SYMPOSIUM F

Magnetic Materials, Structures, and Processing for Information Storage

April 24 – 27, 2000

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* Invited paper

SESSION F1: PATTERNED MAGNETIC RECORDING MEDIA I
Monday Morning, April 24, 2000
Golden 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 written bit. However, at some density, thought to be below 100 Gb/in^2, this scaling process will lead to grains which are susceptible 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. We are 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 focussed 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. Chou, L. Kong, M.T. Li, W. Wu, Z. Yu, and B. Cui, NanoStructure Laboratory, Department of Electrical Engineering, Princeton University, Princeton, NJ.

Since its proposal and initial demonstration [1], the advantages of quantized (or patterned) magnetic disks (QMDs)a new paradigm for magnetic data recording are increasingly being recognized. The recognition stems partially from two facts: (a) conventional magnetic recording medium is approaching its limit, and (b) the economical technologies for manufacturing QMDs can become available soon. 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 Gdots/in^2 have been fabricated. The reading and writing of QMDs with 65 Gbits/in^2 for perpendicular magnetization and 50 Gbits/in^2 with longitudinal magnetization will be shown. The imprint area over 4 inch wafer with excellent uniformity has been demonstrated.
[1] S.Y. Chou, M.S. Wei, P.R. Krauss, P.B. Fischer, J. Appl. Phys. 76 (10), 6673 (1994).
[2] S.Y. Chou, P.R. Krauss, and P.J. Renstrom, Appl. Phys. Lett, 67 (21), 3114 (1995).

11:00 AM F1.3
TOPOLOGICAL AND MAGNETIC PATTERNING OF Co/Pt MULTILAYERS. V. Metlushko, G. Crabtree, V. Vlasko-Vlasov, P. Baldo, L. Rehn, M. Kirk, Materials Science Division, Argonne National Laboratory, Argonne, IL; B. Ilic, School of Applied and Engineering Physics, Cornell University, Ithaca, NY; Wenjun Fan, S.R.J. Brueck, Center for High Technology Materials, 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 [Co4/Pt10]n multilayers were prepared on a Si/SiO_2 substrate. The patterning of submicron periodic arrays were done in two ways, using traditional interference- or e-beam lithography and lift-off which modulates the material composition of the film, and using 30 keV He ion irradiation through 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 10^{15} to 5 x 10^{16} ions/cm^2 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 magneto 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 2.6GBITS/IN^2 RECORDING IN PERPENDICULAR PATTERNED MEDIA. Joyce Wong, Axel Scherer, California Institute of Technology, Dept of Electrical Engineering, Pasadena, CA; Mladen Barbic, Sheldon Schultz, 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 100Gbits/in^2. Using a combination of high resolution electron beam lithography, chemically assisted ion beam etching and electroplating, we have fabricated high aspect ratio Ni columns that are embedded in an $(Al_{0.9}Ga_{0.1})_2O_3/GaAs$ substrate. The etching procedure takes advantage of the high etching rate of AlGaAs and GaAs, and the superb selectivity of GaAs over $(AlGa)_2O_3$ to create high aspect ratio holes in the GaAs substrate. Besides being a robust ion etch mask, the durable $(AlGa)_2O_3$ layer also acts as an ideal surface for chemical mechanical polishing to remove all the overplated Ni mushrooms. 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 a 0.25μm and 1μm 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 $(AlGa)_2O_3$ 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/in^2, using a commercial inductive write/spin-valve 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 1μm, which corresponds to an increased storage density of 5.2Gbits/in^2. In addition to embedding the magnets in the $(AlGa)_2O_3/GaAs$ system, recent work on the fabrication of high aspect ratio Ni columns in an alternative SiO_2/Si embedding material system will also be presented.

11:30 AM F1.5
ON EXTREME DENSITY OF DATA STORAGE IN PATTERNED MAGNETIC MEDIA. E. Meilikhov, B. Aronzon, B. Gurovich, E. Kuleshova, Russian Research Center, Kurchatov Institute, Moscow, RUSSIA.

Patterned magnetic medium is the next step to significant increasing data storage density. To attain extreme density it is necessary to deal with the smallest superparamagnetic granules (each storing a bit of information) admissible from the physical point of view. It is well known that the volume of such granules and their aspect ratio have to be large enough to prevent the thermally activated magnetization relaxation. However, these requirements are not exhaustive. Patterned recording medium is the set of closely-spaced aligned magnetic granules with the random (“up” and “down”) orientations of granules' magnetic moments. Though the exchange interactions between the granules may be neglected, there are long-range intergranular dipole-dipole interactions (DDI) which lead to the significant lowering of activation barrier preventing thermal relaxation. Those interactions limit the acceptable density of ferromagnetic granules and, hence, reduce the extreme density of data storage. Our numerical calculations result in the estimation of the negative role of DDI for the particular case of two-dimensional set of ellipsoidal magnetic granules and allow to determine the extreme density of data storage.

SESSION F2: PATTERNED MAGNETIC RECORDING MEDIA II
Monday Afternoon, April 24, 2000
Golden Gate B3 (Marriott)

1:30 PM *F2.1
FABRICATION AND MAGNETIC PROPERTIES OF PATTERNED 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 model structures for the study of the fundamentals of magnetic switching behavior 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 thin film media. One solution 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 nanostructures 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 nanostructures with periods of 100 nm and above. Arrays of magnetic particles have been made using electrodeposition, evaporation, or etching 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 anisotropy, switching behavior, mutual interactions, and how closely they approximate to the coherent reversal model, and discuss their application in data storage devices.

2:00 PM F2.2
IN-SITU LTEM INVESTIGATION OF SWITCHING OF MAGNETIC PATTERNS PREPARED BY ION-BEAM IRRADIATION. Greg J. Kusinski, Dept of Materials Science and Mineral Engineering, Univ of California, Berkeley, CA; D. Weller, B.D. Terris, L. Folks, C. Rettner, M.E. Best, A.J. Kellock, J.E.E. Baglin, IBM Research Division, Almaden Research Center, San Jose, CA; K.M. Krishnan, Materials Sciences Division, Lawrence Berkeley National Laboratory; G. Thomas, Department of Materials Science and Mineral Engineering, University of California, Berkeley, CA.

Co/Pt multilayers with perpendicular anisotropy were grown on electron transparent Si_3N_4 membranes using electron beam evaporation. Regularly spaced 1 micron sized regions, with the easy axis of magnetization rotated into the plane of the film, were magnetically patterned via ion beam irradiation through a silicon stencil mask. Typical conditions were 700 keV nitrogen ions at doses of 5-10x10^{15}/cm^2. Transmission electron microscope analysis revealed no microstructural or chemical differences between the irradiated and non-irradiated regions. A wide log-normal 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 remanent state the in-plane areas supported 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, (H_C) = 5-6kOe) was confirmed by Kerr measurements of larger, 4x4mm areas exposed to the same doses of ion radiation.

2:15 PM F2.3
MAGNETIC PROPERTIES OF ELECTRODEPOSITED NANOWIRE ARRAYS. L. Sun, The Johns Hopkins Univ, Dept of Materials Science and Engineering, Baltimore, MD; C.L. Chien, The Johns Hopkins Univ, Dept of Physics and Astronomy, Baltimore, MD; P.C. Searson, The Johns Hopkins Univ, Dept of Materials Science and Engineering, Baltimore, MD.

Nanopores with lateral dimensions as small as 20 nm have been fabricated by nuclear track etching in 5 micron thick, single-crystal muscovite mica wafers. The nanopores 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 nanopores. 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 decresaing wire diamete and obeys finite size scaling theory.

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

The natural precessional response of the magnetization to 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 $\sim 10^{-9}$s, the regime where precessional effects become important. At the same time, to achieve these extraordinary linear densities, grain size in media has been reduced to <20 nm with processing optimized to reduce exchange coupling between grains. The result is significantly increased thermal instability, reducing the remanent coercivity which at 10^{-9}s is $\sim$4000-5000 Oe to values below 2500 Oe at long times (10^9s), thus threatening archivability. 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 basic properties of viscosity, irreversible susceptibility and anisotropy. Orientation is shown to have relatively little effect on $H_{CR}R(t)$. In all cses, $H_{CR}(t)$ is well described by a generic form of Sharrocks Law, at least down to 10^{-9}s. Below 10^{-9}s, precessional effects increase $H_{CR}(t)$ more rapidly but the product of the field increment relative to $H_{CR}(t)$ at 10^{-9}s and the field pulse width is only $\sim$100 200 Oe ns. 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. Shaoping Li, Deniel Brown, John Dykes, Jack vonfeldt, Dean Palmer and Rick Draz, Advanced Recording Technology Laboratory, Seagate Technology, Bloominton, 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 have been carried out to study the effect of the microstructure, demagnetizing field and initial magnetizing 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 compatible with the spin-stand 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-superparamagnetism decay-mechanics might exist in the magnetization decay process of magnetic recording media.

3:45 PM *F2.6
REVIEW OF RELAXATION MECHANISMS IN DYNAMIC MAGNETIZATION PROCESSES: APPLICATIONS TO THIN FILMS AND FINE PARTICLES. 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 data rates in 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 planar dimensions exceed a domain wall width or an exchange length, the magnetization dynamics is initially governed by the large thin film demagnetizing factor. As the magnetization becomes almost completely reversed, the excitation of non-linear spin waves removes the "Zeeman energy" allowing the magnetizations to remain in almost the completely reversed state. We will discuss final relaxation by homogenous magnetostatic coupling to the lattice. For fine grains whose size is sufficiently small so that the grain magnetization is virtually uniform, non-linear spin waves cannot assist reversal. 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 a 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, Saipeng Wong, Ning Ke, Wingyiu Cheung, Manfat Chiah, The Chinese Univ of Hong Kong, Dept of Electronic Engineering and Materials Science and Technology Research Center, Hong Kong, CHINA; Gehui Wen, Xixiang Zhang, Hong Kong Univ of Science and Technology, Dept of Physics, Hong Kong, CHINA.

Co_xC_{1-x} (x=49,60,65 at.%) composite thin films of about 20 nm thick were prepared by pulsed filtered vacuum arc deposition. Subsequent annealing was performed in vacuum (<10^{-3} Pa) at 350°C for one hour. The films were characterized by non-Rutherford backscattering spectrometry, 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 $Co_{0.49}C_{0.51}$ film 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 lead to the transformation from superparamagnetism to ferromagnetism.
This work is partially supported by the Research Grants Council of Hong Kong (Ref. No.: CUHK 4152/98E)

4:30 PM F2.8
STATIC AND DYNAMIC MAGNETIC BEHAVIOR OF SUPER-PARAMAGNETIC NANOPARTICLES. Eugene L. Venturini, Jess P. Wilcoxon and Paula N. Provencio, 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-continuous, oxygen- and water-free inverse micelle systems provides samples containing isolated, oxide-free nanoparticles 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 simple model based on a two-level jump process for spin reorientation yields an estimate 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 strong 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 shifts the peak in the AC susceptibility to higher temperatures. The shift provides an independent estimate of the average spin per nanoparticle 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-AC04-94AL85000. 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 MAGHEMITE NANOPARTICLE POWDERS. B. Rellinghaus, A. Kurz, E.F. Wassermann, Experimentelle Tieftemperaturphysik, Gerhard-Mercator University, Duisburg, GERMANY; Ch. Janzen, P. Roth, Institut für Verbrennung und Gasdynamik, Gerhard-Mercator University, Duisburg, GERMANY.

γ-Fe_2O_3 (maghemite) – formerly one of the most widely used materials for analogue magnetic recording – has recently experienced a renaissance 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. Mean particle sizes are in the range 4nm$\leq$d$\leq$12nm and are controlled by varying the concentration of $Fe(CO)_5$ precursor material within the flame gas. Structural and spectroscopic investigations utilizing (HR)TEM, XRD, IRS, and EELS show that the individual particles are singly crystalline and single phase maghemite. 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 occurance of a spin disorder phase becomes obvious from a remaining splitting between field cooled and zero field cooled magnetization curves in external fields as high as H_{ext}=50kOe. The corresponding freezing temperature, T_{fr}, is observed to decrease logarithmically with the external field. Below a minimum field, H_{min}, T_{fr} remains constant, and within the simple model of a magnetic core surrounded by a non-magnetic shell the absolute value of H_{min} is in good quantitative agreement with the surface stray field of the particle core.

[1] J.L. Dormann, R. Cherkaoui, L. Spinu, M. Nogues, F. Lucari, F. D'Orazio, D. Fiorani, A. Garcia, E. Tronc, and J.P. Jolivet, J. Magn. Magn. Mat. **187** (1998) L139.
[2] B. Martinez, X. Obradors, Ll. Balcells, A. Rouanet, and C. Monty, Phys. Rev. Lett. **80** (1998) 181, and references therein.
[3] C. Janzen, B. Rellinghaus, and P. Roth, J. Nanopart. Res. (1999), accepted.

SESSION F3/G1: JOINT SESSION: MAGNETIC RECORDING MEDIA
Tuesday Morning, April 25, 2000
Golden Gate B3 (Marriott)

8:30 AM *F3.1/G1.1

ADVANCED LONGITUDINAL RECORDING MEDIA USING HCP COBALT ALLOYS. Mary F. Doerner, Xiaoping Bian, Kai Tang, Mohammad Mirzamaani, Adam Polcyn, IBM Storage Systems Division, San Jose, CA; Kurt Rubin, Ken Takano, Michael F. Toney, Andreas Moser, Dieter Weller, IBM Almaden Research Center, San Jose, CA.

It is well recognized that thermal stability may place a limit on longitudinal magnetic recording areal density with predictions of a maximum data density limit ranging from 36 to 100 Gbits/in^2 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 Gbits/in^2 using magnetic media that are thermally stable. The very low signal decay rate of 0.63%/decade measured on a Squid magnetometer at 350 K and 500 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 x 10^6 ergs/cm^3 has been measured for polycrystalline HCP Co75Pt12Cr13, 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 issues associated with achieving 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 usable Ku 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-alloy. High coercive squareness (S*) is necessary for good overwrite properties. The grain size distribution plays 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; Marilee Schultz, Brij B. Lal, Michael A. Russak, 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 analysis 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 an MR head reveals magnetic recording properties. These characterization tools have been applied to investigate a series of CoCrPtTa, CoCrPtB, and CoCrPtTaB thin film longitudinal media, prepared under ostensibly 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 CoCrPtTa 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 boron.

9:15 AM F3.3/G1.3

TEM TO SUPPORT MAGNETIC MEDIA DEVELOPMENT IN YR2000. Warren J. MoberlyChan, Tom P. Nolan and Paul Dorsey, Komag, Inc., San Jose, CA.

In this 1 square inch space, hard drive media of 1999 stored >2 Gbytes. This requires reproducibly processing thin films with judicious control of >2000000000000/in^2 magnetic grains. Further constraints include corrosion resistance in all environments, impact resistance involving GPa stresses, >30db signal-to-noise, rapid information transfer, and wear resistance associated with heads flying at 20000 rpm and at a spacing <0.00007$^{\underline{th}}$ the width of a human hair. The price tag for a finished 3.5$''$ disk of media was $8 in 1999. In the year 2000, storage density must increase >100%; and price must drop. To solve this ongoing Y2K problem, statistical and efficient TEM techniques are necessary.
This paper presents traditinal and state-of-the-art TEM methods for the study & control of crystallography in all three directions in these media grains on metal or glass substrates. Electron diffraction, weak-beam dark field, and *in situ* tilting experiments provide structural analysis to advance these materials. Routinized tilting and statistical imaging enable the microscopist to see, study, and improve the spatial inhomogeneities 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 CoCrPtTa RECORDING MEDIA. Kai Ma, Robert Sinclair, Stanford University,

Dept. of Materials Science and Engineering, Stanford, CA; Gerardo Bertero, Wei Cao, Komag Inc., San Jose, CA.

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 those 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 investigation has 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 decrease with underlayer grain size. Considering that the bi-crystal grain boundaries usually are not clearly revealed in normal bright field (BF) Transmission Electron Microscopic (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, CrMo underlayer grain sizes were made to vary from 16nm to 10nm. However, the corresponding CoCrPtTa grain sizes basically remained unchanged. As the underlayer grain size decreased, the ratio of magnetic layer grain size to underlayer grain size increased from 0.87 to 1.40. HRTEM results show that the formation and breakup of bi-crystal clusters play a determinant role in this effect. The significance of these results for the growth of the magnetic layer will be discussed.

9:45 AM F3.5/G1.5

MICROSTRUCTURE AND TEXTURAL CHARACTERIZATION OF Co-ALLOY THIN FILMS BY TRANSMISSION ELECTRON MICROSCOPY. K.M. Moulding, J.S.K. Wong, J. Zheng, MCPF, Hong Kong University of Science and Technology, HONG KONG.

Co-alloy thin films are a popular choice for current magnetic media. As the demand for higher bit densities increases, the crystallography and microstructure of the magnetic thin film becomes increasingly important. Co-alloy films with a small grain size and a highly orientated 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 RF sputtered Co-Cr-Pt films grown on silicon substrates without an intermediate layer, and to compared with those which have an intermediate buffer and seed layer. In the process of the comparison, the roles of the additional layers to enhance the crystallographic 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

TEM CHARACTERIZATION OF CHEMICAL COMPOSITION INHOMOGENEITY IN MAGNETIC THIN FILM MEDIA. J.E. Wittig[1], J. Ma[1], and J. Bentley[2], [1]Vanderbilt University, Nashville, TN; [2]Oak Ridge National Laboratory, Oak Ridge, TN.

The structural requirements for low noise magnetic recording media (small grain size, separation of magnetic particles) increasingly conflict with those for thermally stable 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 10 to 15 nm, high resolution characterization methods such as transmission electron microscopy (TEM), nanoprobe 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 methods using an Mrt series of longitudinal recording media prepared for the extreme high density recording (EHDR) project of the National Storage Industry Consortium (NSIC). These EHDR disks have NiP/Al supersmooth substrates with a 60 nm NiAl seed layer and a 7.5 nm CrMo intermediate layer. The magnetic media is a $Co_{71}Cr_{17}Pt_8Ta_2Nb_2$ 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 media in order to understand the limitations from decreasing magnetic film thickness on the quantification capability. Research at the ORNL SHaRE User Facility was supported by the Division of Materials Sciences, U.S. Department of Energy under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corp., and through the SHaRE Program under contract DE-AC05-76OR00033 with Oak Ridge Associated Universities.

11:00 AM *F3.7/G1.7

CHEMICAL ORDERING AND MICROSTRUCTURE OF FePd THIN FILMS WITH PERPENDICULAR MAGNETIC ANISOTROPY. Bruno Gilles, LTPCM, CNRS Grenoble, FRANCE; Alain Marty, Yves Samson, David Halley, DRFMC, CENG Grenoble, FRANCE.

The $L1_0$ ordered phases in FePd, FePt and CoPt binary alloys in thin films might be promising materials for high density storage media, due to their high magnetocristalline. Depending on the growth temperature, we have been found that FePd 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 perpendicular magnetization 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 3 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 density of anti-phase boundaries is decreased when the growth temperature is increased and STM images have revealed larger atomic and bi-atomic terraces. This suggests that the diffusion length of the ad-atoms on the growing surface may explain the change in the LRO. Attention has been paid to the relaxation of strain which is in favor to 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.E. Baglin, D. Weller, L. Folks, M. Toney, A.J. Kellock, B.D. Terris, E. Fullerton, S. Maat, C.T. Rettner and G.J. Kusinski, IBM Almaden Research Center, San Jose, CA.

We have investigated the physical mechanism whereby ion irradiation produces large changes in the magnetic properties of thin films suitable for magnetic recording, e.g. $[Co/Pt]_n$ multi-layers, or Fe-Pt alloy films. These effects are the basis of ion beam patterning techniques proposed for future high density storage. Samples were irradiated with He, N, Ar or Xe ions at energies between 30 keV and 1 MeV, with doses spanning the range 10^{14} - 5×10^{16} ion/cm^2. We then examined the dependence of the magnetic properties on ion energy, species and dose, and on the media structure, (number and thickness of layers; stoichiometry). Structural characterization was done using AFM, MFM, LTEM, XRR, RBS, and ion channelling. We attribute the magnetic effects primarily to short-range chemical disordering effects at multilayer interfaces or within alloy media, induced by ion beam mixing. The model appears to be supported by TRIM simulations.

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 PROBES OF MAGNETIC MULTILAYER STRUCTURE. B.K. Tanner, 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 buried interfaces. We show how to determine the degree of conformality of the roughness in multiple layer structures such as spin-valves. 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 enables the depth location of impurities, for example 1% Ni in a 20nm Cr film, to be determined. We present evidence for surfactant behaviour of Nb in the growth of Au-Fe multilayers. Soft x-ray scattering enables us to access larger areas of reciprocal space in comparison to the grazing incidence scattering of harder x-rays. 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 L 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

PHOTOEMISSION SPECTROSCOPY OF PSEUDOMORPHIC THIN FILMS OF THE INVAR ALLOY Fe_xNi_{1-x}. Michael Hochstrasser, Roy F. Willis, The Pennsylvania State University, Physics Department, University Park, PA; Frank O. Schumann, James G. Tobin, Lawrence Livermore National Laboratory, Material Science Division, Livermore, CA; Eli Rotenberg, Lawrence Berkeley National Laboratory, Advanced Light Source, Berkeley, CA.

In the bulk, the magnetic moments of Fe_xNi_{1-x} alloys deviate strongly from at an Fe concentration of 65%, 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_xNi_{1-x} films can be stabilized in the fcc phase when grown as ultrathin films on Cu(100). The fcc to bcc structural transformation is quenched, but the magnetic instability persists. We have investigated with angular resolved photoemission the k-space electronic structure of thin Fe_xNi_{1-x} alloy films pseudomorphically grown on Cu(100) over the whole concentration range. We observe changes 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 spectroscopy particular regions in k-space have been further investigated to get a better insight into the changing electronic and magnetic structure of Fe_xNi_{1-x} fcc alloy films. We observe changes at 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. Meza-Aguilar, C. Demangeat, H. Dreyssé, IPCMS, Strasbourg, FRANCE; A. Rakotomahevitra, Department of Physics, Florida Atlantic University, Boca Raton, FL.

Choi *et al* (Phys. Rev. B **58**, (1998) 5166) have studied the magnetic properties of ultrathin Mn films on fcc Co/Cu(100) using the *in situ* magneto-optical Kerr effect (MOKE) and low energy electron-diffraction. They found that a two-dimensional MnCo(001) 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/Co(100) by MOKE and x-ray dichroism. Theoretical electronic and magnetic structure studies on MnCo 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(001) versus the formation of 1 or 2ML-thick MnCo(001) alloys, as well as the inverted Co/Mn/Co(001) system case. The MnCo alloy is found to be more stable than the Mn overlayer on Co(001) substrate, in qualitative agreement with the experimental predictions above. In the case of 2ML-thick MnCo alloy the magnetic coupling between Mn and Co atoms at the surface and the subsurface is found to be ferromagnetic and antiferromagnetic respectively. We discuss the stability of a 2D ordered Fe-Mn alloy on Co(100) versus the buried Co/Fe-Mn/Co(100) alloy. As previously we found that the buried configuration is the ground state. The Mn atom -in the ground state- is 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. Metlushko, P. Vavassori, M. Grimsditch, Materials Science Division, Argonne National Laboratory, Argonne, IL; B. Ilic, School of Applied and Engineering Physics, Cornell University, Ithaca, NY; P. Neuzil, R. Kumar, Institute of Microelectronics, Singapore, SINGAPORE.

We have investigated the shape and thickness dependence of a series of Co and permalloy nano-scale arrays using the Magneto Optic 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 tetragonal arrays with elliptical elements with various sizes and aspect ratios in the range 100nm to 2000nm were fabricated simultaneously, on a single substrate, to avoid complications due to changes in anisotropy and or thickness. Identical patterns were fabricated for 30nm of Co and 20nm and 30nm of permalloy. The effect of element shape on coercivity, extracted from 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

TEM IN SUPPORT OF INDUSTRIAL RESEARCH. Philip M. Rice, Stuart S.P. Parkin, Robin F.C. Farrow, Mary Moore, IBM Almaden Research Center, San Jose, CA; William J. Gallagher, IBM-T.J. Watson Research Center, Yorktown Heights, NY; Tsann Lin, IBM Storage Systems Division, San Jose, CA.

Competition in the storage industry has driven storage research toward ever increasing areal densities. These increases in storage 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 elemental migration between multilayers will also be discussed.

3:45 PM F4.6/G2.6

ULTRATHIN ALLOY FILMS. F.O. Schumann, Freie Universität Berlin, GERMANY; J.G. Tobin, Lawrence Livermore National Lab, Livermore, CA.

We investigated ultrathin alloy films in an element-specific manner by means of dichroism in photoemission (MLDAD). Specifically we investigated fcc Fe_xCo_{1-x} and Fe_xNi_{1-x} films grown on Cu(100). For high Fe concentrations we find contrasting behavior of the two systems. In the case of Fe_xNi_{1-x} we observe a small magnetic signal associated with a moment-volume instability. However for the Fe_xCo_{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 different atomic volumina of fcc Fe upon alloying with Co and Ni. It is now well-established that fcc Fe/Cu(100) can 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 bcc Fe. This moment enhancement in the case of Fe_xCo_{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 magnetometry for ultrathin films is discussed.

4:00 PM F4.7/G2.7

THE STRUCTURE OF POLYCRYSTALLINE AND EPITAXIAL GMR MAGNETIC MULTILAYERS AND SPIN-VALVES GROWN BY SPUTTER DEPOSITION. Hong Geng, Reza Loloee, John W. Heckman, Martin A. Crimp, Dept of Materials Science and Mechnics, Michigan State Univ, East Lansing, MI; Reza Loloee, William P. Pratt, Jr., Dept of Physics and Astronomy, Michigan State Univ, East Lansing, MI.

The study of the GMR effect in magnetic multilayers and spin-valves has shown that the electrical transport in these materials depends on layer quality and interface structures, as well as film orientation. In the present study, a number magnetic multilayers $(Co/Cu)_x$ and spin-valves (FeMn/Py/Cu/Py and Py/Ag/Py/FeMn) were produced by dc magnetron sputtering (Py = Permalloy^{TM} (NiFe)). Initial work on these structures concentrated on polycrystalline materials grown with polycrystalline Nb superconducting contacts. More recent work has focused on epitaxial structures grown on single crystal (1$\bar{1}$0) Nb that was deposited on (11$\bar{2}$0) Al_2O_3 substrates. The grain size, morphology, and orientation of the epitaxially grown films have been characterized using electron back scattered pattern (EBSP). 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 (CTEM and HRTEM). In polycrystalline samples, CTEM 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) analysis 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 sputtered of Cu, Py and Co resulted in two growth variants predicated 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 MRSEC DMR 98-09688.

4:15 PM F4.8/G2.8

SCANNING-APERTURE PHOTOEMISSION MICROSCOPE FOR MAGNETIC IMAGING. Gary M. McClelland and Charles T. Rettner, 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, photo-emission is excited by a laser focused to a 10-micron spot. A scanning aperture above 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 10-nm-thick Co-Pt multilayer thin films on sapphire have been obtained. From a cesiated film, a high quantum efficiency of 0.002 was observed from 458 nm laser light. Circular dichroism of $\pm 2\%$ is recorded by alternating the circular polarization of the light while scanning. The tip distance above the surface is maintained by advancing the tip until 1-nA tunneling to a positive sample is observed, then withdrawing 15 nm and switching polarity to detect photoemission through the tip. The resolution we observe agrees well with the 35-nm-sized aperture in the gold tip. From the observed noise, we project that there is enough signal to image at 5 nm resolution if a small enough aperture can be fabricated. Recent calculations show that image forces on the electron from the aperture walls act 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(001). Patrice Gergaud, Magali Putero, Olivier Thomas, MATOP, CNRS, Universite Aix-Marseille III, Marseille, FRANCE; Claude Lallaizon, Bruno LEPINE, Andre Guivarch, EPSI, CNRS, Universite 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(001) substrates because of the small lattice parameter mismatch (1.4%). Moreover, magnetic measurements performed on Fe films thinner than 3 nm have shown 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 magnetoelastic coupling. In this study, we measured using X-ray diffraction the stresses in a series of iron thin films with thicknesses varying between 1.5 and 80 nm. For the thinnest films the anisotropy of the in-plane strain has been investigated. Very small strains anisotropies are capable of modifying the magnetic anisotropy of iron thin films. Moreover the sign and magnitude of the magnetoelastic coupling seem to depend on the film thickness or film strain [1]. We thus calculated the magnetic anisotropy using both bulk and thin film magnetoelastic coupling. 1. D. Sander, Rep. Prog. Phys. 62 (1999) 1-50.

SESSION F5/G3: JOINT SESSION: MAGNETIC TUNNEL JUNCTIONS AND SPIN-DEPENDENT TRANSPORT

Wednesday Morning, April 26, 2000
Golden Gate B3 (Marriott)

8:30 AM *F5.1/G3.1

SPIN POLARIZED CURRENTS IN MAGNETIC TUNNEL JUNCTIONS. Peter M. Levy, Kuising Wang, Dept of Physics, New York University, New York, NY; Shufeng Zhang, Dept of Physics, University of Missouri, Columbia, MO; Charles B. Sommers, Lab. Phys. Sol., Universite Paris-Sud, Orsay, FRANCE; Laszlo Szunyogh, Technical University Budapest, Budapest, HUNGARY; Peter Weinberger, Technische Universitat Wien, Vienna, AUSTRIA.

The factors that govern the magnetoresistance of magnetic tunnel junctions will be reviewed. Attention will be focused on: the bonding of orbitals at the interfaces between electrodes and the insulating barrier, and the effect of electric fields on redistributing the electron charge and spin distribution at the interfaces, i.e., changing the profile of the tunnel barrier. While the effects of electric field penetration in the metallic electrodes was appreciated as early as the 1960's, we find that: 1) the field induced redistribution is larger for the electrons that spill out of the electrode at the interface into the insulating barrier, and 2) the induced changes in charge in the majority and minority spin channels in the electrode go in opposite directions, so as to produce important changes in the magnetization for relatively small changes in the charge at the interfaces. Changing barrier materials, e.g., from alumina to strontium titanate, has the putative effect of changing the type of spin-polarized electrons (s versus d) that hop from the electrodes into the barrier, and introduces different sets of states for electrons to tunnel through. While there is no spin dependence to these insulating barriers switching, say from s to d type electrons, can change the spin polarization of the tunneling current. In this way magnetoresistance is sensitive to the barrier material.

9:00 AM *F5.2/G3.2

SPUTTER DEPOSITED MAGNETIC TUNNELING JUNCTIONS. S.S.P. Parkin, M.G. Samant, L. Thomas and P.M. Rice, IBM Almaden Research Center, San Jose, CA.

Magnetic tunnel junctions (MTJ) are comprised of thin ferromagnetic electrodes separated by insulating tunnel barriers. These structures have attracted a great deal of interest in recent years because they exhibit large magnetoresistance (MR) effects in small magnetic fields at room temperature which makes them potentially useful for magnetic field sensors and non-volatile magnetic memory cells. For these applications MTJ devices with comparatively low resistances are required. We show that the resistance of MTJ devices with alumina tunnel barriers can be readily and controllably varied over more than 8 orders of magnitude by simply varying the thickness of the alumina layer. This requires extremely thin alumina layers just a few angstrom thick. Nevertheless pin-hole free layers can be formed. We discuss the properties of a variety of MTJ structures including the dependence of resistance and magnetoresistance on details of the structure, for example, the nature of the ferromagnetic electrodes. The thermal stability of these structures is important for applications: mechanisms for degradation on annealing are presented. Finally we discuss a novel indirect magnetic interaction between the ferromagnetic layers across the insulating tunnel barrier mediated by fringing fields from domain walls in one ferromagnetic layer acting on the other ferromagnetic layer. * Work supported in part by DARPA.

9:30 AM F5.3/G3.3

APPARENT SPIN POLARIZATION DECAY IN Cu DUSTED $Co/Al_2O_3/Co$ MAGNETIC TUNNEL JUNCTIONS. P. LeClair, H.J.M. Swagten, J.T. Kohlhepp, R.J.M. van de Veerdonk and W.J.M. de Jonge, Department of Applied Physics and Cobra, Eindhoven University of Technology, Eindhoven, THE NETHERLANDS.

$Co/Al_2O_3/Co$ magnetic tunnel junctions with an interfacial Cu layer have been investigated via *in-situ* X-Ray Photoelectron Spectroscopy, Auger Electron Spectroscopy, and Scanning Tunneling Microscopy as well as *ex-situ* magnetotransport measurements. In identically grown structures, Cu interlayers grown on Co give an exponential decay of the tunneling magnetoresistance (TMR) with $\xi \approx 0.26$nm while Cu grown on Al_2O_3 has a much longer decay length of 0.70nm. The difference in decay lengths can be explained by differing growth morphologies in the two cases, as monitored by the *in-situ* spectroscopies, and in this way clarifies the present disagreement in literature. For monolayer coverage of Cu, for the first time we show that tunneling spin polarization is suppressed by at least a factor of 2 compared to Co. At 2ML the tunneling spin polarization is suppressed by more than a factor of 5, while beyond approximately 5ML it becomes vanishingly small.

9:45 AM F5.4/G3.4
SPIN-DEPENDENT ELECTRON TRANSPORT IN FERRO-MAGNET/SEMICONDUCTOR SCHOTTKY BARRIER STRUCTURES. Atsufumi Hirohata, Yong-Bing Xu, Christian Guertler, Tony Bland, Univ of Cambridge, Dept of Physics, Cambridge, UNITED KINGDOM; Stuart Holmes, Cambridge Res Lab, Toshiba Res Europe Ltd, Cambridge, UNITED KINGDOM.

The possibility of pin-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/GaAs ((100), $10^{23} \leq n^{+}$, $p^{-} \leq 10^{25}$ m^{-3}) and attached two Al electrical contacts to the Au layer and one ohmic contact to the bottom of the substrate. Conventional *I-V* measurements were carried out to define the Schottky characteristics of the samples. Circularly polarised laser light ($515 \leq \lambda \leq 780$ nm) was used to excite electrons with a spin polarisation perpendicular to the film plane in the samples. A helicity-dependent photocurrent, dependent upon the magnetisation configuration of the film ($\vec{\sigma} \perp \vec{M}$ or $\vec{\sigma} // \vec{M}$) 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 supression in the bias dependence of the helicity-dependent photocurrent was observed, suggesting the existence of polarized electron transport from the FM to the SC. The helicity-dependent photocurrent polarisation decreases with increasing doping density and increases with decreasing induced photon energy. These results provide clear evidence of spin-dependent electron transport through the FM/SC direct interface. [1] G. A. Prinz, *Science* **282**, 1660 (1998). [2] A. Hirohata, Y. B. Xu, C. M. Guertler and J. A. C. Bland, *J. Appl. Phys.* **85**, 5804 (1999).

SESSION F6/G4: JOINT SESSION: GMR AND SPIN VALVES I
Wednesday Morning, April 26, 2000
Golden Gate B3 (Marriott)

10:30 AM *F6.1/G4.1
VERTICAL GMR MRAM. Gary 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 has utilized current in-plane (CIP) transport in giant magnetoresistance (GMR) spin-valves. Slightly less developed demonstrations have shown that magnetic tunnel junctions may also provide the basis for MRAM and their vertical structures could occupy less space on a chip. 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
CURRENT-CONTROLLED DOMAIN SWITCHING IN MAGNETIC MULTILAYERS BY MEANS OF SPIN TRANSFER. E.B. Myers, D.C. Ralph, Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, NY; J.A. Katine, F.J. Albert and R.A. Buhrman, School of Applied and Engineering Physics, Cornell University, Ithaca, NY.

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. Slonczewski 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 5-10-nm nanofabricated metal point contact is used to inject current into a Co/Cu/Co trilayer and (in work led by Katine, Albert, and Buhrman) in Co/Cu/Co pillars approximately 100 nm in diameter. In both cases, one of the Co layers is made thinner than the other, in order to make it more easily reoriented. 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 asymmetry in current direction is as predicted by the spin-transfer mechanism. The current densities required for switching are $\sim 10^{9}$ A/cm^{2} in the point contacts and less than 10^{8} A/cm^{2}, in the pillars, well below 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 magnetic moment, but instead stimulates spin-wave excitations. The simple geometry of the 100-nm-pillar experiments allows for quantitative tests of the theories of the spin-transfer mechanism, and provides a new means of measuring 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.

11:30 AM F6.3/G4.3
EFFECTS OF ANNEALING ON THE MICROSTRUCTURE AND GIANT MAGNETORESISTANCE OF Co-Cu-BASED SPIN VALVES. M.A. Mangan, G. Spanos, Naval Research Laboratory, Washington, DC; R.D. McMichael, P.J. Chen and W.F. Egelhoff, Jr., National Institute of Standards and Technology, Gaithersburg, MD.

The effect of annealing on the microstructure and giant magneto-resistive properties of NiO/Co/Cu/Co bottom spin valves is investigated using conventional and high resolution transmission electron microscopy. The value of giant magnetoresistance (GMR) of these spin valves is observed to decrease from 12.2% to 2.7% after annealing in vacuum for 30 minutes at 335 C. This decrease is attributed to an increase in the roughness of the Co and Cu layers. In annealed specimens, grain boundary grooving is also observed in the antiferromagnetic NiO pinning layer at the NiO/Co interface, and the location of these grooves correlates with waviness in the Co/Cu interfaces. An increase in the Neel "orange-peel" coupling between the ferromagnetic Co layers, resulting from the increased roughness of the Co/Cu interfaces, accompanies the degradation of the GMR.

SESSION F7/G5: JOINT SESSION: GMR AND SPIN VALVES II
Wednesday Afternoon, April 26, 2000
Golden Gate B3 (Marriott)

1:30 PM *F7.1/G5.1
ADVANCES IN TUNNEL JUNCTION AND SPIN VALVE TECHNOLOGY FOR MRAM AND READ HEAD APPLICATIONS. P.P. Freitas, Instituto de Engenharia de Sistemas e Computadores, Lisbon, PORTUGAL.

Tunnel junction fabrication for MRAM integration (RxA=1 to 10 kOhm x um2, TMR>40%, tAl=11A, oxide or nitride barriers), and for ultra high density read heads (RxA = 45 Ohm x um2, TMR=20%, tAl=6A) is described. The thermal stability of such devices is analized, in view of the required applications. Head and MRAM designs are discussed and results are shown for vertically integrated tunnel junction- a-Si diode memory elements, with on chip switching time down to 30ns. Ongoing progress in diode technology is discussed 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-on-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 for only 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. Many insights into the chemistry of interdiffusion during the growth of thin films no doubt await discovery. As one example, we find that the heat of 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 be used as a surfactant in giant magnetoresistance spin valves 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 an oxidized Ni surface to convert insulating NiO to conducting Ni metal. This talk will give an overview of and examples of the great usefulness and potential of this so-far under-utilized 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 TRANSPORE EQUATION FOR Co/Cu/Co SPIN Co/Cu/Co SPIN VALVES. J.M. MacLaren, Physics Department, Tulane University, New Orleans, LA; L. Malkinski and J. Wang, AMRI, University of New Orleans, New Orleans, LA.

In this work we use a first principles based semi-classical theory of electron transport based upon solutions to the Boltzmann transport theory to study the CIP and CPP transport in asymmetric Co/Cu/Co spin valves. The inputs to the Boltzmann transport theory include the Fermi energy Bloch waves, the Bloch wave velocities and scattering matrices which describe the reflection and transmission of these Bloch waves from the interfaces. These are obtained from ab-initio local 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 signicant contributions to the GMR come from the channeling of majority electrons in the Cu spacer layer, though with contributions also arising from the adjacent Co layers. In the Co layers the contributions appear to decay with a lengthscale characteristic of the Co minority mean free path. The GMR varies slowly with Cu thickness because both the conductance and change in conductance vary similarly with Cu layer thickness. The most dramatic variation occurs for Co thicknesses around that of the minority mean free path of Co (about 4 nm). The value of the GMR can be changed from about 5% to close to 10%. Unlike CIP, we find that for CPP the GMR ratios are larger and relatively insensitive to the layer thicknesses which simply reflects the fact that in the CPP geometry current cannot avoid the high resistance minority Co channel. This work was supported by DARPA under contract MDA 972-97-1-003.

2:45 PM F7.4/G5.4

MANUFACTURABILITY OF GMR HEADS: 10GB/IN^2 AND BEYOND. Sanghamitra Sahu, Vivien Talghader, Jian Chen, Sining Mao, Seagate Technology, Bloomington, MN.

Consistency of spin-valve stack deposition, both wafer-to-wafer and within a wafer, is key to the manufacturability of GMR heads. For typical GMR heads, film thicknesses are now in the range of 5Å-150Å 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 $1\sigma = 1\%$ uniformity realized for the full stacks 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. Dan Dahlberg, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN.

A microscopic understanding of the Ferromagnetic/AntiFerromagnetic Exchange Anisotropy (F/AF EA) which arises at the interface between a ferromagnet and an antiferromagnet has been elusive since its discovery. Simple models of the F/AF EA 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 determined by irreversible processes. Using two different reversible magnetic techniques, we obtain F/AF EA which are up to an order of magnitude larger than the hysteresis loop method.(B.H. Miller and E. Dan Dahlberg, Appl. Phys. Lett. 69,3932 3931 (1996) and Valter Strom, B.J. Jonsson, K.V. Rao, and Dan Dahlberg, J. Appl.Phys. 81, 5003 5005 (1997)) Although the F/AF EA determined by reversible magnetic rotations is still less than simple models would predict, it does provide a more accurate determination of the average F/AF EA at the interface. As such, the F/AF EA calculated by models and studies of the systematics of this phenomena should be compared only to the F/AF EA determined by reversible processes.

4:00 PM F7.6/G5.6

CHANGES IN STRESS AND MICROSTRUCTURE IN PtMn/CoFe BILAYERS DURING ANTIFERROMAGNETIC PHASE TRANSFORMATIONS. S.P. Bozeman and B.J. Daniels, Seagate Recording Heads, Minneapolis, MN.

PtMn is one of several candidate antiferromagnetic materials for biasing of spin valve giant magnetoresistive (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 fcc to fct 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 Avrami 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 components related to (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. Bonevich, R.D. McMichael, C.G. Lee, P.J. Chen, W. Miller and W.F. Egelhoff, Jr., National Institute of Standards and Technology, Materials 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 underlayers to produce unusually strong uniaxial anisotropy in ultra-thin Co films and demonstrated this technique in a pseudo spin valve. Thin films of Co, $Ni_{80}Fe_{20}$(Py) and Co/Cu/Co pseudo spin valves were DC magnetron sputter deposited on obliquely (60° 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 Py or fcc Co. With 7.5 nm Ta, the measured value of $\mu_0 H_a$, 163 mT, is comparable to that of single crystal hcp Co. A large increase in $\mu_0 H_a$ 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/transition 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 the 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 1-7 (Marriott)

F8.1
A MÖSSBAUER SPECTRAL STUDY OF THE MAGNETIC AND STRUCTURAL PROPERTIES OF $R_3Fe_5O_{12}$, WHERE R IS Dy, Y, AND Eu. D. Vandormael, F. Grandjean, Institute de Physique, Universitè de Liége, BELGIUM; Dimitri Hautot, Gary J. Long, Department of Chemistry, University of Missouri-Rolla, Rolla, MO.

The $R_3Fe_5O_{12}$ 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 $24d$ crystallographic sites of the cubic $Ia3d$ space group. There is 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 $Dy_3Fe_5O_{12}$ 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 $Ia3d$ structure. We propose that the space group is actually $R\bar{3}c$, a group in which there are two magnetically inequivalent $16a_{12}$ and $16a_4$ sites and four magnetically inequivalent $24d_6$ 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 MAGHEMITE IRON OXIDE IN NANOMETER SIZE PREPARED FROM WET CHEMICAL PROCESSING. Jiye Fang, Kevin L. Stokes, Weilie L. Zhou, Joan A. Wiemann, Amar Kumbhar, Thomas Kodenkandath, John Wiley and Charles J. O'Connor, Advanced Materials Research Institute, University of New Orleans, New Orleans, LA.

Maghemite Fe_2O_3 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 maghemite Fe_2O_3 powder using a refined wet chemical processing method. The morphology of as-prepared powder was investigated by employing TEM. Crystalline analysis (XRD) shows that single phase of gama-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 Dahmen, Dept of Chemistry, National High Magnetic Fields Laboratory and Martech, The Florida State University, Tallahassee, FL.

Particles have been prepared by a multifaceted system, which utilizes aerosol, plasma, classic MOCVD, and supercritical fluid techniques. The supercritical fluid system is a complex system utilizing three syringe pumps coupled to three autoclaves. Two of the autoclaves are specially designed for supercritical water capability while the third is for CO_2 or NH_3 use only. By using three autoclaves the system has added capabilities in the use of co-solvents and/or co-solutes. 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 onto 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-Co-Fe-Si-C INTERMETALLICS. Monica Sorescu, A. Grabias, Duquesne University, Bayer School of Natural and Environmental Sciences, Physics Department, Pittsburgh, PA; M. Valeanu, Institute of Atomic Physics, National Institute of Materials Physics, Bucharest, ROMANIA.

In the present work we report on the structural and magnetic properties of novel magnetic compounds of the type $Nd_2Co_{15-x}Fe_xSi_2C_y$ (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 iron substitution on the magnetic hyperfine fields were studied by Mössbauer spectroscopy.
Regardless of carbon content, all $Nd_2Co_{15-x}Fe_xSi_2C_y$ (x=7; 9; 12 and y=0; 1) intermetallics were found to be rhombohedral, with the Th_2Zn_{17} 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 was found to decrease 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 6c, 9d, 18f and 18h 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 opposing factors determining the hyperfine magnetic field: the tendancy of cobalt to increase the hyperfine field at iron sites and the inverse tendancy of iron to increase the hyperfine field at higher concentrations.
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 hyperfine magnetic field of compounds with interstitial carbon had larger values than those in samples without carbon. A similar effect was obtained by us in the case of $R_2Fe_{17-x}V_xC_y$ 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 NANO-CRYSTALLIZATION BEHAVIOR OF AMORPHOUS $(Fe_{0.99}Mo_{0.01})_{78}Si_9B_{13}$ RIBBONS. Xiangcheng Sun and M. Jose Yacaman, National Institute of Nuclear Research (ININ), MEXICO; J. Reyes-Gasga, X. Bockimi, National Univ of Mexico (UNAM), Inst. of Physics, MEXICO; A. Cabral-Prieto, National Inst. of Nuclear Research (ININ), MEXICO; Wensheng Sun, State Key Lab for RSA, Institute of Metal Research, Chinese Academy of Science, Shenyang, PR CHINA.

The intrinsic magnetic properties and nanocrystallization process of ferromagnetic $(Fe_{0.99}Mo_{0.01})_{78}Si_9B_{13}$ ribbons were extensively studied by *in situ* transmission electron microscope (TEM), X-ray Rietveld refinement, Mössbauer spectroscopy (MS), differential scanning calorimeters (DSC) and magnetic moment measurements. The Mössbauer spectrum exhibited an essentially symmetric hyperfine field pattern of 225KOe in as-quenched amorphous state at room temperature. The Curie and crystallization temperature were determined to be T_C=665K and T_x = 750K, respectively. The T_x value was in good agreement with DSC measurement results. X-ray Rietveld refinement have shown a good reconfirm of mail four metastable phases ($(Fe, Mo)_{23}B_6$, $(Fe, Mo)_3B$, α-Fe (Mo, Si), $Fe(Si)_2B$) have ever occurred under in-situ nanocrystallization process. Which these metastable phases embedded in the amorphous matrix have a significant effects on magnetic behavior. The ultimate nanocrystalline phases of α-Fe (Mo, Si) and $Fe(Si)_2B$ 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 ferromagnetism, suggesting the presence of the distribution of exchange interaction in the amorphous phase or high metalloid contents.

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

Iron-carbon based hard, martensitic alloys are usully 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 around room temperature. The alloys have been investigated by EPMA, XRD, XPS, TEM, SEM and microhardness measurements, and their magnetic properties studied by vibrating sample magnetometer. The alloys are found to possess high mechanical hardness, 750-810 HV. 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 behaviour. The coercive force of the as-deposited Fe-C and Fe-Ni-C alloys is 5190 and 549 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 may be of interest in potential applications requiring both soft magnetic properties and improved tribological performance. The effects on tempering of the behaviour of the alloys are also discussed.

F8.7
BN FILMS GROWN AS AN INSULATING BARRIER FOR MAGNETIC TUNNELING JUNCTION. Y. Sheng, R.A. Lukaszew, P.A. Encarnación, 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 them are stoichiometry, hexagonal phase purity and film uniformity. First, the growth conditions for hcp BN films deposited on Si (001) substrates were optimized. This optimization was confirmed by the observation of the distinct hcp BN reflection high-energy electron diffraction (RHEED) pattern *in-situ*. High intensity Fourier transform infrared spectroscopy (FTIR) peaks corresponding to the hexagonal BN A_{2u} and E_{1u} transverse optical phonon modes were also observed. This process was later applied to grow hcp BN films on (001) metallic magnetic films. The morphology 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 coalescence. This coalescence correlates with the stage at which the in-situ RHEED 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 phase with the basal planes perpendicular to the junction interface.
1. R.A. Lukaszew, Y. Sheng, C. Uher, R. Clarke, Appl. Phys. Lett. **75**, 1941 (1999)

F8.8
INFLUENCE OF THE OXYGEN CONCENTRATION ON THE MAGNETOERSISTIVE PROPERTIES OF 1ST AFM Co/Cu MULITLAYERS SPUTTERED IN AN Ar+O_2 ATMOSTPHERE. D. Kubinski and M. Parsons, Ford Research Laboratory, Dearborn, MI.

The large magnetoresistance and low relative hysteresis of Co/Cu multilayers at the 1st antiferromagnetic maximum (t_{Cu} = 9$\AA$) 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 flat, 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 magnetoresistive properties of 1st AFM Co/Cu multilayers. A sequence of $[Co(15\AA)/Cu(9\AA)]_{20}$ multilayers were made using magnetron sputtering in a 2mTorr Ar+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 amounts of O_2 to the Ar sputtering atmosphere ($\lesssim$100 ppm) improved the magnetoresistance. At 1000 ppm O_2 the magneto-resistance reached a maximum value of $\approx$45%, and was found to be quite reproducible. A similar result was also found for the saturation fields. Further increases to the O_2 concentration degraded the magnetoresistance and reduced the saturation fields. The optimal 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. [1]W.F. Egelhoff, P.J. Chen, C. J. Powell, M. D. Stiles, R. D. McMichael, J. H. Judy, K. Takano, and A. E. Berowitz, J. Appl. Phys. 82, 6142 (1997).

F8.9
SPIN GLASS-LIKE BEHAVIOUR IN THE COLOSSAL MAGNETORESISTIVE $La_{0.6}M_{0.1}Ca_{0.3}MnO_3$ (M=Ho (MAGNETIC) AND Y(NON-MAGNETIC)) COMPOUNDS. V. Ravindranath, G. Rangarajan[a] and M.S. Ramachandra Rao, Materials Science Research Centre and [a]Department of Physics, Indian Institute of Technology Madras, Chennai, INDIA; Y. Lu, J. Klein and R. Gross, II. Physikalisches Institut, Universität zu Köln, Köln, GERMANY.

There is a renewed interest in manganese perovskites such as $La_{1-x}M_xMnO_3$ (M=Ca, Sr, Ba etc.) since they exhibit colossal magnetoresistance (CMR) close to the ferromagnetic transition temperature (T_C). The physics of these materials is very interesting because of the complexities involved in isolating effects due to structure, magnetic and electrical properties.These materials are also being intensively studied, since they are promising candidates for device applications such as magnetoresistive read heads and magnetic sensors. In the present study $La_{0.6}M_{0.1}Ca_{0.3}MnO_3$ (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 extent 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 measurements 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 ac-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 mobile charge carrier density[1,2]. In this case the effects due to both the above mentioned factors are the same and so the observed differences in the behaviour of the Y and Ho compounds could be attributed to the magnetic nature of the Ho ion. Charge carrier density measurements are underway.
References:
[1]N. Gayathri et al. Phys. Rev. B. 56 (1997)1345.
[2]M. Rubinstein et al. J. Appl. Phys. 81 (1997) 4974.

F8.10
VERY LARGE MAGNETORESISTANCE AND FINITE SIZE EFFECTS IN ELECTROCHEMICALLY DEPOSITED BISMUTH FILMS ON GaAs SINGLE CRYSTALS. Philippe M. Vereecken, Li Sun, Peter C. Searson, The Johns Hopkins University, Dept. of Materials Science and Engineering, Baltimore, MD; C.L. Chien, The Johns Hopkins University, Dept. 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 (012) oriented films. The resistivity and magnetoresistance were measured as a function of film thickness and temperature. A magnetoresistance effect with ratios as high as 6000 at 5K and 2.3 at room temperature under a 5 tesla magnetic field were seen. Finite size effects were observed for film thicknesses up to 75 micron indicating an electron mean free path larger than 75 micron.

F8.11
ESR INVESTIGATIONS ON $La_{0.65}Ca_{0.35}MnO_3$. M. Chipara, Qin Lan Xu, Sy-Hwang Liou, C. Borca, R. Shoemaker, S. Adenwalla, J. Choi, P.A. Dowben, University of Nebraska, Department of Physics and Astronomy, Lincoln, NE.

Electron spin resonance spectra of a $La_{0.65}Ca_{0.35}MnO_3$ perovskite powder were recorded using a Brukher D 200 spectrometer operating in X band (9 GHz). The resonance spectra in the paramagnetic phase consist of a single broad line, slightly assymetric, localized closed to the g=2 value. This line is ascribed to Mn4+ ions. The absence of the hyperfine structure (resulting from the interaction between the uncoupled electronic spin and the nuclear ones) is due either to motional effects or to exchange interactions between Mn4+ 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=4.0, which would support the presence of bipolarons (characterized by S=1) in our system. The temperature dependence of 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 to the coercive field, the temperature dependence of the resonance line position is proportional to the temperature dependence of the magnetization at saturation. Accordingly, the Zeeman term dominates the features of the resonance line in the magnetically ordered phase.

F8.12
MAGNETOTRANSPORT PROPERTIES OF $La_{0.7}MnO_{3-\delta}$ AND $Pr_{0.65}Ba_{0.05}Ca_{0.3}MnO_{3-\delta}$ SUPERLATTICES. S.V. Pietambaram[1], D. Kumar[1], Rajiv K. Singh[1], C.B. Lee[2]. [1]Department of Materials

Science and Engineering, University of Florida, Gainesville, FL; [2]Department of Electrical Engineering, North Carolina A&T University, Greensboro, NC.

In an effort to achieve high magnetoresistance (MR) ratios at high temperatures and reduced fields, we have fabricated superlattice structures consisting of $La_{0.7}MnO_{3-\delta}$ (LMO) and $Pr_{0.65}Ba_{0.05}Ca_{0.3}MnO_{3-\delta}$ systems, where LMO is believed to act as a ferromagnet biasing source to PBCMO. LMO and PBCMO individually transform to ferromagnetic states at 240 K and 60 K respectively. A series of samples, in which the thickness of LMO is fixed and that of PBCMO varied from 1 to 8 unit cells, have been grown in situ on (100) $LaAlO_3$ substrates using a pulsed laser deposition technique. Microstructural characterizations 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 resistances in zero and applied fields, is found to vary 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 improvement in magnetoresistance properties of superlattices over individual systems (i.e. LMO or PBCMO) will also be discussed in this paper.

SESSION F9: WRITER MATERIALS AND CHARACTERISTICS
Thursday Morning, April 27, 2000
Golden Gate B3 (Marriott)

8:30 AM *F9.1
SPATIAL PROPAGATION OF DYNAMIC MAGNETIC EXCITATIONS IN PERMALLOY MEASURED WITH THE SECOND-HARMONIC MAGNETO-OPTIC KERR EFFECT.
Tom Silva and Pavel Kabos, 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, magnetodynamic 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 μm and a temporal resolution of 70 fs using 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 magnetic flux transmission. Implications for write head design are discussed. [1] E. Valstyn and H. Huang, IEEE Trans. Magn., vol. 29, pp. 3870-3872 (1993). [2] T.J. Silva, C.S. Lee, T.M. Crawford, and C.T. Rogers, J. Appl. Phys., vol. 85, pp. 7849-7862 (1999). [3] P. Kabos and V.S. Stalmachov, Magnetostatic Waves and their Applications, Chapman and Hall, NY, 1994. [4] T.M. Crawford, T.J. Silva, 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 Fe-Co-N THIN FILMS.
N.X. Sun and S.X. Wang, Department 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, $(Fe_{70}Co_{30})_{1-x}N_x$ (or in short Fe-Co-N) films with a thickness of 100nm 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 (5nm) permalloy underlayer and overlayer, we obtained a low coercivity of 0.6 Oe and an excellent in-plane uniaxial anisotropy. This dramatic improvement in soft magnetic properties of Fe-Co-N can not be simply interpreted as a result of the soft magnetism of permalloy because the latter makes 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 layer Fe-Co-N film, Fe-Co-N film 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 compared. The hard-axis 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 almost the same coercivity with 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 Morning, April 27, 2000
Golden Gate B3 (Marriott)

10:00 AM *F10.1
HIGH PERFORMANCE DEMONSTRATION OF MAGNETIC TUNNEL JUNCTION RANDOM ACCESS MEMORY.
W.J. Gallagher, S.L. Brown, Y. Lu, E.J. O'Sullivan, P.L. Trouilloud, D.W. Abraham, J. Bucchignano, R.H. Koch, Y.H. Lee, R. Robertazzi, M. Rooks, J. Yoon, R.A. Wanner, IBM T.J. Watson Research Center; S.S.P. Parkin, K.P. Roche, M.G. Samant, P.M. Rice, R.E. Scheuerlein, IBM Almaden Research Center.

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 multilayer magnetic growth technology available on a research scale. For the demonstration, the wafers were cut into one-inch squares for depositions 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 uv stepper lithography and e-beam lithography were utilized. Patterning 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 and other processing issues were addressed successfully enough that key performance aspects of MTJ 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.
S.J. Pearton, H. Cho, Dept. MSE, Univ of Florida, Gainesville, FL; K.B. Jung, J.R. Childress, IBM Almaden Research Center, San Jose, CA; F. Sharifi, J. Marburger, Dept. Physics, Univ of Florida, Gainesville, FL.

A wide range of GMR and CMR materials have been patterned by high density plasma etching in both corrosive (Cl_2-based) and non-corrosive (CO/NH_3)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_2 plamsas, 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 materials 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.
D.B. Fenner, J.A. Greer, A.R. Kirkpatrick, L.P. Allen, R.P. Torti, T.G. Tetreault, W.R. Brooks, R.J. Chandonnet and W.J. Skinner, Epion Corporation, Billerica Massachusetts; N. Toyoda, Materials Science & Engineering Dept., Massachusetts Institute of Technology.

Thin-film magnetic sensor and memory devices in future generations may benefit from a processing tool for final-step etching and smoothing of surfaces to nearly an atomic scale. Energetic-ion 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 near-normal incidence. GCIB has been found to simultaneously etch and smooth surfaces without accumulating roughness or damage. Implantation and subsurface damage essentially do not occur for cluster energy not too far above the sputtering threshold. While still in its infancy, manufacturing application of GCIB processing to thin-film magnetic materials technology shows considerable promise. Results are reported for etching and smoothing of the surfaces of alumina, gold, silicon, permalloy and tantalum films. For example, the distinct scratches 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.
Rui-hua Cheng, C.N. Borca, 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 magneto-tunnel junction properties between ferromagnetic oxides because it can act as a tunnel barrier both above and below the Neel temperature. We have deposited of the antiferromagnetic Cr_2O_3 chromium oxide from the laser initiated oxidation of $Cr(CO)_6$. Since this deposition procedure is based on photolysis 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 CrO_2 and antiferromagnetic Cr_2O_3 oxides should be possible[1,2] in compositionally modulated heterostructures. Both the technique and the magnetic properties of the films prepared this organometallic CVD process will be described. [1] P.A. Dowben, Yoon-Gi Kim, S. Baral-Tosh, G.O. Ramseyer, Chanyong Hwang, and M. Onellion, J. Appl. Phys. 67 (1990) 5658-5660. [2] K. Perkins, C. Hwang, M. Onellion, Yoon-Gi Kim, and P.A. Dowben, Thin Solid Films 198 (1991) 317-329.

11:30 AM F10.5
GROWTH CHARACTERIZATION OF NICKEL IRON THIN FILMS ON PATTERNED WAFERS USING IN-SITU ELLIPSOMETRY.
Arun Natarajan, Xuefei Tang, Vivien Talghader, Christian Lund, Mark Kief, Brian Sabo, Song Xue and Peter Weyandt, Seagate Recording Heads, Minneapolis, MN; Blaine Johs, J.A. Woollam 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 controlled as well as time controlled deposition are compared for the sheet 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 industries may be significant.

SESSION F11: HALF METALLICS AND CMR
Thursday Afternoon, April 27, 2000
Golden Gate B3 (Marriott)

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 band structure calculation predicts half metallicity for a group of Heusler compounds such as NiMnSb, PtMnSb 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.[1] If true, these compounds can have profound influence on both basic spin polarized transport studies as well as perfect memory elements, switches and sensors for spin electronics application. Experimentally, spin polarized tunneling technique, which probes directly the spin density of tunneling electrons at the Fermi level is ideally suited to unambiguously verify this property. Our tunneling and other transport studies over the years on NiMnSb compound will be presented, along with a brief review work by others on various other candidates, bringing up to date the status of this field. [2]
In collaboration with C. T. Tanaka and J. Nowak
Supported Office of Naval Research grants
1. R.A. de Groot, F.M. Muller, P.G. van Engen and K.H.J. Buschow, Phys. Rev. Lett. **50**, 2024 (1983).
2. C.T. Tanaka, Ph.D Thesis (1999), Massachusetts Institute of Technology, unpublished.

2:00 PM F11.2
SPIN POLARIZED PHOTOEMISSION STUDY OF MAGNETITE FILMS: EVIDENCE FOR HALF METALLIC FERROMAGNETIC BEHAVIOR.
S. Morton, G.D. Waddill, 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 metallic magnets, 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 Fe_3O_4 (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 distructive surface cleaning techniques, using the samples as is. Furthermore, we have demonstrated that harsh sample cleaning procedures such as ion etching causes the loss of the desired spin polarization, which may help explain the failure of other previous experiments to observe half metallic behavior. 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 UCSD. Magnetite films were prepared by reactive sputtering. Epitaxial magnetite films were grown on MgO and sapphire substrates with precise control of gas flows and substrate temperature, Their structure was characterized by RHEED, LEED, and XRD. Further experiments are in progress. References 1. Park *et al*, *Nature* **392**, 794 (1998); *Phys. Rev. Lett.* **81**, 1953 (1998). 2. J.G. Tobin *et al*, *MRS Symp. Proc.* bf 524, 185 (1998).

2:15 PM F11.3
THE SURFACE STRUCTURE OF $Fe_3O_4(100)$ GROWN BY O-ASSISTED MOLECULAR BEAM EPITAXY.
Andrei V. Mijiritskii and Dik O. Boerma, Groningen University, NVSF, Materials Science Centre, Groningen, THE NETHERLANDS.

The surface structure of $Fe_3O_4(100)$ was studied *in situ* by low-energy ion scattering (LEIS) and low-energy electron diffraction (LEED). An epitaxial $Fe_3O_4(100)$ film was grown on MgO(100) at a substrate temperature of 250°C by O_2-assisted molecular beam epitaxy (MBE). The flow of molecular O_2 directed onto the substrate gave rise to a background pressure of 1×10^{-6} mbar. Right after the growth, LEED and LEIS revealed a four-fold symmetry of the surface structure, with a $(\sqrt{2} \times \sqrt{2})$R45 reconstruction relative to the bulk-terminated $Fe_3O_4(100)$. No changes were observed in either LEED or LEIS data after cooling down the sample to RT 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 atoms recoiled from the sample were calculated for trial structures and fitted simultaneously to all experimental data. The best agreement was found for a model where at the $Fe_3O_4(100)$ surface, bulk-terminated by a (tetrahedral) Fe-layer, 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 $La_{0.7}Ca_{0.3}Mn_{1-x}M_xO_3$ (M=Co and Ga).
V.K. Meera, V. Ravindranath and M.S. Ramachandra Rao, Materials Science Research Centre and Department of Physics, Indian Institute of Technology Madras, Chennai, INDIA.

Hole-doped manganese and cobalt oxides such as $La_{1-x}M_xMnO_3$ and $La_{1-x}M_xCoO_3$ (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+}-O-Mn^{4+} short ranged and even a small amount of Co substitution can destroy the ferromagnetic order (FM)[1,2] . The magnetic characteritics 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 $La_{0.7}Ca_{0.3}Mn_{1-x}M_xO_3$ (M=Co and Ga) and x = 0.04, 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=172K for $La_{0.7}Ca_{0.3}Mn_{0.96}Ga_{0.04}O_3$ and 222K for $La_{0.7}Ca_{0.3}Mn_{0.96}Co_{0.04}O_3$ indicating a greater decrease in the ferromagnetic coupling in the former case. ac-susceptibility measurements at frequencies of 313, 626 and 939Hz 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^{4+} ions or when the number of mobile charge carriers are reduced. In this case the number of Mn^{4+} ions is the same for identical compositions of Co and Ga-substituted compounds and hence the observed changes in the defreezing temperature can be attributed to the number of mobile carriers. Carrier density measurements are underway.

References:
[1]N. Gayathri et al. Phys. Rev. B. 56 (1997) 1345.
[2]M. Rubinstein et al. J. Appl. Phys. 81. (1997) 4974.

2:45 PM F11.5
A FLUORINATION STUDY OF $LaSrMnO_4$: STRUCTURAL, ELECTRONIC AND MAGNETIC EFFECTS. Lavinia Aikens 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, recently alternative methods, via anion 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, $Sr_2CuOF_{2+\delta}$, derived from Sr_2CuO_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 far our results show that the initial cell parameters of the parent oxide ($a = b = 3.7952(2)$ Å and c =13.129(1) Å), dramatically change on fluorination with the new phase $LaSrMnO_{4-X}F_X$ having cell dimensions of $a = b = 3.7746(4)$ Å and $c = 14.225(4)$ Å. These changes are due to fluorine insertion between (La,Sr)O 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
COLOSSAL MAGNETORESISTANCE IN SCREEN PRINTED $La_{0.67}Ca_{0.33}MnO_3$ THICK FILMS. A.K.M. Akther Hossain, Department of Physics, Bangladesh University of Engineering, BANGLADESH; L.F. Cohen, Blackett Laboratory, Imperial College, London, UNITED KINGDOM; A. Berenov, J. Macmanus Driscoll, Materials Department, Imperial College, London, UNITED KINGDOM.

Thick films of $La_{0.67}Ca_{0.33}MnO_3$ were fabricated on single crystal (100) $LaAlO_3$ (LAO), single crystal (100) yttria stabilised zirconia (YSZ) and polycrystalline Al_2O_3 by a screen printing technique. The films were sintered at 1200, 1300 and 1400° 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 are that MR is not limited to a small temperature window near the metal-insulator transition at T_{p1}. The MR peak is very broad and for some films a temperature independent CMR is observed at temperatures below T_{p1}. Several repeat films were made and the reproducibility of the results obtained in the first batch were confirmed.