemission (MILAD). Specifically, we investigated Fe-Co$_{1-x}$ and Fe-Ni$_{1-x}$ films grown on Cu(100). For high Fe concentrations we find contrasting behavior of the two systems. In the case of Fe-Co$_{1-x}$ we observe an essentially constant magnetic signal with a moment-volume instability. However for the Fe-Ni$_{1-x}$ alloys we observe an essentially constant and strong dichroism signal for all concentrations, in particular for Fe-rich alloys. This observation can be related to the stabilization of a ferromagnetic latent volume of ferromagnetic alloys with Co and Ni. It is now well-established that for Fe on Cu(100) exist in two different magnetic states. These are a high spin (HS) and low spin (LS) state, the former having the larger atomic volume. It is predicted that this state has a larger magnetic moment than bulk Fe. This moment enhancement in the case of Fe-Co$_{1-x}$ alloys allows us also to resolve fine-structure in the Fe 3p emission. This was theoretically predicted, but so far the experimental observation was missing. Spin-resolving measurements on the Fe 3p level confirm the origin of the fine-structure to be due to the observation of the pure spin states. The importance of this result for element-specific magnetochemistry for ultrathin films is discussed.

4:00 PM F4.7/G2.7
THE STRUCTURE OF POLYCRYSTALLINE AND EPITAXIAL GMG MAGNETIC MULTILAYERS AND SPIN-VALENTES GROWN BY SPATTER DEPOSITION, Hong Geng, Reza Lotofe, John W. Hecken, Martin J. Cring, Dept. of Materials Science and Mechanics, Michigan State Univ., East Lansing, MI; Reza Lotofe, William P. Pratt, Jr., Dept. of Physics and Astronomy, Michigan State Univ., East Lansing, MI.

The study of the GMG effect in magnetic multilayers and spin-valves has shown that the electrical transport in these materials depends on impurity quality and interface structure. The results of this study, in a particular material system, Co/Cu, are presented. The device consists of a number of magnetic multilayers (Co/Cu)$_n$ and spin-valves (FeMn/Pt/Cu/Pt and Py/Pt/FeMn) were produced
by dc magnetron sputtering (Py = Permalloy™ (NiFe)). Initial work on these structures concentrated on polycrystalline materials grown with polycrystalline NiFe precursor electroplated films. More recent work has focused on epitaxial structures grown on single crystal (110) Nb that was deposited on (1120) Al₂O₃ substrates. The grain size, morphology, and orientation of the epitaxially grown films have been characterized using electron backscatter diffraction (EBSD). The structures of both polycrystalline and epitaxial films were also characterized using a variety of cross-sectional transmission electron microscopy (TEM) approaches including conventional and high-resolution TEM (STEM and HRTEM). In polycrystalline samples, STEM has revealed well-defined multilayered structures, which in most cases display columnar grains range up to 90 nm in diameter. The HRTEM study, complemented with fast Fourier transform (FFT) and image simulations, indicated that some non-equilibrium phases exist in certain regions of these spin-valve layers. In epitaxial samples, CTEM and HRTEM revealed large numbers of threading dislocations in the single crystal Nb buffer layer. Subsequent sputtering of Cu, Py, and Co resulted in two growth variants predicted by the stacking sequence of the [111] epitaxial planes. Significant grooving occurs where these variants meet, resulting in notable thinning of the multilayer structures parallel to the growth direction, and possibly pin holes. This work was supported in part by the MSU CFMR, and by the US NSF under grant MRS- DMR 96-06988.

4:15 PM F4.8/G2.8
SCANNING-APERTURE PHOTOEMISSION MICROSCOPE FOR MAGNETIC IMAGING. Gary M. McClelland and Charles T. Rettenmaier, IBM Research Division, Almaden Research Center, San Jose, CA.

We have demonstrated a new technique for magnetic imaging that is ultimately capable of spatial resolution approaching 5 nm. In our instrument, photoemission is excited by a laser focused to a 1.8 mm spot on the sample. Since the surface topography affects the magnetic surface, and the magnetic surface allows only electrons from a small selected region to reach the electron detector. The magnetization in this region is determined from the dependence of photoemission on the circular polarization of the laser. Images of 100-nm-thick Pt-Co multilayer thin films on insulators have been obtained. From a cesiated film, a high quantum efficiency of 0.002 was observed from 458 nm laser light. Circular dichroism of 10% is recorded by alternating the circular polarization of the light while scanning the tip. The surface topography is maintained as the tip advances at 1 nm/s with the sample and the signal. From 1.5 nm resolution at a small enough aperture can be fabricated. Recent calculations show that image formation on the electronics from the aperture and the surface topography is expected to make the effective aperture even smaller than the physical diameter. The insensitivity of the instrument to varying magnetic fields should make it ideal for time dependent magnetization measurements in an applied field.

4:30 PM F4.9/G2.9
RESIDUAL STRESSES AND MAGNETOELASTIC COUPLING IN ULTRATHIN Fe FILMS DEPOSITED ON GaAs(100). Patricia Gregoire, C. Olivier Thomas, L. Thomas, CNRS, Université Aix-Marseille III, Marseille, FRANCE; Claude Lallaisson, Bruno Lepine, Andre Guittreau, EPSI, CNRS, Université Rennes, FRANCE.

The growing interest in the behavior of magnetic thin films on semiconductor substrates is due in part to their potential application in spin-sensitive heterostructure devices. The metal-semiconductor interface is expected to have a strong influence on the magnetic and electronic properties of the heterostructure. It has been shown previously that high-quality epitaxial iron thin films can be grown on GaAs(100) substrates because of the small lattice parameter mismatch. (1.4%). Measurements performed on Fe films thinner than 3 nm showed that such films exhibit an in-plane uniaxial magnetic anisotropy although an ideal bcc Fe(001) film should have fourfold symmetry. The source of this uniaxial component remains an open question and one of the mechanisms which may contribute to this is the epitaxial strain, through magnetostatic coupling. In this study, we measured using X-ray diffraction the strains in a series of iron thin films with thicknesses varying between 20 and 80 nm. For the thinnest films, the uniaxial anisotropy of the in-plane strain has been investigated. Very small strains uniaxialities are capable of modifying the magnetic anisotropy of iron thin films. Moreover the sign and magnitude of the magnetostatic coupling seems to depend on the films thickness [1]. We thus calculated the magnetic anisotropy using both bulk and thin film magnetostatic coupling. 1. D. Sanders, Rep. Prog. Phys. 62 (1999) 1-50.
The possibility of spin-polarized electron injection from a ferromagnet (FM) to a semiconductor (SC) has stimulated a great number of researchers to realize spin-electronic devices such as spin-polarized STM [1]. One attempt to control the electron polarization in the SC using photoexcitation with circularly polarized light has recently been demonstrated [2]. In this study, we produced samples of 3 nm Au/5 nm FM/Ge(100), $10^6 \leq n \leq 10^7$ cm$^{-3}$ and attached two Al electrical contacts to the Au layer and one ohmic contact to the bottom of the substrate. Convective $\text{CV}$ measurements were carried out to define the Schottky characteristics of the samples. Circularly polarized laser light ($515 \leq \lambda \leq 780$ nm) was used to excite electrons with a spin perpendicular to the film plane in the samples. A helicity-dependent photocurrent, dependent upon the magnetization configuration of the film ($\# \downarrow \uparrow \downarrow$ or $\# \downarrow \uparrow \downarrow \downarrow$) and the Schottky barrier height, was detected with NiFe as the FM. An almost constant difference between the helicity-dependent photocurrent for perpendicular and parallel configurations is observed at negative bias, which corresponds to the spin-dependent photocurrent passing from the SC to the FM. At an applied bias voltage approximately equal to the Schottky barrier height, a minor suppression in the bias dependence of the helicity-dependent photocurrent was observed, suggesting the existence of polarized electron transport from the SC to the FM. The helicity-dependent photocurrent polarization decreases with increasing bias with decreasing photon energy. These results provide clear evidence of spin-dependent electron transport through the FM/SC direct interface.


SESSION F6/G4: JOINT SESSION
GMR AND SPIN VALVES I

10:30 AM *F6. 1/G4. 1

VERTICAL GMR/MRAM: Grey A. Prinz, Naval Research Laboratory, Materials Science and Technology Division, Washington, DC.

In recent years there have been announcements of programs to develop nonvolatile random access memory based upon magnetic storage of the information (MRAM). The most advanced demonstration highlights bi-directional current switching in giant magnetoresistance (GMR) spin-valves. Slightly less developed demonstration has shown that magnetic tunnel junctions may also provide the basis for MRAM and their vertical structure could even be compatible with CMOS. In this talk, a third approach will be described, which exploits current perpendicular to the plane (CPP) transport in GMR multilayers fabricated into vertical structures.

11:00 AM *F6. 2/G4. 2

We demonstrate that spin-polarized currents flowing perpendicularly through magnetic multilayers can apply sufficient torques to the magnetic layers to reorient their moments, by means of a mechanism based on local exchange interactions instead of current-generated magnetic fields. The idea of the new mechanism, as predicted by J. Skomski and L. Berger, is that when a spin-polarized current is scattered by a magnetic layer, spin angular momentum is transferred to the layer, meaning that a torque is applied. We have observed this effect in two experimental geometries: devices in which a 5-16nm nanofabricated metal point contact is used to inject current into a Co/Cu/Co/Cu multilayer and (in work led by Krane, Albert, and Buhrow) in Co/Cu/Co/Cu pillars approximately 100 nm in diameter. In both cases, s-curr injection scheme is made easier than the other in order to make it more easily controllable. At low magnetic fields, we can controllably switch the magnetic moments in the two Co layers parallel with a current pulse in one direction, and switch them antiparallel with a reversed current. The symmetry in current direction is as predicted by the spin-transfer mechanism. The current densities required for switching are $\sim 10^7$ A/cm$^2$ in the point contacts and several $10^8$ A/cm$^2$ in the pillars, well, in the pillars, well, in the pillars, well. To the levels at which the devices are damaged by the current. When large magnetic fields are applied, the spin-polarized current no longer fully reverses the moment, but instead stimulates spin-wave excitations. The simple geometry of the 100-nm pillars experiments allows for quantitative tests of the theories of the spin-transfer mechanism, and provides a new means of using the damping parameter controlling the motion of individual magnetic domains. We observe greater damping for domains which are exchange-coupled to a continuous film than we do for isolated domains.

SESSION F7/G5: JOINT SESSION
GMR AND SPIN VALVES II

Wednesday, Afternoon, April 26, 2000
Golden Gate B 3 (Marriott)

1:30 PM *F7. 1/G5. 1

ADVANCES IN TUNNEL JUNCTION AND SPIN VALVE TECHNOLOGY FOR MRAM AND READ HEAD APPLICATIONS: P.P. Feitas, Instituto de Engenharia de Sistemas e Computadores, Lisbon, PORTUGAL.

Tunnel junction fabrication for MRAM integration (Rs=1.10 kOhm x um2, TMR>50%, tAl=11A, oxide or nitride barriers), and for ultra high density read heads (Rs=15 Ohm x um2, TMR=20%, tAl=6A) is described. The thermal stability of such devices is analyzable, in view of the required applications. Head and MRAM designs are discussed and results are shown for vertically integrated tunnel junctions -Si SiO2 dielectric memory elements, with ohmic switching time of 30ns. Ongoing progress in diode technology & in order to maximize memory density. Progress in spin valve technology is reported in two areas. Increase in GMR signal from 8% to 14% is reported when inserting thin oxide layers in the middle of the free and pinned ferromagnetic layers, increasing specular scattering. Decrease in the spin valve free layer thickness[10A], and increase in sensor sensitivity is obtained by using synthetic free layers, together with synthetic AF layers.

2:00 PM *F7. 2/G5. 2

REAL-TIME CONDUCTIVITY STUDIES OF INTERDIFFUSION IN THIN-FILM GROWTH: William F. Egelhoff, Jr., Magnetic Materials Group, National Institute of Standards & Technology, Gaithersburg, MD.

Measurements of thin-film conductivity made in real-time during thin-film growth are well-known for providing much insight into growth modes. This insight is based on the fact that a random alloy of two metals usually has a larger electrical resistivity than either metal in pure form. We have applied this technique to investigate interdiffusion in a variety of metal-metal systems. Although many other experimental techniques are available for identifying interdiffusion during growth, few are as rapid and as easy to use as this one. It is noteworthy that, among the possible metal-on-metal combinations, experimental data on interdiffusion during growth is presently available only for a few systems. For example, considering two metals chosen at random from the periodic table it is very unlikely that any experimental data is available to indicate whether such interdiffusion will occur in their case. In the above, insights into the chemistry of interdiffusion during the growth of thin films no doubt await discovery. As one example, we find that the best alloying is not a particularly good predictor of the extent of interdiffusion. Often in a bi-metal system, A on B will exhibit interdiffusion while B on A...
will not. Clearly, kinetic factors are important. As another example, we have found experimental support for our earlier claim that oxygen can cause a significant increase in giant magnetoresistance spin valve values to suppress interdiffusion during the growth of Co on Cu. The technique is not limited to observations of interdiffusion alone. We have also used it to observe other chemical changes at metal surfaces, such as the reaction of Al with oxygen on oxidized Ni surface to form an insulating NiO layer. Ni metal. This will talk give an overview of examples of the great usefulness and potential of this scarf for utilizing this technique.

The author would like to acknowledge his collaborators in this work, including P. J. Chen, C. J. Powell, M. D. Stiles, and R. D. McMichael.

2:30 PM F7.3/G5.3
FIRST PRINCIPLES-BASED SOLUTION TO THE BOLTZMANN TRANSPORT EQUATION FOR Co/Cu/Co SPIN VALVES, J. M. MacLaren, Physics Department, Tulane University, New Orleans, LA, L. Malek and J. Winger, AMR, University of New Orleans, New Orleans, LA.

In this work we use a first principles based semi-classical theory of electronic transport based upon solutions to the Boltzmann transport theory to study the CIP and CPP transport in symmetric Co/Cu/Co spin valves. The inputs to the Boltzmann transport equation include the Fermi energy Bloch waves, the Bloch wave velocities and scattering matrices which describe the reflection and transmission of these Bloch waves in the interfaces. The results are useful for designing and optimizing giant magnetoresistance spin density calculations. In particular we study the role of individual layer thicknesses on properties and compare with our Co/Cu/Co samples grown by magnetron sputtering. Our results show that significant changes can only arise from the Co/Cu interfaces and not from the Co/Cu/Cu interfaces themselves. Effects come from layer thicknesses in the Co spacer layer, even though contributions arise from the adjacent Co layers. In the Co layers the contributions appear to decay with a length scale characteristic of the Co minority free path of about 4 nm. The results of the GMR can be changed from the original GMR by 10% with only a 5% change in the Co layer thickness, which itself is unusual. The obtained data is lower than the predictions, which simply reflects the fact that the CPP geometry cannot avoid the high resistance minority Co channel.

This work was supported by DARPA under contract MDA 972-97-I-0103.

2:45 PM F7.4/G5.4
MANUFACTURABILITY OF GM HEADS: 10GB/IN2 AND BEYOND, Sanghitarina Sahu, Vivien Trigghander, Jian Chen, S. Mao, Seagate Technology, Bloomington, MN.

Consistency of spin-valve stack deposition, both wafer-to-wafer and within layers of individual GMR heads. The layer thicknesses of GM heads, film thicknesses are now in the range of 5A–15Å and process control is becoming a challenge.

This paper discusses the importance of characterizing the thickness and uniformity of each material in the spin-valve stack within the context of single layer sheet films. For this study, single layer sheet films and spin-valves were deposited in a multi-target cluster tool. The sheet resistance and thickness of the single layer sheet films were measured using a 4-point probe and ellipsometry respectively. Results were then correlated to the sheet resistance and magnetic performance (i.e., GMR ratio, exchange field, and magneto-static coupling field) of the full spin-valve stacks with a synthetic antiferromagnet as the pinned layer. The 1σ of 1% uniformity realized for the full stack is a strong indicator of a manufacturable process.

Model calculations of the sheet resistance and GMR were carried out to provide theoretical understanding of the film thickness dependence. The calculated results are well correlated with the experimental measurements. The model is based on band structures and implicitly includes the momentum-dependent reflection and transmission coefficients at the interfaces. Results from both experiments and calculations show that process control and repeatability (both within a wafer and from wafer to wafer) are crucial to the spin-valve manufacturability, offering a critical challenge to the disc drive industry as it heads into the next generation of GMR heads.

3:30 PM F7.5/G5.5
EXCHANGE ANISOTROPY DETERMINED FROM REVERSIBLE PROCESSES, E. de Boer, U. Danielsson, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN.

A microscopic understanding of the Ferromagnetic/Antiferromagnetic Exchange Anisotropy (FA/AF) which arises at the interface between a ferromagnet and an antiferromagnet has been elusive since its discovery. Simple models of the FA/AF would predict energies roughly a factor of a hundred times larger than those determined by measurements of the shift in magnetization hysteresis loops. However, a hysteresis loop is generally not reversible.

Using two different reversible magnetic techniques, we obtain FA/AF values which are in order of magnitude larger than the hysteresis loop method. [B.H. Miller and E. de Boer, J. Appl. Phys. Lett. 63, 3812-3813 (1993) and Valuev, Shumov, B.J. Jonsson, K.V. Rao, and Don Dahlberg, J. Appl. Phys. 81, 5083-5085 (1997)]. Although the FA/AF determined by reversible magnetic rotations is still less than simple models would predict, it provides a more accurate determination of the average FA/AF at the interface. As such, the FA/AF calculated by models and studies of the systematics of this phenomenon should be compared only to the FA/AF determined by reversible processes.

4:00 PM F7.6/G5.6
CHANGES IN STRESS AND MICROSTRUCTURE IN PtMn/CoFe BILAYERS DURING ANTFERROMAGNETIC PHASE TRANSFORMATIONS, S.P. Horozov and B.J. Daniels, Seagate Recording Heads, Minneapolis, MN.

PtMn is one of several candidate antiferromagnetic materials for biasing of spin valve giant magneto-resistive (GMR) sensors used in magnetic recording heads. The as-deposited crystal structure of PtMn is face-centered cubic (fcc), which is not antiferromagnetic, and it is commonly annealed to transform it to the face-centered tetragonal (fct) structure, which is antiferromagnetic. This phase transformation is accompanied by significant increases in stress and substantial changes in microstructure. Changes in the thin film stress during the fct to fcc transformation have been reported previously [Daniels et al., MRS Fall 99] and can be up to 1.5 GPa. Stress vs time data from in situ annealing experiments were shown to fit well with the Arrhenius equation, suggesting that the changes in stress are dominated by the fcc to fct transformation. In spite of this good agreement, stress changes can originate from [1] the phase transformation, [2] interdiffusion, and [3] grain growth. In order to resolve the effect of microstructural changes on the stress in these films, we have obtained XRD data for PtMn/CoFe bilayers before and after annealing. Further, since the magnetic behavior of these films has been observed to depend strongly on the PtMn composition, the behavior of the transformation has been studied for PtMn compositions over a range of ~10 atomic percent.

4:15 PM F7.7/G5.7
LARGE ANISOTROPY INDUCED BY OBLIQUE SPUTTERING OF Ta UNDERLAYERS, J.E. Benedick, R.D. McMichael, C.G. Lee, P.J. Chen, W. Miller and W.T. Egelhoff, Jr., National Institute of Standards and Technology, Material Science and Engineering Laboratory, Gaithersburg, MD.

Applications of the giant magnetoresistance (GMR) effect rely on precise magnetization control of the constituent layers. A number of control schemes have been developed including the use of antiferromagnetic materials for exchange biasing and the use of hard magnetic materials. We have obliquely sputtered Ta layers to stagger the production of unusually strong uniaxial anisotropy in ultrathin Co films and demonstrated this technique in a pseudo spin valve. Thin films of Co, Ni48Fe42(Pt) and Co/Cu/Cu pseudo spin valves were DC magnetron sputter deposited on obliquely [30°] to substrate normal, sputtered Ta underlayers and capped with Au. The anisotropy field values for the films deposited on obliquely sputtered Ta are quite large compared to magnetocrystalline anisotropy fields of Co or Cu. With 7.5 nm Ta, the measured value of μ0Hc2, 183 mT, is comparable to that of single crystal hcp Co. A large increase in μ0Hc2 is also observed for Py films, thus the magnetocrystalline anisotropy apparently does not play a large role. Relatively narrow FMR resonances also indicate a surprising degree of uniformity in the anisotropy. Additionally, the damping parameter is nearly isotropic. Cross-sectional HRTEM reveals the Ta/Fe multilayer metal interface to be corrugated with ridges and grooves extending perpendicular to the Ta incidence plane. The presence of roughly aligned ridges and grooves on the length scale of a few nm is expected to give rise to magnetostatic anisotropy. Because the periodicity of the grooves is not significantly larger than the magnetostatic exchange length, ≈4 nm, the magnetization will not be able to follow the contours of surface and magnetostatic charges will exist on the sides of the ridges, giving rise to a demagnetization field in the plane of the film.
SESSION F8: POSTER SESSION  
MEDIA/GMR/CMR  
Wednesday Evening, April 26, 2000  
8:00 PM  
Salon 1-L (Merriott)

F8.1 A MöSSBAUER SPECTRAL STUDY OF THE MAGNETIC AND STRUCTURAL PROPERTIES OF $\text{R}_2\text{Fe}_5\text{O}_{12}$, WHERE $\text{R}$ IS Dy, Y, AND Eu. D. Vandremer, F. Indrem, Institute of Physique, Université de Liège, Belgium; Dimitri Gautot, Gary J. Long, Department of Chemistry, University of Missouri-Rolla, Rolla, MO.

The $\text{R}_2\text{Fe}_5\text{O}_{12}$ rare-earth iron garnets are potential candidates for efficient magneto-optical recording at blue wavelengths. Above the Curie temperature, $T_C$, the iron in these ferrimagnetic oxides occupies the octahedral 16a and tetrahedral 2d3 crystallographic sites of the cubic $\text{R}_3\text{Fe}_5\text{O}_{12}$ space group. There are apparently no change in the structural space group below $T_C$ and in general in garnets the magnetization is oriented along [111]. The iron-57 Mössbauer spectra of the garnets have been obtained between 4.2 and 295 K. The spectra of Dy$_2$Fe$_5$O$_{12}$ indicate that below 15 K the magnetization is in the (110) plane and makes an angle of 17° with the [111] direction. Between 15 and 295 K, in all three compounds, the magnetization is along [111] and the Mössbauer spectra are not compatible with the expected $\text{R}_3\text{Fe}_5\text{O}_{12}$ structure. We propose that the space group is actually $\text{R}_3\text{Fe}_5\text{O}_{12}$, a group in which there are two magnetically inequivalent 16a12 and 16a4 sites and four magnetically inequivalent 2d3 sites. The Mössbauer spectra, which are sensitive to the angle between the principal axis of the electric field gradient tensor and the magnetization, have the unique ability of revealing these magnetically inequivalent iron sites. The decrease below $T_C$ of structural symmetry in these garnets has been observed for the first time by Mössbauer spectroscopy.

F8.2 NEEDLE-LIKE MAGEMITE IRON OXIDE IN NANOMETER SIZE PREPARED FROM WET CHEMICAL PROCESSING. Jye Fang, Kevin L. Stokes, Wei Le. Zhao, Juan A. Wiemann, Amar Rambabu, Theodor Kaden, Kevin O’Brian, and Chuck O’Connor, Advanced Materials Research Institute, University of New Orleans, New Orleans, LA.

Magemite Fe$_3$O$_4$ is one of the most widely used magnetic recording materials. It has been reported that the magnetic properties of iron oxide were largely dependent on its particle size, size distribution and particle morphology. We have successfully prepared needle-like magemite Fe$_3$O$_4$ powder using a refined wet chemical processing method. The morphology of as-prepared powder was investigated by employing TEM. Crystalline analysis (XRD). shows that a single phase of magemite iron oxide was obtained. Other techniques, such as TGA, and SQUID Susceptometer, are also used to characterize the formation temperature and related magnetic properties.

F8.3 PRELIMINARY RESULTS OF A MULTIFACETED SYSTEM FOR THE PRODUCTION OF NANOPARTICLES. James L. Guidry, Klaus-Hermann Dahlen, Dept of Chemistry, National High Magnetic Fields Laboratory and Motech, The Florida State University, Tallahassee, FL.

Particles have been prepared by a multifaceted system, which utilizes aerosol, plasma, chemic MOCVD, and supercritical fluid techniques. The supercritical fluid system is a complex system utilizing three syringe pumps coupled to three autochews. Two of the autochews are specially designed for supercritical water capability while the third is for CO$_2$ or NH$_3$ use only. By using three autochews the system has added capability by the use of co-oxides. The MOCVD system consists of three vaporizers, one of which incorporates a liquid delivery system for use with liquid precursors and one for depositing coatings on the particles themselves. Using an ultrasonic nebulizer allows controlled evaporation of pure liquid precursors or precursor- solvent mixtures. The plasma setup gives the system an additional method for powder production. Included in this presentation will be an overview of the particle preparation, characterization, and observed magnetic properties.

F8.4 STRUCTURE AND MAGNETIC PROPERTIES OF Nd$_2$Ce$_{0.5}$Fe$_{1.5}$Si$_{0.5}$C$_x$ INTERMETALLICS. Monica Sereca, A. Grăinescu, Dacșea University, București School of Natural and Environmental Sciences, Physics Department, University of Munich, Germany; M. Vlásceanu, Institute of Atomic Physics, National Institute of Physics, Bucharest, Romania.

In the present work we report on the structural and magnetic properties of novel magnetic compounds of the type Nd$_2$Ce$_{0.5}$Fe$_{1.5}$Si$_{0.5}$C$_x$ ($x$ = 7, 9, 12 and $y$ = 0, 1), synthesized with and without carbon introduced by melting. The symmetry and lattice parameters were determined by XRD, while the effects of substitution on the magnetic hyperfine fields were studied by Mössbauer spectroscopy. Regardless of carbon content, all Nd$_2$Ce$_{0.5}$Fe$_{1.5}$Si$_{0.5}$C$_x$ ($x$ = 7, 9, 12 and $y$ = 0, 1) intermetallics were found to be rhombohedral, with the Th$_3$Si$_2$ structure. Both lattice constants $a$ and $c$ were found to increase with increasing iron content in the intermetallics with and without interstitial carbon introduced by melting. Moreover, the Curie-temperature decrease was found to increase with increasing iron content in the compounds without carbon and to increase correspondingly in the intermetallics with carbon.

The Mössbauer spectra were analyzed with two models: with 4 sextets, corresponding to the 4c, 4d, 4f, and 4h inequivalent iron sites in the rhombohedral structure and with a hyperfine magnetic field distribution, to yield the average hyperfine magnetic field. The four-site model could not convincingly discriminate between the two opposite factors determining the hyperfine magnetic field: the tendency of cobalt to increase the hyperfine field at iron sites and the inverse tendency of iron to increase the hyperfine field at higher cobalt contents. However, the field distribution fit clearly showed that the average hyperfine magnetic field increases with increasing iron content in both types of compounds (with and without carbon additions). Moreover, it was demonstrated that the average hyperfine magnetic field for iron compounds with interstitial carbon had larger values than those in samples without carbon. A similar effect was obtained by us in the case of Nd$_2$Fe$_{1.5}$V$_2$C$_x$ compounds and attributed to an increased contribution to magnetization of the iron magnetic moments, due to narrowing of the 3d band.

F8.5 INTRINSIC MAGNETIC PROPERTIES AND NANOCRYSTALLIZATION BEHAVIOR OF AMORPHOUS (Fe$_{90}$Mo$_{10}$)$_2$Si$_{13}$ RIBBONS. Xiangzeng Sun and M. Jose Yuncam, National Institute of Nuclear Research (ININ), Mexico; J. Reyes-García, X. Bodíni, National Univ of Mexico (UNAM), Inst. of Physics, Mexico; A. Chakrabarti, National Inst. of Nuclear Research (ININ), Mexico; Wensheng Sun, State Key Lab for RSA, Institute of Metal Research, Chinese Academy of Science, Shenyang, P.R. China.

The intrinsic magnetic properties and nanocrystallization process of ferromagnetic (Fe$_{90}$Mo$_{10}$)$_2$Si$_{13}$ ribbons were extensively studied by in situ transmission electron microscopy (TEM), X-ray Rietveld refinement, Mössbauer spectroscopy (MS), differential scanning calorimetry (DSC) and magnetic moment measurements. The Mössbauer spectrum exhibited an essentially symmetric hyperfine field pattern of 225 Koe in as-quenched amorphous state at room temperature. The Curie and crystallization temperature were determined to be $T_C$ = 655 K and $T_F$ = 751 K, respectively. The $T_F$ value was in good agreement with DSC measurement results. X-ray Rietveld refinement have shown a good agreement with the metattle phases ($\text{Fe, Mo}_2$)$_2$B$_2$ ($\text{Fe, Mo}_2$)$_2$B, $\text{Fe, Mo}_2$, $\text{Fe, Mo}_2$)$_2$B, $\text{Fe, Mo}_2$) have ever occurred under in situ nanocrystallization process. Which these metattle phases embedded in the amorphous matrix have significant effects on magnetic behavior. The ultimate nanocrystalline amorphous phases of $\alpha$-Fe ($\text{Mo, Si}$) and $\text{Fe, Si}_2$B at in situ optimum annealing temperature have been observed respectively. It is notable that the magnetization of the amorphous phase decreases more rapidly with increasing temperature than those of nanocrystalline amorphous magnetism, suggesting the presence of the distribution of interaction exchange in the amorphous phase or high metallerd contents.

F8.6 MAGNETIC BEHAVIOR AND STRUCTURE OF ELECTRO- DEPOSITED, MECHANICALLY HARD Fe-C AND Fe-Ni-C ALLOYS. A. S.M.A. Haseeb, V. Vajpayee, and M. Mendis, Department of Materials Science & Engineering, Kyushu University, Fukuoka, Japan.

Iron-carbon based hard, martensitic alloys are usually produced by the conventional high temperature heat treatment. In the present work, galvanostatic electrodeposition method has been employed to obtain hard, martensitic Fe-C and Fe-Ni-C alloys at room temperature. The alloys have been investigated by EMPA, XRD, XPS, TEM, SEM and microhardness measurements, and their magnetic properties studied by vibrating sample magnetometer. The alloys are found to possess high magnetic hardness, 750-800 HY. Both alloys exhibit a smoother surface morphology as compared with pure iron film obtained under similar electrochemical conditions. The mechanically hard alloys show reasonably good soft magnetic behavior. The coercive force of the as-deposited Fe-C and Fe-Ni-C alloys is 508 and 542 A/m respectively. In comparison, pure iron film deposited under similar conditions possesses a coercive force of 1592
A/m. The alloys, particularly the Fe-Ni-C alloy thus possess a good combination of high mechanical hardness and soft magnetic properties, which are of interest in applications requiring both soft magnetic properties and improved tribological performance. The effects on tempering of the behaviour of the alloys are also discussed.

**FS. 7**

**BN FILMS GROWN AS AN INSULATING BARRIER FOR MAGNETIC TUNNELING JUNCTION: Y. Sheng, R.A. Laskawie, F A. Encarnation, R. Clarke, Dept of Physics, The Univ of Michigan, Ann Arbor, MI.

Hexagonal close-packed (hcp) boron nitride (BN), grown by plasma-assisted sputtering, has been used as an insulator barrier for a magnetic tunneling junction, in which a large magnetoresistance was observed [1]. In order to use BN for this application, several characteristics of the film must be controlled and optimized. Among these are the required thickness, its surface roughness, and its magnetic anisotropy. First, the growth conditions for hcp BN films deposited on Si (100) substrates were optimized. This optimization was confirmed by the observation of the distinct hcp BN reflection high-energy electron diffraction (HREED) pattern in situ. High intensity Fourier transform infrared spectroscopy (FTIR) peaks corresponding to the hexagonal BN $A_g$ and $B_g$ transverse optical phonon modes were also observed. This process was later applied to grow hcp BN films on (100) met4llic magnetic films. The morphological characterization of the different growth stages of the BN layer was studied using atomic force microscopy (AFM) on a series of BN films of differing thickness. Relatively uniform layers 1-3nm thick, essential to our tunneling application, are achieved just after cooling. This consequence correlates with the stage at which the $B_g$ in situ HREED pattern changes from that of the magnetic electrode layer to the pattern characteristic of hcp BN. AFM images of these films indicate that the surface roughness increases with thickness. Cross-sectional high resolution transmission electron microscopy (HRTEM) of the complete tunneling junction shows the well-defined structure of the hcp BN layer: highly oriented hexagonal planes parallel to the junction interface.


**FS. 8**

**INFLUENCE OF THE OXYGEN CONCENTRATION ON THE MAGNETORESISTIVE PROPERTIES OF 1ST AFM Co/Cu MULTILAYERS SPATTERED IN AN Ar+O$_2$ ATMOSPHERE.

D. Rubinski and M. Parsons, Ford Research Laboratory, Dearborn, MI.

The large magnetoresistance and low relative hysteresis of Co/Cu multilayers at the first ferromagnetic maximum ($H_{sat}=9A$) make them attractive for use in many position sensor applications. Unfortunately, their magnetoresistive properties can be difficult to reproduce, perhaps a consequence of the difficulties in growing thin, pin-hole free layers. A prior study demonstrated improved magnetoresistive properties for Co/Cu spin valves deposited in the presence of a small background of O$_2$, suggesting the O$_2$ acts as a surfactant. [1] In this study we investigate the influence of adding O$_2$ to the sputtering gas on the magnetoresisitive properties of the first AFM Co/Cu multilayers. A sequence of [Co(1.5nm)/Cu(9.3nm)]$_n$ multilayers were made using magnetron sputtering in a 3nm Ar $+$ 2nm O$_2$ atmosphere, with the O$_2$ partial pressure ranging from 0-10,000 ppm. In the absence of O$_2$ added to the Ar, the magnetoresistance was typically less than 10%. These values depended strongly on the residual background pressure of O$_2$ in the chamber. The addition of small amount of O$_2$ to the Ar sputtering atmosphere ($\leq$100 ppm) improved the magnetoresistance. At 10,000 ppm O$_2$ the magnetoresistance reached a maximum value of 45%, and was found to be quite reproducible. A similar result was also found for the saturation fields. Further increases in the O$_2$ concentration decreased the magnetoresistance and increased the saturation fields. The optimum O$_2$ concentration was much larger than that reported previously for the spin valves. Auger depth profiling revealed no evidence for the O$_2$ incorporation into the films, even for those fabricated in 10,000 ppm O$_2$. TEM observations of the influence of the O$_2$ on the microstructure of the multilayers are discussed. [2]


**FS. 9**

**SPIN GLASS-LIKE BEHAVIOUR IN THE COLOSSAL MAGNETORESISTIVE L$_{10}$M$_{5}$Mn$_{3}$O$_{12}$ (M=Ho (MAGNETIC) AND Y (NON - MAGNETIC)) COMPOUNDS. "R". W. Kranich, G. Hangst, and M.S. Repaccha, Raso, Materials Science Research Centre and "Department of Physics, Indian Institute of Technology Madras, Chennai, INDE, Y. Lin, J. Klein and R. Gross, II.

Physicals Institute, University of Kiel, Kiel, GERMANY.

There is a renewed interest in manganese perovskites such as $L_{10}$M$_{5}$Mn$_{3}$O$_{12}$ (M=Ca, Sr, Ba etc.) since they exhibit colossal magnetoresistance above the ferromagnetic transition temperature ($T_C$). The physics of these materials is very interesting because of the structure, magnetic and electrical properties. These materials are also being well studied, since they are promising candidates for device applications such as magnetoresistive read heads and magnetic sensors. In the present study $L_{10}$M$_{5}$Mn$_{3}$O$_{12}$ (M=Ho and Y) compounds were prepared by the solid state reaction method. The aim of the study was to understand the effect of doping a magnetic ion (Ho) in comparison with a nonmagnetic ion (Y) both having almost the same ionic radius. It is interesting to note that although the effect of suppression in $T_C$ is the same in both the cases, resistivity of the Ho compound is less than that of the Y compound indicating a coupling of the Ho moment with that of the Mn moment in the lattice. Magnetisation measurements show a large deviation in the FC and ZFC curves for the Y compound at low temperatures indicating a spin-glass like behaviour. However, in the case of Ho (0.1) - doped compound the deviation is very marginal. We have also observed shifts in the peak temperature with variation in frequency using a susceptibility technique confirming spin glass like behaviour. The magnetic frustration in these systems is due to the decrease in the overall ferromagnetic exchange interactions by either the decrease in the Mn$^{4+}$ concentration or the magnetic nature of the Ho. Charge carrier density measurements are underway.

References: 

**FS. 10**

**VERY LARGE MAGNETORESISTANCE AND FINITE SIZE EFFECTS IN ELECTROCHEMICALLY DEPOSITED BISMUTH FILMS ON GaAs SINGLE CRYSTALS. Philippe M. Vereecken, Li Sun, Peter C. Scaife, The Johns Hopkins University, Department of Physics and Astronomy, Baltimore, MD.

Bismuth films were deposited electrochemically on n- and p-type GaAs from a bismuth nitrate solution. Annealing of the films resulted in (102) oriented films. The resistivity and magnetoresistance were measured as a function of film thickness and showed very large magnetoresistance effect with ratios as high as 6000 at 5K and 2.3 $\mu$m at room temperature under a 5 kOe magnetic field. Finite size effects were observed for film thicknesses up to 75 micron indicating an electron mean free path larger than 75 micron.

**FS. 11**

**ESR INVESTIGATIONS ON L$_{10}$M$_{5}$Ca$_{3}$Mn$_{3}$O$_{12}$ AND L$_{10}$Ca$_{5}$Mn$_{3}$O$_{12}$ PROPERTIES OF L$_{10}$Ca$_{5}$Mn$_{3}$O$_{12}$ PEROVSKITE powder recorded using a Bruker D 200 spectrometer operating in X band (9 GHz). The resonance spectra in the paramagnetic phase consist of a single broad line, slightly asymmetric, localizedized close to the center of the spectrum. This line is not shifted to Mn$_2$ ions. As part of the hyperfine structure (resulting from the interaction between the uncoupled electronic spin and the nuclear spin) is due to motion on effective or to exchange interactions between Mn$_2$ ions. Taking into account the electrical conductivity of perovskites, we have tentatively discussed the experimental data within the polaron description. We have failed to notice the presence of any ESR signal at $g=4$, which would support the presence of bipolarons (characterized by $S=1$) in our system. The temperature dependence of the resonance spectra (g value, peak to peak line width, line intensity, line shape and the double integral of resonance line) in the temperature range 250 K to 400 K, is investigated in detail. Attention is paid to the paramagnetic ferromagnetic transition. Below the Curie temperature, the temperature dependence of the resonance line parameters is discussed. Taking into account the shape almost spherical of the particles and the low value of the magnetocrystalline anisotropy field in comparison with the coercive field, the temperature dependence of the resonance line position is proportional to the temperature dependence of the magnetisation at saturation. Accordingly, the Zeeman term dominates the features of the line in the magnetically ordered phase.

**FS. 12**

**MAGNETOTRANSPORT PROPERTIES OF L$_{10}$M$_{5}$Ba$_{2}$Mn$_{3}$O$_{12}$ AND Pd$_{6}$Bi$_{3}$Ca$_{5}$Mn$_{3}$O$_{12}$ SUPERLATTICES. S. V. Praneshwar, D. Kumari, R. Rajee K. Singh1, C.B. Lee2. Department of Materials Science and Engineering, Baltimore, MD, C.I. Chien, The Johns Hopkins University, Dept. of Physics and Astronomy, Baltimore, MD.
In an effort to achieve high magnetic responsivity (MR) ratios at high temperatures and reduced fields, we have fabricated superstructure devices consisting of La2/3-xMnxO3–α (LMO) and Pr0.5Fe0.5O3 as Ca0.5MnO2–α systems, where LMO is believed to act as a ferromagnetic biasing source to PBCMO. LMO and PBCMO individually transmute to ferromagnetic states at 240 K and 60 K respectively. A series of samples, in various thicknesses of LMO films of PBCMO varied from 1 to 8 unit cells, have been grown in situ on [100] LaAlO3 substrates using a pulsed laser deposition technique. Microstructural characteristics carried out on these films show the presence of characteristic intense satellite peaks indicating the chemical modulation of the superlattice structure. The insulator to metal transition and the MR ratio, defined as \( R(0) - R(H)/R(0) \), where \( R(0) \) and \( R(H) \) are resistance in zero and applied fields, is found to increase with the number of unit cells of spacer layer. The samples with 1, 2, 5 and 8 unit cells of PBCMO show metal-to-insulator transitions of 240 K, 230 K, 150 K and 160 K and MR ratio of 87\%, 87\%, 97\%, and 97\%, respectively. The mechanism responsible for improved performance in magnetoresistance properties of superlattices over individual systems (i.e., LMO or PBCMO) will also be discussed in this paper.

**SESSION F9: MATERIALS AND CHARACTERISTICS**

Thursday, April 27, 2000

Golden Gate B3 (Marriott)

**8:30 AM **F9.1 SPATIAL PROPAGATION OF DYNAMIC MAGNETIC EXCITATIONS IN PERMALLAY MEASURED WITH THE SECOND-HARMONIC MAGNETO-OPTIC KERR EFFECT**

Tovon Silvino, Isumail N. Koubas, National Institute of Standards and Technology, Boulder, CO.

The recording gap of a magnetic recording head is spatially removed from the flux excitation coils. Present day transmission line models for flux propagation consider only magnetostatic effects [1]. However, as disk drive data rates approach gigahertz frequencies, magnetoelectrical effects such as Larmor precession become more important [2]. In the long wavelength limit, flux propagation should obey magnetostatic spin wave theory. This is cause for concern since magnetostatic spin wave modes in thin films suffer from severe dispersion effects. In the particular case of Damon-Eshbach surface modes, where the propagation direction is orthogonal to the average magnetization direction, the velocity of propagation scales inversely with the frequency of excitation [3]. It is therefore of great importance to measure these dispersion effects in thin films to be used for future generations of recording heads. We measured the spatial decay of magnetic excitations in Permalloy propagating away from a waveguide pulsed field source. Measurements were made with a spatial resolution of 5 mm and a temporal resolution of 100 ps. The second-harmonic magneto-optic Kerr effect (SH-MOKE) [4]. In particular, we determine the propagation velocity and dispersion of the magnetic excitations in response to step field pulses. Results are compared with existing models of spin wave flux transmission. The second harmonic head design are discussed. [1] E. Vukstek and H. Huang, IEEE Trans. Magn., vol. 29, pp. 3873-3872 (1993). [2] T.J. Silvino, C.S. Lee, T.M. Crawford, and C.T. Rogers, J. Appl. Phys., vol. 85, pp. 7815-7862 (1999). [3] P. Koubas and V.S. Sahnuchov, Magnetostatic Waves and their Applications, Chapman and Hall, NY, 1994. [4] T.M. Crawford, T.J. Silvino, C.W. Teplin, and C.T. Rogers, Appl. Phys. Lett., vol. 74, pp. 3386-3388 (1999).

**9:00 AM **F9.2 MICROSTRUCTURES AND SOFT MAGNETIC PROPERTIES OF HIGH SATURATION FERRO-CO-N THIN FILMS: NX, X=x-x, and X=S.

Wang, Dept of Materials Science and Engineering, Stanford University, Stanford, CA.

High saturation soft magnetic materials are required for future high density recording heads. In this work, Fe0.5Co0.5-x-\( x \)N, (or short Fe-Co-N) films with a thickness of 100 nm were synthesized with a high saturation magnetization of 24.5 kG and a coercivity of 5 Oe. After depositing the Fe-Co-N films with two very thin (500 A) permalloy underlayers on top of the Fe-Co-N layers, we obtained a low coercivity of 0.6 Oe and an excellent in-plane uniaxial anisotropy. This drastic improvement in soft magnetic properties of Fe-Co-N can not be simply interpreted as the result of the soft magnetic of permalloy because the last two layers up only 10% (in volume) of the composite films. In order to understand the effects of the permalloy layers on the Fe-Co-N films, we fabricated single-layers Fe-Co-N films, Fe-Co-N films with two permalloy layers on both sides as underlayer and overlayer, and Fe-Co-N films with one permalloy layer being either the overlayer or the underlayer. All these films were both magnetically and structurally characterized and measured. The back coercivity of the Fe-Co-N film with a 5 nm permalloy underlayer drops to around 1 Oe from 5 Oe, and further drops to 0.6 Oe with two permalloy layers on both sides. In contrast, the Fe-Co-N film with a permalloy layer on the top has a coercivity similar to the Fe-Co-N single layer. Structural characterization shows that there is no significant difference in the mean grain size of the Fe-Co-N films with and without the permalloy underlayer. However, the crystallographic textures of the Fe-Co-N films vary significantly. A much better [110] texture appears to be correlated to the observed improvement in soft magnetic properties of Fe-Co-N films.

**SESSION F10: MAGNETIC STRUCTURE PROCESSING TECHNIQUES**

Thursday, April 27, 2000

Golden Gate B3 (Marriott)

**10:00 AM **F10.1 HIGH PERFORMANCE DEMONSTRATION OF MAGNETIC TUNNEL JUNCTION RANDOM ACCESS MEMORY


We describe a magnetic tunnel junction (MTJ) RAM demonstration involving the integration of 0.25 micron CMOS technology with a special research-scale magnetic tunnel junction back-end. The magnetic back-end is based upon state of the art multi-layer magnetic growth technology available on a research scale. For the demonstration, the wafers were cut into one-inch squares for deposition of bottom-pinned exchange biased magnetic tunnel junctions. The samples were then processed through four additional lithographic levels to complete the circuits. Special care was required to achieve fine lithography on the one-inch pieces aligned to the underlying circuits. Both deep ultraviolet lithography and electron lithography were utilized. Patternning of the magnetic layers involved physical removal of the magnetic material by means of ion beam milling, an etching process not commonly used in semiconductor technology. These issues were addressed successfully enough that key performance aspects of MYJ MRAM were demonstrated in 1 K bit arrays, including reads and writes in less than 10 ns and nonvolatility. While other issues remain to be addressed, these results suggest that MTJ MRAM might simultaneously provide much of the functionality now provided separately by SRAM, DRAM, and NVRAM.

Work supported in part by DARPA contract MDA972-96-C-0014.

**10:30 AM **F10.2 DRY ETCHING OF MRAM STRUCTURES.


A wide range of GMR and CMR materials have been patterned by high density plasma etching (CI-teg, and non-critical (CO/NH3) plasma chemistries. The former produce much higher etch rates but require careful in-situ or ex-situ post etch cleaning to prevent corrosion of the metallic multilayers. The former may have application for shallow etching of NiFe-based structures but there is little chemical contribution to the etch mechanism and mask erosion can be a problem. The magnetic performance of patterned MRAM elements is stable over long periods (>1 year) after etching in Cl-based plasma, provided a suitable cleaning protocol is followed. The effects of UV illumination during plasma etching have also been examined - in some cases there is enhanced photo-assisted desorption of the chlorinated etch products. It is also clear that high ion energies during patterning of magnetic multilayers can have a significant influence on their coercivity. The effects of ion energy, ion flux and process temperature will be discussed.

**11:00 AM **F10.3 SMOOTHING THIN FILMS WITH GAS CLUSTER ION BEAMS.


Thin film magnetic sensor and memory devices in future generations may benefit from a processing tool for fine step etching and smoothing of surfaces to nearly an atomic scale. Energetication sputter and etch processes generally cause shallow damage and accumulated roughness. The unique physics and chemistry of sputtering with ion
beams composed of small droplets (i.e., clusters) of condensed gas was recognized some years ago. Such gas-cluster ion-beam (GCIB) systems make possible improved surface sputtering and processing for many types of materials. With this technique, argon gas expanding in a nozzle forms clusters (few thousand atoms each) which are injected into vacuum, singly ionized, accelerated (10-30 kV), focused, scanned, and impact at normal or nonnormal incidence. GCIB has been found to simultaneously etch and smooth surfaces without accumulating roughness or damage. Implantation and surface damage essentially do not occur for cluster energy not too far above the sputtering threshold. While still in its infancy, manufacturing applications of GCIB processing to thin-film magnetic materials technology shows considerable promise. Results are reported for etching and smoothing of the surfaces of aluminum, gold, silicon, permalloy and tungsten films. For example, the linear etch-rate and tracks seen in atomic-force microscopy of CMP-processed surfaces, including iron alloys, are essentially removed entirely by GCIB exposure of a few minutes. The technique sputters high spatial-frequency roughness primarily and renders the topographic surface elevations more nearly gaussian (randomly) distributed with short-range height-height autocorrelation functions.

11:15 AM F10.4
SELECTIVE AREA CHEMICAL VAPOR DEPOSITION OF ANTIFERROMAGNETICALLY COUPLED CHROMIUM OXIDE.
Ruhan Cheng, C.N. Borel, P.A. Dowben, Dept. of Physics and Astronomy and the Center for Materials Research and Analysis, University of Nebraska-Lincoln, Lincoln, NE.

The insulating antiferromagnetic chromium oxide is a material suitable for testing magnetic tunnel junction properties between ferromagnetic oxides because it can act as a tunnel barrier both above and below the Neel temperature. We have deposited the antiferromagnetic Cr2O3 chromium oxide from the laser initiated oxidation of CrE2O4. Since this deposition procedure is based on photoysis of volatile organometallic complex, the process can be used to selectively deposit ultrathin films (<1 nm) of material with spatial resolution of a micron or less. Deposition of both the ferromagnetic Cr2O3 and antiferromagnetic Cr2O3 oxides should be possible[1,2] in compositionally modulated heterostructures. Both the technique and the magnetic properties of the films prepared this organometallic Cr2O4 process have been described.[1,2] P.A. Dowben, Yoon-Geum Kim, S. Burnak-Boh, C.O. Ramsey, Chunying Hwang, and M. Onellion, J. Appl. Phys. 67 (1990) 5688-5690.[2] K. Perkins, C. Hwang, M. Onellion, Yoon-Ge Kim and, P.A. Dowben, Thin Solid Films 198 (1990) 371-379.

11:30 AM F10.5
GROWTH CHARACTERIZATION OF NICKEL IRON THIN FILMS ON PATTERNED WAFERS USING IN-SITU ELLISOMETRY.
Arum Nathanam, Xuefei Tang, Vivian Thakher, Christian Lund, Mark Kief, Brian Sabo, Song Xue and Peter Weyandt, Scantec Recording Hens, Minneapolis, MN; Blaine Jobs, J.A. Woolham Co Inc., Lincoln, NE.

In-situ Ellipsometry has been effective in monitoring the growth and optical properties of thin metallic multilayer sheet films. This paper examines the feasibility of in-situ growth characterization on patterned wafers. The methodology for real-time extraction of film thickness is illustrated for thin NiFe deposition on two completely different patterned substrates. The results from growth monitoring using ellipsometry were compared with electron diffraction as well as total reflection x-ray diffraction. In-situ ellipsometry was found to be a good method in determining the degree of ordering in the deposited films. Good consistency is demonstrated by comparing the in-situ ellipsometry results on patterned wafers to those on sheet films. Thus, it is shown that in-situ growth monitoring during multilayer metal deposition on patterned wafers would facilitate process control in production. The future impact on metrology in the information storage and semiconductor industry may be significant.

SESSION F11: HALF METALLICS AND CMR
Thursday Afternoon, April 27, 2000
Golden Gate B3 (Merritt)
1:30 PM #F11.1
EXPERIMENTALLY SPEAKING, ARE HALF-METALLIC FERROMAGNETIC MATERIALS REALLY SO?
Jagadeesh S. Moodera, Francis Bitter Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, MA.

The bond structure calculation predicts half metallicity for a group of Heusler compounds such as NiMnSb, PdMnSb, etc., meaning that the Fermi level lies in the majority spin band and a gap in the density of states (DOS) for the minority spins, creating 100% spin polarized conduction electrons. If true, these compounds can have profound influence on both spin polarized transport studies as well as perfect memory elements, switches and sensors for spin electronics application. Experimentally, spin polarized tunneling is observed and it probes directly the spin density of tunneling electrons at the Fermi level is ideally suited to unambiguously verify this prediction. Our tunneling and other transport studies over the years on NiMnSb compounds will be presented and its implications to various other candidates, bringing up to date the status of this field.

In collaboration with C. T. Tanaka and J. Novak
Supported Office of Naval Research grants

2:00 PM F11.2
SPIN POLARIZED PHOTOEMISSION STUDY OF MAGNETIC FILMS: EVIDENCE FOR HALF METALLIC FERROMAGNETIC BEHAVIOR.
S. Merton, G.D. Wudl, University of Missouri-Rolla, Rolla, MO; J.G. Tobin, Lawrence Livermore National Laboratory, Livermore, CA; S. Kim and I. Schuller, University of California-San Diego, La Jolla, CA.

Many materials have been predicted to be half magnetic metals, but only one example was provided experimentally so far. [1] Using the spin-resolving photoelectron spectrometer at the Spectromicroscopy Facility (Beamline 7) at the Advanced Light Source [2], we have found evidence for half-metallic behavior in thin films of Fe3O4 (magnetite). Thin films of magnetite hold out the possibility of use in devices as pure spin sources. Because our spin resolving experiments are performed at higher photon energies, we were able to monitor the spin polarization of the near Fermi energy electrons without resorting to destructive surface cleaning techniques, using the samples as is.

Furthermore, we have demonstrated that high 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. The ability to perform the experiments at higher energies is a direct result of the high brightness of the ALS and is probably a unique capability of 3rd Generation Synchrotron Radiation Sources. The experiments at the ALS were supported by growth and characterization studies at UCSB. Magnetite films were prepared by reactive sputtering. Epitaxial magnetic films were grown on MgO and sapphire substrates with precise control of gas flows and substrate temperature. Their structure was characterized by RIHHF, LEED, and XRD. Future experiments are in progress. References 1. Park et al, Nature 392, 794 (1998); Phys. Rev. Lett. 81, 1583 (1998); 2. J.G. Tobin et al, MRS Symp. Proc. Bd 524, 185 (1998).

2:15 PM F11.3
THE SURFACE STRUCTURE OF Fe3O4(100) GROWN BY O-ASSISTED MOLECULAR BEAM EPITAXY.
Andre V. Mijiritskii and O. O. Boerma, Groningen, Netherlands.

The surface structure of Fe3O4(100) was studied in situ by low-energy ion scattering (LEIS) and low-energy electron diffraction (LEED). An epitaxial Fe3O4(100) film was grown on MgO(100) at a substrate temperature of 250°C by O2-assisted molecular beam epitaxy (MBE). The flow of molecular O2 directed onto the substrate gave rise to a background pressure of 1.0x10^-8 mbar. Right after the growth, LEED and LEIS revealed a four-fold symmetry of the surface structure, with (√2 x √2)R45° reconstruction relative to the bulk-terminated Fe3O4(100). No changes were observed in either LEED or LEIS data after cooling down the sample to 80 K in UHV. To understand the surface reconstruction in greater detail, computer simulations of the LEIS process were carried out. Azimuthal scans of both scattered particles and Fe and O ions recorded from the sample were calculated for full structures and fitted simultaneously to experimental data. The best agreement was found for a model where at the Fe3O4(100) surface, bulk-terminated by a (tetrahedral) Fe-Jayer, every second Fe ion was removed while the remaining Fe ions were placed into the octahedral sites formed by the underlying mixed Fe-O layer. This model explains most of the observations reported to date and is in agreement with a recent theoretical prediction. The details of the lattice relaxation are discussed.

2:30 PM F11.4
MAGNETOTRANSPORT STUDIES IN Lnc-Co, Mn-x -Mn-x -Mn-x -Co-2-x (M=Co and Ga). V. K. Meena, R. Ravindranath and M. Ramakrishna Rao, National Centre for Department of Physics, Indian Institute of Technology Madras, Chennai, INDIA.

Hole-doped manganese and cobalt oxides such as Ln-x -Mn-x -Mn-x -Co-2-x (M=Ca and Sr) exhibit the property of colossal
magnetoresistance (CMR) and have attracted considerable attention in recent years. It is well known that substitution of Co for Mn makes the double exchange interaction (DE) between Mn$^{3+}$/Mn$^{4+}$ short ranged and even a small amount of Co substitution can destroy the ferromagnetic order (FM)\textsuperscript{1,2}. The magnetic characteristics of the CMR compounds are still not very clear and the present study was aimed at understanding the effect of substitution of a magnetic ion like Co in comparison to a non-magnetic ion like Ga at the Mn site. In the present study $La_{0.8}Ca_{0.2}Mn_{x-y}Ga_{y}O_{3}$ and $La_{0.8}Ca_{0.2}Mn_{x-y}Co_{y}O_{3}$ and $x = 0.4, 0.1$ and $0.2$ compounds were prepared by the solid state reaction method. Resistivity measurements show a large suppression in the peak resistivity temperature ($T_{p}$) for the Ga substituted compounds compared to that of the Co substituted compounds ($T_{p} = 172$K for $La_{0.8}Ca_{0.2}Mn_{0.8}Ga_{0.2}O_{3}$ and $223$K for $La_{0.8}Ca_{0.2}Mn_{0.8}Co_{0.2}O_{3}$ indicating a greater decrease in the ferromagnetic coupling in the former case. In-situ measurements at frequencies of 313, 626 and 339Hz show a shift in the Curie temperature ($T_{c}$) for Co compounds compared to the Ga compounds indicating a cluster glass kind of behaviour. It has been seen that clustering of the spins take place either when the number of Mn$^{3+}$ ions or when the number of mobile charge carriers are reduced. In this case the number of Mn$^{3+}$ ions is the same for identical compositions of Co and Ga substituted compounds and hence the observed decrease in the defreezing temperature can be attributed to the number of mobile carriers. Carrier density measurements are underway.

References:

2:45 PM F11.5
A FLUORINATION STUDY OF LaSrMnO$_4$
STRUCTURAL, ELECTRONIC AND MAGNETIC EFFECTS.
Lawmin Alkens and Colin Greaves.
University of Birmingham, School of Chemistry, Birmingham, UNITED KINGDOM.

High $T_c$ superconductivity in cuprates and colossal magnetoresistance (CMR) behaviour in manganite systems are chemically similar in as far as both require mixed valent Cu$^{2+}$/Cu$^{3+}$ and Mn$^{3+}$/Mn$^{4+}$ ions, respectively. Although the oxidation state of these ions has generally been controlled through the use of cationic substitutions, recent alternative methods, via ion manipulation, have been successful. Fluorination, for example, was shown to be a powerful tool in both the enhancement and induction of high $T_c$ superconductivity in layered cuprate systems and the first superconducting oxide fluoride, Sr$_2$Cu$_2$OF$_4$, derived from Sr$_2$Cu$_2$O$_3$, was found to have a $T_c$ of 46K. Here we will show that similar fluorination procedures can be used to control the oxidation state of the manganese ions within the low dimensional phase, LaSrMnO$_4$. So for our results show that the initial cell parameters of the parent oxide ($a = 6 = 3.7592(2) \text{Å}$ and $c = 13.129(1) \text{Å}$) dramatically change on fluorination with the new phase LaSrMnO$_{4-x}$F$_x$, having cell dimensions of $a = b = 3.774(4)$ $\text{Å}$ and $c = 14.225(4) \text{Å}$. These changes are due to fluorine insertion between [LaMnF] layers perpendicular to $c$ which results in the oxidation of the Mn$^{3+}$ ion. The synthesis, structure and magnetic properties of both LaSrMnO$_4$ and LaSrMnO$_{4-x}$F$_x$ will be reported. The chemical nature of the fluorine insertion and its structural consequences will be discussed.

3:00 PM F11.6
COLLOSAL MAGNETORESISTANCE IN SCREEN PRINTED
La$_{0.8}$Ca$_{0.2}$Mn$_{0.8}$O$_3$ THICK FILMS.
A K M Akther Hasin.
Department of Physics, Bangladesh University of Engineering, BANGLADESH. L.F. Cohen, Blackett Laboratory, Imperial College, London, UNITED KINGDOM; A. Berenov, J. Moxonius Driscoll, Materials Department, Imperial College, London, UNITED KINGDOM.

Thick films of La$_{0.8}$Ca$_{0.2}$Mn$_{0.8}$O$_3$ were fabricated on single crystal (100) LaAlO$_3$ (LAO), single crystal (100) yttria stabilised zirconia (YSZ) and poly-crystalline Al$_2$O$_3$ by a screen printing technique. The films were sintered at 1200, 1300 and 1400$^\circ$ C, in air, oxygen and nitrogen atmospheres to explore the optimum annealing conditions of manganite thick films. Magnetic and DC resistance properties were measured on all films. So-called colossal magnetoresistance (CMR) behaviour was found to occur for films on all substrates under certain preparation conditions. The salient feature of the CMR observed in these thick films is that MR is not limited to a small temperature window near the metal-insulator transition at $T_{MI}$. The MR peak is very broad and for some films a temperature independent CMR is observed at temperatures below $T_{MI}$. Several repeat films were made and the reproducibility of the results obtained in the first batch were confirmed.