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 PATTERED MEDIA
Charles T. Retterer, Manfred Albrecht, Simone Anders, Gary M. McClelland, Mark W. Hart, Srikanta Ganesan, Margaret E. Best, and Bruce D. Terra, 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 all patterns needed to permit bit transitions. One approach to progressing further is to go to a limit to which lithographically define small magnetic islands, producing patterns with single-domain bits. We have pursued a number of approaches to developing such patterns and 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/in2, limited by our lithographic resolution. We have measured 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 Co/Pt/Cr media yields distributions that are narrower than the corresponding continuous films. Recording measurements made on patterned granular Co/Pt/Cr using a quasi-static GMR head demonstrate the sensitivity to detect single 60 nm islands, and the read-back jitter from the patterned film 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 PATTERNERED VIA ‘DIP-PEN’ NILLOGRAPHY: Xingguo Lin, Seunghun Hong, Chaol A. Hou, Helene Blanchard, Northwestern University, Evanston, IL; Lei Bi, Vinayak P. Dravid, Northwestern Univ, Dept of Material 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) fabricate new magnetic storage devices with higher storage densities and faster access times; 2) prepare arrays of interactive magnetic nanoparticles with precisely-controlled magnetization orientation and interparticle spacing; and 3) develop better understanding of the relationship between magnetic feature size and magnetization. A variety of techniques, including electron-beam lithography, scanning tunneling microscope lithography, electrochemical etching, and electrodeposition have been used to fabricate magnetic nanostructures 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 time-consuming processing steps. Herein, we present a new and forward 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: Chao Lai, Albrecht, Gang Xiang, Michael Cooke, Derek Ackerson, Russell Cochrane, Durham University, Dept of Physics, Durham, UNITED KINGDOM

Magnetic nanostructures with sub-100 nm features are usually fabricated by electron 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. By operating the ion beam in a repetition mode, an ion dose density of 11 Cm−2 was used to ensure the complete removal of Permalloy at milling sites. Magnetization measurements were provided by a magneto-optical Kerr effect (MOKE) magnetometer. Single 200 nm wide nanowires were patterned with the FIB scanning either parallel, orthogonal or ±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, although 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 ∼60 Oe for parallel scanned wires and 64 Oe for orthogonal and 45 degree scanned wires, respectively. 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 wires with a diameter of 100 nm, 1000 nm and 5000 nm width, whose hysteresis loops showed them to be of similar quality to e-beam defined structures. The elimination of the multi-step patterning 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: Huey Young, Hao Hum, Yuan-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 making the super-paramagnetic 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 self-assembled magnetic film is utilized to fabricate highly uniform monocrystalline magnetic oxide thin films directly onto Si and SiO2 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 monocrystalline 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 micro-magnetic properties such as coercivity and hysteresis are measured using a SQUID magnetometer. This bottom-up self-assembly assisted nanofabrication technique has the potential to achieve patterned magnetic structures with data storage densities higher than 500 Gbit/in2. Besides the ultra-high data storage density, the patterned magnetic disk can enable to achieve a preferential magnetic material for the substrate, which is strongly favored by read/write head technologies.

10:15 AM E1.5
FROM SELF-ORDERING TO TOWARDS IMPRINT LITHOGRAPHY: LARGE SCALE PERIODIC NICKEL NANOARRAYS: Kornelius Niehle, Jinshu Cui, Riccardo Hertel, Ralf B. Wehrspohn, Jürgen Kirchner, and Ulrich Gösele, Max Planck Institute of Microstructure Physics, Halle, Germany; Jürgen Kirchner, 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 ordered nanowire arrays with a desired magnetic structure compared to the commonly hexagonal arrangement of the nanowires. Nickel is used for the nanowires due to its small magnetic anisotropy and small magnetic moment which lead to weak dipole interactions inside the arrays and a large anisotropy resulting from the nanowire shape which enables nickel as a suitable material for patterned magnetic media. Self-ordered alumina pore channel arrays are used as templates for the fabrication of magnetic nanowire arrays with a periodicity of 60 nm (180 Gbit/in2). 100 nm (75 Gbit/in2) and 500 nm (3 Gbit/in2). A nearly perfect hexagonal arrangement for the columns occurs only inside very narrow process windows for periodic dipole interactions. 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. In hexagonal nanowire arrays or monocrystalline arrangement on a cm2-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 $\geq 20\%$ and for the polycrystalline and monocrystalline arrangements dropped to $<5\%$. We observed that the total magnetic anisotropy increased 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 determined 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 EL6
LATERAL ANTIMAGNETIC 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 nanomagnets in a chain will usually be such that the magnetization 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. Therefore, phase defects arise due to thermal fluctuation. Differences between the information transmission capability of chains of ferromagnetic and antiferromagnetically coupled nanomagnets are discussed. [1] Cowburn et al. Science 287, 1486 (2000).

10:45 AM EL7

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 states 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 diminished. We found that the rings magnetic elements exhibit two different highly stable "laminar" states in addition to the vortex state. The results of systematic characterization of arrays of small ring elements with SQUID magnetization and magnetic force microscopy (MFM) and magnetic force microscopy (MFM) to determine the topology 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 EL8
MEMORY EFFECT AND LOGIC OPERATIONS IN L-SHAPED MAGNETIC NANOSTRUCTURES. Dan Allwood, Greg Xiang, 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 memories 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 10 nm by 5 nm thick) fabricated by electron beam lithography, magnetic force microscopy (MFM) and magnetic force microscopy (MFM) to determine the topology and the magnetic patterns inside the rings, and with magneto-optical imaging to visualize the moment reversal process during a magnetization cycle. Furthermore, we find that reversing the magnetization in one arm, even through many cycles, does not cause the other arm to change its magnetization direction. One arm can thus act as a programmable memory, with the state 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 to the other arm. We show that the switching in the horizontal arm is the logical AND operation between the magnetization 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 larger magnetic field range 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, 1486 (2000).

SESSION E3: CHEMICAL AND BIOLOGICAL ROUTES TO MAGNETIC NANO PARTICLES
Chair: Tom Thomson
Tuesday Afternoon, April 2, 2002
Salon 13 (Marrick)

1:30 PM E2.1
SELF-ASSEMBLED MAGNETIC NANOSTRUCTURE ARRAYS. Kenneth M. Krashen, 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 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 presented.

2:00 PM E2.2
DIRECT FABRICATION OF MONODISPERSE AND HIGHLY-CRYSTALLINE MAGNETIC NANOCRYSTALS WITHOUT AN SIZE SELECTION PROCESS. Tae Hyun Byun, Jeongmin Park, Jin Joo, Young-hee Chung, and Hyun Rim Na, School of Chemical Engineering, Seoul National University, Seoul, KOREA.

We have developed new synthetic procedures to fabricate monodisperse magnetic nanocrystals. The 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 nanocrystals were synthesized by the thermal decomposition of iron-oleic acid metal complex. The resulting iron nanoparticles were transformed to monodisperse gamma-Fe2O3 nanocrystals by controlled oxidizing using trimethylamine oxalate, 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 iron and iron oxide particles showed the highly crystalline nature of the gamma-Fe2O3 structures. Using a similar procedure, highly crystalline and monodisperse cobalt ferrite nanocrystals were synthesized from the thermal decomposition of cobalt oleic acid organometallic complex, followed by the controlled oxidiation. Iron core/coherent shell nanocrystallites were fabricated by the thermal decomposition of cobalt oleic acid organometallic compound in the presence of the monodisperse magnetic nanocrystals. 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-segregated. Two-dimensional alignment of these monodisperse nanocrystal arrays onto substrates and the magnetic characterization of these materials will be discussed. We fabricated novel iron nanorods with dimensions of 2 nm (thickness) $\times$ 8 nm (length), 2 nm $\times$ 12 nm, 2 nm $\times$ 20 nm, and 2 nm $\times$ 36 nm by the controlled growth of uniform 2 nm sized spherical nanoparticles. These nanorods exhibited high magnetic moments and magnetic characterization of iron and maghemite nanorods will be presented.

2:30 PM E2.3

Monodisperse, ninuclear Co (diameter 11.4 nm, size deviation $<5\%$) and CoAg (11 nm diameter, $<10\%$) 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. CoO core nanoparticles consist 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 discussed in context to the particles’ magnetic properties measured by FMR (i.e. magnetic nanotopography), SQUID magnetometry (i.e. magnetic moment per particle) and magnetic circular dichroism (ratio of orbital to spin magnetic moment). [U. Wieswald et al, J. Vac. Sci. Technol. A 12 (4) (2001) 1773. [5] M. Spasov et al, J. Magn. Magn. Mater. Dec. 2001.

3:15 PM #E24
Angela Belcher, Univ. of Texas-Austin, Austin, TX

ABSTRACT NOT AVAILABLE

3:45 PM E2.5
SYNTHESIS AND CHARACTERIZATION OF OPTICALLY TRANSPARENT FERROMAGNETIC POLYMER: COHOLT OXIDE NANOCOMPOSITES. Sani R. Ahmed, Steven J. 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 norbornadiene (CopolyNOR) were synthesized by ring opening metathesis polymerization (ROMP). The polymer film was then treated with H2O2, 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 XRD, 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 0.1 mm. The density of cobalt oxide nanoparticles is in the order of 10^7 per cm^3. This study provides a better understanding of formation of magnetic nanoparticles with 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. Peer Ackermann, Dept. of Chemical Engineering, University of Maryland, College Park, MD; Robert Brubier, 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 the 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-based norbornadiene-copolymer acid diblock copolymers were synthesized by ring-opening 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 SAXS 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.
Layer-by-layer adsorption process of polyelectrolytes has been conventionally used for the fabrication of the ultrathin 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 heterostructures to fabricate the multilayers of barium ferrite nanoparticles. The Barium ferrite particles can be applied to the perpendicular magnetic recording media by arranging them so as to align the easy axis with a direction perpendicular to the substrate surface using a flexible process. In 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 techniques. Barium ferrite were prepaing the method. The glasses were prepared by mixing H2O, B2O3 and Fe2O3 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 BaFe2O4 powder was leached from them by using a weak acid. The particles were wrapped with poly allylamine hydrochloride (PAH) and polystyrene and polystyrene (PAA). The thickness of the self-assembled bilayer [Ba ferrite & PAH] / PAA was systematically controlled using the automatic dip coating method.

The magnetic measurements were performed to characterize the magnetic properties of the prepared multilayer 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.

Knowledge of the recoilless fraction is of utmost importance in Mössbauer spectroscopy for many reasons, including for the determination of both 57Fe and 57Co in steel. The recoilless fraction is a measure of the fraction of 57Fe and 57Co that are not recoilless in the Mössbauer measurement. The method is demonstrated for the case of iron and metallic glass two-slit system and is next generalized for the case of iron and metallic glass two-slit system.

Using a variable level of RF power, it is possible to measure the local miniraxity field at the different sites. The NMR spectra are highly dependent on the RF power. For the 57Fe-Bi based alloys, we observe well-defined 57Fe resonance signals from three distinct sites, distinguished by the number of Bi atoms in their neighborhood. In the spectra of Fe2O3, CaO, Na2O, and BaO, both 57Fe and 57Co were detected at different temperatures. Experiments were carried out at 4.2 K and applied magnetic field. This technique of measurement allows us to observe the Fe, Bi, and N moves. Using a variable level of RF power, it is possible to measure the local anisotropy field at the different sites.

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 nanoscale ferrites. For example, a film with a particular composition of Co2Pt2xCux, the coercivity and the grain size were observed to increase with increasing temperature, up to a value of 7 Ke at an annealing temperature of 750°C, and the film size increased from 8 to 20 nm. The correlation between the properties and structures of these films was reported and discussed. This work is supported in part by the Research Grants Council of Hong Kong SAR (Ref. No.: CUHK/416/00E).

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

Knowledge of the recoilless fraction is of utmost importance in Mössbauer spectroscopy for many reasons, including for the determination of both 57Fe and 57Co in steel. The recoilless fraction is a measure of the fraction of 57Fe and 57Co that are not recoilless in the Mössbauer measurement. The method is demonstrated for the case of iron and metallic glass two-slit system and is next generalized for the case of iron and metallic glass two-slit system.
Pulsed laser deposition has been extensively used in obtaining thin films of ferromagnets and superconductors. Recently, it became a promising method to 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 substitution represent a challenging approach and was undertaken in the present study. Under the same deposition and conversion electron microscopy conditions, 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<sub>20</sub>Co<sub>30</sub>, Fe<sub>30</sub>Co<sub>20</sub>, Fe<sub>2</sub>O<sub>4</sub>·Co<sub>2</sub>O<sub>4</sub>·Co<sub>2</sub>O<sub>3</sub>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.

2000 PM 4E3/7/37 EVOLUTION OF FREE VOLUME IN ULTRASOFT MAGNETIC Fe-Zn, Mg-Zn, and Al-Zn ALLOYS. L.G. Chouteau<sup>1</sup>, D.J. Leamy<sup>2</sup>, A. van Veen<sup>3</sup>, H. Schur<sup>4</sup>, A.R. Cheetham<sup>1</sup>, D.O. Boomsma<sup>5</sup>, T. Vianello<sup>6</sup>, J. Th. M. de Hosson<sup>7</sup>; "Materials Science Centre, University of Groningen, Groningen, NETHERLANDS; Interfaculty Reactor Institute, Delft University of Technology, Delft, NETHERLANDS.

Ultrasonic magnetic films with low coercive magnetic field of ~1 Oe, an induced uniaxial magnetic anisotropy of 15-50 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 Fe-Zn 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, nanostructured size depending on the sputtering temperature and for reduction of the intrinsic stray field. The films were studied using 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 3 nm, while HREM 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 800°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 nanometric 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 grain growth and 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 4E4/7/4 MICROSTRUCTURAL EFFECTS IN SINGLE LAYER AND ANTIFERRROMAGNETICALLY COUPLED MAGNETIC MEDIA. Mary DiGiovanni, Suyeon Fong, Xing Fu, IBM Storage Technology Division, San Jose, CA; Shawn McKinlay, Robert Sinclair, Stanford Univ., Stanford, CA.

Microstructural control for magnetic recording media is becoming ever more critical with the rapid increase in bit densities 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 Co-75Cr underlayer is 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 unfavorable microstructure. One example of this effect and its explanation is discussed for CoPtCr on Co-alloy underlayers. Antiferromagnetically-coupled (AFC) media are used to improve thermal stability. Since at least part of the increase in stability is obtained through microstructure, 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 4E5/7/5 QUANTITATIVE NANOMETER-RESOLUTION MAPPING OF BORON IN MAGNETIC RECORDING MEDIA BY ANALYTICAL ELECTRON MICROSCOPY. Barry H. Benner, Bellcore, Foundry Laboratory, Belmar, NJ; John F. Wittig, J.F. Al-Shara, Vanderbilt University, Nashville, TN.

Measurements of composition at the nanometer scale are critical for structure-property correlations aimed at understanding the performance of CoCr-based thin-film longitudinal magnetic recording media. We have previously established and applied reliable methods for mapping Cr segregation and 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 image filter (GIF) on a LaB<sub>6</sub> Philips CM200 and spectrometer imaging in the scanning transmission electron microscopy (STEM) mode on a Philips CM200FEG with Enspec ESIView and a GIF. For B measurements, the presence of MgO from 3d transition metals (TM) results in low signal-to-background (S/B) and a background shift that does not follow an AE<sup>-2</sup> 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 lower-order polynomial was fit to log(intensity) versus log (energy-loss). For Co-CrPt-B media, limited success has been achieved employing such an approach 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 best background fitting methods. In EFTEM methods, energy 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 S-window method, custom scripts within the Gatan Digital Micrograph software have been employed 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 intergranular segregation. Continuing work on the remaining issues for robust quantitative B concentration mapping will be fully described.

Research at the Oak Ridge National Laboratory is sponsored by the Division of Materials Science and Engineering, U.S. Department of Energy, under contract DE-AC05-000227275 with UT-Battelle, LLC. Support from an IBM Faculty Partnership is also gratefully acknowledged.

3:30 PM 4E6/7/6 SPIN-DEPENDENT QUANTUM SIZE EFFECTS IN THIN IRON MICROCRYSTALS. Ryszard Zylb, 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 thicknesses 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 Haugmark et al. From the amplitudes of the QSE oscillations as a function of energy and thickness mean free paths (MFP) 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 ~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 quarter sine-bond model is only a first approximation in the theory of the MFP. [1] K.B. Hauge and others, Phys. Rev. B31, 7603 (1985) [2] Jiang Hong and E.L. Miller, Phys. Rev. B62, 5589 (2000)

3:45 PM 4E7/8/7 COMPARISON OF Fe, O<sub>2</sub>, AND Ag SURFACANTS IN SPATTERED 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 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 XSTM. In this study, we focused particularly on the differences between metallic surfactants (Ag, Pb) and oxygen. DC magnetron sputtered (Cr/Cu) multilayers were deposited on Si02 and Pt/Al2O3 substrates. Typical rates were ~1 Ås. The Pt seed layers were grown at low power densities to create a regular metal template for growth, with wide (~50Å) 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 during the final deposition step in increasing smoothness and layer to layer roughness. 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 J178
CONTROL OF NOVEL MAGNETIC PROPERTIES IN COBALT-BASED THIN FILMS BY USE OF MO/COVD. Marian Chiacchia, Fedor Ogrin, Brian Ruthven, Peter Haycock, Jian Shi, Anthony Wright, Gillian Maglione, Samantha Stockton, Keely 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 occurrence of inverse magnetic hysteresis in Co/Cu-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 with respect to the magnetic hysteresis in the bulk. Currently, we are studying the effects of growth on the magnetic properties of Co/Cu-based films, and a number of 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 occurrence of a certain microstructure, namely a nanostructured array of hexagonally shaped grains of dimension around 150 nm. The remanence curve indicates that there is competition between different anisotropies in the film, each favouring a different orientation of the magnetization. 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 hysteresis 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 of measurements and discuss the implications of these results for quantum and the molecular magnetic properties of thin 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 (Merriot)

E5.1 MAGNETICALLY CONTROLLED PHOTOVOLTAIC DIODE STRUCTURE, V.K. Dagney, Yu. Vygnemenko, M. Vieira, Dept. of Electronics and Communications, ISEL, Lisbon, PORTUGAL; Y.I. Litvinov, Yowleland Corp., Torrance, CA; J. Barnad, Dept. of Physics, A. Mieczkowski Univ., Poznan, POLAND.

We propose a new integrated device for spintronics, which is based on magnetic/semiconductor hybrid structures. The device consists of a p-n-Schottky photodiode 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 semiconducting layer is greater than the separation of the electron-hole pairs, the spin-polarized charge carriers can diffuse freely to the contact layer, where the spin-polarized current is collected. The direction of the spin-polarized current is determined by the magnetic moment of the ferromagnetic layers. This is due to a difference in the reflectivity 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. In general, the magnetic field effect into a semiconductor photovoltaic device enables including parameters to control the effect, for instance the polarization and the wavelength of incident light. The latter enables to control the depth of the light absorption, which is crucial in single photon detectors and light level generation. Transport properties of the proposed device have been simulated by the methods similar to those used in the case of nonmagnetic p-n junctions. Our main objective was to estimate the magnitude of the effect and also to determine the role of blocking material parameters.

E5.2 INTRINSIC MAGNETIC PROPERTIES AND NANOCRYSTALLIZATION BEHAVIOR OF AMORPHOUS Fe2SiB13 RIBBONS. Xiong-Cheng Sun, Prog. Molecular Simulation, Instituto Mexicano del Petróleo (IMiP), DF, Mexico, MEXICO; R. Gomez, Faculty of Science, National University of Mexico (UNAM), DF, Mexico, MEXICO; J. Reyes-Grana, Institute of Physics, National University of Mexico (UNAM), DF, Mexico, MEXICO.

Ferromagnetic properties and nanocrystallization process of soft ferromagnetic Fe2SiB13 ribbons were studied by in-situ transmission electron microscopy (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 H2(T)/T and the Curie temperature Tc 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 Fe3+ in which the electronic spins are uncoupled. The Curie and crystallization temperature were determined to be Tc=685K and Tc = 750 K using hyperfine interaction experiments. On the other hand, when the samples were maintained near Tc, three new magnetic phases were detected in the Mössbauer spectra. The magnetic behavior of these phases is also described by the Weiss model and has been assigned as nanostructured phases. The magnetic properties were measured by transmission electron microscopy (TEM) and electron diffraction (SAED), Rietveld x-ray diffraction (XRD), Mössbauer spectroscopy, thermal analysis and FT-IR spectroscopy. TEM, SAED, and XRD analysis confirmed that the amorphous iron oxide hydrate (FeO(OH)) particles were synthesized by chemical co-precipitation method and had a size of medium. The nanophases, microstructure and phase transformation of these nanostructured iron oxide hydrate particles was characterized by transmission electron microscopy (HR-TEM) and x-ray diffraction (SAED). Rietveld x-ray diffraction (XRD), Mössbauer spectroscopy, thermal analysis and FT-IR spectroscopy. HR-TEM, SAED, and XRD analysis confirmed that the amorphous iron oxide hydrate (FeO(OH)) particles were consisted of mainly amorphous Fe-OH nanocrystal. HR-TEM images and SAED patterns indicated the amorphous or needleshaped features of nanostructured amorphous Fe-OH 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 amorphous FeO(OH) to γ-FeOOH and α-Fe2O3 or γ-Fe2O3 had been found to occur during annealing the amorphous FeO(OH) samples at different conditions. In particular, the change of amorphous or needleshaped features had been evidenced by HR-TEM observations. On the other hand, magnetic M(T/Fc) / H(T/Fc) data indicated that distinct magnetic behavior (superparamagnetic or ferromagnetic) in these nanostructured FeO(OH) particles had been observed by means of VSM, SQUID and Mössbauer spectroscopy magnetometers. It was found that the surface magnetic and magnetic coupling between these nanostructured FeO(OH) particles were supposed to be responsible for the inner broadening of the Mössbauer spectral lines. In addition, the details of the behavior of magnetic viscosity and temperature dependence of the nanostructured Fe-OH and γ-FeOOH particles at low temperature were also discussed and summarized.
E5.4 PREPARATION OF Co/Cr thin film by facing targets SPOTTING SYSTEM: K.H. Kim, Y.J. Kim, WH Park, Kyungwon Univ., Dept of Electrical Information Eng., Kyunggi-do, KOREA; S.H. Keng, 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 CoCrTs/Si thin film that was prepared by facing target spotting system, crystalline orientation of CoCrTs magnetic layer was improved highly and it was found that Si underlayer is effective to improve crystallographic property. Also, in order to increase the coercivity together with improving of crystalline orientation Pt was added to Co targets instead of Ta.

E5.5 EXAFS AND MAGNETIC CHARACTERIZATION OF MULTIPURPOSE Chromium-Fe-Ni-Based Films: Edol C. C. C. R. C. Hille, C. N. Tatsuno, Laboratorio Nacional de Luz Sintética, Campinas, BRAZIL; Marcelo Koshel, UNICAMP, Campinas, BRAZIL.

Granular alloys composed by a low concentration of magnetic material in a non-magnetic matrix are the most promising candidates for magnetic media because they display giant magnetoresistance effect (GMRE) comparable to the ones found in multilayered systems. Usually, the alloy compositions are invariable at room temperature, this is a remarkable condition due to the 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 (size, shape, distribution, concentration) determine the magnetic behavior of the alloy, and its characterization are of key importance to understand the GMRE phenomenon. Copper-Permalloy systems are very interesting from the magnetic point of view, once that they present the great magnetoresistance (GMRE) phenomenon and are composed by the same elements of a commercial spin valve magnetic reader head. Here are presented the results of EXAFS measurement on CoFeB and CoFeB$_6$ 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 beamline of LNLS (Campinas, Brasil), 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 than the nominal composition Fe$_2$Ni$_{6}$. 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. Y. Le, University of Idaho, Dept. of Physics, Moscow, ID; B.L. Justus, Naval Research Lab, Washington, D.C.

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 resides 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 using nanocolumn glass wafers as substrates. The magnetic dot density as high as 10$^{11}$ per square 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 properties of the dots are studied by magnetic force microscopy.

E5.7 Abstract Withdrawn.

E5.8 ENHANCED MAGNETIC TRANSITION OF CORE-SHELL TYPE COBALT-PLATINUM NANOALLOYS: Jong-Hi Park$^*$, Nam-Jung Kang$^*$, Sang-Min Lee$^*$, Sohan Kim$^*$, S.J. Oe$^*$, H.C. Ri$^*$, Jeinwoo Cheon$^*$, Department of Chemistry and School of Molecular Science (BK21), Korea Advanced Institute of Science and Technology, Korea Basic Science Institute.

Synthesis of "solid solution" and "core-shell" types of well defined Co-Pt based nanomaterials smaller than 10nm have been achieved by redox transmetalization reaction. This redox transmetalization can be 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 facetercentered trigonal (fct) structures, which show large coercivity and ferromagnetism at room temperature. These nanoparticles can potentially be used as an independent single magnetic bit of terabit information storage. Also, this kind of redox transmetalization reaction can be utilized as a general process to synthesize various types of nanomaterials with controlled composition in a selective fashion.

E5.9 SYNTHESIS OF COLLOIDAL COBALT NANOPARTICLES WITH CONTROLLED SIZE AND SHAPES: Victor Pastes, 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 cyanide in an inert atmosphere was employed to produce monodispersed, stabilized, defect-free cobalt nanoparticles 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 nanoparticles 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 nanoparticles have been observed to produce self-assemblies, which are segmented 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 superstructures.

SESSION E6: MATERIALS FOR MAGNETIC RECORDING HEADS

Chair: Li Tung

Thursday Morning, April 4, 2002

Saalon 13 (Marriott)

8:15 AM E6.1 REDUCTION IN PROCESS VARIATION AND IMPACT ON YIELD BY USING PICOSECOND ULTRASONIC LASER SONAR TECHNOLOGY: Arun Narayanan, Darrell Louder, Matthew Dietz, Peter Weyands, Joseph Imaweky, Sensage Technology, Bloomington, MN; Chris Moseh, 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 micro-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 cycle time 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 ANTIFERROMAGNETIC/FEAROMAGNETIC INTERFACES: A SPECTROMICROSCOPY STUDY: D. O"Hagan, A. Scholl, F. Nolting, T.J. Regan, S. Anders, N.B. Weber, F.U. Ellmer, 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 Inst. für Mikrostrukturforschung, 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 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 dichromate x-ray absorption spectroscopy in a photoemission electron microscopy study to investigate 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 (0.4-5nm) a random magnetic state of the antiferromagnetic axes takes place. The uniaxial anisotropy axes of the ferromagnet and the antiferromagnet are then aligned parallel by domain swapping. It is shown that the Co deposition causes a chemical reaction and formation of an interfacial CoNiOx layer. Microscopy images reveal its polycrystalline 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 polycrystalline and parallel exchange coupling. An imbalance between free and pinned interfacial moments as origin of the uniaxial 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. Ohkohri, A. Scholl et al., Phys. Rev. Lett. 86(15), pp. 3149, 2001. [2] F.U. Hillebrecht, H. Ohkohri et al., Phys. Rev. Lett. 86(15), pp. 3149, 2001. [3] H. Ohkohri, 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. Shin X. Wang, Namjoong 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 0.01 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 undamped time-domain signals. The biggest challenge facing integration of magnetic materials into silicon is the compatibility of magnetic materials with standard silicon processing techniques. Integrated inductors were realized using ground planes of CoTaZr and CoZr. The magnetic properties of CoTaZr showed no change even after undergoing high temperature processing. Inductors with 0.6 mm 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 MAGNETIC FLUX DENSITY. Jia Liu, Hong Kong University of Science and Technology, Hong Kong, Manfat Chinh, Chiyu Poon, Wingying Cheung, Ning Ke, The Chinese Univ. of Hong Kong, Dept. of Electronic Engineering, Hong Kong, PR CHINA.

Granular-like amorphous CoC_{1-x} nanocomposite thin films, with x in the range of 68-75% 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 μΩ.cm, and magnetic saturation flux densities in the range of 6 to 13 K. The structural, electrical and magnetic properties of the films are thermal stable upon annealing up to 200°C in a vacuum furnace. These films possess promising potential as magnetic write head core materials for high recording density and high bit density data storage. Acknowledgement: This work was supported in part by the Research Grants Council of Hong Kong SAR (Ref. No. CUHK4216/03E).

9:45 AM E6.5
Abstract Withdrawn.

10:30 AM *E6.6

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 magnetic field of nanocomposite soft magnetic materials including FINEMET, NANOPERM and CMU’s HTPERM materials. Thin film and laminated multilayer magnets of the HTPERM composition (FeCoSi)[xZr][xHf] have been synthesized and examined as potential recording head materials. Zr containing HTPERM, developed by McHenry, Laughlin and Willard, has a literature reported induction of 1.7 T and permeability ≅1000 at 10 kHz and 2.1 T at 1 kHz. AHTPERM, developed by McHenry, Laughlin and Iwambe, has a literature reported induction of 2.1 T. Thin film and multilayers of HTPERM modulated with Si thickness have been produced by sputtering. Magnetic film thicknesses have been optimized at 80-100 nm and interlayer magnetic spacings of ~4-5 nm. Room temperature coercivities of ~2.5 Oe have been achieved for single HTPERM layers and <0.4 Oe for multilayer laminated structures. Thus, laminated HTPERM films possess order of magnitude lower coercivity than single layer films. The SiO2 intermediate layers play an important role in reducing the magnetoelastic coupling between layers and reducing the coercivity He. They are also anticipated to increase the high frequency response of these materials. Finally, a brief review of the status of soft magnetic/ferrite 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 N. ECDIPS 07068 from National Science Foundation and sponsored in part by the Air Force Office Scientific Research, Air Force Material Command, USAF, under Grant No. F49620-06-0-0154. 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 ETCHING. 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 resulting in an etched surface that is more or less completely roughened or smoothed mostly depending on the ion beam incident angle. The final roughness depends also on the thickness removal of the thin films. At high incident angles with highly energetic ion etch can be used to remove the material 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. L.C. de Carvalho Lima, L. Loureiro da Silva, M.A. Bocchi, 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)GaAs_{1-x}Mn_{x}As (for x = 0.2-0.5) in its metallic ferromagnetic phase was used to explore the feasibility of observing spin-polarized Bloch miniband transport in those magnetic superlattices. Mn substitutes Ga providing at the same time a 5-20% localized magnetic moment, and a high concentration (of the order of 10^{20} cm^{-2}) of free hole density, which occurring in 4H-InP 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, the resistive switching of the superlattice, 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, together with the valence band structure, we obtain as 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 E6.5 INTERFACIAL CONTRIBUTIONS TO MAGNETOSTRICTION OF FEHROMAGNETIC LAYERS FOR MAGNETORESISTIVE SENSORS. E.W. Singleton and K.J. Dusuel, Seagate Technology, Minneapolis, MN.

We have experimentally measured magnetostriiction 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 separate modeling of bulk and interface contributions to the measured magnetostriiction. The interface contributions show a clear trend that is dependent upon the material at the interface of the magnetic layer. The results demonstrate surface contributions to the magnetostriiction 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 NANOstile BASED MAGNETIC TUNNEL JUNCTIONS FOR ELECTROMAGNETIC NONDESTRUCTIVE EVALUATION. Bzez Wachelski, Min Namkung, NASA Langley Research Center, Hampton, VA; Sun Mck Paik, Kangyoun University, Cheonhon, KOREA; Jan Smith, 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. Nanomagnetism 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 magnetic-transport properties. 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 FILM FOR INVESTIGATION USING SINGLE CRYSTAL PERPENDICULAR MAGNETIC THIN FILM SAMPLES. M. Putumoto, K. Terasilna, K. Sato, N. Isaiha, and Y. Hirayama, Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo, JAPAN; "Tokyo Univ. of Agri. & Tech", Kogane, Tokyo, JAPAN.

Improvements of magnetic properties and thermal stability are important issues for perpendicular magnetic recording media development. The magnetic 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 A12O3 [0001] single crystals when Co-Cr-Pt films are deposited via a non-magnetic CoCrPtRuS underlayer. The Pt composition is varied between 0 and 17 at%, 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 microscopical 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 CoCrPtRuS non-magnetic underlayer. Weak Cr segregation at ≤ 5% at a around the average composition CoCrPtRuS is recognized for representative structures in the present TEM analysis. 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 CoCrPtS thin film, for example, decreased from 3.2 x 10^-6 erg/cc to 2.3 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, and 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 SPINDOMAL DECOMPOSITION. G. A. Horsen, 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 a single step, characterized by its high purity and high throughput, spinodal decomposition in a homogenous alloy within a certain compositional range is unstable with respect to compositional fluctuations. Cahn theory of the early stage 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 a desired length scale to be achieved. 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. Amorphous precursors such as Co-Cu and Co-Al alloys are used. Cobalt and copper from elemental targets are deposited on a substrate to form the Co-Cu alloy. The film is then annealed to form nano-grained CoNI films. In the early stages of decomposition, the film thickness is varied between 6 and 100 nm by changing the Co composition. The thickness and the aspect ratio are measured using an atomic force microscope. The magnetic properties are measured using a vibrating sample magnetometer. The grain size and distribution of the decomposed films are being investigated using small angle X-ray scattering.

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

The process of spinodal decomposition can produce composition fluctuations, and eventual phase separation. Controlled, we examine the possibility of using spatially-varying strain fields, for example those associated with an array of misfit dislocations, to induce 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 composition instability. We discuss the application of this effect to control magnetic phase distributions.

2:30 PM E7.4 Abstract Withdrawn


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 size. Shrinkage of the grain size, however, will eventually compromise thermal stability and ultimately limit the areal density due to superparamagnetic decay. To postpone the onset of superparamagnetic 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 reveal densities >60 Gbit/in² have been reported [2]. Of particular interest are granular media with large perpendicular magnetic anisotropy ($K_u \sim 3 \times 10^6$ erg/cm²), large remanence ratio (SQ 1) and onset of magnetization reversal at large negative fields ($|\Delta H_m| > 1000$ Oe). These properties have been achieved in CoX/Pd-shell layers or CoPt/CrX-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 Co-magnetron sputtered amorphous Fe-Co-B films with (magnetron) field-induced radial anisotropy $H_k > 40$ 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. Kasebe, A. Ishikawa, H. Aoi, H. Murakami, Y. Nishimura, K. Uchi, "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$_2$O$_3$ COMPOSITE FILMS FOR PERPENDICULAR RECORDING.
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Li$_x$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$_2$O$_3$ nanocomposite thin films, which are deposited directly on oxidized Si wafer by using a multilayer Co/Pt/Co/B$_2$O$_3$ deposition plus appropriate thermal processing. Our results show that as-deposited films are disorder for CoPt phase and magnetically soft. After necessary processes of annealing, the CoPt undergoes a phase transition from disorder to the ordered fct structure with high degree of (001) texture. Besides annealing processes, the interested features of CoPt-B$_2$O$_3$ films are that film microstructures and magnetic properties are strongly dependent on Co content, initial B$_2$O$_3$ thickness and total film thickness. Fig. 1 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 2 kOe to 10 kOe and Ms ranging from 300 to 800 emu/cc were obtained. Grain size, estimated by Scherrer's formula, is small than 3 nm. 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.
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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 those of the natural crystals. Well-known artificial structures include fcc Fe on Cu, hcp Co on GaAs and hcp Ni on Fe. Cr crystallizes in a hcp 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 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.Y. Yoon et al., Phys. Rev. B 47 (1993) 5689. [2] W.F. Pong et al., J. Synchrotron Radiat. 6 (1999) 746. [3] M. Albrecht et al., Phys. Rev. Lett. 85 (2000) 5344.