SYMPOSIUM E

Nanostructural Magnetic Materials for Data Storage

April 2 – 4, 2002

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* Invited paper

SESSION E1: PATTERNING AND PROPERTIES OF NANOMAGNETIC STRUCTURES
Chair: Tom Thomson
Tuesday Morning, April 2, 2002
Salon 13 (Marriott)

8:30 AM *E1.1
FABRICATION, MAGNETIC CHARACTERIZATION, AND RECORDING PROPERTIES OF PATTERNED MEDIA
Charles T. Rettner, Manfred Albrecht, Simone Anders, Gary M. McClelland, Mark W. Hart, Srikanth Ganesan, Margaret E. Best, and Bruce D. Terris, IBM Almaden Research Center, San Jose, CA.

The so-called "super-paramagnetic limit" in the conventional approach to magnetic storage occurs because of the thermal instability of small grains needed to permit sharp bit transitions. One approach to progressing to higher recording densities is to lithographically define small magnetic islands, producing patterned media with single-domain bits. We have pursued a number of approaches to developing such patterned media and have studied the magnetic and recording properties. We have also developed "imprinting" methods for replicating lithographic patterns, as a step towards low-cost manufacturing. We have fabricated patterned perpendicular media both by removing media from continuous magnetic films and by depositing magnetic films onto topographically patterned substrates. We have produced arrays of single-domain islands with densities close to 200 Gbit/in^2, limited by our lithographic resolution. Studies of the magnetic properties of the films reveal, for example, that the switching-field distributions of Co/Pt multilayers deposited on a patterned substrate are wider than for continuous films, but that patterning of granular CoPtCr media yields distributions that are considerably narrower than the corresponding continuous films. Recording measurements made on patterned granular CoPtCr media using a quasi-static GMR head demonstrate the sensitivity to detect single 60 nm islands, and the read-back jitter from the patterned region is found to be dramatically reduced compared to that measured for continuous media at the same linear density. We have also developed "imprinting" methods for replicating lithographic patterns, as a step towards low-cost manufacturing.

9:00 AM E1.2
ARRAYS OF MAGNETIC NANOPARTICLES PATTERNED VIA "DIP-PEN" NANOLITHOGRAPHY.
Xiaogang Liu, Seunghun Hong, Chad A. Mirkin, Northwestern Univ, Dept of Chemistry, Evanston, IL; Lei Fu, Vinayak P. Dravid, Northwestern Univ, Dept of Materials Science and Engineering, Evanston, IL.

There has been considerable recent interest in developing methods for patterning ultrafine magnetic particles because of their potential technological applications in molecular electronics, magnetic storage devices, and biosensors. Advances in nanofabrication technology and lithographic methods have made it possible to: 1) innovate new magnetic storage devices with higher storage densities and faster speeds, 2) prepare arrays of interactive magnetic nanoparticles with precisely-controlled magnetization orientation and interparticle spacing, and 3) obtain a better understanding of the relationship between magnetic feature size and magnetism. A variety of techniques, including electron-beam lithography, scanning tunneling microscope lithography, electrochemical etching, and electrodeposition have been used to fabricate arrays of magnetic structures on semiconductor substrates with dimensions in the sub-100 nm to micron length scale. However, there are some inherent limitations associated with these methods including the need for complex instrumentation, costly fabrication procedures, and complex and time-consuming processing steps. Herein, we present a new and straightforward strategy, based upon Dip-Pen Nanolithography (DPN), for preparing nanometer-scale magnetic structures with precise feature size control.

9:15 AM E1.3
NANOPATTERNING OF SOFT MAGNETIC MATERIALS BY FOCUSED ION BEAM MILLING.
Dan Allwood, Gang Xiong, Michael Cooke, Derek Atkinson, Russell Cowburn, Durham University, Dept of Physics, Durham, UNITED KINGDOM.

Magnetic nanostructures with sub-100 nm features are usually fabricated by e-beam lithography but the process involves several steps and can be time inefficient in the production of small numbers of development samples. We report here the use of focused ion beam (FIB) milling to directly pattern ferromagnetic thin films as a rapid method of fabricating nanostructures. 5 nm thick, thermally evaporated Permalloy films were patterned with 30 keV Ga ions. The FIB spot diameter was 10 nm and, after milling depth calibration, an ion dose density of 11 C.m^{-2} was used to ensure the complete removal of Permalloy at milling sites. Magnetization analysis was provided by a magneto-optical Kerr effect (MOKE) magnetometer. Single 200 nm wide nanowires were patterned with the FIB scanning either parallel, orthogonal or at 45 degrees to the wire long axis. Easy axis hysteresis loops from these structures all exhibited very sharp coercive transitions, suggesting that magnetization reversal takes place by nucleation and propagation of domain walls, and that the wires are relatively free of domain wall traps. However, we observe that the coercivity depends upon the FIB scan direction used, with coercive fields of 96 Oe for parallel scanned wires and 67 Oe for orthogonally and 45 degree scanned wires being found. We account for this by assuming that orthogonally and 45 degree scanned wires have an increased edge roughness due to wire edges being defined across successive FIB scan-lines, rather than a single FIB scan-line in parallel scanned wires. We also investigated FIB-milled arrays of 100 nm diameter circles and 500 nm wide elongated hexagons, whose hysteresis loops showed them to be of similar quality to e-beam defined structures. The elimination of the multi-step processing required by electron beam lithography makes FIB milling ideal for rapid laboratory-scale investigations in nanomagnetism.

9:30 AM E1.4
SELF-ASSEMBLED MAGNETIC NANOSTRUCTURES FOR ULTRA-HIGH DENSITY DATA STORAGE APPLICATIONS.
Haoyue Zhang, Hao Hua, Yuantao Peng, and Zhibo Zhang, Dept. of Electrical and Computer Engineering, NC State University, Raleigh, NC.

Conventional magnetic storage media employ magnetic thin films composed of weakly coupled magnetic domains with random preferential orientations. In order to maintain a reasonable signal-to-noise ratio, the number of magnetic domains in each data bit has to be no less than a few hundreds. With increasing data storage density, the volume of each magnetic domain has to be reduced accordingly, which is quickly approaching the superparamagnetic limit. Patterned magnetic disk, which consists of an array of discrete single magnetic domain elements with a uniaxial magnetic orientation, offers a viable alternative to overcome such a thermal instability. In this project, a controlled self-assembly process is utilized to fabricate highly uniform nanoporous anodic aluminum oxide thin films directly onto Si and SiO_2 substrates, which can improve the mechanical properties of the self-assembled nanostructure. Novel techniques that promote the long-range order of the self-assembled nanostructure are examined. An electroplating process is utilized to selectively deposit nickel into the nanochannels of the porous oxide template. Patterned magnetic disks with various packing densities, domain sizes, and element aspect ratios are produced by this low-cost nanofabrication technique. The nanostructural and magnetic properties of individual magnetic elements are carefully characterized by scanning electron microscopy (SEM), atomic force microscopy (AFM) and magnetic force microscopy (MFM) techniques, and their macro-magnetic properties such as coercivity and hysteresis are examined using a SQUID magnetometer. This bottom-up self-assembly assisted nanofabrication technique has the potential to achieve patterned magnetic disks with data storage densities higher than 500 Gbits/inch^2. Besides the ultra-high data storage density, the patterned magnetic disk can easily achieve a preferential magnetic orientation perpendicular to the substrate, which is strongly favored by read/write head technologies.

10:15 AM E1.5
FROM SELF-ORDERING TOWARDS IMPRINT LITHOGRAPHY: LARGE SCALE PERIODIC NICKEL NANOWIRE ARRAYS.
Kornelius Nielsch, Jinsub Choi, Riccardo Hertel, Ralf B. Wehrspohn, Jürgen Kirschner, and Ulrich Gösele, Max Planck Institute of Microstructure Physics, Halle, GERMANY; Saskia F. Fischer, Dept of Electrical Engineering, Ruhr University Bochum, GERMANY; Helmut Kronmüller, Max Planck Institute of Metal Research, Stuttgart, GERMANY.

In this paper, we will analyze the impact of the nanowire arrangement on the total anisotropy of magnetic nanowire arrays and the deviation of the switching fields of individual nanowire inside magnetic arrays for nickel nanowire arrays with a disordered, polycrystalline and monocrystalline hexagonal arrangement of the nanowires. Nickel is used for the nanowires due to its small magneto-crystalline anisotropy and small magnetic moment which lead to weak dipolar interactions inside the arrays and a large anisotropy resulting from the nanowire shape which enables nickel as a suitable material for patterned perpendicular magnetic media. Self-ordered alumina pore channel arrays are used as templates for the fabrication of magnetic nanowire arrays with a periodicity of 65 nm (180 Gbit/in^2), 100 nm (75 Gbit/in^2) and 500 nm (3 Gbit/in^2). A nearly perfect hexagonal arrangement for the columns occurs only inside very narrow process windows for periodic distances of 65, 100 and 500 nm, and - in contrast to most publications in this field - a degree of pore filling of almost 100% was achieved. In analogy to polycrystallites, the nanowires are hexagonally arranged in domains, which are extended over more than ten lattice periods. We obtain a perfect hexagonal or monocrystalline arrangement on a cm^2-scale, when we introduce imprint lithography in the fabrication process of our magnetic arrays.

For the disordered arrays the standard deviation of the nanowire diameter is >20% and for the polycrystalline and monoystalline arranged samples <10% and <5%, respectively. We observe that the total magnetic anisotropy increases by either reducing the deviation in nanowire diameter or by improving the ordering of the nanowire arrangement. In the case of a high degree of ordering, we have detected the highest coercivity (1200 Oe) and total anisotropy (100% squareness) reported for a high-density Ni nanowire array with 100 nm periodicity and a column diameter of 30 nm.

10:30 AM E1.6
LATERAL ANTIFERROMAGNETIC COUPLING OF PERMALLOY NANOELEMENTS. Russell Cowburn, Durham Univ, Durham, UNITED KINGDOM.

We have performed an experimental study into magnetostatic coupling between single domain Permalloy nanomagnets arranged in linear chains. Such systems have potential application as magnetic logic devices [1]. The dipolar coupling between nanoelements in a chain will usually be such that the magnetisation of each element will lie along the axis of the chain. By engineering the anisotropy of each nanomagnet, however, we have forced the nanomagnets to couple in an antiferromagnetic arrangement. Using a novel magneto-optical method, we show experimentally how the phase of the ordering can be forced by a larger dot and that the antiferromagnetic coupling remains perfect for the next 4 nanomagnets in the chain. Thereafter, phase defects arise due to thermal fluctuation. Differences between the information transmission capability of chains of ferromagnetic and antiferromagnetic coupled nanomagnets are discussed. [1] Cowburn et al. Science 287, 1466 (2000).

10:45 AM E1.7
PERIODIC ARRAYS OF MAGNETIC RING ELEMENTS. V. Metlushko, University of Illinois at Chicago, Chicago, IL; B. Ilic, Cornell University, Ithaca, NY; U. Welp, V. Vlasko-Vlasov, G. Crabtree, M. Grimsditch, Materials Science Division, Argonne National Laboratory, Argonne, IL; J. Bekaert, V.V. Moshchalkov, and Y. Bruynseraede, Katholieke Universiteit Leuven, Leuven, BELGIUM.

The major challenge in technological applications of magnetic arrays for storage is to control the magnetic switching precisely. To achieve this one needs first to have reproducible remanent state and, second, the switching process itself must be simple and reproducible. Only in very few cases with well-defined anisotropies does the reversal take place via a coherent rotation of the magnetization. More common, however, is that the reversal occurs via the domain formation. For arbitrary shape nano-scale elongated elements, in general, it has been impossible to reliably calculate the field at which domain first forms from basic principles. If the magnetization orientation in a memory element is circular or ring instead of linear, the magnetization flux forms a closure in the circular mode and the problems associated with the ends of the linear elements are eliminated. We found that the rings magnetic elements exhibit two different highly stable "onion" states in addition to the vortex states. The results of systematic characterization of arrays of small ring elements with SQUID magnetization to determine the magnetic moment, with atomic force microscopy (AFM) and magnetic force microscopy (MFM) to determine the topography and the magnetic patterns inside the rings, and with magneto optical imaging to visualize the moment reversal process during a magnetization cycle, will be presented.

11:00 AM E1.8
MEMORY EFFECT AND LOGIC OPERATIONS IN L-SHAPED MAGNETIC NANOSTRUCTURES. Dan Allwood, Gang Xiong, Derek Atkinson, Michael Cooke, Russell Cowburn, Durham Univ, Durham, UNITED KINGDOM.

The study of magnetism reversal and domain wall motion within extended nanostructures such as magnetic nanowires is important for new technological applications, including magnetic sensors, magnetic memory and magnetic logic devices. We present the results of a study into magnetization reversal in L-shaped nanostructures (arms 100 nm by 8μm) fabricated by e-beam lithography from 5 nm thick Permalloy. Spatially-resolved magneto-optical Kerr effect (MOKE) magnetometry provided magnetization analysis of these single, continuous structures. We report a dramatic shift in the hysteresis loop of one arm, controlled by the magnetization direction of the other arm. Furthermore, we find that reversing the magnetisation in one arm, even through many cycles, does not cause the other arm to change its magnetisation direction. One arm can thus act as a programmable memory, with output being read from the hysteresis shift in the other arm. In addition to a memory effect, we show how this behaviour can be adapted for logic operations. One arm is set using a vertical pulsed magnetic field whilst a sinusoidal horizontal magnetic field with a small static bias is applied. We show that the switching in the horizontal arm is the logical AND operation between the magnetisation in the vertical arm and the applied sinusoidal field. This logic effect is similar to that found recently using chains of 100 nm diameter dots [1]. However, the continuous structures studied here have a wider magnetic field operating region and less stringent fabrication requirements than the chains of dots investigated previously, making them more attractive for use in practical logic devices. [1] Cowburn et al. Science 287, 1466 (2000).

SESSION E2: CHEMICAL AND BIOLOGICAL ROUTES TO MAGNETIC NANOPARTICLES
Chair: Tom Thomson
Tuesday Afternoon, April 2, 2002
Salon 13 (Marriott)

1:30 PM *E2.1
SELF-ASSEMBLED MAGNETIC NANOSTRUCTURE ARRAYS. Kannan M. Krishnan, Univ of Washington, Seattle, WA.

Magnetic nanocrystals, monodisperse in size, shape and surface structure are now routinely synthesized by the rapid injection of an organometallic precursor into a hot coordinating solvent containing appropriate surfactants. For practical applications these nanocrystals must be organized into ordered arrays with well-defined inter-particle distances. In such nanocrystals, with a weak (van der Waals) attractive interaction and a weak steric repulsion, entropy-driven self-assembly processes dominate. If particles of two different sizes are allowed to self-assemble, entropy driven wetting arising from depletion forces can be used to control the final organization. Details of the growth of Co nanocrystals with controlled size and shape, their subsequent self-assembly into ordered arrays, their characterization by a range of electron microscopy measurements and their magnetic properties will be discussed.

2:00 PM *E2.2
DIRECT FABRICATION OF MONODISPERSE AND HIGHLY-CRYSTALLINE MAGNETIC NANOCRYSTALLITES WITHOUT A SIZE SELECTION PROCESS. Taeghwan Hyeon, Jongnam Park, Jin Joo, Yunhee Chung, and Hyon Bin Na, School of Chemical Engineering, Seoul National University, Seoul, KOREA.

We have developed new synthetic procedures to fabricate monodisperse magnetic nanocrystallites. Monodisperse and highly crystalline magnetic nanoparticles were fabricated without a size selection process, which is very important for large-scale production of the materials. Monodisperse iron nanoparticles were synthesized by the thermal decomposition of iron-oleic acid metal complex. The resulting iron nanoparticles were transformed to monodisperse gamma-Fe2O3 nanocrystallites by controlled oxidation using trimethylamine oxide, as a mild oxidant. Particle size can be varied from 2 nm to 20 nm by controlling the experimental parameters. Transmission electron microscopic images of the particles showed 2-dimensional and 3-dimensional assembly of particles, demonstrating the uniformity of these nanoparticles. Electron diffraction, X-ray diffraction, and high resolution TEM images of the nanoparticles showed the highly crystalline nature of the gamma-Fe2O3 structures. Using a similar procedure, highly crystalline and monodisperse cobalt ferrite nanocrystallites were synthesized from the thermal decomposition of bimetallic iron-cobalt organometallic complex, followed by the controlled oxidation. Iron core/cobalt shell nanocrystallites were fabricated by the thermal decomposition of cobalt organometallic compound in the presence of the monodisperse iron nanoparticles. The particle sizes are quite uniform and high resolution TEM image revealed that highly crystalline iron core and cobalt shell was clearly visible and well-separated. Two-dimensional alignment of these monodisperse nanocrystallites onto substrates and the magnetic characterization of these materials will be discussed. We fabricated novel iron nanorods with dimensions of 2 nm (thickness) * 8 nm (length), 2 nm * 12 nm, 2 nm * 20 nm, and 2 nm * 36 nm from the controlled growth of uniform 2 nm sized spherical nanoparticles. These iron nanorods exhibited high shape anisotropy. The synthesis and magnetic characterization of iron and maghemite nanorods will be presented.

2:30 PM E2.3
STRUCTURE AND MAGNETISM OF Co AND CoAg NANOCRYSTALS. M. Spasova[a], T. Radetic, N. Sobal[b], M. Hilgendorff[b], U. Wiedwald[a], M. Farle[a], M. Giersig[a], U. Dahmen; [a] IHO, Technische Universitaet Braunschweig, GERMANY; NCEM, Lawrence Berkeley Lab. USA; [b] Hahn-Meitner-Institut Berlin, GERMANY.

Monodisperse, air-stable Co (diameter 11.4 nm, size deviation s <5%) and CoAg (11 nm diameter, s <10%) nanocrystals were prepared by thermal decomposition and self-assembled into regular 2D superlattices [1,2]. High resolution transmission electron microscopy and spatially resolved X-ray energy dispersive spectroscopy (XEDS)

reveal a multiple-twinned fcc Co metallic core covered with a 1-2 nm thick CoO shell. The lattice parameters are the ones of bulk Co and CoO. CoAg composite particles consist of precipitates of fcc Co and fcc Ag grains. No evidence for alloy formation was observed. Spatially resolved, element-specific TEM images (XEDS, EELS) indicate that Co is predominantly found in the surface region of the composite particle. These results are dicussed in context to the particles' magnetic properties measured by FMR (i.e. magnetic anisotropy), SQUID magnetometry (i.e. magnetic moment per particle) and magnetic circular dichroism (ratio of orbital to spin magnetic moment). [1] U. Wiedwald et al; J. Vac. Sci. Technol. A 19 (4) (2001) 1773. [2] M. Spasova et al; J. Magn. Magn. Mater. (Dec. 2001).

3:15 PM *E2.4
Angela Belcher, Univ of Texas-Austin, Austin, TX.

ABSTRACT NOT AVAILABLE

3:45 PM E2.5
SYNTHESIS AND CHARACTERIZATION OF OPTICALLY TRANSPARENT FERROMAGNETIC POLYMER- COBALT OXIDE NANOCOMPOSITES. Sufi R. Ahmed, Steven E. Bullock, Dept of Materials & Nuclear Engineering, University of Maryland, College Park, MD; Peter Kofinas, Dept of Chemical Engineering, University of Maryland, College Park, MD.

We have used the self-assembly of diblock copolymers as templates for the growth of nanoscale cobalt oxide particles, and investigated their optical and magnetic properties. Diblock copolymer of norbornene (NOR) and norbornene-cobalt (Co[bTAN]) were synthesized by ring opening metathesis polymerization (ROMP). The polymer film was then treated with H_2O_2, which oxidized the cobalt present within one of the blocks of the copolymer. Transmission electron micrographs of the polymer show that the cobalt oxide nanoparticles exhibit a spherical morphology with an average diameter of 15 nm and are uniformly distributed within the polymer matrix. The presence of cobalt oxide was verified using XPS. The magnetic properties of the polymer were studied using a vibrating sample magnetometer (VSM). The optical properties of the polymer were investigated using UV-Vis and FTIR spectrophotometry. The polymer is optically transparent and ferromagnetic at room temperature with a coercivity of 200 Oe and a saturation magnetization of 6.0 emu/g. The density of cobalt oxide nanocluster is in the order of 10^9 per cm^2. This study provides a better understanding of formation of magnetic nanoparticles within self-assembled diblock copolymers, and might lead to the fabrication of novel high density memory devices.

4:00 PM E2.6
NEUTRON SCATTERING OF MAGNETIC BLOCK COPOLYMER NANOCOMPOSITES. Pinar Akcora, Dept. of Chemical Engineering, University of Maryland, College Park, MD; Robert Briber, Dept of Materials and Nuclear Engineering; Peter Kofinas, Dept of Materials Engineering.

The main goal of this research is to synthesize diblock copolymers containing self-assembled spherical magnetic nanoparticles and employ magnetic neutron scattering to separate and compare the ordering of nanoparticles to the microphase separated diblock copolymer morphology.We developed the synthesis of uniformly distributed magnetic oxide nanoparticles within deuterated block copolymer polymer matrices. Deuterated norbornene-norbornenedicarboxylic acid diblock copolymers were synthesized by ring opening metathesis polymerization. Spherical nanoparticles were formed by incorporating metal salts into one of the domains of microphase separated diblock copolymers. The metal oxide particle distribution was observed by transmission electron microscopy. The magnetic properties of the polymer nanocomposites were studied by SQUID magnetometry. The microstructure of the deuterated block copolymer was characterized by conventional SANS experiments. The intrinsic and magnetic domain structures of polymers containing magnetic metals was analyzed by magnetic small-angle scattering. The magnetic ordering of self-assembled metal nanoparticles was determined from magnetic scattering experiments.

SESSION E3: FERROMAGNETIC SEMICONDUCTORS, MAGNETIC NANOWIRES AND HYPERFINE TECHNIQUES
Chair: Tom Thomson
Wednesday Morning, April 3, 2002
Salon 13 (Marriott)

8:30 AM *E3.1
FERROMAGNETIC IMPRINTING OF NUCLEAR SPINS IN SEMICONDUCTOR HETEROSTRUCTURES. Roland K. Kawakami, David D. Awschalom, Department of Physics, University of California, Santa Barbara, CA.

There is a growing interest in the use of electronic and nuclear spin in semiconductor nanostructures as a medium for the manipulation and storage of classical and quantum information. Femtosecond-resolved optical experiments reveal a remarkable resilience of electronic spin states to environmental decoherence in a variety of bulk semiconductors, heterostructures, and quantum dots. Spin lifetimes are seen to exceed hundreds of nanoseconds, enabling the transport of coherent spin packets over hundreds of microns. Furthermore, coherent spin information can flow across interfaces of dissimilar materials in engineered structures over a broad range of temperatures, and the transport of spin information can be controlled with both electric and magnetic fields [1]. Even in materials where momentum scattering is strongly enhanced by defects, spin coherence persists to room temperature [2]. Hybrid ferromagnet/semiconductor systems [3] have the potential for controlling coherent states by combining photonic, electronic, and magnetic manipulation of spin, thereby introducing new possibilities for engineering multifunctional spin-based electronics. Recent experiments examine how a ferromagnetic layer affects the coherent electron spin dynamics in a neighboring GaAs semiconductor. Dynamical measurements in a series of hybrid structures reveal that the magnetization of the ferromagnet is "imprinted" in the GaAs nuclear spin system. The polarized nuclei generate large effective fields ($\sim$1T in $\sim$0.1T applied field) on the coherent electron spins and ultimately control their precession frequency [4]. The results suggest new strategies for manipulating electron and nuclear spins in semiconductor nanostructures. [1] I. Malajovich et al., Nature 411, 770 (2001). [2] B. Beschoten et al., Phys. Rev. Rapid Commun. B63, 12102-1, (2001). [3] R.K. Kawakami et al., Appl. Phys. Lett. 77, 2379 (2000). [4] R.K. Kawakami et al., Science 294, 131 (2001).

9:00 AM E3.2
SYNTHESIS AND CHARACTERIZATION OF DOPED SEMICONDUCTOR NANOPARTICLES. Khalid M. Hanif, Geoffrey F. Strouse, Robert Meulenberg, University of California, Santa Barbara, CA.

Doped semiconductor quantum dots (QD) have been shown to have potential applications as phosphors, magnetic-recording media and sensors. We have synthesized monodisperse $Cd_{1-x}Co_xSe$ and $Cd_{1-x}Cu_xSe$ quantum dots that have been doped with 1- 30% Co and 1-10% Cu in the core of the particles. In these materials, the site occupation of the dopant atoms can substantially influence the properties of the QD host lattice. We report the concentration dependent PM to AFM phase transition in Co doped QDs. Inspection of the observed optical and magnetic data provides insight into the lattice site occupation in these materials. Analysis of these compounds has been performed using Raman Spectroscopy, XRD, TEM, Superconducting Quantum Interference Device (SQUID), Atomic Emission spectroscopy, Photoluminescence Spectroscopy, and UV-Vis Absorption to verify site and concentration of dopant ions.

9:15 AM E3.3
TERABIT DENSITY COBALT NANOWIRE ARRAYS WITH TUNABLE MAGNETIC PROPERTIES. Andrei Ursache, Mustafa Bal, James Goldbach, Thomas Russell, Mark Tuominen, University of Massachusetts, Amherst, MA; Robert Sandstrom, Charles Black, Watson Research Center, Yorktown Heights, NY.

Nanoporous diblock copolymer films are used as templates for electrochemical fabrication of hexagonal arrays of vertical cobalt magnetic nanowires at terabit/in^2 density. The wire diameter and wire areal density are determined by the copolymer molecular weight, and the length of the wires can be controlled by monitoring the electrodeposition growth process. While the wire size and interwire distance are kept constant, the magnetic properties of the nanowires can be tuned by varying the electrolyte pH and electrodeposition conditions, which have an effect on the wire internal structure. Exchange bias exhibited by the nanowires is also investigated. This work is supported by NSF NIRT grant DMI-010324.

10:00 AM E3.4
CHARACTERIZATION OF FePt-C AND CoPt-C NANO-COMPOSITE FILMS PREPARED BY PULSED FILTERED VACUUM ARC DEPOSITION. M.F. Chiah, S.P. Wong, H. Wang and W.Y. Cheung, Dept of Electronic Engineering and Materials Science and Technology Research Center, The Chinese Univ of Hong Kong, Hong Kong SAR, CHINA.

Magnetic thin films of metal nanocrystals encapsulated in carbon were investigated as potential media for high-density recording. In this work, the FePt-C and CoPt-C nanocomposite thin films of various carbon compositions were prepared by a pulsed filtered vacuum arc deposition technique. The composition of the films was controlled by monitoring the integrated charges arriving from the

respective arc sources and determined by Rutherford backscattering spectrometry. The dependence of the magnetic properties on the carbon composition and annealing temperature was studied. Both x-ray diffraction and magnetic force microscopy analyses confirmed the formation of nano-crystallites of face-centered-tetragonal CoPt phase in the carbon matrix after annealing at a sufficiently high temperature, depending on the carbon composition. For example, for a film with a particular composition of $Co_{24}Pt_{31}C_{45}$, the coercivity and the grain size were observed to increase with increasing annealing temperature, up to a value of 7 kOe at an annealing temperature of 750°C, and the grain size increased from 9 to 20 nm. The correlation between the properties and structures of these films will be reported and discussed. This work is supported in part by the Research Grants Council of Hong Kong SAR (Ref. No.: CUHK4216/00E).

10:15 AM E3.5
LAYER-BY-LAYER SEQENTIALLY DEPOSITED MULTILAYERS OF FERRITE PARTICLES FOR MAGNETIC RECORDING MEDIA. Seimei Shiratori, Yousuke Hayashi and Tetsuya Sato, Keio Univ, Yokohama, Kanagawa, JAPAN.

Layer-by-layer adsorption process of polyelectrolytes has been conventionally used for the fabrication of the ultra-thin organic film formed by various polymers with different polarity of charge. In this study, we successfully applied the technique for the deposition of inorganic/organic hetero structures to fabricate the multilayers of barium ferrite nano particles. The Barium ferrite particles can be applied to the perpendicular magnetic recording media by arranging them so as to align the easy axes with a direction perpendicular to the substrate. However, no feasible work of the preparation of the magnetic film consisting of the oriented Ba ferrite has been reported. In this work, we proposed the new possibility of the magnetic recording media using the layer-by-layer sequential deposition technique. Barium ferrite was prepared by glass crystallizing method. The glasses were prepared by melting B_2O_3, BaO and Fe_2O_3, in a furnace at 1400 for 4h in a Pt crucible and pouring the liquid into a stainless steel mold. These glasses were heated and the $BaFe_{12}O_{19}$ powder was leached from them by using a weak acid. The particles were wrapped with poly allylamine hydrochloride (PAH), and were assembled with poly acrylicacid (PAA). The thickness of the self-assembled bilayer ((Ba ferrite & PAH) / PAA) was systematically controlled using the automatic dipping system with mass-controlled system we developed. It was found that the mass of the adsorbed particles significantly dependent on the pH of the solutions. From TEM observation, it was found that Barium ferrite particles with 5nm in diameter were uniformly arranged in the layer of the films. The magnetic measurements were performed to characterize the magnetic properties of the prepared multiplayer film using a super conducting interference device (SQUID) magnetometer. It was found that the magnetic properties were systematically controlled by changing the number of layers.

10:30 AM E3.6
NMR STUDY OF THE CRYSTALLIZATION KINETICS OF IRON-BASED SOFT MAGNETIC NANOCRYSTALLINE MATERIALS. C.F. Barbatti, E.H.C.P. Sinnecker, R.S. Sarthour, A.P. Guimarães, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, BRAZIL.

NMR was used to study the evolution of the structural and magnetic properties of Fe-based melt-spun ribbons of $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, $Fe_{73.5}Cu_1Nb_3Si_{18.5}B_{14}$ and $Fe_{86}Zr_7Cu_1B_6$, both as-cast and annealed at different temperatures. Experiments were carried out at 4.2 K and zero applied magnetic field. This type of measurement allows us to observe the Fe, B and Nb sites. Using a variable level of RF power, it is possible to measure the local anisotropy field at the different sites. The NMR spectra are highly dependent on the RF power. For the Fe-Si based alloys, we observe well-defined ^{93}Nb resonance signals from three distinct sites, distinguished by the number of Fe atoms in their neighborhood. In the spectra of $Fe_{73.5}Cu_1Nb_3Si_{18.5}B_{14}$ as-cast and treated at 500°C we also observe a peak around 30 MHz, connected to the ^{11}B resonance in different Fe-B local environments. From the RF power dependence of the ^{93}Nb signal, it is evident a minimum in the local anisotropy for samples treated at temperatures near 500°C. For the sample treated at 640°C, the increase in magnetic hardness attributed to the presence of Fe_3B is observed.

10:45 AM E3.7
RF SUSCEPTIBILITY IN MAGNETIC NANOPARTICLES AND NANOCOMPOSITES. H. Srikanth, R. Hajndl, J. Sanders, Dept of Physics, University of South Florida, Tampa, FL; E.E. Carpenter, Complex Materials Section, Naval Research Laboratory, Washington, DC; L. Spinu, AMRI, Univ New Orleans, New Orleans, LA; T.S. Sudarshan, Materials Modification Inc., Fairfax, VA.

Magnetic nanoparticles embedded in non-magnetic matrices like polymers or dielectric oxides are of great technological interest as the coating provides encapsulation and prevents grain growth and agglomeration. Moreover, in electromagnetic applications, the systems can be considered as nanocomposites with possible multi-functionality resulting from the magnetic and dielectric response. We have studied the static and dynamic magnetic properties of as-prepared nanoparticles (Fe, Co, γ-Fe_2O_3, $MnFe_2O_4$) and particles dispersed in a matrix (like polystyrene, SiO_2). The systems ranged from polymerized magnetic nanopowders synthesized using a microwave plasma method to highly monodisperse nanoparticles prepared by reverse-micelle techniques. The magnetic anisotropy and switching fields in these materials were systematically tracked over a wide range in temperatures and fields using a novel resonant RF method based on a tunnel-diode oscillator (TDO) developed by us. This technique accurately probes the dynamic transverse susceptibility and has been validated in several nanoparticle systems. While the overall behavior of the transverse susceptibility can be described by standard Stoner-Wohlfarth formalism, there are subtle variations in the transverse susceptibility features including the approach to saturation that are different in the particles embedded in a dielectric matrix. A comparison between several systems and the role of matrix-mediated interactions will be discussed.

11:00 AM E3.8
A NEW METHOD FOR DIRECT DETERMINATION OF THE RECOILLESS FRACTION WITH APPLICATION TO MAGNETIC NANOPARTICLES. Monica Sorescu, Duquesne University, Pittsburgh, PA.

Knowledge of the recoilless fraction is of utmost importance in Mössbauer spectroscopy, since it provides unique information on the lattice dynamics, phonon softening, crystallization processes and phase transformations occurring in solids incorporating the Mössbauer isotopes. However, direct determination of the recoilless fraction has been to date very difficult, since the method available relied on the temperature dependence of the recoilless fraction and the determination of the Debye temperature from complicated equation plots. We propose a two-lattice method for direct determination of the recoilless fraction using a single room-temperature transmission Mössbauer measurement. The method is demonstrated for the case of iron and metallic glass two-foil system and is next generalized for the case of physical mixtures of two powders. We further apply this method to determine the recoilless fraction of hematite and magnetite particles. Finally, we provide direct measurement of the recoilless fraction in nanohematite and nanomagnetite with an average particle size of 19 nm. A significant reduction of the recoilless fraction with particle size is observed in both cases. A list of values obtained for the recoilless fraction in various materials using the two-lattice method is given.

SESSION E4/J7: JOINT SESSION
MICROSTRUCTURAL AND PROCESSING ASPECTS OF MAGNETIC THIN FILMS
Chairs: Li Tang and Jerzy A. Szpunar
Wednesday Afternoon, April 3, 2002
Nob Hill A/B (Marriott)

1:30 PM E4.1/J7.1
GROWTH AND TEXTURE OF GaMnAs GROWN ON GaAs BY MOVPE. Kerstin Volz, Michael Lampalzer, Torsten Torunski, Wolfgang Stolz, Philipps University Marburg, Materials Science Center, Marburg, GERMANY; Leander Tapfer, PASTIS CNRSM, Brindisi, ITALY.

Magnetic semiconductors are important for the progress of magneto-optics and spin-opto-electronics. In this study, GaMnAs films have been grown successfully on GaAs substrates under non-equilibrium conditions by metal organic vapour phase epitaxy (MOVPE). The layers exhibit a high structural perfection, as will be shown by X-ray diffraction and mainly by high resolution transmission electron microscopy (TEM). Depending on the growth conditions, clusters are found in these films. These clusters are responsible for the ferromagnetic coupling of the films, also observed at temperatures exceeding room temperature. The clusters are shown to have hexagonal NiAs crystal structure and contain a considerable amount of Ga. Despite of the different crystal structure from the surrounding matrix, the hexagonal GaMnAs clusters as well as the surrounding GaAs:Mn matrix grow defect-free. A heteroepitaxial relationship to the cubic matrix crystal can be observed for all clusters. Depending on the growth temperature and the substrate orientation, different cluster shapes as well as different epitaxial relationships of the clusters to the surrounding GaAs:Mn are found. The texture of these films will be shown in dependence on the growth conditions and will be correlated to the magnetic properties.

1:45 PM E4.2/J7.2
BULK VERSUS SURFACE MAGNETIC TEXTURE IN THIN FILMS OBTAINED BY PULSED LASER DEPOSITION.
Monica Sorescu, Duquesne University, Pittsburgh, PA; A. Grabias, Institute of Electronic Materials Technology, Warsaw, POLAND; D. Tarabasanu-Mihaila and L. Diamandescu, Institute of Atomic Physics, Bucharest, ROMANIA.

Pulsed laser deposition has been extensively used in obtaining thin films of ferroelectrics and superconductors. Recently, it became a promising method for fabricating thin films from several classes of magnetic materials, such as metallic glasses. In this regard, laser ablation deposition of iron oxides and intermetallics both with and without substitutions represent a challenging approach and was undertaken in the present study. Using X-ray diffraction, transmission and conversion electron Mössbauer spectroscopy, the magnetic properties of these systems are related to those of the corresponding bulk materials. In this study we present a direct comparison between the properties of bulk magnetic systems and those of corresponding thin films obtained by pulsed laser deposition: $Fe_{50}Co_{50}$, Fe_3O_4, Fe_3O_4:Co and Fe_2O_3:Cr. Using complementary techniques, we present results on the bulk and surface hyperfine magnetic fields, site populations and magnetic texture. Our results support an increase in the hyperfine field values at the surfaces, a more pronounced out-of-plane magnetic texture in the films, as well as a perfect transfer of stoichiometry and substitution level from target to substrate materials.

2:00 PM E4.3/J7.3
EVOLUTION OF FREE VOLUME IN ULTRASOFT MAGNETIC FeZrN FILMS DURING THERMAL ANNEALING.
N.G. Chechenin[a], A. van Veen[b], H. Schut[b], A.R. Chezan[a], D.O. Boerma[a], T. Vystavel[a], J. Th. M. de Hosson[a]; [a]Materials Science Centre, University of Groningen, Groningen, NETHERLANDS; [b]Interfaculty Reactor Institute, Delft University of Technology, Delft, NETHERLANDS.

Ultrasoft magnetic films with low a coercive magnetic field of ∼1 Oe, an induced uniaxial magnetic anisotropy of 10-50 Oe and a high saturation magnetization of ∼1.5-2 T, are required for future high frequency applications in the GHz region. We obtain excellent magnetic parameters in FeZrN films, deposited by DC reactive sputtering on different substrates at various temperatures. The grain size is a crucial parameter of the microstructure of a magnetic film: nanometer size of the grains is required for averaging out the magnetocrystalline anisotropy and for reduction of the intrinsic stray field. The films were studied with XRD, TEM and positron beam analysis. The films with the best soft magnetic properties were almost amorphous: the grain size estimated using XRD was about 2-3 nm, while HRTEM showed only a weak ordering. The main emphasis of this study was on nano-grain formation, grain growth and evolution of the intergranular free space during a thermal treatment in the temperature range up to 300°C. The microstructural evolution was investigated by HRTEM and by Lorentz TEM using an in-situ heating stage. Positrons proved to be a sensitive probe for the free volume in the near-amorphous and recrystallized films. Due to the nanometer size of the grains nearly all positrons diffuse to the grain boundary and are trapped and annihilated there. The size and character of the free volume on an atomic scale was monitored for films with different deposition parameters and its evolution is followed during thermal annealing, where two competing processes are involved: the reduction of the free space by the formation of dense grains and by a decrease of intergranular space during the grain growth on one side, and an increase of the free volume due to nitrogen release, on the other side.

2:15 PM *E4.4/J7.4
MICROSTRUCTURAL EFFECTS IN SINGLE LAYER AND ANTIFERROMAGNETICALLY-COUPLED MAGNETIC MEDIA.
Mary Doerner, Kai Tang, Qi-Fan Xiao, IBM Storage Technology Division, San Jose, CA; Shaun McKinlay, Robert Sinclair, Stanford Univ, Stanford, CA.

Microstructural control for magnetic recording media is becoming ever more critical with the rapid decrease in bit dimensions and the threat of thermal instability. The crystallographic texture and grain size of the Co-alloy magnetic layer is obtained through epitaxy with the underlying layers. Improvement of the grain size distribution and texture in the Cr-alloy underlayer is therefore a key priority, however, previous researchers have shown that the epitaxial relationship between the underlayer and magnetic layer is not perfect. This can result in an uncontrolled microstructure in the magnetic layer. One example of this effect and its explanation is discussed for CoPtCrB on Cr-alloy underlayers. Antiferromagnetically-coupled (AFC) media are used to improve thermal stability. Since at least part of the increase in stability is obtained through increased thickness of the top magnetic layer, optimum performance is obtained for microstructures that maintain recording properties as a function of magnetic layer thickness. The implications of this will be discussed and demonstrated for different microstructures.

3:15 PM E4.5/J7.5
QUANTITATIVE NANOMETER-RESOLUTION MAPPING OF BORON IN MAGNETIC RECORDING MEDIA BY ANALYTICAL ELECTRON MICROSCOPY.
J. Bentley, N.D. Evans, Oak Ridge National Laboratory, Metals and Ceramics Division, Oak Ridge, TN; J.E. Wittig, J.F. Al-Sharab, Vanderbilt University, Nashville, TN.

Measurements of composition at the nanometer scale are critical for structure-property correlations aimed at understanding the performance of Co-Cr-based thin-film longitudinal magnetic recording media. We have previously established and applied reliable methods for mapping Cr segregation by energy-filtered transmission electron microscopy (EFTEM). Of particular interest is the extension of such work to map B distributions. Two methods are being employed: EFTEM mapping with a Gatan imaging filter (GIF) on a LaB_6 Philips CM30 and spectrum imaging in the scanning transmission electron microscopy (STEM) mode on a Philips CM200FEG with Emispec ESVision and a GIF. For B measurements, the presence of M-edges from 3d transition metals (TM) results in low signal-to-background (S/B) and a background shape that does not follow an AE^{-r} inverse power law. Previous quantitative analysis of TM borides was successful with the use of a log-polynomial (LP) background fitting procedure in which a low-order polynomial was fit to log(intensity) versus log (energy-loss). For Co-Cr-Pt-B media, limited success has been achieved employing such an approach with spectrum imaging in STEM. However, Cr increases and Co decreases concurrent with local B enrichment appear to subtly change the background shape, leading to limited reliability at low B levels, even with LP background fitting. In EFTEM methods, multiple acquisitions are required to increase the detected signal in order to overcome the low S/B statistical limitations. In addition, rather than using the conventional 3-window method, custom scripts within the Gatan DigitalMicrograph software have been developed for optimized acquisition and LP background fitting from an extended set of energy-filtered images. Mapping B at ∼1-nm resolution by EFTEM and spectrum imaging has clearly indicated inter- and intra-granular segregation. Continuing work on the remaining issues for robust quantitative B concentration mapping will be fully described.
Research at the Oak Ridge National Laboratory SHaRE Collaborative Research Center was sponsored by the Division of Materials Sciences and Engineering, U.S. Department of Energy, under contract DE-AC05-00OR22725 with UT-Battelle, LLC. Support from an IBM Faculty Partnership is also gratefully acknowledged.

3:30 PM E4.6/J7.6
SPIN-DEPENDENT QUANTUM SIZE EFFECTS IN THIN IRON MICROCRYSTALS.
Ryszard Zdyb, Ernst Bauer, Arizona State University, Dept of Physics and Astronomy, Tempe, AZ.

The spin-dependent quantum size effects (QSE) of slow electrons reflected from atomically flat Fe microcrystals with well-defined thicknesss are studied by spin-polarized low energy electron microscopy. From the energy values of the extrema of the QSE oscillations between 0 and 20 eV the band structure of the exchange-split sp band along the [110] direction is derived. It agrees well with that calculated by Hathaway et al [1]. From the amplitudes of the oscillations as a function of energy and thickness the inelastic mean free paths (IMFP) of spin-up and spin-down electrons are obtained. Although their magnitudes agree qualitatively with recent calculations [2] their energy dependence does not: they increase from 5 - 6 eV up to the threshold of sp excitations at about 8 eV and then decrease again. This discrepancy is attributed to the simplified description of the sp contributions in the calculations and indicates that the excited state band structure has to be taken into account in the theory of the IMFP.
[1] K.B. Hathaway et al, Phys. Rev. B31, 7603 (1985) [2] Jisang Hong and D.L. Mills, Phys. Rev. B62, 5589 (2000)

3:45 PM E4.7/J7.7
COMPARISON OF Pb, O_2, AND Ag SURFACTANTS IN SPUTTERED Co/Cu MULTILAYERS.
Brennan L. Peterson, Bruce M. Clemens, Robert L. White, Stanford University, Department of Materials Science and Engineering, Stanford, CA.

The addition of so-called surfactants to thin films in order to improve their structural properties is an interesting and potentially, a particularly useful area of study. In the case of Co/Cu growth, a variety of surfactants have been used, in a variety of growth systems. Our specific interest is in sputter deposited systems, where surface stresses, intermixing, growth rates, and kinetics can be significantly different than in evaporated and CVD films. Because of the variety of surface growth phenomena involved, several techniques are necessary for a good understanding of the processes which govern growth. In order to quantify the effect of surface stresses and intermixing, in-situ

stress measurements were undertaken. In order to quantify the structure of the film, *ex-situ* low angle x-ray scattering studies were combined with *in-situ* STM. In this study, we focused particularly on the difference between metallic surfactants (Ag, Pb) and oxygen. DC magnetron sputtered [Co/Cu] multilayers were deposited on SiO_2 and Pt/Al_2O_3 substrates. Typical rates were ~1Å s. The Pt seed layers were grown at high temperatures, and provide a single crystal metal template for growth, with wide (~500Å) terraces. Surfactants were added at interfaces and at the base, in order to determine where surfactants were most efficient. Oxygen was introduced during growth at various partial pressures, as well as puffed onto interfaces. Both lead and silver move effectively to the surfaces, but nowhere near as efficiently as earlier work in evaporated films had shown. The addition of a partial pressure of oxygen during growth had the largest effect in increasing smoothness and layer to layer roughness correlation. At interfaces, the oxygen effect was minimal. We also compare simple models of the effect of surfactants on nucleation and growth, especially at the non-equilibrium rates of sputter deposition.

4:00 PM E4.8/J7.8
CONTROL OF NOVEL MAGNETIC PROPERTIES IN COBALT-BASED THIN FILMS BY USE OF MOCVD. Mariana Chioncel, Feodor Ogrin, Brian Ruthven, Peter Haycock, Jilan Shah, Anthony Wright, Gillian Maddison, Samantha Stockton, Keele University, School of Chemistry and Physics, Staffordshire, UNITED KINGDOM.

The magnetic properties of thin films can be modified significantly from those of the bulk material through careful control of the growth process. We have made use of conventional and assisted metal-organic chemical vapor deposition to control the occurrance of inverse magnetic hysteresis in cobalt-based films. Changing the process parameters, including the balance between photolytic and pyrolytic decomposition of the cyclopentadienylcobalt dicarbonyl precursor enables the development and control of a range of anomalous magnetic properties. The occurrence of inverted hysteresis is now well established, but extant data on other magnetic properties of such systems is scarce. We present here the results of hysteresis measurements, remanence curves, ferromagnetic resonance studies, magneto-optic magnetometry and magnetotransport experiments on samples which exhibit large, fully inverted hysteresis loops when the magnetic field is applied perpendicular to the plane of the film. The anomalous properties can be correlated with the occurrance of a certain microstructure and texture, namely amorphous, randomly shaped grains of dimension around 150 nm. The remanence curves indicate that there is competition between different anisotropies in the film, each favouring a different orientation of the magnetization with respect to the applied field. Ferromagnetic resonance studies have confirmed the unconventional anisotropy and shown the presence of an extra, strong spin mode in the range of orientations within which the inverted hystesis is exhibited. Magnetotransport measurements have shown that there appears to be a strong in-plane moment re-orientation taking place when the hysteresis loop contains a section with negative dynamic susceptibility. In this paper we bring together the results from a wide range a measurements and discuss these in the light of the microstructural and textural features of the films. We also indicate how to control the microstructure through the growth process parameters.

SESSION E5: POSTER SESSION
Chair: Samuel D. Harkness
Wednesday Evening, April 3, 2002
8:00 PM
Salon 1-7 (Marriott)

E5.1
MAGNETICALLY CONTROLLED PHOTOVOLTAIC DIODE STRUCTURE. V.K. Dugaev, Yu. Vygranenko, M. Vieira, Dept of Electronics and Communications, ISEL, Lisbon, PORTUGAL; V.I. Litvinov, Waveband Corp, Torrance, CA; J. Barnaś, Dept of Physics, A. Mickiewicz Univ, Poznań, POLAND.

We propose a new integrated device for spintronics, which is based on magnetic/semiconductor hybrid structures. The device consists of a *p-i-n* Si-based photoelectronic structure sandwiched between two thin layers of a ferromagnetic metal (3d ferromagnets or half-metallic systems). Electron-hole pairs are created in the semiconductor part of the structure by light illumination. When the spin diffusion length in the central (semiconductor) part of the device is sufficiently long, the light-generated electron and hole currents are sensitive to the relative orientation of magnetic moments of the ferromagnetic layers. This is due to a difference in the specular reflection (as well as in the diffuse scattering) of spin-up and spin-down electrons and holes from magnetically polarized layers – similarly as in the ordinary GMR effect in metallic multilayers. This, in turn, results in the dependence of the photovoltaic current on the magnetic configuration of the device. Owing to the fact, that the magnetic configuration can be changed by an external magnetic field, the photovoltaic current can be controlled by the magnetic field as well. Integrating the GMR effect into a semiconductor photovoltaic device enables including new parameters to control the effect, like for instance the polarization and the wavelength of incident light. The latter enables to control the depth of the light absorption and, in turn, the depth of photocarrier generation. Transport properties of the proposed device have been simulated by the methods similar to those used in the case of nonmagnetic *p-i-n* structures. Our main objective was to estimate the magnitude of the effect and also to determine the role of basic material parameters.

E5.2
INTRINSIC MAGNETIC PROPERTIES AND NANO-CRYSTALLIZATION BEHAVIOR OF AMORPHOUS $Fe_{78}Si_9B_{13}$ RIBBONS. Xiang-Cheng Sun, Prog. Molecular Simulation, Instituto Mexicano del Petróleo (IMP), DF Mexico, MEXICO; R. Gomez, Faculty of Science, National University of Mexico (UNAM), DF, Mexico, MEXICO; J. Reyes-Gasga, Institute of Physics, National University of Mexico (UNAM), DF, Mexico, MEXICO.

Ferromagnetic properties and nanocrystallization process of soft ferromagnetic $Fe_{78}Si_9B_{13}$ ribbons were studied by in-situ transmission electron microscope (TEM), X-ray diffraction (XRD), in-situ Mössbauer spectroscopy (MS), differential scanning calorimetry (DSC) and magnetization measurements. The investigation on the temperature evolution of the hyperfine H_{hf}(T) and the Curie temperature (T_C) of the amorphous phase was carried out. It is found that the magnetic field originally present in the amorphous phase can be described by the Weiss molecular field theory. The total angular momentum of the iron atoms turns out to be 5/2 and this indicate Fe^{+3} in which the electronic spins are uncoupled. The Curie and crystallization temperature were determined to be T_C=665K and T_x = 750K using hyperfine field and DSC thermal analysis measurements. On the other hand, when the samples were maintained near T_C, three new magnetic phases were detected in the Mössbauer spectra. The magnetic behavior of these phases is also described by universal Brillouin curvs with J_1 = 3/2, J_2 = 5/2 and J_3 = 5/2. The XRD pattern, Mössbauer spectra and in situ TEM observations revealed that the ultimate main nanophases are the α-Fe(Si) (bcc) solid solution and the Fe_2B (bct). It is notable that the magnetization of the amorphous phase decreases more rapidly with increasing temperature than these of nanocrystalline ferromagnetism, suggesting the presence of the distribution of exchange interaction in the amorphous phase or high metalloid content.

E5.3
MICROSTRUCTURE CHARACTERIZATION AND MAGNETIC PROPERTIES OF NANOSTRUCTURED MAGNETIC FeOOH PARTICLES. Xiang-Cheng Sun, Prog. Simulación Molecular, Instituto Mexicano del Petróleo (IMP), DF, Mexico, MEXICO; J. Reyes-Gasga, Institute of Physics, The National University of Mexico (UNAM), DF, Mexico, MEXICO; J.A. Toledo, N. Nava, Prog. Simulación Molecular, Instituto Mexicano del Petróleo (IMP), DF, Mexico, MEXICO.

Nanostructured acicular iron oxyhydroxide (FeOOH) particles were synthesized by chemical co-precipitation method using aqueous medium. The nanophases, microstructure and phase transformation of those nanostructured iron oxyhydroxide particles was characterized by transmission electron microscopy (HR-TEM) and electron diffraction (SAED), Rietveld x-ray diffraction (XRD), Mössbauer spectroscopy, thermal analysis and FT-IR spectroscopy. HR-TEM, SAED, and XRD analysis confirmed that the as-synthesized iron oxyhydroxide (FeOOH) particles were consisted of mainly acicular α-FeOOH nanocrystal. HR-TEM images and SAED patterns indicated the acicular or needle-shaped features of nanostructured α-FeOOH with average length of 70 nm and an aspect ratio of 7. Most interesting to note that, from XRD analysis, Mössbauer spectroscopy and FT-IR spectroscopy, phase transformation from α-FeOOH to γ-FeOOH and α-Fe_2O_3 or γ-Fe_2O_3 had been found to occur during annealing the as-synthesized FeOOH samples at different conditions. In particular, the change of acicular or needle-shaped features had been evidenced by HR-TEM observations. On the other hand, magnetization M(ZFC/FC) verse T data indicated that distinct magnetic behavior (superparamagnetic or ferrimagnetic) in those nanostructured FeOOH particles had been observed by means of VSM, SQUID and Mössbauer spectroscopy magnetometers. It was found that the surface magnetism and magnetic coupling between those nanostructured FeOOH particles were supposed to be responsible for the inner broadening of the Mössbauer spectroscopic lines. In addition, the details of the behavior of magnetic viscosity verse temperature for two nanostructured α-FeOOH and γ-FeOOH particles at low temperature were also discussed and summarized.

E5.4
PREPARATION OF CoCrx/Si THIN FILM BY FACING TARGETS SPUTTERING SYSTEM. K.H. Kim, Y.J. Kim, W.H. Park, Kyungwon Univ., Dept of Electrical Information Eng., Kyunggi-do, KOREA; S.H. Kong, S. Nakagawa, Tokyo Institute of Technology, Dept. of Physical Electronics, Tokyo, JAPAN.

In the perpendicular magnetic recording method that was proposed to achieve ultra-high recording density, perpendicular magnetic recording media requires a good crystalline orientation and high perpendicular coercivity. Therefore in this study we introduced the underlayer to improve the characteristics of magnetic thin film for perpendicular magnetic recording. As a result of CoCrTa/Si thin film that was prepared by facing targets sputtering system, crystalline orientation of CoCrTa magnetic layer was improved highly and it was found that Si underlayer was effective to improve crystallographic property. Also, in order to increase the coercivity together with improving of crystalline orientation Pt was added to CoCr targets instead of Ta.

E5.5
EXAFS AND MAGNETIC CHARACTERIZATION OF MELTSPUN $Cu_{80}Fe_4Ni_{16}$. Júlio C. Cezar, Hélio C.N. Tolentino, Laboratório Nacional de Luz Síncrotron, Campinas, BRAZIL; Marcelo Knobel, UNICAMP, Campinas, BRAZIL.

Granular alloys composed by a low concentration of magnetic material in a non-magnetic matrix attracted the interest of the magnetism and materials science community because they display giant magneto-resistance effect (GMR) comparable to the one found in multilayered systems. Usually the alloy components are imiscible at room temperature, but reach a metastable condition due to a very fast cooling. The concentrations of elements are chosen in such a way that an application of a heat treatment enables the coalescence of the magnetic material, originating magnetic clusters. The properties of these magnetic clusters (e.g., average size, size distribution, concentration) determine the magnetic behavior of the alloy, and its characterization are of key importance to understand the GMR phenomena. Copper-Permalloy systems are very interesting from the magnetic point a view, once that they present the giant-magnetoresistance (GMR) phenomenon and are composed by the same elements of a commercial spin valve magnetic reader head. Here are presented the results of EXAFS measurements on meltspun $Cu_{80}Fe_4Ni_{16}$ samples. The samples were annealed under vacuum in a resistive furnace at several temperatures up to 600°C. The spectra were measured at the XAS beam line of LNLS (Campinas, Brazil), at the K edge of copper, nickel and iron. The results show a negligible variation in the nickel average first neighbor distance, whereas the average first neighbor distance of iron decreases with increasing annealing temperatures. The results were interpreted as an indication of almost constant dissolution of nickel in the copper matrix and formation of iron-nickel clusters for annealing above 400°C. These clusters are richer in Fe then the nominal composition $Fe_{20}Ni_{80}$. This fact is corroborated by the low iron solubility in copper. Furthermore, magnetic and transport measurements on these samples show that they present an overall superparamagnetic behavior superimposed with a small ferromagnetic component.

E5.6
REGULAR ARRAY OF NANO-MAGNETIC DOTS PREPARED BY METAL MASK MEMBRANES. Bo Cheng, Kun Yang, W.J. Yeh, University of Idaho, Dept of Physics, Moscow, ID; B.L. Justus, Naval Research Lab, Washington, DC.

In magnetic recording technology, barriers based on fundamental physical limits are being approached for the current longitudinal recording mode. However, demands for higher data storage escalate in recent years. Discrete perpendicular recording is a viable method to achieve 100 Gb per square inch and beyond. We report on the development of a novel technique to fabricate uniform arrays of nano-sized magnetic dots. The order and size of magnetic dots are obtained by magnetron sputtering deposition via metallic mask membranes. The membranes containing uniform, hexagonally patterned voids with diameters as small as 40 nanometers, made of platinum, are prepared by thin-film deposition on nanochannel glass wafers as substrates. The magnetic dot density as high as 10^{11} per squre inch can be obtained. Our method provides a simple yet effective way to create regularly arranged discrete magnetic media that can be used for perpendicular magnetic recording. The magnetic perperties of the dots are studied with magnetic force microcopy.

E5.7
Abstract Withdrawn.

E5.8
ENHANCED MAGNETIC TRANSITION OF CORE-SHELL TYPE COBALT-PLATINUM NANOALLOYS. Jong-Il Park[a], Nam-Jung Kang[a], Sang-Min Lee[a], Sehun Kim[a], S.J. Oh[b], H.-C. Ri[b], Jinwoo Cheon[a], Department of Chemistry and School of Molecular Science (BK21), Korea Advanced Institute of Science and Technology[a], Korea Basic Science Institute[b].

Synthesis of "solid solution" and "core-shell" types of well defined Co-Pt based nanoalloys smaller than 10nm have been achieved by redox transmetalation reactions. This redox transmetalation are selectively observed only if the redox potential between two metals is favorable. The composition of the magnetic alloys can also be tuned by adjusting the ratio of reactants. Annealed core-shell nanoparticles transformed into mixed nanoalloys with face centered tetragonal (fct) structures, which show large coercivity and ferromagnetism at room temperature. These nanoparticles can potentially be used as an independent single magnetic bit of tera-bit information storage. Also, this kind of redox transmetalation reaction can be utilized as a general process to synthesize various types of nanoalloys with controlled composition in a selective fashion.

E5.9
SYNTHESIS OF COLLOIDAL COBALT NANOPARTICLES WITH CONTROLLED SIZE AND SHAPES. Victor Puntes, A. Paul Alivisatos, College of Chemistry, UC Berkeley, Berkeley, CA.

A method of producing high quality single crystal magnetic colloidal dispersions by the rapid pyrolysis of cobalt carbonyl in an inert atmosphere was employed to produce monodispersed, stabilized, defect-free cobalt nanocrystals with spherical shapes and sizes ranging from 3 to 17 nm, as well as cubic and rod-like shaped particles. The size distribution and the shape of the nanocrystals were controlled by varying the surfactant composition (oleic acid, phosphonic oxides and acids), its concentration and the reaction temperature. Besides, by varying the surfactant and the reaction temperature different crystal structures (cubic and hexagonal) could be obtained. These particles have been observed to produce 2D self-assemblies when evaporated at low rates in a controlled atmosphere. A combination of x-ray powder diffraction, transmission electron microscopy and SQUID magnetometry has been used to characterize both the dispersed nanocrystals and the assembled superlattices.

SESSION E6: MATERIALS FOR MAGNETIC RECORDING HEADS
Chair: Li Tang
Thursday Morning, April 4, 2002
Salon 13 (Marriott)

8:15 AM E6.1
REDUCTION IN PROCESS VARIATION AND IMPACT ON YIELD BY USING PICOSECOND ULTRASONIC LASER SONAR TECHNOLOGY. Arun Natarajan, Darrell Louder, Matthew Dietz, Peter Weyandt, Joseph Ivanecky, Seagate Technology, Bloomington, MN; Chris Morath, Rudolph Technologies, Flanders, NJ.

Picosecond ultrasonic laser sonar (PULSE) technology has proven effective in measuring both single and multilayer metal films, in the thickness range from 50A - 3 um, on GMR read/write head product wafers. This paper examines the utility of this technology in reducing in-line process variation during the production of GMR heads. It will be shown that PULSE technology is capable of early detection of both mis-process and contamination on GMR product wafers. Good agreement between PULSE data and parameters measured on other in-line metrology tools is demonstrated, thereby presenting the opportunity to significantly improve product wafer throughput and cycletime by reducing the need for multiple in-line measurements during wafer processing. Additionally, some of the advantages of PULSE technology over other conventional in-line metrology tools will be discussed. Thus, the contributions of PULSE technology towards improving wafer yield as well as correlation to downstream test parameters will be presented.

8:30 AM *E6.2
UNDERSTANDING MAGNETIC COUPLING AT ANTI-FERROMAGNETIC/FERROMAGNETIC INTERFACES - A SPECTROMICROSCOPY STUDY. H. Ohldag, A. Scholl, F. Nolting, T.J. Regan, S. Anders, N.B. Weber, F.U. Hillebrecht, R.L. White and J. Stöhr, Stanford Synchrotron Radiation Laboratory, Stanford, CA; Advanced Light Source, Berkeley, CA; University Düsseldorf, Düsseldorf, GERMANY; Stanford University, Stanford, CA; Max Planck Institut für Mikrostrukturphysik, Halle, GERMANY.

Today's magnetic storage devices consist of magnetic multilayers that are magnetically coupled across their interface. While the interface itself is supposed to dominate the magnetic behavior of the entire system, the identification and characterization of its magnetic properties remains an experimental challenge. A prominent example is the loop shift (*unidirectional anisotropy, exchange bias*) and the

coercivity increase (*uniaxial anisotropy*) found if a ferromagnet is coupled to an antiferromagnet. The exchange bias effect is utilized in magnetic data storage device to form a pinned magnetic reference layer. Although exchange bias was discovered over 40 years ago by Meiklejohn our understanding of its origin is still poor. We use dichroism x-ray absorption spectromicroscopy in a photoemission electron microscope to study the magnetic coupling between antiferromagnetic NiO(001) and ferromagnetic Co across its interface. We observe large (1-20μm) antiferromagnetic domains at the surface of bare NiO(001) single crystals. Upon in situ deposition of thin ferromagnetic Co layers (1.5nm) a reorientation of the antiferromagnetic axes takes place. The uniaxial anisotropy axes of the ferromagnet and the antiferromagnet are then aligned parallel domain by domain. Spectroscopy data show that the Co deposition causes a chemical reaction and formation of an interfacial $CoNiO_x$ layer. Microscopy images reveal its polarization to be aligned parallel to the Co layer. Upon annealing both, the uniaxial anisotropy and the amount of interfacial spins increases indicating the direct link between interfacial polarization and parallel exchange coupling. An imbalance between free and pinned interfacial moments as origin of the unidirectional anisotropy will be discussed. Our findings clearly show that a proper description of magnetic coupling in Co/NiO as well as in other AFM/FM systems needs to consider the properties of a distinct interfacial layer that can deviate significantly from the bulk properties of each material. [1] H. Ohldag, A. Scholl et al., Phys. Rev. Lett. 86(13), pp. 2878, 2001. [2] F.U. Hillebrecht, H. Ohldag et al., Phys. Rev. Lett. 86(15), pp. 3419, 2001. [3] H. Ohldag, A. Scholl et al., Phys. Rev. Lett., accepted for publication (2001).

9:00 AM *E6.3
ADVANCED SOFT MAGNETIC MATERIALS FOR RECORDING HEADS AND INTEGRATED INDUCTORS. Shan X. Wang, Nianxiang Sun, Ankur M. Crawford, Dept. of Materials Science & Engineering, Stanford University, Stanford, CA.

The Fe-Co-N films with Ni-Fe nanolayer seed has a saturation magnetization of 24 kG and a ferromagnetic resonance frequency of 2 GHz at zero-bias field, showing a great promise for applications in write heads and integrated inductors in a frequency range of >1 GHz. Magnetization dynamics measurements at sub-nanosecond scale have been performed. The damping parameter varies from 0.011 to 0.018, depending on applied bias field. The peak frequencies of the imaginary permeability spectra and the zero-crossing frequencies of real permeability spectra cannot be fitted with a fixed value of anisotropy field, indicating that the Kittel equation is only qualitatively valid for these films. A phenomenological damping criterion is established based on a small-signal solution of the Landau-Lifshitz-Gilbert equation. The experimentally observed damping parameters are generally smaller than the critical value, so the films display underdamped time-domain signals. The biggest challenge facing integration of magnetic material onto silicon is the compatibility of magnetics with standard silicon processing techniques. Integrated inductors were realized using ground planes of CoTaZr and CoNbZr. The magnetic properties of CoTaZr showed no change even after undergoing high temperature processing. Inductors with 1mm CoTaZr produced inductance values up to 60% higher than the air core inductors at frequencies up to 1.4 GHz.

9:30 AM E6.4
MAGNETICALLY SOFT CoC GRANULAR-LIKE AMORPHOUS THIN FILMS WITH HIGH RESISTIVITY AND HIGH SATURATION FLUX DENSITY. Hao Wang, Saipeng Wong, Manfat Chiah, Chiyu Poon, Wingyiu Cheung, Ning Ke, The Chinese Univ of Hong Kong, Dept of Electronic Engineering, Hong Kong, PR CHINA.

Granular-like amorphous Co_xC_{1-x} nanocomposite thin films, with x in the range of 60-75% in atomic percentage, have been prepared by pulsed filtered vacuum arc deposition. The structure of the films is characterized by non-Rutherford backscattering spectrometry, transmission electron microscopy, x-ray diffraction, x-ray photoelectron spectroscopy, and Raman spectroscopy. The in-plane magnetic hysteresis loops are measured by a superconducting quantum interference device magnetometer at room temperature. The electrical transport properties are measured by four-probe technique at various temperatures ranging from 20 to 300 K. The films are magnetically soft with coercivities in the range of 2 to 12 Oe, resistivities in the range of 130 to 300 $\mu\Omega$-cm, and magnetic saturation flux densities in the range of 6 to 13 KG. The structural, electrical and magnetical properties of the films are thermal stable upon annealing up to 200°C in a vacuum furnace. These films have promising potential as magnetic write head core materials for high recording-density and high data rate applications. Acknowledgement: This work was supported in part by the Research Grants Council of Hong Kong SAR (Ref. No. CUHK4216/00E).

9:45 AM E6.5
Abstract Withdrawn.

10:30 AM *E6.6
NANOCRYSTALLINE SOFT MAGNETIC MATERIALS FOR DATA STORAGE APPLICATIONS. M.E. McHenry, S. Jeong, C.L. Lee, Y.N. Hsu, M.-Q. Huang, H. Okumura and D.E. Laughlin, Carnegie Mellon University, Pittsburgh, PA.

This talk will begin by reviewing current applications of soft magnetic materials in data storage applications. These include soft layers in spin valve structures, and magnetic underlayers for recording media and heads. This will be followed by a review of the developing field of nanocomposite soft magnetic materials including FINEMET, NANOPERM and CMU's HITPERM materials. Thin film and laminated multilayer magnets of the HITPERM composition $(Fe,Co)_{88}(Zr,Hf)_7B_4Cu$ have been synthesized and examined as potential recording head materials. Zr containing HITPERM, developed by McHenry, Laughin and Willard, has a literature reported induction of 1.7 T (and permeabilities >3000 at 10 kHz and 2.5 Oe field amplitude) and Hf containing HITPERM, developed by McHenry, Laughlin and Iwanabe, has a literature reported induction of 2.1 T. Thin film and multilayers of HITPERM modulated with SiO_2 interlayers have been produced by sputtering. Magnetic film thicknesses have been optimized at ~80 nm and interlayer laminate spacings of ~4.0 nm. Room temperature coercivities of ~2.5 Oe have been achieved for single HITPERM layers and <0.4 Oe for multilayer laminated structures. Thus, laminated HITPERM films possess order of magnitude lower coercivity than single layer films. The SiO_2 intermediate layers play an important role in reducing the magnetostatic coupling between layers and reducing the coercivity Hc. They are also anticipated to increase the high frequency response of these materials. Finally, a brief review of the status of soft magnet/oxide nanocomposites for high frequency applications will be presented.
Acknowledgements: This research was partially supported by the Data Storage Systems Center at CMU under a grant of No. ECD-89-07068 from National Science Foundation and sponsored in part by the Air Force Office Scientific Research, Air Force Material Command, USAF, under Grant No. F49620-96-0454. The U.S. Government is authorized to reproduce and distribute reprints for governmental purposes notwithstanding any copyright notation thereon.

11:00 AM E6.7
MODIFYING THE SURFACE ROUGHNESS AND TEXTURE OF NiFe AND CoFe THIN FILMS BY ION BEAM ETCH. Dong Lin, Lijuan Zou, Ralph D. Knox, Seagate Technology, Minneapolis, MN.

Ion beam is commonly used to etch metal thin films and the surface topography is typically modified during the etching process. In this study, we report the surface topographic changes of NiFe and CoFe thin films at various ion beam etch conditions. The thin films are prepared on wafers using sputtering deposition and the surface topography is characterized using AFM. Starting with the surface roughness of a few nanometers, typically, the surface topography develops during the etching process and can become roughened or smoothened mostly depending on the beam incident angles. The final roughness also depends on the thickness removal of the thin films. At high incident angles, highly anisotropic texture can be created on the etched surface. It suggests that the ion beam etch can be used in manufacturing process to tailor the surface roughness and the texture in certain ranges. The surface topographic changes have been explained in terms of the angle dependence of etch rate and the shadowing effect.

11:15 AM E6.8
ON THE OCCURRENCE OF SPIN-POLARIZED BLOCH MINIBAND TRANSPORT IN III-V DILUTED SEMICONDUCTOR SUPERLATTICES. I.C. da Cunha Lima, L. Loureiro da Silva, M.A. Boselli, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, BRAZIL; X.F. Wang, Concordia University, Montreal, CANADA.

A model superlattice based on the diluted magnetic semiconductor (DMS)$Ga_{1-x}Mn_xAs$ (for $x \approx 0.4 - 0.5$) in its metallic ferromagnetic phase is used to explore the possibility of observing spin-polarized Bloch miniband transport in those magnetic superlattices. Mn substitutes Ga providing at the same time a $5/2\hbar$ localized magnetic moment, and a high concentration (of the order of $10^{20} cm^{-3}$) of free holes. The *pd* interaction (-1.2 eV) occurring in that material makes each ferromagnetic layer to work as a potential barrier for holes with spins aligned parallel to the average magnetization of the Mn ions, while these same layers work as potential wells for the inverse polarization. Therefore, two effective superlattices are present, one for each spin polarization. As a consequence we obtain spin-polarized effective masses and momentum relaxation times, among other properties. By choosing properly the magnetic and the non-magnetic layers widths, together with the valence band mismatch determined by the composition of the non-magnetic layer, a spin-polarized transport

with a large difference on the mobilities for each spin polarization is observed. Calculations are performed using the Balance Equations formalism, including scattering by the ionized Mn impurities.

11:30 AM E6.9
INTERFACIAL CONTRIBUTIONS TO MAGNETOSTRICTION OF FERROMAGNETIC LAYERS FOR MAGNETORESISTIVE SENSORS. E.W. Singleton and K.J. Duxstad Seagate Technology, Minneapolis, MN.

We have experimentally measured magnetostriction of thin CoFe or CoFe/NiFe layers when deposited with various seed and capping layers. Seed and capping layers were chosen to be materials that can be used adjacent to the magnetic free layer in spin-valve (SV) type structures used in giant magnetoresistive (GMR) sensors. Materials deposited adjacent to the magnetic layer(s) include Cu, Ta, TaN and oxides. The experimental results are interpreted using a model that allows separation of bulk and interface contributions to the measured magnetostriction [1]. Results show a clear interfacial contribution that is dependent upon the material at the interface of the magnetic layer. The results demonstrate surface contributions to the magnetostriction dominate as layer thickness decreases. [1] H.J. Hatton and M.R.J. Gibbs, J. of Magn. Magn. Mater. 156, 67 (1996).

11:45 AM E6.10
CARBON NANOTUBE BASED MAGNETIC TUNNEL JUNCTIONS FOR ELECTROMAGNETIC NONDESTRUCTIVE EVALUATION. Buzz Wincheski, Min Namkung, NASA Langley Research Center, Hampton, VA; Sun Mok Paik, Kangwon University, Chunchon, KOREA; Jan Smits, Lockheed Martin Engineering and Sciences Corporation, Hampton, VA.

Spin coherent transport in carbon nanotubes enables single-nanotube devices for magnetic field sensing. This unique transport properties of single walled carbon nanotubes (SWCNT) has been studied for development into advanced sensors for nondestructive evaluation (NDE). Coupling of a single walled carbon nanotube to ferromagnetic electrodes is predicted to form a carbon nanotube magnetic tunnel junction. Fabrication of such devices has been performed through scanning probe and electron beam lithography. Purified single walled carbon nanotubes are deposited across electrodes to complete device fabrication. Nanomanipulation and self-assembly techniques are also utilized for precise placement of individual SWCNTs. A spin-coherent quantum transport theory based on a nonequilibrium Greens function method has been established to predict conductance and magneto-conductance across junctions. Experimental measurements of the transport properties of SWCNT magnetic tunnel junctions have been performed and compared to theoretical predictions with good agreement.

SESSION E7: MAGNETIC RECORDING MEDIA
Chair: Samuel D. Harkness
Thursday Afternoon, April 4, 2002
Salon 13 (Marriott)

1:30 PM *E7.1
MAGNETIC AND CRYSTALLOGRAPHIC PROPERTIES OF Co-Cr-Pt THIN FILMS INVESTIGATED USING SINGLE-CRYSTAL PERPENDICULAR MAGNETIC THIN FILM SAMPLES.
M. Futamoto, K. Terayama[a], K. Sato[a], N. Inaba, and Y. Hirayama, Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo, JAPAN; [a] Tokyo Univ. of Agri. & Tech., Koganei, Tokyo, JAPAN.

Improvements of magnetic properties and thermal stability are important issues for perpendicular magnetic recording media developments. These properties depend on the crystallographic quality, composition, and thickness of the recording layer. This paper discusses the possibilities of improving perpendicular magnetic properties of Co-Cr-Pt-alloy recording layer based on the data obtained from well-defined single-crystal magnetic thin film samples. Good single-crystal magnetic thin films with the c-axis perpendicular to the substrates are obtained on Al_2O_3(0001) single crystals when Co-Cr-Pt films are deposited via a non-magnetic $CoCr_{25}Ru_{25}$ underlayer. The Pt composition is varied between 0 and 17at%, while the Cr composition is kept nearly constant at 17 - 20 at%. The film thickness is varied between 6 and 100 nm.
The structure and microscopic compositions are investigated using high resolution TEM equipped with a compositional analysis facility. The Co-Cr-Pt thin films are confirmed to be single crystals grown epitaxially on the $CoCr_{25}Ru_{25}$ non-magnetic underlayer. Weak Cr segregations of ± few at% around the average compositions are recognized for respective samples in the plan-view TEM analyses. Stacking fault density and compositional distributions of alloying elements along the film growth direction are also investigated. The composition, thickness, and temperature dependences of basic magnetic properties (Hk, Ku) are determined. The Ku of 25nm-thick $CoCr_{18}Pt_7$ thin film, for example, decreased from 3.2 x 10^6 erg/cc to 2.0 x 10^6 erg/cc for increasing the temperature from 4.2 to 275 K. It is shown that the basic magnetic properties depend on the composition, crystallographic quality, and thickness of magnetic layer. These results are useful to design the practical perpendicular magnetic recording media that are polycrystalline thin films with more complicated microstructures.
A part of this work was supported by ASET program of NEDO, Japan.

2:00 PM E7.2
CREATION OF MAGNETIC MEDIA BY SPINODAL DECOMPOSITION. Guleid N.A. Hussen, Bruce M. Clemens, William D. Nix, Stanford Univ, Dept of Materials Science and Engineering, Stanford, CA.

Advances in magnetic information storage devices are being driven primarily by the desire for decreased media noise and increased storage density. If the current rate of increase in storage capacity is to be maintained, processing techniques that enable tighter control over both the grain size and grain size distribution will be required. Spinodal decomposition is a possible route by which a regular array of cobalt nanoparticles may be produced from amorphous thin film precursors. In alloy systems characterized by a positive heat of mixing and a single, continuous free energy curve across the entire composition range, there exists a critical temperature below which homogeneous alloys within a certain composition range are unstable with respect to compositional fluctuations. Cahns theory of the early stages of spinodal decomposition predicts a dominant wavelength in the spatial composition profile, which will, in turn, lead to a spatially varying nucleation rate. This dominant frequency can be tuned over a wide range by altering the chemical composition and the annealing temperature, thus allowing for a desired length scale to be selected. The cobalt-copper system exhibits the necessary thermodynamic properties for spinodal decomposition and is being investigated with the goal of producing a monodispersed array of cobalt nanoparticles. Amorphizing agents such as boron and zirconium are co-sputtered with cobalt and copper from elemental targets to create alloy thin films in a Co-rich composition range. Studies have been undertaken to determine the requirements for creating amorphous precursors and the crystallization pathway of each composition. X-ray diffraction has been utilized to determine the structure and orientation of the phases present. The magnetic properties of these films have been studied with vibrating sample magnetometry. Grain size and distribution of the decomposed films are currently being investigated by small angle x-ray scattering.

2:15 PM E7.3
STRAIN-DRIVEN, THIN-FILM SPINODAL DECOMPOSITION.
B.M. Clemens, V. Ramaswamy, Department of Materials Science and Engineering, Stanford University, Stanford, CA; D.C. Chrzan, Department of Materials Science and Mineral Engineering, University of California, Berkeley, CA.

The process of spinodal decomposition can produce composition fluctuations, and eventual phase distributions, with a characteristic length scale in the nanometer range. This length scale is determined by the thermodynamics of the alloy system and can only be partially controlled. We examine the possibility of using spatially-varying strain fields, for example those associated with an array of misfit dislocations, to impose a length scale on phase separation. We apply the Cahn-Hilliard model to spinodal decomposition of a thin film on a substrate with a spatially varying strain field. We find that the compositional and spatial variation of the strain energy term can drive composition fluctuations at the wavelength of the strain field, even producing some segregation in systems with no decomposition instability. We discuss the application of this effect to control magnetic phase distributions.

2:30 PM E7.4
Abstract Withdrawn.

3:15 PM *E7.5
FUTURE PERPENDICULAR MAGNETIC RECORDING MEDIA.
D. Weller, Y. Kubota, B. Lu, G. Ju, J. Ahner, J. Yu, X. Wu, D. Karns, A. Sunder, Seagate Technology, LLC, Pittsburgh PA; Ch. Chang, Ch. Brucker, R. Ranjan, Seagate Technology, LLC, Fremont, CA.

Media noise suppression is a key element in approaches to extremely high-density magnetic recording, requiring continued reduction in the media grain size and improvement in grain uniformity and magnetic grain isolation. Shrinking the grain size, however, will eventually compromise thermal stability and ultimately limit the areal density due to superparamagnetic decay. To postpone the onset of superparamagetic decay, one seeks to increase the magnetic hardness (anisotropy) of the media, which requires enhanced write fields.

Recently introduced antiferromagnetically coupled media structures provide some near term relief, however, pushing significantly beyond already demonstrated densities of >100 Gbit/in2 [1], may soon require new technologies, such as perpendicular magnetic recording (PMR), heat-assisted magnetic recording (HAMR) or patterned media recording. The talk will concentrate on the first new technology option and in particular on double-layer PMR media, which offer the least disruptive technology change in the ongoing quest for higher storage densities. In PMR, a single-pole write-head is combined with a double layer hard/soft magnetic medium. The presence of the soft magnetic underlayer (SUL) permits flux closure directly through the recording layer, enabling enhanced fields and sharper (compared to longitudinal) cross track gradients. Such media have been developed and areal densities >60 Gbit/in2 have been reported [2]. Of particular interest are granular media with large perpendicular magnetic anisotropy (Ku 3-6x106 erg/cm3), large remanence ratio (SQ 1) and onset of magnetization reversal at large negative fields ($\|Hn\| \geq$ 1000 Oe). These properties have been achieved in CoX/Pd-multilayers or CoPtCrX-alloys and will be reviewed. One of several proposals to low noise SULs is high moment and high permeability soft magnetic films with radial anisotropy. We have pursued dc-magnetron sputtered amorphous FeCoB films with (magnetron) field-induced radial anisotropy Hk>40 Oe. These structures have excellent frequency response and add no additional media noise, as confirmed in spin stand recording experiments. [1] Fujitsu and Seagate reported laboratory demonstrations of >100 Gbit/in2 using longitudinal magnetic recording technology in August and November 2001, respectively. [2] H. Takano, Y. Nishida, A. Kuroda, H. Sawaguchi, T. Kawabe, A. Ishikawa, H. Aoi, H. Muraoka, Y. Nakamura, K. Ouchi, "A practical approach for realizing high-recording density hard disk drives", paper CA-01, MMM/Intermag 2001, San Antonio, TX, January 7-11.

3:45 PM E7.6
NON-EPITAXIAL, HIGHLY TEXTURED (001) CoPt-B_2O_3 COMPOSITE FILMS FOR PERPENDICULAR RECORDING.
M.L. Yan, N. Powers and D.J. Sellmyer, Center for Materials Research and Analysis and Department of Physics and Astronomy, University of Nebraska, Lincoln, NE.

$L1_0$ FePt, CoPt-based composite films are promising materials for extremely high-density recording media because of high magnetic anisotropy. If the films are used as perpendicular recording media, the easy axis of CoPt or FePt grains in films should be aligned perpendicular to the film plane. Normally, MgO(100) substrate was used for film deposition in order to realize CoPt or FePt grains growth epitaxially and obtain (001) texture. For practical purpose, however, it is very useful to explore new methods to obtain textured films. Here we report non-epitaxial growth, highly textured (001) CoPt:B_2O_3 nanocomposite thin films, which are deposited directly on oxidized Si wafer by using a multilayer Co/Pt/Co/B_2O_3 deposition plus appropriate thermal processing. Our results show that as-deposited films are disordered fcc CoPt phase and magnetically soft. After necessary processes of annealing, the CoPt undergoes a phase transition from disordered fcc to the ordered fct structure with a high degree of (001) texture. Besides annealing processes, the interested features of CoPt:B_2O_3 films are that film microstructures and magnetic properties are strongly dependent on Co content, initial B_2O_3 thickness and total film thickness. Fig1. shows the XRD patterns of the films. The development of (001) texture can be seen clearly with different total film thickness and annealing temperature. From the magnetic measurement, coercivities ranging from 4kOe to 10kOe and Ms ranging from 300 C 800 emu/cc were obtained. Grain size, estimated by Scherrers formula, is small than 8nm. These tailored properties and highly perpendicular anisotropy make CoPt-based films very attractive for next-generation high-density recording. *Research supported by NSIC, NRI and CMRA

4:00 PM E7.7
FIRST-PRINCIPLES STUDIES OF THE MAGNETIC PROPERTIES OF HCP Cr IN Cr/Cu(111) AND Cr/Ru(0001) SUPERLATTICES.
G.Y. Guo, Dept of Physics, National Taiwan Univ, Taipei, TAIWAN.

The advent of modern thin-film growth techniques has stimulated enormous interest in fabricating artificial crystalline structures that do not exist in nature. These artificial systems would allow one to better understand the growth mechanisms and structural phase stabilities and also to explore physical properties distinct from that of the natural crystals. Well-known artificial structures include fcc Fe on Cu, bcc Co on GaAs and bcc Ni on Fe. Cr crystallizes in a bcc structure under ambient conditions. Recently, experimental evidence for the formation of ultrathin close-packed Cr films in epitaxial Cr/Co multilayers [1-2] and of ferromagnetic hcp Cr/Ru(0001) superlattices [3] has been reported. Here in this contribution, we will present the results of our recent first-principles theoretical calculations of the structural and magnetic properties of 3 monolayer hcp Cr/Cu(111) and Cr/Ru(0001) superlattices. The calculations are based on the density-functional theory with local spin-density approximation plus generalized-gradient corrections by using the highly accurate all-electron full-potential linearized augmented plane wave method. We find that bulk hcp Cr would be a paramagnet with a large density of states at the Fermi level and that no ferromagnetic state could be stabilized over a wide range of volume. Interestingly, the ultrathin Cr/Cu(111) and Cr/Ru(0001) superlattices are both found to be ferromagnetic with a small magnetic moment on the Cr atoms. The calculated results, especially, the x-ray absorption spectra, will be compared with the experiments. [1] W. Vavra, et al., Phys. Rev. B 47 (1993) 5500. [2] W.F. Pong, et al., J. Synchrotron Radiat. 6 (1999) 746. [3] M. Albrecht, et al., Phys. Rev. Lett. 85 (2000) 5344.