SYMPOSIUM R
Nanomagnetism
April 22 – 24, 2003

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*Invited paper
SESSION R1: NANOAGENTS PREPARATION I
Chairs: Dieter Weller and Kai Liu
Tuesday Morning, April 28, 1998
Golden Gate C3 (Marriott)

8:30 AM R1.1
ARRAYS OF MAGNETIC NANOQUANTUM VIA BLOCK COPOLYMERS TEMPLATES. Thomas Russell, Polymer Science and Engineering Department, University of Massachusetts Amherst, Amherst, MA; M Tsuchimori, Physics Department, University of Massachusetts Amherst, Amherst, MA.

Arrays of magnetic nanowires and nanowire devices were fabricated using nanoporous templates derived from self-assembling diblock copolymer films. Diblock copolymers, such as PMMA-b-PS, self-assemble into micro- and nanostructures. Arrays of magnetic nanowires were formed by filling these micro- and nanostructures with magnetite nanocrystals doped with a suitable surfactant agent to produce monodispersed spherical diblock copolymers as porous templates that were used to fabricate hexagonal arrays of vertical nanowires with densities of exceeding $10^{12}$ per square inch. Electropolishing within the template produces lines grating arrays of magnetic nanowires with arrays that exhibit large perpendicular coercivity and remanence making them potential candidates for ultrahigh-density perpendicular magnetic storage media. The internal crystal morphology of the nanowires, and consequently magnetic properties, can be manipulated and tuned by electropolishing process parameters. The copolymer templates have been patterned interally using conventional lithographic exposure to fabricate novel 3D magnetic nanowire devices. This includes current-in-plane magnetoresistive devices and current perpendicular wires switching field devices. Anisotropic magnetoresistance measurements show a sharp and complete magnetic reversal, indicating single-domain magnetic switching behavior. Such properties offer promising potential for new magnetic devices built upon on single-domain elements. This work is supported by National Science Foundation Nanoscale Interdisciplinary Research Team, Materials Research Science and Engineering Center and the Department of Energy.

9:00 AM R1.2
MAGNETIC PROPERTIES OF NANOSTRUCTURES MADE USING INTERFERENCE AND BLOCK COPOLYMER LITHOGRAPHY. C.A. Ross, F.J. Castano, J.Y. Cheng, Y. Hao, Henry J. Smith, Massachusetts Institute of Technology, Cambridge, MA.

Arrays of small magnetic particles have been proposed for use in various magnetic, electronics, and magnetic logic devices. For these applications, it is important to control the magnetization state, switching field, and uniformity of the particles and to understand the size-dependent magnetic behavior. We will review recent progress in the fabrication, characterization, and analysis of large arrays of sub-100 nm magnetic particles made by interference and block copolymer nanolithography techniques. The sizes, shapes, compositions, and two-dimensional arrangement of the particles on the substrate can be controlled, enabling a wide variety of different magnetic behaviors to be obtained. In particular, we will describe the thermal stability of closely-spaced 30 nm-diameter Ni and Co particles made using a block copolymer as a template, and the behavior of magnetized Co/Cu/NiFe rectangular pseudospin-valve bars made by interference lithography. We will also discuss the magnetic properties of ringshaped thin-film elements in which interesting domain configurations can be observed.

10:00 AM R1.3
NANOPATTERNING OF MAGNETIC NANOSTRUCTURES OF BARIUM FERRITE VIA DIP-PEN NANO LITHOGRAPHY (DPN) AND A SOL- GEL PROCESS. Lei Fu and Vinayak P. Dravid, Department of Materials Science and Engineering and Institute for Nanotechnology, Northwestern University, Evanston, IL; Xingnan Liu, Yi Zhang, and Chad A. Mirkin, Department of Chemistry and Institute for Nanotechnology, Northwestern University, Evanston, IL.

A direct-write approach with size- and shape-specificity for functional inorganic nanostructures is demonstrated with a example of fabrication of “hard” magnetic barium hexaferrite (BaFe$_3$O$_4$) nanostructures on a syngentic combination of dip-pen nanolithography (DPN) and sol-gel process. This method includes generation of BaFe precursor patterns using a conventional atomic force microscope tip that is coated with the BaFe precursor solution, followed by thermal treatment to convert patterned organic-inorganic composites into functional BaFe oxide of appropriate structure and functionality. BaFe patterns ranging from several hundred nanometers down to 90 nm were generated and examined using AFM, superconducting quantum interference device (SQUID), and x-ray photoelectron spectroscopy (XPS). This approach suggests a novel way of direct patterning of magnetic nanostructures at sub-100 nm scale with size and shape-specificity for improved magneto-electronic devices.

10:15 AM R1.4
SIZE-CONTROLLED FERRHYDRITE MAGNETIC NANOPARTICLES ANCHORED IN A SOL- GEL DERIVED ORGANIC-INORGANIC HYBRID MATRIX. N.J.O. Silva, V.S. Amiral and L.D. Carlos, Departamento de Fisica and CICECO, Universidade de Aveiro, PORTUGAL; V. de Zena Bermudez, Departamento de Quimica, UTAD, Vila Real, PORTUGAL.

Ferrhydrite (FeOOH$_n$) particles formed within an organic-inorganic hybrid matrix were obtained by the sol-gel process. In using the sol-gel to precipitation techniques, sol-gel process appears as a suitable way to achieve size-controlled nanoscopic magnetic particles anchored in a hybrid structure. The hybrid matrix here reported, chosen as Au-silicate, is composed of poly(oxyethylene) chains grafted to silicate groups by means of Si-O-PMMA-b-PS diblock copolymers as porous templates that were used to fabricate hexagonal arrays of vertical nanowires with densities of exceeding $10^{12}$ per square inch. Electropolishing within the template produces lines grating arrays of magnetic nanowires with arrays that exhibit large perpendicular coercivity and remanence making them potential candidates for ultrahigh-density perpendicular magnetic storage media. The internal crystal morphology of the nanowires, and consequently magnetic properties, can be manipulated and tuned by electropolishing process parameters. The copolymer templates have been patterned interally using conventional lithographic exposure to fabricate novel 3D magnetic nanowire devices. This includes current-in-plane magnetoresistive devices and current perpendicular wires switching field devices. Anisotropic magnetoresistance measurements show a sharp and complete magnetic reversal, indicating single-domain magnetic switching behavior. Such properties offer promising potential for new magnetic devices built upon on single-domain elements. This work is supported by National Science Foundation Nanoscale Interdisciplinary Research Team, Materials Research Science and Engineering Center and the Department of Energy.

10:30 AM R1.5
MAGNETIC PROPERTIES OF CoCr$_2$-THIN FILMS ON SELF-ASSEMBLED PS-PVP DIBLOCK COPOLYMER TEMPLATE. Jong Ryul Jeong, Myung Chul Choi, Mi-Young Im, Min-Won Kim, and Sung-Chul Shin, Dept. of Physics and Center for Nanosciences of Spatio-Temporal Materials, Korea Advanced Institute of Science and Technology, Daejeon, KOREA.

CoCr$_2$-PS-PVP thin films are attracting wide attention for applications to high-density magnetic recording media and hard magnetic layer in spin valve structure due to their high coercivity and strong magneto-crystalline anisotropy. Diblock copolymer templates are one of the most promising candidates for nanoscopically patterning otherwise inaccessible by lithographic procedures. In this study, we have investigated magnetic properties of Co$_{0.5}$Cr$_{0.5}$Pt$_{14}$ thin films deposited on nanopatterned PS$_200$(stylene)-P$_{200}$(vinyl pyridine) diblock copolymer. The PS-PVP diblock copolymer were coated on Si(100) substrate via 20 second dipping diblock copolymer/20 second solvent solution of concentration 10 mg/ml and 5 second rinsing with toluene. Non contact AFM microscopy revealed that size of the micelles are very uniform and highly ordered with the micelle islands height of 4 nm. The CoCr$_2$-PS-PVP thin films were deposited on this self-assembled diblock copolymer surface. The surface morphology of CoCr$_2$-PS-PVP also shows a regular and highly ordered spherical islands similar to the PS-PVP template. Magnetic property of CoCr$_2$-PS-PVP films were measured by magneto-optical microscope micrometer magnetometer and torque magnetometer. The perpendicular magnetic anisotropy (PMA) of CoCr$_2$-PS-PVP films strongly enhanced when we deposited the films on nanopatterned PS-PVP template. The squareness ratio, defined as the remanent Kerr rotation angle divided by the saturation one, increased from 0.34 to 0.85 for the samples of 200Å CoCr$_2$-PS-PVP/PS(100) and 200Å CoCr$_2$-PS(100), respectively. The coercivity is also increased dramatically from 150 Oe to 544 Oe. Considering the magnetic dipolar interaction together with the magneto-crystalline anisotropy, we will discuss the origins of enhanced PMA in CoCr$_2$-PS-PVP films as well as the growth mode of CoCr$_2$-PS-PVP films. This work is supported by the Korean Ministry of Science and Technology through the Creative Research Initiatives Project.
ferrite) was sintered for 3h. The magnetic nanoparticles were obtained by mechanical milling. Their average grain size has been estimated to be 10 μm, from the X-Ray diffraction lines. Viscerating sample magnetometry was used to study the magnetic properties of magnetic nanocomposites in the temperature range 25°C to 200°C. The dependence of the magnetization on the external magnetic field was fitted by using the relation $M = M_s(1 - H/H_{eff})$, after extracting a linear contribution due to the diamagnetic and paramagnetic contributions. $M_s$ is the magnetization at saturation and $H$ is related to the magneto-crystalline anisotropy. A magnetic measurement was observed to change the temperature dependence of $M_s$ and $H$ close to the glass transition temperature of the polystyrene phase and confirmed by the temperature dependence of the magnetic properties in a concentration and Fe3O4-Ox. This result suggest that magnetic nanocomposites the time evoluzione of the magnetization in external magnetic fields may contain a cooperative term, which is sensitive to the motion of the whole nanoparticle. This effect is more visible within the glass transition range, due to the segmental dynamics. Segmental motion near several chain lengths characterized by persistence lengths of about 10 nm, are activated at the glass transition temperature, and present deviations from a simple Arrhenius-like temperature dependence [1]. When the size of the magnetic nanoparticle becomes comparable to the size of nearest free volume cluster, a jump of the nanoparticle, eventually accompanied by its reorientation, occurs. The competition between the dynamics of magnetic nanoparticles and the spin reorientation is analyzed in detail. Reference: 1. M. Chipara, Physica B, 234-236, 265-266, 1995.

11:00 AM RL3
SYNTHESIS AND CHARACTERIZATION OF MONODISPERSE MAGNETITE AND COHABT FERRITE NANO- Particles.
Hao Zeng and Shouzheng Sun, IBM T.J. Watson Research Center, Yorktown Heights, NY.

Fe3O4 and CoFe2O4 nanoparticles are synthesized by high temperature reaction of Fe(acac)3 and/or Fe(acac)3/Co(acac)2 with alcohol. Using small nanoparticles as seeds and coat them with more large particles sizes can be tuned from 4 nm to 16 nm. These nanoparticles are spherical, monodisperse and single crystalline, allowing them to self-assemble into three-dimensional superlattices. The nanosynthesized magnetic particles are superparamagnetic in size range used. Increasing the blocking temperature increases significantly, from 10 K for 4 nm to 260 K for 12 nm particles. Besides superparamagnetic behavior, which is manifested as a peak at the blocking temperature in the ZFC curve, a drop in the magnetization at -100 K in both the ZFC and FC curves is observed. This may be attributed to Verwey transition in mixed valent magnetite systems. The CoFe2O4-x is synthesized with x = 2, 1, 0.5, 1, and 0 respectively, where x is determined by the amount of the Co(acac)2 precursor under constant amount of Fe(acac)3. 4 nm CoFe2O4 and CoFe2O4-x nanomaterials were shown to have great coercivity at low temperatures (above 120 K) while their blocking temperatures reach above 170 K. These are consistent with the large magnetic anisotropy and have cobalt ferrites. The iron oxide based nanomaterials and their self-assemblies may have potential in microwave and biological applications.

11:15 AM RL8
COOPERATIVE MAGNETISM IN DIPOLAR NANO COMPOSITES.
Eugene Venturini, James Martin, Dale Huber and Paula Provencio, Sandia National Laboratories, Albuquerque, NM.

We present experimental data and detailed numerical simulations demonstrating substantial changes in the magnetic response arising from cooperative dipolar interactions among 7 nm iron nanoparticles in nanoscale arrays. The isolated particles, synthesized by iron carbonyl decomposition in dioctyl ether, exhibit approximately half the saturation magnetization of bulk iron and have a superparamagnetic blocking temperature near 60 K. These particles, suspended in a three solvent mixture, self-assemble into ordered field-structured at room temperature. Dipolar forces in a static magnetic field assemble the particles into one-dimensional chain-like structures. The formation of these one-dimensional composites is modeled in a detailed numerical calculation and compared to TEM images; the rapid evolution of these structures is described by light scattering. These structures without composites exhibit greater than 100 fold, magnetic anisotropy due to large, cooperative susceptibility enhancements along the chains. As expected, the cooperative susceptibility reaches a maximum just above the isolated particle blocking temperature and then decreases at lower temperatures where the magneto-crystalline anisotropy restricts the rotational freedom of the giant spins in the individual nanoparticles. The blocking temperature in the nanostructures is raised by the dipolar interactions, and, at temperatures well below blocking, the interactions provide an additional rotational anisotropy that leads to a doubling in the remanence coercivity compared to that of noninteracting particles. The experimental observations are in

good agreement with Brownian dynamics simulations of the cooperative magnetic behavior for numerically-derived nanocomposites. This work is supported by the U.S. Department of Energy, Office of Basic Energy Sciences. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

11:30 AM RL19
MAGNETIC NANOCOMPOSITE THIN FILMS PREPARED BY SOL-GEL PROCESS. Neely Della Santina Mohalleh, Luciana Moreira Senna, Dept. of Chemistry, UFAM, Belo Horizonte, BRAZIL.

Nanostructured oxide thin films have potential technological use for their high surface/volume ratio, which leads them unique properties different from those of similar polycrystalline materials. The use of an inorganic matrix as a nanocrystalline particle host allows uniform particle size, and homogeneous distribution and dispersion. Magnetic nanocomposite thin films that are characterized by persistence lengths of about 10 nm, are prepared by sol-gel process using tetraethylorthosilicate (TEOS) as a precursor of silica, and metallic nitrates as precursors of the ferrite. CoFe2O4/SiO2 films were prepared with 5, 10 and 30 wt% ferrite contents and deposited on glass, quartz and silicon plates using the dip-coating process. The films obtained were adherent, transparent, homogeneous, and free of microcracks. The atomic force microscopy showed films with homogeneous topography with particles sizes in the order of 30 nm. The nanocomposite films presented the formation of crystalline CoFe2O4 phases dispersed in amorphous SiO2 matrix and saturation magnetization of 30 emu/g and coercivity of 156 Oe.

11:45 AM RL10

Organic-inorganic hybrid materials can provide very useful properties by coupling the unique characteristics of the individual organics (e.g. plasticity, efficient luminescence) and inorganics (e.g. magnetic, electrical mobility) compounds in the molecular level. We demonstrate that a promising alternative strategy for novel nanocomposites is the inclusion of functional layers from hybrid perovskites within a carefully selected polymer matrix. For this purpose, a series of highly-crystalline two-dimensional (2-D) perovskite compounds (C8H16+2NH3)2MnCl4 [n = 3, 9, 12, 18] were synthesized by a solid-state chemistry route in order to act as the building blocks for organic-inorganic magnetic nanocomposite materials. Powder X-ray diffraction has resolved the parent perovskites orthorhombic structure (space group Cmca), while SQUID magnetometry has probed the transition to no antiferromagnetic state at low temperatures (<4 K). We note that their magnetic behaviour is marginally affected by the varying d, of the organic double-layer separaror (d=1.1-4.5 nm). Utilizing the chemical activity and structural flexibility of the organics, polycrystalline perovskite particles have been dispersed in a neutral polymer matrix (PDMS). In a typical procedure, the parent perovskite powders were mixed with tetrahydrofuran (THF) solution (10 wt%) to form a slurry. The slurry was stirred for 12 h and then ultrasonicated for 20 minutes. Perovskite-PDMS nanocomposites were prepared by speed mixing the appropriate amount of (C8H16+2NH3)2MnCl4/THF slurry with cross-linked PDMS at 3000 rpm for 5-7 minutes - allowed to cure at room temperature. Transmission electron microscopy shows that only longer chain hybrid perovskites form bundles (200-400 nm along by ~100 nm across) of layers that spontaneously orient themselves with respect one to another within the polymer matrix. The skyrmions characteristic afford control over the particle size and structure. The magnetic properties of such samples were further studied by the electron spin resonance and dc SQUID susceptibility methods. The synthetic approach results in novel nanocomposites materials where non-linear excitations or solitons prevail in a similar fashion to that in the parent hybrid perovskite systems, however, at reduced transition temperatures. We suggest that changing the magnetic behaviors (e.g. by applied stress) of the polymer matrix we can modify the magnetic exchange character of the 2-dimensional perovskite arrays that may lead to a potentially switchable magnetic composite material.

SESSION R2: NANO MAGNETIC PREPARATION II
Chairs: Mark Tuominen and David Lederman

Tuesday Afternoon, April 22, 2003
Golden Gate C3 (Marriott)
1300 P.M. R.2.1
FERROMAGNETIC NANOWIRE ARRAYS IN POROUS ALUMINA  FROM 3-D POLYCRYSTALLINE TOWARDS SINGLE CRYSTAL ARRANGEMENT. Kornelia Nielsch*, Ralf B. Wehrspohn, Jinsub Choi, Riccardo Hertel, and Ulrich Gätke, Max Planck Institute of Microstructure Physics, Halle, Germany. "Current Address: MIT, Department of Materials Science and Engineering, Cambridge, MA.

Nanomagnet arrays have recently attracted scientific interest due to their potential application as patterned perpendicular magnetic storage media. Using interference lithography large scale arrays of nickel columns with aspect ratios of up to h/Dp = 2.5 [1] (ratio of wire length h to diameter Dp) have been achieved by C.A. Ross et al. In order to obtain magnetic columns with larger aspect ratios (h/Dp > 10), self-ordered porous alumina based on the approach of Mansah et al. [2] is a suitable template. Currently, highly ordered nanomagnetic nanowire arrays exhibit a 3-D polycrystalline arrangement with a density of 40% of the bulk. The fabrication of Ni nanowire arrays based on imprint lithography will be presented, which show a perfect hexagonal arrangement on a cm²-scale and ∆Dp / Dp ≈ 5%. Additionally, we will analyze experimentally as well as theoretically the influence of the degree of order of the Ni nanowire arrays on its magnetic properties. The small deviation of the nanowire diameter allows for the first time, detailed Brillouin light scattering studies of electrodeposited nickel nanowires. The Brillouin data on spin waves in the nickel nanowires reveal strong quantization effects on their bulk magnetic properties. Additionally, a short introduction of the development of porous alumina as a template material in our group in the recent years will be given. This work was performed in collaboration with the Max Planck Institute of Metal Research in Stuttgart, Germany, the Institute of Applied Physics at the University of Regensburg, Germany, the Instituto de Ciencia de Materiales de Madrid, the Technical University of Vienna, and the National University of Singapore.[1] C.A. Ross et al., J. Vac. Sci. Technol. B 17, 3168, (1999).[2] H. Mansah and K. Fukuda, Science 268, 1466, (1995).

2000 P.M. R.2.2
USING TRIAXIAL MAGNETIC FIELDS TO CREATE HIGH SUSCEPTIBILITY PARTICLE COMPOSITES. James E. Martin, Eugene Venturini, and Gerald Guiley, Sandia National Laboratories, Albuquerque, NM.

We have recently discovered that it is possible to create a rich variety of magnetic particle/polymer composites by applying equal amplitude audio-frequency magnetic fields to particle/resin dispersions along three orthogonal directions. The magnetic fields create particle dipole moments that rotate about three dimensions. A little thought will convince one that such whirling dipoles should have zero mean interaction, but a second order effect leads to pronounced dipolar interactions that are strongly dominated by many-body interactions. The field components can be heterodirectional and/or amplitude modulated to create all manner of oscillating structures, and during resin polymerization these fibrillate into highly organized composites, such as cellular honeycombs and three-dimensional particle forms. Such structures should exhibit unique viscoelastic and magnetic properties and we have performed the computer simulations to demonstrate these effects. These composites have susceptibilities that are greatly enhanced over random particle composites, and we have shown that large susceptibilities (as high as 1000 %) can be created through modest field amplitude imbalances.

2:15 P.M. R.2.3
ENHANCED MAGNETIC RESPONSE OF DILUTE COBALT NANOPARTICLES IN AN ORGANIC MATRIX. J.P. Wiksson, E.L. Venturini, and P. Provencio.

We report studies of the magnetic response of nanocrystallites of extremely small, D=1.5 and 1.9 nm dilute Co particles in frozen organic matrices. An air and water-free inverse micelle synthesis is described and the evoluation of the magnetic response is found to increase from 1% 20% of the bulk saturation magnetism Most one day after synthesis to a value exceeding that of the bulk HCP magnetite over a period of 3-60 days under Ar at ambient T. Max maintains its high value independent of the subsequent matrix media as predicted by the Langevin equation. The effects of various surface passivators and molecular O2 on the magnetic response is discussed as well as experiments to grow both homo- and heteroatomic [core/shell] clusters on the monomers "Nanomagnetic Seeds." The origin of the "Seeds" evolution in the magnetic response with age is likely due to structural changes or reconstruction of the nanocluster surface and depends on the chemical nature of the inverse micelle surfactant used in the synthesis. The size and the magnetic behavior for all T>8 K does not change with age. Acknowledgement: This work was supported by the Division of Materials Sciences, Office of Basic Energy Research, US Department of Energy under contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the US Department of Energy.

3:00 P.M. R.2.4
G-FACTOR FOR Fe3O4-NANOPARTICLES ASSEMBLY. Magdalena Umanow, Gerhard-Mercator-Universität Duisburg, Exp. Tiemperaturphysik, GERMANY; Carolin Antoniak, Technische Universität Carolo-Wilhelmina Braunschweig, GERMANY; Ulf Winkler, Gerhard-Mercator-Universität Duisburg, Exp. Tiemperaturphysik, GERMANY; Shounag Sun, IBM T.J. Watson Research Center, Yorktown Heights, NY; Michael Färle, Gerhard-Mercator-Universität Duisburg, Exp. Tiemperaturphysik, GERMANY.

Chemically produced Fe3O4 nanoparticles with various compositions (x = 38, 56, 70) have been deposited on different substrates: SiN, quartz and Si. Low resolution Transmission Electron Microscopy (TEM) pictures show that the as-prepared Fe3O4 nanoparticles consist of round shape nanoparticles with a mean size diameter of 2.6 nm and 3.5 nm, depending of the composition. Ferrimagnetic Magnetic Resonance (FMR) spectra at 9.829, 9.121 GHz frequencies have been recorded at room temperature. The g-factors are 2.104, 2.070, 2.041 for x = 38, 56, and 70 respectively were determined. The g-factor deviates from the bulk fec value (g = 2.08) in respect with the Fe contents in the nanoparticles. Moreover it is to be mentioned that the contribution of the orbital moment decreases almost linearly with the increasing of the Fe content. This indicates the importance of spin orbit interaction in these composite nanoparticles.

3:15 P.M. R.2.5
ANOMALOUS MAGNETIC BEHAVIOUR OF NANOGRAINAL COBALT FILMS DEPOSITED BY MOVD. Peter Haycock, Feodor Ogrin, Miriana Chioncel, Brian Ruthven, Anthony Wright, Jonathon Stirling, Keele Univ, School of Chemistry and Physics, Keele, Staffordshire, UNITED KINGDOM; Steve Hoon, Manchester Metropolitan Univ, Dept of Environmental and Geographical Sciences, Manchester, UNITED KINGDOM; Sarah Thompson, York Univ, Dept of Physics, York, UNITED KINGDOM.

The magnetic properties of materials can change significantly when the dimensions of the constituent particles fall below a critical size. If the material is granular and there is a distribution of grain sizes that encompasses the critical size, competing anisotropies can lead to anomalous magnetic behaviour. This paper is concerned with the magnetic properties of granular cobalt films, with thickness of a few tens of nanometres and a distribution of lateral grain dimensions with a mean around 130 nm, that exhibit inverse hysteresis. This is a very rare phenomenon, in which the major hysteresis loop is traversed clockwise, the magnetization falls to zero while the applied field is still in the forward direction and the remanence is negative. It has been observed in a few different magnetic systems, including those based predominantly on cobalt. Here we present the results of vibrating sample magnetometry, magnetotransport, MOKE and ferromagnetic resonance studies of cobalt based films which exhibit very large, fully inverted major hysteresis loops. The inverse hysteresis has been produced by metastable chemical vapour deposition, which is a particularly suitable deposition technique for the tight and reproducible control of the microstructure and stoichiometry of films in this thickness range. Analysis of the combined data allows a determination of the magnetic anisotropy and the magnetization reversal mechanism. The anomalous magnetic behaviour appears to be due to competing anisotropies between grains either side of the critical size, coupled with exchange anisotropy between the cobalt and its oxide lattice. The magnetic properties will be correlated with the microstructure, crystallography, surface roughness and stoichiometry of the films, together with the growth mode of the cobalt grains.

3:30 P.M. R.2.6
MAGNETIC PROPERTIES AND SPIN-TRANSPORT IN MAGNETITE NANOPARTICLES. Kui Liu, L. Zhao, P. Khivs, Physics Department, University of California, Davis, CA; Frank E. Osterloh, and H. Hiramatsu, Chemistry Department, University of California, Davis, CA.

Nanoparticles of magnetite (Fe3O4) have been synthesized using an aqueous precipitation technique. The particles are spherical in shape, with an average size of 8-9 nm and a small size distribution, revealed by transmission electron microscopy and atomic force microscopy. X-ray diffraction and chemical titration confirm a single cubic spinel phase with expected stoichiometry. Dispersed nanoparticles display superparamagnetic behavior above 150 K over a 30 at a time scale. The blocking behavior is modified by the packing density, or the average inter-particle distance, of the particle assembly. For the packed superparamagnetic, the saturation magnetization in nanoparticles decreases...
faster with increasing temperatures, still according to $T^{3/2}$, due to enhanced contributions from surface magnetizations. In a compressed pellet 50 nm thick, the transport is determined by isolated particles. Negative magnetoresistance, $-8.6 \%$ at 200 K and $-4.5 \%$ at 300 K, has been observed. This is due to the field-induced alignment of the nanoparticles magnetization directions.

3:45 PM R2.7
THE EFFECT OF THERMAL SINTERING ON THE MAGNETISM OF FePt NANOPARTICLES. Sonja Spodden, Bernd Rellermann, Mehdi Ashour, A. Wietzke, L. Wagner, H. Klapper, TiefTemperaturphysik, Gerhard-Mercator-Universität, Duisburg, GERMANY.

Stoichiometric FePt nanoparticles in the chemically ordered L1$_2$ phase have a large magnetocrystalline anisotropy, which makes them attractive for future high density magnetic data storage media. However, independent of the preparation method employed, a thermal annealing procedure is necessary in order to stabilize the FePt phase, therefore, studied the thermal sintering of gas-phasre prepared FePt nanoparticles and its impact on their magnetic properties. Fe$_{23}$Pt$_{77}$ particles are prepared by DC sputtering in an Ar/He gas mixture. Prior to their deposition, the particles are sintered in situ at temperatures of up to $T = 1273$K. The influence of the sintering process on the particle morphology and crystal structure and the magnetic properties are investigated by means of (HR)TEM and SQUID magnetometry, respectively. The gas-phase preparation results in the formation of particle agglomerates which are increasingly compacted to single particles with increasing sintering temperatures $T$. At temperatures $293 K < T < 673 K$, inter-particle coalescence occurs. Below $T = 673 K$, we observe neck growth between the primary particles. Above this temperature, the agglomerates are compacted, and the primary particles grow from $d_p = 50 \text{nm}$ at $T = 673 K$ to $d_p = 200 \text{nm}$ from the variation of $d_p$ with $T$. We estimate an activation energy for this growth process of roughly $E_a \approx 68 \text{kJmol}^{-1} \text{cm}^{-2}$ indicating that surface diffusion and/or grain boundary diffusion are the predominant sintering mechanisms in this temperature regime. From $T = 673 K$ to $T = 1273 K$, we observe the onset of intra-particle recrystallization, which leads to an increasing amount of single crystals and the formation of L1$_2$ order within the particles. An analysis of both the diffusion lengths and sintering times shows that in this temperature regime, volume diffusion dominates. The magnetic investigations reveal that, concurrently with the increasing amount of L1$_2$ ordered particles, both the effective magnetic anisotropy constant and the coercivity $H_{C0} = H_C(T = 0)$ increase from $K_{eff} = 3.6 \times 10^3 \text{Jm}^{-3}$ at $T = 293 K$ to $K_{eff} = 3.6 \times 10^3 \text{Jm}^{-3}$ at $T = 1273 K$ and from $H_{C0} = 1.98 kOe$ at $T = 293 K$ to $H_{C0} = 4.05 kOe$ at $T = 1273 K$, respectively.

4:00 PM R2.8
STRUCTURAL AND MAGNETIC PROPERTIES OF SELF-ORGANIZED Co CLUSTERS. F. Luís, L. M. García, J. M. Torres, F. Bartolome, J. Bartolome, ICMA, CSIC-Universidad de Zaragoza, Zaragoza, Spain; J. E. Gubern, M. J. Barredo, UMP CNRS/Thales and Université Paris-Sud, Orsay, FRANCE; D. Buhmann, LMP-Université de Poitiers, Futuroscope Chasseneuil, FRANCE.

We have fabricated granular multilayers consisting of successive planes of nanosized cobalt clusters separated by alumina along the growth direction. Combining grazing-incidence small-angle x-ray scattering and transmission electron microscopy experiments, we show that, in a given range of thickness, the vertical arrangement of clusters from plane to plane is not random but shows a topology induced self-organization. The magnetic properties of the Co clusters were studied down to the smallest available mesas (50 nm) by ac and dc susceptibility experiments. We found a strong enhancement of their effective magnetic anisotropy originating from the surface of the Co clusters. Furthermore, the distribution of the magnetic activation energies is clearly linked to the distribution of the particle sizes but not of the volume distribution. We will also show that Co/Al$_2$O$_3$ granular multilayers appear as a model system to study the effect of dipole-dipole interactions between magnetic nanoparticles and its influence on their relaxation times. Our data clearly demonstrate that magnetic relaxation becomes slower as the degree of interactions increases. The blocking temperature and the effective activation energy increase almost linearly with the number of nearest neighbor clusters. From a 2D-3D behavior, it is nearly reached for 5 layers of Co clusters. The experimental results agree quantitatively with the predictions of a simple phenomenological model.

4:15 PM R2.9
PULSED LASER DEPOSITION ASSISTED SELF-ASSEMBLED GROWTH OF Ps AND Ni NANOPARTICLES. D. Komis, Department of Mechanical Engineering, North Carolina State University, Greensboro, NC, S. J. Pennycott, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN; J. Smitke, Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC.

The present study focuses on developing pulsed laser deposition (PLD) assisted self-organized growth of uniform magnetic nanoparticles (islands) within matrices of aluminum or nickel (such as TiN). The advantage of using PLD for the fabrication of self-assembled thin film heterostructures is that there are relatively few deposition parameters to optimize, but the range of chemical compositions, the structural, physical and magnetic properties and film structure attainable is enormous. PLD assisted self-assembled growth is driven by an underlying instability, such as misfit strain in heteroepitaxial systems. The size, shape and volume fraction of magnetic nanoparticles is controlled by varying PLD parameters, in particular substrate temperature, laser energy density which determining the number density of arriving adatoms on substrate surface, and pressure of the gas ambient. The uniformity in particle size distribution was manipulated by changing the laser fluence. The thermodynamic instability and kinetic effects. The studies of magnetic properties was focused around [a] size effect [b] shape, crystal, and surface magnetocrystalline anisotropy, and [c] core-shell morphology of the nanostructured magnetic particles. Investigation using scanning transmission electron microscopy with atomic number contrast (STEM) and atomic resolution electron energy loss spectroscopy (EELS) have indicated these nanoparticles are free of any interfacial oxide layer in the case of Ni particles while a shell of oxide exists in the case of Fe particles.

4:30 PM R2.10
COAT-ERIZATION OF CORE/SHELL MAGNETIC NANOPARTICLIES BY X-RAY ABSORPTION SPECTROSCOPY. S. Calvino, F.E. Carpenter, V.G. Harris, Naval Research Laboratory, Materials Physics Branch, Washington, DC.

Passivated nanoparticulate iron has long been a goal of nanotechnology research. These materials are expected to represent a significant improvement over current magnetic materials for applications such as permanent magnets, hard disk drives and magnetic filters in the MHz range. In addition, they hold promise in the fields of targeted drug delivery and biological systems. In this study, nanoparticles with iron cores and oxide shells were synthesized using the reverse micellar method. TEM confirms the core/shell structure and with an approximate diameter 10 nm. X-ray absorption spectra of these samples were collected at the National Synchrotron Light Source, and subjected to a variety of methods of analysis. The ratio of core to shell was determined by comparing the x-ray absorption near-edge structure (XANES) to metal and mixed-oxide standards, with the results indicating about 60% of the iron atoms reside in the metallic core. This information was then used to constrain a fit of the extended x-ray absorption fine structure (EXAFS). Successful EXAFS fits to the data were obtained for a model consisting of amorphous iron oxide, nanocrystalline bcc iron, and amorphous close-packed iron. The structure of the core was strongly dependent on the surfactant used to form the micelles. TEM and EXAFS confirm that, under certain conditions (nonionic surfactant) is used, the metallic core is entirely amorphous; when CTAB (anionic) is used, the metallic core is partially nanocrystalline. Magnetic measurements performed with a superconducting quantum interference device (SQUID) and a vibrating sample magnetometer (VSM) are consistent with the structural interpretation, yielding $(10 \text{K})$ saturation moments of approximately 90 emu/g for the amorphous core samples and as much as 170 emu/g for the samples with partially nanocrystalline cores. In keeping with the core-shell model, smaller size of the particles, coercivities are less than 100 Oe in both cases.

4:45 PM R2.11
SELF-ORGANIZATION OF MAGNETIC PARTICLES IN 2D. J.-C. S. Lévy, Laboratoire de Physique théorique de la Matière Condensée, Université Paris 7, FRANCE; A. Ghezzi, Groupe de Physique des Solides, UMR 7688-CNRS, Université Paris 6 et Paris 7, FRANCE.

Confined or non confined 2D self-assembly of magnetic particles under the action of dipole-dipole interactions [1] are investigated by Monte Carlo simulations with or without an applied magnetic field. These systems reveal a slow relaxation towards equilibrium at all densities. At low density and without field, chains and rings of magnetic particles are formed with a gradual length increase. The individual magnetic moments are aligned along the chains and the rings. With an in-plane field, rectilinear chains parallel to the field are formed, while rings are broken. A strong enough out-of-plane field keeps the particles separate with mutually repulsive moments that are directed parallel to the field. They form amorphous arrangements. At moderate density without field, chains and rings of particles are formed with numerous spirals. Their magnetic moments are lying in-plane and arranged in vortexes that are constrained in a 3D spin lattice simulations [2]. The interaction between neighbors is rather weak. This explains numerous inhomogeneities in the particle assembly. At higher...
the fringes. The observed features are analyzed based on a model where in addition to the longitudinal oscillation of the transverse component of magnetization, there is also a transverse oscillation of the longitudinal component with a somewhat smaller periodicity than the periodicity of the fringes. We discuss the effects of oscillations of the thin film topography due to the roughness of the substrate, and variation of the magnetization of the nanocrystalline structure of the film. 1. N.G. Chechkin, C.B. Cross, A.R. Cheeni, T. Vastavl, D.O. Boerma, Th. M. De Hosson and L. Niesen, 2002 MRS Spring meeting: Symposium H: Materials Issues for Tunable RF and Microwave Devices and Applications, Jeff Th. M. De Hosson, Nicola G. Chechkin, Damn Hein Ahlem, Tomas Vastavl, Ban Koci, Antoni Cezar, Dik Boerma, Microscopy and Microanalysis 8, 274-287, 2002.

11:45 AM R3.7
ATOMIC RESOLUTION MAGNETIC RESONANCE DIFFRACTION: Milad Barbag and Axel Scherer, Departments of Applied Physics and Electrical Engineering, Caltech 104-36, Pasadena, CA.

We present our recent proposal [1] for the observation of sharp spectral peaks in the magnetic resonance signal for the case of a crystal in close proximity to a ferromagnetic nanosphere. The appearance of the peaks is a direct signature of the discrete atomic sites in the crystal lattice, and the positions of the spectral peaks are sensitive to the crystal unit cell size thereby providing a magnetic resonance diffraction method for determination of the basic parameters of the crystal at the atomic scale. Therefore, the technique provides a magnetic resonance alternative to the other three well-known atomic resolution crystallography techniques of x-ray, electron, and neutron diffraction. Applications to the studies of crystals, thin films, and crystallites will be discussed, and potential measurement methods for the confirmation of the diffraction theory will be proposed [2]. The technique significantly reduces the magnetic resonance sensitivity requirements by allowing many spins to coherently contribute to the signal while still providing atomic scale information. The analysis suggests that the long desired goal of detecting atomic resolution magnetic resonance diffraction [3] is well within reach of current experimental techniques such as Magnetic Resonance Force Microscopy (MRFM) [4, 5]. [1] M. Barbag, J. Phys. 91, 3667 (2002) [2] M. Barbag and A. Scherer, J. Appl. Phys. (in press 2003) [3] P. Mansfield and P.K. Grannell J. Phys. C: Solid State Phys. 6, L422 (1973). [4] Sidles J.A. et al. Rev. Mod. Phys. 67, 249 (1995).

SESSION R4: TRANSPORT AND MAGNETISM IN NANOMAGNETS
Chair: Ivan B. Brumberg, Wednesday Afternoon, April 23, 2003 Golden Gate C3 (Marriott)

13:00 PM R4.3

The magnetic properties of planar 10 nm Fe/ x nm MgO/ 10 nm Fe (x=1, 2, 5 & 7 nm) epitaxial ferromagnetic tunnel-junctions have been measured for different edge sizes in the micrometer range. When top and bottom electrodes' magnetizations are exchange uncoupled, they orient antiparallel in the zero field state due to the magnetostatic energy reduction. On the other hand, the two electrodes' magnetizations orient parallel when exchange couples them effectively through the barrier, most probably due to pinholes. This happens for 1 nm thick MgO barrier, which is just about two MgO unit cells, for junctions of ~4 μm lateral size. The field range where magnetic switching occurs agrees reasonably well with predictions from a simple analytical model, in which we solve the energetic balance between magnetostatic energy reduction and potential energy gain for our Fe/MgO/Fe sandwich geometry. In addition, we obtain evidence that when top and bottom electrodes are exchange uncoupled, the junctions can be bias controlled before they interact laterally. This is due to a preferred magnetic flux closure along the growth direction instead of in the plane, reducing the field distribution at both interfaces. The same argument implies that the junctions are exchange uncoupled down to sizes smaller than single-layer Fe films. For the thinnest barrier, InMgO, partialing reduces the ratio of exchange-coupled junctions in the array. The effect of patterning in rectangular shaped epitaxial junctions is also discussed.

2600 PM R4.2
MAGNETIZATION STABILIZATION IN ARRAYS OF Fe NANODOTS WITH EXCHANGE BIAS: Igor V. Roshchina, C.P. Li, Physics Department, UCSD, La Jolla, CA; Kai Liu, Physics Department, UC Davis, Davis, CA; K. Nishio, H. Masuda, Applied Chemistry Dept., Tokyo Metropolitan Univ., Hachioji, Tokyo, JAPAN; Ivan K. Schuller, Physics Department, UCSD, La Jolla, CA.

Magnetism at nanoscale, when the size of the structures is smaller than both the ferromagnetic (FM) and antiferromagnetic (AF) domain sizes, offers a great potential for new physics. Advancements of technology demand techniques capable of producing nanometer-sized structures over large areas. Using self-assembled nanomagnets in novel alternate anisotropy (1) magnetic shape 100 nm dots covering over 1 cm² are deposited by electron-beam evaporation. This method provides a good control over dot size and separation. Samples with Fe and Fe/Fe2O3 nanodots as well as continuous Fe and Fe/Fe2O3 films are simultaneously grown on the same substrate. Typically 15-20 nm of Fe and 20-80 nm of Fe2O3 are used, and the samples are capped with a 5-8 nm thick Al layer to prevent Fe oxidation. Comparative studies of magnetic properties of these nanomagnets in a wide range of geometries and sizes are presented. All samples are cooled from 150 K in an applied 2 kOe field. Improved squarness of the magnetization loops for Fe nanodots with the Fe2O3 is attributed to an exchange bias, which value is measured to be up to 80 Oe at 10 K. Such improvement of thermal stability of the Fe nanodots by coupling to an AF layer is discussed.

Work is supported by AFOSR.


2:30 PM R4.4
MAGNETORESISTANCE IN PATTERNED NANO-BRIDGES ON EPITAXIAL Ni FILMS: R. Alejandro, Lukaszew, University of Toledo, Physics and Astronomy Department, Toledo, OH; Antonio Zambra, Physics and Astronomy Department, Michigan State University, East Lansing, MI.

The latest results on BMR research have shown surprising ballistic magnetoresistance values with values over 300% in Ni nano-contacts at room temperature. [1] It has been postulated that the ballistic magnetoresistive effect arises from non-admisible spin scattering across very narrow (atomic scale) magnetic domain walls trapped at nano-sized constriction. [2] The reported BMR effect has been observed at room temperature and low magnetic field in Ni nano-contacts electrodeposited between Ni wires. Much of the published data so far, is still poorly understood. In an attempt to clarify some of the possible processes present in the observed phenomenon we have used e-beam lithography applied to epitaxial Ni films to fabricate nano-bridges in more controlled fashion than electrochemical deposition. The idea behind this scheme is that epitaxial ferromagnetic thin films may have ballistic regime provided that the nano-contact is small enough. Thus we have patterned nano-bridges with a similar T geometry to that utilized by Chopra and Garcia [3, 13]. The combined shape and magnetocrystalline anisotropies provide the required two states for the magnetization at each side of the nano-structure. Our preliminary results indicate that the key results indicate that the key results indicate that the rate of spin in the nano-bridges are high enough to do play a role in the magneto-resistance of these nano-bridges but the order of magnitude of the observed effect is considerably smaller than the reported observations for electrochemically prepared nano-contacts. [1, 2, 3, 4, 5] R.G. Chopra, Phys. Rev. B, 66, 020403(R), 2002. [2] P. Bruno, Phys. Rev. Lett. 83, 2425 (1999) [3] N. Garcia, M. Munoz, V.V. Osipov, E.V. Ponizovskaya, G.G. Quin, I.G. Smelev and Y.-W. Zhao, J. Magn. Magn. Mater. 240, 92 (2002).

3:15 PM R4.5
SPIN DEPENDENT TRANSPORT IN CO NANOSTRUCTURES: M.I. Mazitova, R. Duman, O.M. Stull, University of California, San Diego, Physics Department, La Jolla, CA; W.A.A. Masedo, Laboratorio de Física Aplicada, Centro de Desenvolvimento da Tecnologia Nuclear, Belo Horizonte, MG, BRAZIL; and Ivan K. Schuller, University of California San Diego, Physics Department, La Jolla, CA.

Submicron scale ferromagnetic wires are a research topic of considerable interest from both technological and basic research points of view. For ballistic ferromagnetic nanowires, the magnetoresistance values of up to 3000% have been reported recently [1, 2]. We developed a method to prepare magnetic nanowires using standard e-beam lithography and dry etching techniques. The process allows us to fabricate mechanically stable nanowires with different widths on a single sample. The nanowire widths are in the range of 20 to 100 nm. The transport properties of Co nanowires on different semiconductor substrates produced by this method have been measured. We have studied the dependence of the magneto-transport properties with the temperature and the magnetic configuration of the nanowires. Magnetoresistance values of 1.2% have been found for temperatures up to 300 K. The obtained values of magnetoresistance are in good agreement with reported values for permalloy [3] and Co [4] nanocontacts with similar sizes.

S 3:30 PM R 4.5

TUNABLE MAGNETIC PROPERTIES OF SINGLE ELEGANT AND MULTILAYERED NANOWIRES, Ryan Cohen and Bethanie Stadler, Univ of Minnesota, Dept of Electrical and Computer Engineering, Minneapolis, MN.

Magnetic nanowires have recently attracted attention for both device applications and fundamental research. These nanowires can be cost effectively fabricated by electrochemical deposition into nanoporous templates. In addition, multilayered nanowires can be fabricated from a single electrochemical bath by using a pulsed DC electrochemical deposition technique. We have created Co nanowires, as well as Co/Cu and Ni/NiMn multilayered nanowires using metal sulfate electrolytes and nanoporous alumina templates. In this study, we systematically altered several deposition parameters in order to influence the magnetic properties of the wires. They were characterized using SEM, TEM, XRD, and VSM. First, we examined the crystallographic orientation of the Co nanowires and found that it can be influenced by three parameters: contact material, pH of the electrolyte, and applied fields during deposition. Using XRD, we determined that Co nanowires deposited on an Ag contact have [100] texture regardless of an applied field during deposition. However, the texture of Co wires deposited on a Cu contact is sensitive to even relatively small fields during deposition (less than 400 Oe). Second, we deposited Co/Cu multilayered nanowires and alternated an applied field to influence the texture of individual Co layers. TEM analysis showed that the texture of individual Co layers in a Co/Cu multilayer nanowire was similar to that of plain Co wires. This allows some control over the magnetic nanostructure of individual layers in a CMR structure. Third, we fabricated Computer Engineering University Ni/NiMn multilayered nanowires in the presence of an applied field to influence the exchange between the ferromagnetic Ni layer and the antiferromagnetic NiMn layer. Creating Ni/NiMn multilayered nanowires with good exchange coupling is the first step towards creating Ni/Cu/Ni/NiMn spin-valve structured nanowires.

3:45 PM R 4.6


Recent studies show that the narrow ring-shaped magnetic elements exhibit two different stable "onion" states at room temperature in addition to the vortex state. Those two onion states, forward or reverse magnetized, respectively, as remanence can be used for magnetic storage. In ultra-high density memory the elements placed so close together that element-element interactions compete with single element energies and can lead to totaly different switching dynamics. The results of systematic characterization of arrays of small Co and permalloy ring elements with zero separation between elements (touching rings) with SQUID magnetization to determine the magnetic moment, magnetic force microscopy (MFM) and Lorentz TEM to determine magnetic and magnetic free space of two. Here we report on recent measurements of space of touching rings with magneto optical imaging to visualize the moment reversal process during a magnetization cycle, will be presented. Work at ANL was supported by US Department of Energy, BES Materials Sciences under contract DE-AC02-06CH11357, the U.S. NSF, grant EEC 0292780 and U.S. Dept of Energy Grant DE-FG02-97ER45653.

4:00 PM R 4.7

INTERMEDIATE METASTABLE STATES DURING MAGNETIZATION REVERSAL IN SQUARE RINGS, M. Grisditch, Materials Science Division, Argonne National Laboratory, Argonne, IL; P. Vivasario, INFM, National Research Center on Nanostructures and Biosystems at Surfaces (S^2)-Dipartimento di Fisica, Universita di Ferrara, ITALY, V. Metlushko, University of Hamburg, Hamburg, Germany; J. Zhang, University of Illinois at Chicago, Chicago, IL; and B. Lie, School of App. and Eng. Physics, Cornell University, Ithaca, NY.

Magnetization reversal in permalloy square rings has been investigated using magneto-optical Kerr-effect (MOK) combined with numerical micromagnetic simulations and MFM imaging. Diffused "MOKE" loops show a two-step switching process for external fields along both the ring edge and diagonal. However, hysteresis loops extracted from micromagnetic simulations show that a square ring is expected to occur via a single step - from one onion to the reversed onion state - for both directions of the applied field. We have found that in order to reproduce the observed two-step reversal, an asymmetric first stage is required. This asymmetric square rings a metastable intermediate state appears during the switching, and the calculated hysteresis loops reproduce the experimentally measured case. When the external field is applied along the rings edge the intermediate state is a new bi-domain state, which we term the honeycomb state. For the external field applied along the ring's diagonal the intermediate state is a vortex state. These states have been mapped and imaged with MFM techniques. P.V. gratefully acknowledges financial support from INFM under the "MAGDOT" PARI research program as well as from MURST-COFIN 2000. Work at ANL was supported by US Department of Energy, BES Materials Sciences under contract DE-AC02-06CH11357, and at UIC by the U.S. NSF, grant EEC-0292780.

4:15 PM R 4.8

IMAGING OF SPIN DYNAMICS IN CLOSED DOMAIN AND VORTEX STRUCTURES. Jozio Park, Peter Emene, Dave Engels, Jesse Berzowsky, Paul A. Crowell, Univ of Minnesota, Dept of Physics, Minneapolis, MN.

We have studied spin dynamics in closure domain and vortex structures using time-resolved scanning Kerr microscopy as a local spectroscopic probe. The thin film structures for this experiment were prepared by electron beam lithography and lift-off, using films sputtered on GaAs (100) substrates. Sputters of thickness 15 nm with edge dimensions of 10, 5, 3, 2, and 1 µm and 60 nm thick disks with diameters of 2, 1, and 0.5 µm were studied in zero external field. We have identified two distinct modes in squares forming closure domain structures. The lower mode corresponds to precession of the magnetization about the local demagnetizing field in each quadrant, while the higher mode is localized in the domain walls. The remnant state of each vortex is shown in a contact with a singularity at the center. The higher frequency mode observed in the vortex is due to precession of the magnetization about the line of symmetry internal field, while the lower frequency mode corresponds to the gyrotropic motion of the entire vortex, as can be seen clearly by looking at the plane at each position. Measurements in non-zero fields indicate that the normal mode frequencies are nearly independent of field in the field range between the annihilation and the creation of vortex. These results demonstrate clearly the existence of well-defined excitations of inhomogeneously magnetized microstructures. The overall mode structure that we observe is in qualitative agreement with micromagnetic simulations based on the Landau-Lifshitz-Gilbert equation. The frequencies of the vortex gyrotropic mode are also in reasonable agreement with a recent analytical theory [Guslenko et al., Appl. Phys. 91, 8337 (2002)]. This work was supported by NSF DMR-085777, the Research Corporation, the Alfred P. Sloan Foundation, the University of Minnesota's MRSEC (DMR-021392), and the Minnesota Supercomputing Institute.

4:30 PM R 4.9

MAGNETISATION REVERSAL STUDIES IN NANOWIRE LINES USING AN ENHANCED TEM CAPABILITY. J.N. Chapman, S. McVitie, W.A.P. Nicholson, G. Yi, C.K. Lim, Department of Physics and Astronomy, University of Glasgow, Glasgow, UNITED KINGDOM.

Much can be learned of the magnetisation reversal mechanism of small elements by in-situ experimentation in the transmission electron microscope. Here we report recent results of experiments using a small, 2µm square, rectangular, permalloy elements with lengths 1000 nm and widths down to 150 nm. In the first we show how the field at which the magnetisation reversal can be reduced reached by gently curving the ends of another rectangular element. Vortices which become better defined at elevated temperatures, are found to play an important role. In the second set, attention is focused on how the switching field varies with the angle between the element long axis and the applied field direction. For all but the smallest elements, higher fields are required as the angle increases, a characteristic of reversal in which domain processes, rather than coherent magnetisation rotation, are dominant. To determine how, the different elements, orientation and configuration should not change during the course of a magnetisation experiment if it does, attention needs to focus on the instrument rather than on what is happening to the small elements themselves. Much of the results referred above to an environment technique in which pure in-plane fields can be generated without the electron beam suffering any significant deflection. The method is
particularly suited to experiments in which the specimen is subjected to (repeated) pulsed fields and has application not only in the study of switching processes but also to how, for example, the properties of multilayer films change on repeated cycling.

4:45 PM  R4-10
TEMPERATURE-DEPENDENT MAGNETIC DOMAIN STRUCTURES IN Sr-DOPED CMR THIN FILMS. M.E. Hawley, Los Alamos National Laboratory, Los Alamos, NM.

Previously known and bubble-like magnetic domain structures have been observed under ambient conditions in La$_{1-x}$Sr$_x$MnO$_3$ films by magnetic force microscopy (MFM) for films grown on a compressive (LaA03) percent lattice mismatched substrate and a direct correlation was seen between growth temperature, grain size, and coercivity. X-ray data confirmed an approximately one percent distortion of the c lattice parameter resulting in out-of-plane magnetic structure. The strain-induced stress in this soft magnetic material appears to be responsible for the appearance of these structures. In order to better understand these magnetic structures, we have examined films grown by pulsed-laser deposition at 750°C and 800°C by magnetic force microscopy at different temperatures to study the behavior of the domain structures. Since the average transition temperature for these films was about 350°C, they were ideal for temperature dependent magnetic force microscopy (MFM) imaging. The films were studied by MFM in a variable temperature scanning probe stage at temperatures between room temperature and above Tc to determine the behavior of the domains at and below the Curie temperature. In particular, although the 800°C films were nominally grown under the same conditions, there were subtle differences in the domain structure, wall spacing, and nucleation behavior due in part to differences in film thickness.

SESSION R5. POSTER SESSION
NANOstructured MAGNETISM
Chair: Maria Isabel Meloero
Wednesday Evening, April 29, 2003
8:00 PM
Salon 1.7 (Merriott)

R5.1
Abstract Withdrawn.

R5.2
MAGNETIC AND STRUCTURAL PROPERTIES OF NANO-METER FeNi PARTICLES. Xianghong Sun and D.E. Nicks, Center for Materials for Information Technology (MINT), The University of Alabama, Tuscaloosa, AL.

Nanometer FeNi particles were prepared by the hydrogen plasma-metallization reaction method. Structural analysis of X-ray diffraction (XRD), transmission electron microscopy (TEM), and electron diffraction (SAED) and energy dispersive spectroscopy (EDS) showed that particle size was about 10-20 nm in spherical shape, the NiFe was identified as mainly γ-FeNi. X-ray diffraction indicated an average value of Fe$_3$Ni as in this Fe-γ-FeNi particles. Superconducting tunneling quantum interference device (SQUID) magnetometer and vibrating sample magnetometer (VSM) measurements indicated that the saturation magnetization ($M_s$) and coercivity ($H_c$) were higher than that of the bulk FeNi material due to the nano-metre particle nature. Hyperfine fields ($H_a$) values that from Mössbauer spectra at room temperature confirmed this FCC γ-FeNi nanophase. SQUID, VSM and Mössbauer spectra suggested those FeNi nano-meter particles exhibited ferromagnetic behavior at room temperature, no superparamagnetic properties. And magnetic anisotropy was the dominant factor under magneto manipulation.

R5.3

Magnetic properties of Ni nanostructures electrodeposited into cylindrical porous alumina templates have been investigated. Usually magnetic properties vary with the wire diameter, length and wire distribution. In this work we observed the size and shape effect on the magnetic properties of Ni nanostructures deposited in alumina for different lengths of time. The physical and chemical properties of obtained nanostructures have been investigated by XRD, SEM, TEM, AFM and SQUID. The coercivity of Ni nanostructures was found to depend on aspect ratio, $L_d/d_a$, (wire length divided by wire diameter), increasing from 300 Oe at $L_d/d_a=1$ (spherical form) to 2000 Oe at $L_d/d_a=100$ (nanowire form).

R5.4
PREPARATION AND TRANSFORMATION OF FERROMAGNETIC Fe-Co AND Fe-Co NanoPARTICLES SYNTHESIZED BY CHEMICAL VAPOR CONDENSATION. Chul-Hun Choi and Byoung-Kee Kim, Korea Institute of Machinery and Materials, Changwon, Kyungsng, KOREA; Oleg Tolochko, State Technical University,Politchechnicheskaya, St. Petersburg, RUSSIA.

Ferromagnetic Fe and Fe-Co nanoparticles were synthesized by Chemical Vapor Condensation (CVC) Process using the precursor of Fe$_3$Co$_2$ and Co$_3$Co. We investigated the magnetic properties of the nanoparticles and their oxidation behavior during annealing systemically by means of HITTEM, DTA-TGA, Mössbauer spectroscopy and magnetization measurement. The temperature of synthesis of nanoparticles was varied in the interval of 400-1100°C. The spherical nanoparticles of the mean diameter of 6-25nm comprise of the metal core and oxide shell. To form oxide shell, the slow oxidation of particles was achieved by exposure of iron nanoparticles in the inert atmosphere with controlled reduction potential. The effect of CVC parameters on the microstructure and particle size distribution had been investigated. The increase of lattice parameter of metallic core with the decreasing particle size can be explained by the exponential growth of oxide shells. The saturation magnetization and coercivity increased with increasing Co content, and the saturation magnetization reached its maximum at 40 wt% Co.

R5.5
MAGNETO-CHEMICAL STUDIES OF Co, Fe, and Co/Fe NANO-ParticLes ON SOL-GELED PREPAREd ALUMINA: HYDROGEnATION OF CO/H$_2$ AND CO$_2$/H$_2$ MIXTURES. Seok-Y. Naik, Akhuni N.K., Joseph L. McGinn, and Charlene Jones, Department of Physics, Grambling State University, Grambling, LA; Upali Sripadawala, Sriwani Naga Vagesha, Sireesh Vuduthal, Ramkiran Godupachiya, Buddy G. Barnett, Edwin Everett, Sheila Anderson, Karen L. Vinek, Laura Holeman, and Andrew Enge, Department of Chemistry and IM, Louisiana Tech University, Ruston, LA.

The alumina granules, containing metal oxide nano-particles, CoO, Fe$_3$O$_4$, and CoO/Fe$_2$O$_3$, were prepared by sol-gel/citrob method. Synthesis was carried out using both aluminum tri-sec butoxide (ALTSB) and aluminum tri-iso-propoxide (ALTIP). The optimum calcining exotherm temperatures were studied by differential thermal analysis (DTA) and found to be below 450°C. The metal oxides were reduced in hydrogen at 450°C. The surface areas of the catalyst granules were determined by nitrogen desorption. They were in the mesoporous range of 200-400 m$^2$/g. These catalysts were examined by powder X-ray diffraction and the results showed that the metal oxides were in the nanoparticle range. The particle sizes and metal loading of granules were studied by scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) analysis. The metal loading results used to optimize the synthesis process to obtain consistent metal compositions. The catalytic activities of Fe, Co, and Co/Fe on alumina for the hydrogenation of CO/H$_2$/N$_2$ and CO$_2$/H$_2$/N$_2$ were investigated. Both $\alpha$, $\beta$, and $\gamma$-phase Fe-Co mixed metal catalyst has greater activity compared to Co and Fe catalysts. Vibrating sample magnetometer (VSM) was used to study the magnetic characteristics of $\gamma$-Fe-Co mixed metal particles catalyst. Most of the reduced samples exhibit super-paramagnetic character. Comparative study of the ferromagnetic component of these samples allowed us to gain insight into the reduction efficiency and the changes in metal centers during catalytic reactions. Magnetic studies of post-reduction Co and Fe nano-catalysts showed that the formation of carbides is higher for iron compared to cobalt. In the Fe/Co mixed catalyst it is observed that the presence of iron enhances the cobalt oxide reduction. We have correlated the catalytic activities with the magnetic characteristics. Work supported by a grant from Department of Energy.

R5.6
X$\alpha$S STUDIES OF SUPERPARAMAGNETIC NANO-PARTICLES IN COLOIDAL SUSPENSIONS FOR BIOMEDICAL APPLICATIONS. M. Hoff, Rutgers Univ, Phys. Dept., Picaterm, N.J. Doliva, S. Wolniak, T. Tkachakos, Rutgers Univ, Department of ceramics, Picaterm, N.J. Anzani, Seton Hall Univ, Physics Dept, S. Orange, N.J. D. Kim, M. Møller, T. Topar, Z. Zhang, Royal Institute of Technology, Division, Stockholm, SWEDEN; B. Bjelke, Karolinska Institute, MR Center, Experimental Unit, Stockholm, SWEDEN; J. Kehr, Karolinska Institute, Division of Cellular and Molecular Neurochemistry, Stockholm, SWEDEN; M. Møller, Royal Institute of Technology, Materials Chemistry Division, Stockholm, SWEDEN.
Superparamagnetic iron oxide nanoparticles SPION have been of great interest in recent years for potential biomedical applications and for use in building blocks for assembly of 3D structures. Biocompatible and bio-compatible SPION applications of interest include selective structure enhancement in MRI, directed drug delivery and site-specific enhanced microwave absorption. SPION applications involve the colloidal aggregation of the size and shape of magnetic materials on the magnetic properties. So far, the study of the properties changes of magnetic materials in nanoscale has been limited to nanowires and multilayers. We formed the nano-sphere, nanohoneycomb, and nanodouble ring patterns of NiFe$_{2}$O$_{4}$ on the macular aluminum oxide template by sputtering. For fabricating nano-sphere, thermal treatment technique was added. Additionally we observed that nano-sphere, nano-honeycomb and nano-double ring patterns have their magnetic properties dependent on their size and shape.

R5.10 SOLID STATE TRANSFORMATION AND TWO-PHASE NANOCOMPOSITES IN Fe-Pd (Li$_{2}$)-BASE FERROMAGNETIC ALLOYS. H. Okumura, S. Sipta, H. Heinrich, J. M. Wiesczek, J. A. Beran, and W. A. Sofo. Department of Materials Science and Engineering, University of Pittsburgh, Pittsburgh, PA. "Now at Carnegie-Mellon University, Department of Materials Science and Engineering" On sabbatical leave from ETH Zurich, SWITZERLAND.

Intense interest has been generated in the possibility of tailoring two-phase microstructures consisting of hard and soft ferromagnetic phases that are exchange coupled on the nanoscale to produce a unique combination of properties for various applications. The optimal conditions for developing effective nanostructured exchange hardened magnets depend critically on the size, morphology and distribution of the hard and soft phases comprising these multiphase aggregates. The Fe-Pd alloy system characterized by the FePd (Li$_{2}$) unit cell is an example of a ferromagnetic phase offers great promise as a basis for producing nanocomposite hard magnets through solid state transformation in off-stoichiometric compositions. This paper reports on the recent studies of the evolution of microstructure and structure-property relationships in nanostructured two-phase alloys produced through phase transformations in the R-Pd system over a range of compositions. Enhanced coercivities compared to bulk 50Fe-50Pd alloys have been achieved in an off-stoichiometric Fe<sub>34</sub>Pd alloy utilizing non-equilibrium decomposition of the parent austenite phase. The magnetic hardening will be discussed in terms of the microstructural evolution and inter discretionary changes in the properties during isothermal transformation. This work was supported in part at the University of Pittsburgh by NSF/DMR and DARPA.

R5.11 STUDY OF INTERACTION EFFECTS IN MAGNETIC NANOSIZED MATERIALS. Loredana Spini, Leonard Spini, Advanced Materials Research Institute & Physics Department, University of New Orleans, New Orleans, LA; Alexander Stancu, Faculty of Physics, 'Al. I. Cuza' University, Iasi ROMANIA; Le Duc Tu; Xue Feng, Charles O'Connor, Advanced Materials Research Institute, University of New Orleans, New Orleans, LA.

An effective way to evaluate the interactions in fine particulate systems is the DeltaM curves. As it is very well known, in order to determine the regular DeltaM curves we need to start from an ac demagnetizing state. When the relaxation phenomena are not very important, the procedure can be performed even at room temperature. In the case of nanoparticle systems, in order to obtain regular DeltaM plot one would need to obtain the initial ac demagnetizing state at low temperatures, which experimentally it is not trivial. This is why there was attempts to obtain the regular DeltaM plots substituting the ac demagnetizing state with a thermal demagnetization one. However, this approach was proven to be greatly misleading for the interpretation of the classical DeltaM curves. In this study we present a new approach, the Integral Generalized DeltaM plots, based on the classical DC demagnetized (DCD) curve and a number of Isothermal Remanent Magnetization (IRM) type curves, referred as forenamed IRM curves and the Integral Generalized DeltaM plots. In order to investigate the role of the interactions, we performed experiments at various temperatures on samples of Co nanoparticles, dispersed in different concentrations in a wax matrix. The degree of dilution in the wax controls the interparticle distance and therefore the strength of interactions. Two samples were considered for this study: a sample of CV=0.011 volume fraction of Co nanoparticles dispersed in wax and a sample containing only Co nanoparticles. The experimentally obtained DeltaM curves are analyzed with a Generalized Moving Preisach Model.
R5.12 FABRICATION AND MAGNETIC PROPERTIES OF COBALT FERRITE/SILICA NANOCOMPOSITE THIN FILMS. Liying Chen, Jian H. Zhang. Department of Chemistry, Xavier University, New Orleans, LA; Volodymyr O. Golub, Advanced Materials Research Institute, University of New Orleans, New Orleans, LA.

Coob ferrite / silica (CoFe2O3)xSiO2(1-x) nanocomposite thin films have been prepared by spin coating method from a new sol-gel type single layer composite sol. The influence of gel composition and annealing temperature to the morphology and magnetic property of the thin films have been investigated. The results indicate that the fabricated thin films have uniform morphologies with controlled thickness and show enhanced coercivity.

R5.13 MAGNETISM AND STRUCTURE OF NANOCOMPOSITE OF IRON AND GOLD SYNTHESIZED BY REDUCTION OF METAL ION IN AQUEOUS SOLUTION. Takaya Koshidai, Rentaro Sato, Yosuke Otsuka, Hiroki Maruyama, Takashi Nakayama, and Takao Y. Haramoto. Osaka Univ, Japan. Department of Nuclear Engineering, Osaka, JAPAN; Tadahiko Nakayama, Osaka Univ, ISIR, Osaka, JAPAN; Okitsu Kenji, Japan Society for the Promotion of Science, Tokyo, JAPAN.

Nanocomposite powder materials composed of single-nanometer magnetic grains of iron-oxide, and gold as a nonmagnetic phase were synthesized by the reversed micelle method or a method in which aqueous metal ions are reduced by gamma-ray irradiation. Formation of nanosized metallic gold colloids was checked by monitoring the absorption band due to the phenomenon with an UV-VIS spectrophotometer and XRD. The X-ray absorption new edge structure indicated that iron was Fe3O4. The average grain size and size distribution determined from TEM micrographs were in a range of 4.1 to 17.2 nm in more than 10 images of geometric standard-deviation, respectively. The magnetization data set measured with a SQUID magnetometer indicated occurrence of superparamagnetism at temperatures 80 K and above. This result indicated that magnetic moment of the Fe3O4 grains were well described from each other by the gold layer or grains in spite of its low contents. The chemical composition determined with the inductively coupled plasma spectrometry was Fe:Au = 2.2 in atomic ratio. The average grain sizes were fairly consistent with those determined by fitting an equation based on the Langevin superparamagnetism to the magnetization data.


The magnetic properties of artificial structures with finite dimensions are of great interest and technological important subjects that have attracted much attention recently accompanied with the advance of nanotechnology. Interesting phenomenon such as the pinning of magnetic domains and nanostructures in patterned structures is one example showing the impact of dimensionality in spatially confined systems. In this study, the X-Ray Photoemission Electron Microscope (X-PEEM) coupled with the XMCD effect is utilized to acquire magnetic image of two series of patterned structures, NiFe and Ni/Fe/NiFe. The structures are prepared by thermal evaporation, electron beam lithography, and lift-off patterning technique. By varying the size and shape of the structures, the impact of dimension and geometry on magnetic domain configuration is studied.


The magnetic nanowire arrays are very important both for basic research and for their potential applications in magnetic recording media, sensors and other devices [1]. NiFe, Ni, Co polycrystalline magnetic nanowires prepared by chemical electrodeposition were reported. This paper focuses on the preparation conditions, structure characterization and magnetic properties of amorphous NiP nanowires. It is found that only such kind of materials were prepared for the first time as nanowires in our group. The nanowires were obtained by electrochemical deposition into the nanoscale porous microstructured polycrystalline nichrome in a two-electrode chemical cell. The influence of the bath composition, pH value and the temperature of the solution on the amorphous phase is presented in detail. Structural investigations by XRD show the presence of only broad peaks characteristic to amorphous phase. Superparamagnetic behavior of about 25 emu/g, Curie temperature of 150°C, and coercive fields of about 25 kA/m were measured using a vibrating sample magnetometer. The crystallization temperature is around 450°C. The influence of the thermal and thermomagnetic treatments on the magnetic characteristics of the NiP nanowires will be presented. The ferromagnetic resonance studies results will be also discussed. [1] A. Fert and L. Piran, J. Magn. Magn. Mater. 223 (1999) 388.

R5.16 GROWTH OF Cu NANOPARTICLES IN AN AMORPHOUS SiC MATRIX FOR APPLICATION IN NOVEL CPP GMRI SPIN VALVES. Dong-Woon Shin, Sun X. Wang, Ann F. Marshall, Stanford Univ, Dept of Materials Science and Engineering, Stanford, CA.

We report the first successful growth of Cu nanoparticles embedded in insulating SiC matrix for applications in novel spin valve devices. Small resistance--area (RA) product has been one of the most demanding drawbacks in the applications of current-perpendicular-to-plane (CPP) GMR spin valve, because nonmagnetic Cu particles introduced to the V-MT-J or C-V-MT-J junctions. One way to increase RA product is to insert nano oxide layer (NOL) in the CPP elements, decreasing the effective area for the current paths. However, this approach will not increase the MR ratio itself since RA and MR are not independent. We have investigated nanoparticle-imbedded spacer layer as a potential solution to the problem. Such a spacer layer is expected to increase both RA and MR ratio due to point-like contacts localized to a few nanometers. A thin film stack of SiC/Cu/SiC was grown by DC magnetron sputtering in ultrahigh vacuum. We found that the Cu film of 3 nm nominal thickness did not wet SiC layer so that it formed discrete nanocrystals. The two SiC layers above and below the Cu film formed an insulating SiC matrix to contain the Cu particles. Both transmission electron microscopy and cross-sectional transmission electron microscopy (TEM) images confirmed the presence of nanocrystalline Cu particles imbedded in an amorphous matrix. The sizes of the particles range between 5 to 10 nm in diameter. Finally, CPP spin valve based on IrMnRh/CoFe/Cu/SiC/Cu/SiC/CoFe/NiFe system were fabricated. All layers were deposited in situ by DC magnetron sputtering and ion beam deposition under UHV condition. The contact areas of 4.81 mm2 were fabricated using liftoff process. Magnetoresistance was measured in four-point geometry configuration to remove resistances incorporated in the leads. MR data show that MR was 43 m% at room temperature.

R5.17 PREPARATION AND CHARACTERIZATION OF FIBROUS ELECTROMAGNETIC WAVE ABSORBER USING FERRITE COMPOSITES. Joong-Hee Nien, Byoung Gil Ahn and Nams-Pal Hur*, Korea Institute of Ceramic Engineering and Technology, Seoul, KOREA. *M.E. Industry, Hwasung, KOREA.

Ferrite has been widely used as an electromagnetic wave absorber (EWA) at high frequency range. EWA properties of ferrites are mainly determined by its magnetic permeability, thickness of specimen and dielectric constants. We have developed materials possessing based on improved compositions for preparation of fibrous EWA. These materials consist of cohesively mixed and bonded polymer fibers filled with ferrite encapsulated by polymer from non-magnetic fibers. The development of effective and cheap EWA composites proceed into goods by high-productive techniques remains an urgent problem of modern science and engineering. Those ferrite materials of typical magnetic properties such as a superparamagnetic behavior dispersed in the polymer matrix of functional filters of different component exist the optimal thickness and filling degree of the binder. The polymer composite materials processing in this study presents a unique possibility to vary in applications of fibrous EWA. It was also investigated that ferrite powders as fillers and composites including monodisperse nanostructure with magnetic particles were prepared to form EWA at high frequency range of GHz.

R5.18 Si-DOPING OF Co/Pd MULTILAYERS FOR IMPROVED SIGNAL-TO-NOISE IN PERPENDICULAR MAGNETIC RECORDING MEDIA. Xiaoyang Qi, Michael J. Hatch, Randall Victoria and Jack Judy, University of Minnesota, Department of Electrical and Computer Engineering, Minneapolis, MN.

Co/Pd based multilayers were Si-doped in order to enhance their potential for perpendicular magnetic recording (PMR) media. Co/Pd multilayers have high interface-induced perpendicular anisotropy, high coercivity and high squareness, all of which make them excellent candidates for PMR. Dopants can be utilized to reduce grain size as well as to reduce magnetic coupling between grains via compositional segregation to the grain boundaries. Ta, Cr, C, O, and especially B have all been used in longitudinal media, and to some extent in perpendicular media, with inhibitory effects. Si was chosen as a dopant because the phase diagrams indicated that Si should to
migrate form silicides at the grain boundaries. An additional benefit of Si as a dopant is that it can be detected chemically, unlike B which is a lighter element. The multilayers were deposited by DCMagnetron sputtering in a high vacuum system with background pressures of 8x10^{-8} Torr and target-substrate distances of 5.5 inches. The growth sequence was 2nm-ITO seed layer, 3nm-Pd adhesion layer, and multilayers of 10 layers of [Co(0.26nm)/Si(0.50nm)/Pd(1nm)] or [Co(0.26nm)/Si(0.50nm)/Pd(1nm)]. The Si-doped multilayers static magnetic properties were very promising as measured by vibrating sample magnetometry. Hc=50000oe, Ms=2000emu and a = 4pM/4H = 1. The latter term is expected to be unity for media in which the grains are magnetically decoupled which promises low noise. Several samples were sputtered for X-ray measurements, see [2] for technique details. The samples were found to have 12 nm grains in 50nm clusters as opposed to 24 nm grains and 80nm clusters in our previous Si-doped samples. In addition, Si-doped multilayers were spin tested at IBM showed an increase in signal-to-noise ratio of a striking 3:1 relative to the best-performing Si-doped samples. [1] E. Fullerton et al. IEEE Trans. Magn. 38, 1583 (2002).

R5.19
MAGNETIC PROPERTIES THICKNESS DEPENDENCE IN NANO-CLUSTERED Nd0.8Fe0.2Al magnetically MELT-SPUN RIBBONS. N. Iapu, H. Chiricu, National Institute of Research and Development for Technical Physics, Iasi, ROMANIA; A. Tokeschi, A. Ioue, Institute for Materials Research, Tohoku University, Sendai, JAPAN.

Extensive structural and magnetic studies on Nd0.8Fe0.2Al melt-spun ribbons different thicknesses (20 to 200 μm) were performed for understanding the specific magnetic behavior of ternary Nd-Fe-Al amorphous alloys. Large coercive fields at room temperature up to 3 T depending on ribbons thickness were obtained, whereas the magnetic moments remain almost unchanged for a given composition. It is important to point out that the mechanism that determines large coercivities in thickness ribbons seems to be different than the one that is responsible for the magnetic behavior of the thin ribbons owing to the different microstructure, which strongly depends on the cooling rate and the preparation conditions. We assume that the microstructure consists of very small B-Nd magnetic clusters, whose size approaches a single magnetic domain, dispersed in the amorphous matrix. The microstructure is more homogeneous in thick amorphous ribbons leading to a higher percolation limit in comparison with the thin ones, as proved by the HRTEM images and neutron diffraction measurements. The dimensions of the magnetic clusters is about 3.3 nm and their composition approaches Fe77Nd23.

R5.20
ELECTRIC CURRENT CONTROL OF MAGNETIZATION IN MAGNETIC NANOSTRUCTURES. V.K. Dyagov, Inst for Problems of Materials Science, Chernovylt, UKRAINE; J. Burnel, Dept of Physics, A. Mickiewicz, Univ Poznáń, POLAND; M. Veeran, Dept of Electronics and Communications, ISEL, Lisbon, PORTUGAL.

Several recent experiments clearly showed that electric current can be used to switch magnetic polarization in magnetic heterostructures. In this paper we present the summary results of our theoretical and experimental studies on the possibility of controlling the magnetic properties by electric current. A theoretical analysis is based on the theory of non-equilibrium distribution of the magnetic polarization and spin-density current created by an external electric field. In the framework of linear response formalism, we calculate the Green's functions of the structure with the spin-dependent potential profile taken into account. Since we are using the basis of scattering states for the Green functions, our calculations can be applied to structures with an arbitrary shape of the confining potential. The approach is based on a quantum description and therefore is applicable to nanostructures, contrary to the existing theories based on quasiclassical methods which are applicable rather to thick magnetic layers. We present the results of analytical and numerical calculations of the non-equilibrium spin density distribution and the magnetic torque. These quantities are calculated as a function of the basic parameters characterizing the heterostructure consisting of magnetic layers with different orientations of the magnetic moments.

R5.21
SPIN STATES OF Mn AND M IN NANOCRYSTALLINE LaMnO2, LaMnO3, MnO2, CoO. N. S. Joly, J.P. Joy, S.K. Date, Physical and Materials Chemistry Division, National Chemical Laboratory, Pune, INDIA.

The nanometer sized polycrystalline ferromagnetic oxides, LaMnO3, MnO2, CoO, Mn, synthesized by a low-temperature technique, exhibits interesting magnetic behavior. A lower ferromagnetic transition temperature observed for the nanomaterial was found to be the highest in agreement with different states of Mn and M when compared to the spin states of these ions in the bulk material and not due to the decrease in the particle size. The nanocrystalline materials form a different phase of these oxides. The interesting structural and magnetic behavior of these nanocrystalline ferromagnetic oxides will be discussed.

SESSION R6: MAGNETIC THIN FILMS

Chair: Vitali V. Melezhik and K. V. Rao

Thursday Morning, April 24, 2008
Golden Gate C3 (Mission)

8:30 AM R6.1
MAGNETISM IN LaFeO3: EXCHANGE BIASED SYSTEMS. Jean-Pierre Loquet, IBM Research Division, Zurich Research Laboratory, Rochester, SWITZERLAND.

Epitaxial films of the antiferromagnetic LaFeO3 grown by MBE have recently opened several exciting avenues to explore the properties of exchange biased systems. The observation of the magnetic signature of large antiferromagnetic domains using PEEM was reported. Next it was demonstrated that these antiferromagnetic domains are exchange coupled with a substantially deposited ferromagnetic film. With the same technique, it was demonstrated that the AFM vector in thin films can point along a different direction than in bulk samples. Such films were also used to measure for the first time soft x-ray speckle in magnetic scattering from antiferromagnetic domains. Finally the neutron reflection measurements suggest that the antiferromagnet has developed a finite magnetic moment confined close to the interface which does not reverse upon field reversal.

9:00 AM R6.2
ENHANCEMENT OF NÉEL TEMPERATURE IN THIN ANTIFERROMAGNETIC NiFe FILMS. Hongtao Shi and D. Lederman, Physics Department, West Virginia University, Morgantown, WV; K. V. O'Donnell and J.A. Borchers, Institute of Standards and Technology, Gaithersburg, MD.

(110)-oriented thick NiFe films were deposited on single crystal NiFe substrates via molecular beam epitaxy, followed by 18 nm thick Co layers. Neutron diffraction revealed that the Néel temperature (TN) in single NiFe film (60 nm thick) and NiFe/Co bilayer was enhanced to ~80 K, compared to TN = 73 K bulk single crystal NiFe. Exchange bias in the bilayer was enhanced [HxB] after cooling the bilayer sample in a magnetic field of 2400 Oe. The film thickness dependence of the NiFe thickness was measured. [J.W. Scott and E. Burstein, J. Chem. Phys. 25, 1965 (1956)].

9:15 AM R6.3
ON THE MAGNETIC INSTABILITY OF Fe1-xNi1-xLx PSEUDOMORPHIC THIN FILMS EXHIBITING THE INVAR EFFECT: J.G. Tobin, M. Hochstrasser, S.A. Morton, Livermore National Laboratory, Livermore, CA; G.D. Wilks, University of Missouri-Rolla, Rolla, MO; N.A.R. Gilman, R.F. Wills, Pennsylvania State University, University Park, PA.


9:30 AM R6.4
EFFECT OF Cu DIFFUSION ON MICROSTRUCTURE AND MAGNETIC PROPERTIES OF Cu110FePt (001) FILMS AT LOW DEPOSITION TEMPERATURE. J.P. Wang, MINT & Electrical and Computer Engineering Department, University of Minnesota, Minneapolis, MN; J. S. Chen, Data Storage Institute, SINGAPORE.

Ordered FePt films with high magnetic anisotropy have been studied due to their high potential for use as recording media at ultrahigh densities approaching 1Tb/in^2. 110 FePt films with perpendicular [1] and longitudinal [2] anisotropy has been prepared on Cr90Ru10/glass at substrate temperature 400°C or below dc magnetron sputtering. Effect of Ru pinning layer in FePt films has been employed to control the reversal mechanism [3]. Strong exchange coupling between grains would cause the increase of media noise. It is of interest to investigate the possibility of controlling exchange coupling by chemical segregation. In this work, Cu top layer with the
thickness from 0 to 4 mm was deposited on the FePt layer at the temperature 350°C. The XRD results indicate that with 2 and 4 mm Co top layer thickness, the FePt phase was not observed. The rocking curves of the X-ray diffraction peaks showed that the FePt (001) orientation starts to deteriorate when the Cu top layer is above 4 nm. The c/a, which is not dependent on the Cu top layer, is 0.986 and FePt phase is fully ordered. The coherency of the films increases from 2.1 koe to 7.8 koe. The slope of c decreases to about 1/4 after the introduction of Cu top layer, which indicates a well exchange-coupling. The increase in the coercivity is assumed to the change in reversal mechanism of magnetization. The FePt layer is nucleated on the Co substrate and the growth is in the (111) orientation mode.


10:30 AM R6.5
INTERFACIAL TRANSFORMATION LAYERS PROBED BY SOFT-X-RAY RESONANT MAGNETIC SCATTERING. Bryan M. Barnes, John J. Kelly IV, Don Sauge, Eric Wiedman, and Mac G. Loganley, University of Wisconsin-Madison, Madison, WI.

Understanding the effect of morphology on the magnetic properties of thin films is critical to understanding such diverse phenomena as spin-dependent transport (e.g., giant magnetoresistance (GMR)) in-plane magnetic reversal, coupling between magnetic films, and exchange bias. X-ray resonant magnetic scattering (XRRS) provides element-specific information about both the magnetization and structural properties of magnetic materials. Specifically, resonant XRRS measurements provide a depth profile of the magnetization of thin films while the diffusely scattered component of XRRS (XRRS) provides a depth profile of the morphology of both the chemical and magnetic boundaries. If the magnetic boundary does not coincide with the chemical boundary, it lies more in the magnetic material, implying a non-magnetic transition layer near the interfaces. Two models can explain the existence of a transition layer that is magnetically inactive or less active than the bulk of the film. Interface moments could be pinned out-of-plane by surface micromotry, or interface moments could become decoupled from the bulk moments. We perform XRRS on ultrathin Co films to determine aspects of the physics of transition layers. By examining bare and capped Co films on both smooth and rough substrates, we find that spins that are decoupled from bulk moments, and can move more or less freely at the temperature of the measurements are the primary cause of the loss of magnetic order at surfaces or interfaces. In addition we are able to show, via the ability to probe buried interfaces, that the transition layers at the bottom and top of a magnetic film can be of unequal thickness, and thus for Co films less than 10nm thick, the top and bottom transition layers meet so that the film exhibits no magnetism. We show the dependence of these results on interface roughness.

Research supported by ONR and Seagate Technologies, Inc.

10:45 AM R6.7

A first order reversal curve (FORC) technique has been used to investigate the magnetic properties of small magnets in a series of exchange-spring magnet systems. For each of the samples studied, the coercivity distribution was centered around the coercivity value determined from the major loop. Surprisingly, however, the bias distribution exhibits a displacement from the zero bias axis, similar to exchange biased films. The bias distribution is centered around 0 mT, even though the major loop is centered about 0 mT. Furthermore, with decreasing Ni thickness, the coercivity distribution monotonically shifts towards higher values, while the bias distribution first increases and then eventually decreases as Ni thickness decreases.

11:00 AM R6.8
MAGNETIZATION REVERSAL DETAILS IN EXCHANGE BIASED Fe/FexCo/FexNi. K. Liu, H.G. Koning, C.R. Pike, L. Zhao, R.T. Scelletar, K.L. Veroush, G.T. Zmami, University of California, Davis, CA, W. Schulz, University of California, San Diego, La Jolla, CA.

Details of the magnetization reversal processes have been investigated by a first order reversal curve (FORC) technique in an exchange biased Fe (27 nm)/FexNi (20 nm) thin film. After measuring a family of 1000 reversal curves along the major hysteresis loop, we transform the second order mixed derivative of the magnetization relative to the magnetic field to the second order mixed derivative of the coercivity and exchange field in a FORC diagram. At 100 K, above the FeFexNi temperature of 80 K, the FORC diagram shows a narrow distribution of coercivity and exchange field that are consistent with the major-loop kopp values. Surprisingly, the tail of higher coercivity regions bends towards lower exchange fields, contrary to the belief that the exchange field measured in a major loop is the lower limit of the exchange field across the sample. Comparisons of the FORC diagrams generated from the decreasing- and increasing-field branches of the major loop will also be presented.

This work is supported by NSF and UC Davis. 1C.R. Pike, A.P. Roberts, and K.L. Veroush, J. Appl. Phys. 85, 6660 (1999).

11:15 AM R6.9

Quantum well states (QWS) in metallic ultrathin films play an important role in many phenomena such as the oscillatory magnetic interlayer coupling in magnetic multilayers. Photoemission provides the most direct observation of QWS. In the last two years, we have improved significantly the quantum film thickness determination at the atomic scale and allows us to address some issues that we could not address before. One important issue is the quantization condition of the electronic states in the metallic layer. QWS have been widely described by the phason accumulation model (PAM) in which the phason at the interface/surface is calculated by assuming a step function of the potential well. With our recent photoemission data, we can determine the phase value in experiment. We found that the experimental phase value is different from the phason accumulation model. This can be due to the nature of the Co energy gap which results from the hybridization of the s-d electrons, thereby changing the local potential geometry at the interface. First-principle calculations were performed in order to verify the phase determined by the PAM. However, a more sophisticated microscopic wavefunction fitting procedure is required.

11:30 AM R6.10
IN SITU SCANNING PROBE IMAGING OF CO FILMS UPON ANNEALING. Jorge Espinosa, Hongtao Shi, and David Lederman, Physics Department, West Virginia University, Morgantown, WV.

Atomic force microscopy (AFM) and scanning tunneling microscopy (STM) were employed to investigate the surface roughness of 3.0 - 5.0 nm thick Co films as a function of annealing temperature. Films were epitaxially grown on Si (110) substrate at 315°C via MBE and magnetron sputtering. As-grown films had a surface roughness of approximately 0.7 nm. Images were acquired in situ at temperatures ranging between room temperature and 600°C. The surface roughness at room temperature and increased to 5.0 nm at 600°C. Magnetic properties of the samples and thermal hysteresis of the roughening transition will be discussed.

11:45 AM R6.11
ANALYTICAL ELECTRON MICROSCOPY CHARACTERIZATION OF MULTILAYER PERPENDICULAR RECORDING MEDIA.
High-spatial-resolution analytical electron microscopy (AFM) characterization has been performed on several sets of nanoscale mask layer reference and model materials for perpendicular magnetic recording, such as CoPt/CrTa/Co/CoZrN/CoAl and (Fe/CoN/FeMn) multilayers. The main techniques employed were spectrum imaging and spectrum profiling of cross-sectioned specimens with simultaneous energy-dispersive X-ray (EDS) and electronic energy-loss spectroscopies (EELS) in the scanning transmission electron microscopy (STEM) mode on a Philips CM200FEG AEM equipped with an Emsite Vision integrated data acquisition system. Elemental mapping by energy-filtered transmission electron microscopy (EFTEM) has also been performed on some samples. An important issue in structure-property correlations for such materials is the degree of chemical mixing at the interfaces between the various layers. AFM has revealed some unexpected and interesting compositional profiles. However, the data rarely yield compositional profiles simply or easily because of potential artifacts arising from sample preparation, specimen limited spatial resolution from probe-size and beam spreading, and complications in analysis of the spectra due to a severe peak overlap and background fitting. With carefully controlled data acquisition, advanced spectral processing methods, and care in specimen preparation, many of the artifacts or limitations can be minimized or eliminated in improved confidence in compositional data. Research at the ORNL SHARE Collaborative Research Center was sponsored by the Division of Materials Science and Engineering, U.S. Department of Energy, under contract DE-AC05-00OR22725 with UT-Battelle, LLC. Support from an IBM Faculty Partnership and the National Storage Industry Consortium is also gratefully acknowledged.

SESSION R7: UNCONVENTIONAL MAGNETS AND DYNAMS

Chair: Samuel B. Bodie and Jean-Pierre Lozach
Thursday Afternoon, April 24, 2003
Golden Gate C (Marriott)

1300 PM **R7.1**
MAGNETISM OF FERROMAGNETIC SEMICONDUCTOR STRUCTURES. Hideo Ohno, Lab. for Electron. Intelligent Systems, Res. Inst. of Electrical Commun., Tohoku University, Sendai, JAPAN.

Carrier-induced ferromagnetism in magnetic III-Vs has allowed integration of magnetic cooperative phenomena with III-V heterostructures. I will review a number of new structures and phenomena that have been exploited and demonstrated using ferromagnetic III-V structures, including isotropic and irreversible electric field control of ferromagnetism.

2000 PM **R7.2**
NANO-MAGNETICS IN MAGNETOELECTRONIC/SPINTRONIC APPLICATIONS. Jo De Boeck, IMEC, Leuven, BELGIUM.

The electronic properties of magnetic materials and multilayers are well recognized as being essential for a wide range of applications we use today or expect in the near future. These range from magnetic read-heads, over discrete and integrated magnetic sensors to magnetic random access memories. Many of these application areas are on a so-called roadmap towards down scaling and performance increase. In all cases this implies nanoscale dimensions in the device structures and full control over the properties at that scale. Further, the improved understanding of nanoscale magnetic features lead to proposals for new applications like magnetic logic or novel device concepts. In the novel-device corner, hybrid magnetic / semiconductor spintronic device structures are appearing. In case these latter devices, currently fabricated with micron-size dimensions, endeavor to challenge the mature advanced electronic components in the future, nanoscale dimensions will be a must. With respect to the above application potential of nano-magnetic structures one needs to take into account the stability and reliability of the device/fabrication operation, power consumption, the complexity (cost) of fabrication and the [in-process] testing of magnetoelectronic / spintronic characteristics. Many of these requirements lead straight back to the nanoscale material that will be at the heart of these applications. The views and challenges will be illustrated by examples from the recent literature, illustrated further by results from our own research activity. Further, the author acknowledges the contributions of W. Van Roy, P. Van Dorpe, V. Moens, Z. Liu, W. Hebert, L. Lagae, J. Dha, W. Eckmans, J. Bekker, R. Wirix-Spetjens, J.L. Primas and G. Borghs.

2:30 PM **R7.3**
A NEW ROOM TEMPERATURE FULLERENE-BASED ORGANIC FERROMAGNET. K.V. Rie, Lisbeth Belev, Wolfgang Voit, Department of Materials Science-Tinyf-MSE, Royal Institute of Technology, Stockholm, SWEDEN, Frank J. Owens [Army Armament Research, Development and Engineering Center, Picatinny, New Jersey (USA)], and Zafar Iqbal [Department of Chemistry, New Jersey Institute of Technology, Newark, New Jersey].

We report the discovery of ferromagnetism with a Curie temperature well above room temperature, in a compound consisting of C60 and the paramagnetic organic molecule 2,2,6,6-tetramethyl-4-oxy-piperidinoxy (TMOP). Samples containing approximately 10 weight percent of the magnetic phase, determined by conducting quantum interference device (SQUID) magnetometry measurements, have been obtained by mixing nominal 1:1 molar ratios of C60 and TMOP dissolved in an organic solvent in the presence of traces of a catalytic reagent, under ambient conditions. The absence of magnetic metallic elements down to the parts per billion range is shown by inductively coupled plasma mass spectrometry (ICP-MS). Ferromagnetic resonance (FMR) and SQUID magnetometry results clearly show the existence of soft ferromagnetism at and above room temperature. The ability to produce patterned ferromagnetic films of C60 based ferromagnets on various substrates will also be presented.

3:30 PM **R7.4**
EXCHANGEBIAS SYSTEMS: EFFECT OF NANOPATTERNING AND MAGNETIZATION REVERSAL. Michael Fraune, Andrea Trupin, Ulrich Rüdiger*, Bernhard Beschten, S. Cardinal, T. Freisert*, Gernot Glüherdott, H. Physical Institut, RWTH Aachen, Aachen, GERMANY; Fachbereich Physik, Universität Konstanz, Konstanz, GERMANY, INESC, Lisbon, PORTUGAL.

The domain state model for exchange bias (EB) presented recently [1,2] considers defects at the magnetic sites in the volume of the antiferromagnet (AFM), thus stabilizing volume domains in the AFM. This domain state in the volume of the AFM carries after field cooling a surplus magnetization. These uncompensated, irreversibly pinned magnetic moments in the AFM couple at the interface to the ferromagnetic (FM) layer and thus cause exchange bias. In order to tune the domain state model and to identify a characteristic length scale of the domains in the volume of the AFM layer we have patterned FM/AFM layer systems to lateral dimensions down to 100 nm. As low anisotropy AFM material yielding large domain wall widths and sizes we have chosen NiO. In the NiO/Ni system the exchange bias field at room temperature is reduced by a factor of four in going from the continuous layer system to wires of minimum width 120 nm [4]. This decrease is consistent with the domain state model. No such reduction is found at 5K. The reduction in the EB field at room temperature is paralleled by an increase in the coercive field proportional to the inverse wire width. The effect of etching on the exchange bias field and the coercivity will be discussed by comparing iron milling vs. reactive ion etching processes. The magnetization reversal in exchange bias systems has been measured by means of a magneto-optic Kerr setup using both longitudinal and transverse configurations. The asymmetry of the hysteresis loops, i.e., coherent rotation of the magnetization during domain nucleation and propagation processes, has been tested [5] on the very same samples studied before using polarized neutron reflectometry [6]. The coherent rotation of the magnetization can clearly be identified by the transverse Kerr component. The effect of patternning of exchange bias systems on the magnetic [v/symmetric] magnetization reversal will be discussed. Work supported by Deutsche Forschungsgemeinschaft through SPP 1130, grant no. BE 2441/3-1 and by EC RTN Networks SUBMAGNET and SERNHAS. [1] P. Milotny, J. Keller, B. Beschten, G. Glüherdott, U. Nowak, K.D. Undel, Phys. Rev. Lett. 84, 4294 (2000) [2] U. Nowak, K.D. Undel, P. Milotny, J. Keller, B. Beschten, G. Glüherdott, Phys. Rev. B 65, 144501-1-5 (2002) [3] J. Keller, P. Milotny, B. Beschten, G. Glüherdott, K.D. Undel, Phys. Rev. B 66, 144511-1-11 (2002) [4] M. Fraune, U. Rüdiger, G. Glüherdott, S. Cardoso, T. Freisert, Appl. Phys. Lett. 77, 3815 (2000) [5] Work in cooperation with I.K. Schaller, C. Leighton, J. Eisenmenger, M.R. Fitzsimmons [6] M.R. Fitzsimmons, P. Yash, C. Leighton, I.K. Schaller, J. Nogues, C.F. Mijakowski, J.A. Dura, Phys. Rev. Lett. 84, 3866 (2000).

4:00 PM **R7.5**
MULTIBAND TIGHT-BINDING MODEL OF LOCAL MAGNETISM IN Gd1- xMnx As. Jins-Ming Tsai, Michael Flatté, University of Iowa, Department of Physics and Astronomy, Iowa City, IA.
The spin-resolved local density of states and the spin polarization of the valence band around Mn atoms in GaAs are presented. We use the Koster-Slater technique to calculate the local density of states, and the GaAs host is described by a spin-tight-binding Hamiltonian that incorporates spin-orbit coupling. The enhancement of the local density of states near the band edge due to the resonance states of Mn is very different for the two spin components, which influences the interaction between Mn atoms within GaAs. The valence band edge local density of states is enhanced by a factor of 5 over that in the absence of Mn. We also calculate the splitting of the acceptor level for two neighboring Mn atoms. The splitting of the acceptor level exceeds 20 meV for Mn atoms separated by 3 lattice constants, which perhaps could be imaged with scanning tunneling spectroscopy.

4:15 PM R7.6
MAGNETO-TRANSPORT OF MAGNETIC TUNNEL JUNCTIONS WITH AN MnSb ELECTRODE. Alex F. Panchula, Christian Kaiser, Stuart P. Parkin, IBM Almaden Research Center and Stanford University.

Surface studies show that thin films of NiMnSb, a proposed half-metal, can suffer from surface segregation of Mn and Sb. [Hiscox et al. Appl. Phys. Lett. 76 (2000) 2349]. This segregation at the electrode-barrier interface in magnetic tunnel junctions (MTJs) has the potential to destroy the halfmetallic behaviour. MnSb is a ferromagnetic metal with a large width of formation and a Curie temperature above room temperature. The spin polarization of Mn(x)Sb(1-x) for x = -0.5 has been explored via spattering MTJs using CoFe as a counter-electrode, and by spin polarized tunneling into superconductors. MnSb shows a tunnel spin polarization of 30%, and a tunneling-resistance of about 18%. These results are compared to reported data on NiMnSb. [Tanaka et al. J. Appl. Phys. 86 (1999) 6239] and support the theory that surface segregation of Mn and Sb effects the spin transport.

4:30 PM R7.7
LOSSLESS ENHANCEMENT OF GHz PRECESSIONAL FREQUENCY IN Ni_{1-x}Fe_{x} using dilute Eu impurities. Lili Cheng, William E. Bailey, Sean G. Reddy, Columbia University, Department of Applied Physics and Mathematics, Materials Science Program, New York, NY.

Dopant elements in ferromagnetic thin films can be used to control the ultrafast (<1ns) response of magnetization. In this work, we show that dilute concentrations (2 to 5%) of Eu in Ni_{1-x}Fe_{x} can boost the precessional frequency of the system by over 400 MHz without effect on Gilbert magnetic damping parameter a. This is equivalent to a dynamic anisotropy field of over 9 Oe “stiffening” the system. The source of the effect is under investigation. Comparison of microwave inductive measurements and MOKE magnetometry indicates that static and dynamic anisotropy do not correlate well for the doped films. Kittel plot analysis shows that the $g_eff M_s$ product is not strongly affected. The results indicate that it is possible to tailor the resonance frequency in magnetoelectronic devices over a large range without effect on damping characteristics.

4:45 PM R7.8
CURRENT-INDUCED SPIN EXCITATIONS IN SEVERAL MAGNETIC MULTILAYER SYSTEMS. Matthew R. Pufahl, W.H. Ripplard, T.J. Silva, National Institute of Standards and Technology, Magnetic Technology Division, Boulder, CO.

We are investigating current-induced spin excitations in magnetic multilayers as sources of coherent spin populations. In a multilayer, a perpendicularly-flowing current polarized by one layer will transfer its spin angular momentum to another layer, an effect called spin-momentum transfer. This induces magnetization motion observable as a field-dependent step in the resistance vs. current for a point contact. Skomorowski and Berger attribute this step to the onset of coherent, high-frequency (10-1000 GHz) spin excitations [1,2]. Previous work demonstrated these excitations only in antiferromagnetically-coupled (AF) Co/Cu multilayers in large out-of-plane fields [3], or in patterned Co/Cu nanowires [4]. Subsequent work has extended these results, but again using the Co/Cu system. Using point contact spectroscopy, we found these excitations to occur for both in- and out-of-plane fields, for ferromagnetically (F), AF, and un-coupled multilayers, and for several material systems: Co/Cu, CoFe/Cu, NiFe/Cu, Fe/Cu, and NiFe$_{0}$Co$_{2}$Cu/Cu. For all systems, the excitations were of similar character, with the critical onset current $I_c$ exhibiting a linear field dependence, implying a general effect. We have also found the excitations occur in zero field for F-coupled multilayers. Spin transfer efficiencies have been extracted for several systems using the Skomorowski theory, and are found to be in the range expected for the polarization values of the constituent materials. These data are strong indirect evidence that the measured resonance steps are coherent spin excitations. We also discuss our work toward direct measurement of the frequency spectrum of the excitations, using microwave circuitry and on-chip Josephson junctions as radiation detectors. [1] L. Berger, Phys. Rev. B 54, 17983 (1996) [2] J.C. Skomorowski, J. Magn. Magn. Mater. 159, L1 (1996) [3] M. Tsoi et al., Phys. Rev. Lett. 80, 4281 (1998) [4] J.A. Katine, et al., Phys. Rev. Lett. 84, 3149 (2000).