SYMPOSIUM R

Nanomagnetism

April 22 – 24, 2003

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* Invited paper

SESSION R1: NANOMAGNETS PREPARATION I
Chairs: Dieter Weller and Kai Liu
Tuesday Morning, April 22, 2003
Golden Gate C3 (Marriott)

8:30 AM *R1.1
ARRAYS OF MAGNETIC NANOWIRES VIA BLOCK COPOLYMER TEMPLATES. Thomas Russell, Polymer Science and Engneering Department, University of Massachusetts Amherst Amherst, MA; M.Tuominen, 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. Poly(styrene-methacrylate) (PS-PMMA) diblock copolymers as porous templates that were used to fabricate hexagonal arrays of vertical nanowires with densities of exceeding $1x10^{12}$ per square inch. Electrodeposition within the template produces 10nm-scale magnetic cobalt nanowire arrays that exhibit large perpendicular coercivity and remanance 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 electrodeposition process parameters. The copolymer templates have been patterned laterally using conventional lithographic exposure to fabricate novel 3D magnetic nanowire devices. This includes current-in-plane magnetoresitive devices and current-through-wire switching field devices. Anisotropic magnetoresistance measurements show a sharp and complete magnetization reversal, indicating single-domain nanowire switching behavior. Such properties offer promising potential for new magnetic nanodevices 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 I. Smith, Massachusetts Institute of Technology, Cambridge MA.

Arrays of small magnetic particles have been proposed for use in various magnetoelectronic 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 their size-dependent magnetic behavior. We will review recent progress in the fabrication, characterization, and analysis of large area 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 behavior 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 multilayered Co/Cu/NiFe rectangular pseudo-spin-valve bars made by interference lithography. We will also discuss the properties of ring-shaped 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 NANOLITHOGRAPHY (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; Xiaogang Liu, Yi Zhang, and Chad A. Mirkin, Department of Chemistry and Institute for Nanotechnology, Northwestern University, Evanston, IL.

A direct-write approach with site- and shape specificity for functional inorganic nanostructures is demonstrated with the example of fabrication of "hard" magnetic barium hexa-ferrite (BaFe) nanostructures, based on a synergistic combination of dip-pen nanolithography (DPN) and sol-gel process. This method includes generation of BaFe precursor patterns using a conventional atomic force microscope (AFM) tip that is coated with the BeFe precursor solution, followed by a thermal treatment to convert patterned organic-inorganic complexes 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, magnetic force microscope (MFM), and x-ray photoelectron spectroscope (XPS). This approach suggests a novel way of direct patterning of magnetic nanostructures at sub-100nm scale with size and shape-specificity for improved magneto-electronic devices.

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

Nanometric Ferrihydrite ($FeOOH.nH_2O$) particles formed within an organic-inorganic hybrid matrix were obtained by the sol-gel process. In contrast to precipitation techniques, sol-gel process appears as suitable way to achieve size-controlled nanoscopic magnetic particles anchored in a hybrid structure. The hybrid matrix here reported, classed as di-ureasil, is composed of poly(oxyethylene) chains grafted to siloxane groups by means of urea cross-linkages(1). Iron was incorporated during the sol-gel process as nitrate leading to the formation of Ferrihydrite particles, whose size is determined by the iron concentration in the hybrid. From 1.2 to 5.8% iron mass concentration, SAXS studies give particle gyration radius from 18 to 37$\AA$ (2). The average distance beteween particles is of the order of 200 $\AA$. The magnetic susceptibility shows thermal irreversibility with a blocking temperature $T_B \approx 13K$. The magnetization shows coercive and exchange fields, of the order of 1000 Oe at 5K, rapidly decreasing with temperature, due to an anisotropy and an exchange coupling between surface-canted and core spins. The magnetic relaxation was also studied. Above the irreversibility the magnetization follows a Langevin function modified with a linear term, as found in antiferromagnetic particles (3,4). The overall properties are characteristic of systems of magnetically independent nanoparticles, as found in ferritin (3), rather than in nanometric-aggregated ferrihydrite powders(4). 1. V. de Zea Bermudez, L.D. Carlos, L. Alccer Chem. Mater. 11, 569 (1999). 2. N.J.O. Silva, K. Dahmouche, C.V. Santilli, V.S. Amaral, L.D. Carlos, V. de Zea Bermudez and A.F. Craievich, J. Appl. Cryst., submitted. 3. S.A. Makhlouf, F.T. Parker and A.E. Berkowitz, Phys. Rev. B 55, 14720 (1997). 4. M.S. Seehra, V.S. Babu, A. Manivannan and J.W. Lynn, Phys. Rev. B 61, 3513 (2000).

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

CoCrPt alloy 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 magnetocrystalline anisotropy. Diblock copolymer templates are one of the most promising candidates for nanoscale pattering otherwise inaccessible by lithographic procedures. In this study, we have investigated magnetic properties of $Co_{68}Cr_{18}Pt_{14}$ thin films deposited on nanopatterend PS_{21400}(styrene)-PVP_{20700}(vinyl pyridine) diblock copolymer. The PS-PVP diblock copolymer were coated on Si(100) substrate via 20 second dipping in diblock copolymer/toluene 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 CoCrPt thin films were deposited on this self-assembled polymer surface. The surface morphology of CoCrPt also shows a regular and highly ordered spherical islands silmilar to the PS-PVP template. Magnetic property of CoCrPt films were measured by magneto-optical microscope magnetometer (MOMM) and torque magnetometer. The perpendicular magnetic anisotropy (PMA) of CoCrPt films strongly enhanced when we deposited the films on nanopatterned PS-PVP polymer. The squareness ratio, defined as the remnant Kerr rotation angle divided by the saturation one, increased from 0.34 to 0.85 for the samples of 200-$\AA$ CoCrPt/PS-PVP/Si(100) and 200-$\AA$ CoCrPt/Si(100), respectively. The coercivity is also increased drastically from 150 Oe to 544 Oe. Considering the magnetic dipolar interaction together with the magnetocrystalline anisotropy, we will discuss the origins of enhanced PMA in CoCrPt/PS-PVP films as well as the growth mode of CoCrPt films. This work is supported by the Korean Ministry of Science and Technology through the Creative Research Initiatives Project.

10:45 AM R1.6
THE MAGNETIC PROPERTIES OF STYRENE-BUTADIENE-STYRENE - BARIUM FERRITE NANOCOMPOSITES. Mircea Chipara, Indiana University Cyclotron Facility, Bloomington, IN; Diandra Leslie Pelecky, David Sellmyer, Amy Bender, and Lanping Yue, Dept of Physics, University of Nebraska, Lincoln, NE.

Magnetic nanocomposites have been obtained by dispersing various amounts of barium ferrite ($BaFe_2O_{19}$) nanoparticles in a dilute solution of copolymer. To achieve an uniform distribution of magnetic nanoparticles, the solution (styrene-butadiene-styrene and barium

ferrite) was sonicated for 24h. The magnetic nanoparticles were obtained by mechanical milling. Their average grain size has been estimated to be about 15 nm, from the width of X-Ray diffraction lines. Vibrating 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 $M=M_S(1-A/H-B/H^2)$, after extracting a linear contribution due to the diamagnetic and paramagnetic contributions. M_S is the magnetization at saturation and B is related to the magnetocrystalline anisotropy. A matrix effect was observed in the temperature dependence of M_S and B close to the glass temperature of the polystyrene phase and confirmed by the temperature dependence of the magnetic properties in a composite based on cement and $BaFe_2O_{19}$. This result suggest that in magnetic nanocomposites the time evolution 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 motions involve several molecules, are 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, 263-265, 1997.

11:00 AM R1.7
SYNTHESIS AND CHARACTERIZATION OF MONODISPERSE MAGNETITE AND COBALT FERRITE NANOPARTICLES.
Hao Zeng and Shouheng Sun, IBM T.J. Watson Research Center, Yorktown Heights, NY.

Fe3O4 and CoxFe3-xO4 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 material, particle sizes can be tuned from 4 nm to 16 nm. These nanoparticles are spherical, monodisperse and single crystalline, allowing them to be self-assembled into three-dimensional superlattices. The as-synthesized magnetite particles are superparamagnetic. With increasing sizes, the blocking temperature increases systematically, 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 ~100K in both the ZFC and FC curves is observed. This may be attributed to Verwey transition in mixed- valent magnetite systems. The CoxFe3-xO4 is synthesized with x = 2, 1.5, 1 and 0.6, 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 Co1.5Fe1.5O4 nanoparticle assemblies show large coercivity at low temperatures (above 12 kOe at 10 K), while their blocking temperatures reach above 170 K. These are consistent with the large magnetocrystalline anisotropy constant reported for cobalt ferrites. The iron oxide based nanoparticles and their self-assemblies may have potential in microwave and biological applications.

11:15 AM R1.8
COOPERATIVE MAGNETISM IN DIPOLAR NANOCOMPOSITES.
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 nanostructural 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 an oxygen-free solvent with a surfactant, are field-structured at room temperature. Dipolar forces in a static magnetic field assemble the particles into one-dimensional chain-like structures. The formation of three-dimensional composites is modeled in a detailed numerical calculation and compared to TEM images; the rapid evolution of these structures is demonstrated by light scattering. These structured nanocomposites exhibit greater than 10-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 magnetocrystalline anisotropy restricts the rotational freedom of the giant spins on 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 and an increased 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 was 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-AC04-94AL85000.

11:30 AM R1.9
MAGNETIC NANOCOMPOSITE THIN FILMS PREPARED BY SOL-GEL PROCESS.
Nelcy Della Santina Mohallem, Luciana Moreira Seara, Dept of Chemistry, UFMG, Belo Horizonte, BRAZIL.

Nanostructured oxide thin films have potential technological use for their high surface/volume ratio, which lends them unique properties diverse 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 formed by cobalt ferrite dispersed in silica matrix were prepared by sol-gel process using tetraethylorthosilicate (TEOS) as a precursor of silica, and metallic nitrates as precursors of the ferrite. $CoFe_2O_3/SiO_2$ 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 20 nm. The nanocomposite films presented the formation of crystalline $CoFe_2O_4$ phases dispersed in amorphous SiO_2 matrix and saturation magnetization of 30 emu/g and coercivity of 196 Oe.

11:45 AM R1.10
HYBRID PEROVSKITES FOR POLYMER-BASED MAGNETICALLY ACTIVE NANOCOMPOSITES.
Etienne Wortham and Alexandros Lappas, Inst of Electronic Structure & Laser, Foundation for Research & Technology - Hellas, Heraklion, Crete, GREECE; Rabindra N. Das and Emmanuel P. Giannelis, Cornell Univ, Dept of Mat Sci & Eng, Ithaca, NY; Andrej Zorko and Denis Arcon, Inst Jozef Stefan, Ljubljana, SLOVENIA.

Organic-inorganic hybrid materials can provide very useful properties by coupling together characteristics of the individual organic (e.g. plasticity, efficient luminescence) and inorganic (e.g. magnetism, 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 $(C_nH_{2n+1}NH_3)_2MnCl_4$ (n = 2, 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 an antiferromagnetic state at low temperatures (<43 K). We note that their magnetic behaviour is marginally affected by the varying width, d, of the organic double-layer separator (d≅ 1.1-4.5 nm). Utilizing the chemical activity and structural flexibility of the organic cations, 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 hrs and then ultrasonicated for 25 minutes. Perovskite-PDMS nanocomposites were prepared by speed mixing the appropriate amount of $(C_nH_{2n+1}NH_3)_2MnCl_4$/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 alkylamine chain lengths afford control over the particle size and prevent possible agglomeration. 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 nanocomposite materials where non-linear excitations or solitons prevail in a similar fashion to that in the parent hybrid perovskitic systems, however, at reduced transition temperatures. We suggest that changing the mechanical attributes (e.g. by applied stress) of the polymeric matrix we can modify the magnetic exchange characteristics of the 2-dimensional perovskitic arrays that may lead to a potentially switchable magnetic composite material.

SESSION R2: NANOMAGNETS PREPARATION II
Chairs: Mark Tuominen and David Lederman
Tuesday Afternoon, April 22, 2003
Golden Gate C3 (Marriott)

1:30 PM *R2.1
FERROMAGNETIC NANOWIRE ARRAYS IN POROUS ALUMINA: FROM 2D-POLYCRYSTALLINE TOWARDS SINGLE CRYSTALLINE ARRANGEMENT. Kornelius Nielsch[a], Ralf B. Wehrspohn, Jinsub Choi, Riccardo Hertel, and Ulrich Gösele, Max Planck Institute of Microstructure Physics, Halle, Germany; [a]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 $h/D_P = 2.5$ [1] (ratio of wire length h to diameter D_P) have been achieved by C.A. Ross et al.. In order to obtain magnetic columns with larger aspect ratios ($h/D_P > 10$), self-ordered porous alumina based on the approach of Masuda et al. [2] is a suitable template. Currently, highly-ordered magnetic nanowire arrays exhibit a 2D-polycrystalline arrangement with a dispersity $\Delta D_P / D_P \geq 8\%$. The fabrication of Ni nanowire arrays based on imprint lithography will be presented, which show a perfect hexagonal arrangement on a cm^2-scale and $\Delta D_P / D_P \approx 2\%$. 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*, Spain, 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. Masuda and K. Fukuda, *Science* **268**, 1466, (1995).
[3] Z.K. Wang et al., *Physical Review Letters* **89**, 027201 (2002).

2:00 PM R2.2
USING TRIAXIAL MAGNETIC FIELDS TO CREATE HIGH SUSCEPTIBILITY PARTICLE COMPOSITES. James E. Martin, Eugene Venturini, and Gerald Gulley, 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 in 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 heterodyned 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 foams. That such structures should evolve is not obvious, but molecular dynamics simulations we have performed clearly demonstrate these effects. These composites have susceptibilities that are greatly enhanced over random particle composites, and we have shown that large susceptibility anisotropies can be created through modest field amplitude imbalances.

2:15 PM R2.3
ENHANCED MAGNETIC RESPONSE OF DILUTE COBALT NANOPARTICLES IN AN ORGANIC MATRIX. J.P. Wilcoxon, E.L. Venturini, and P. Provencio.

We report studies of the magnetic response of nanocrystals of extremely small, D=1.5 and 1.9 nm dilute Co particles in frozen organic matrices. An air and water-free inverse micellar synthesis is described and the time evolution of the magnetic response is found to increase from 10-20% of the bulk saturation magnetism Msat one day after synthesis to a value exceeding that of the bulk HCP materials over a period of 30-60 days under Ar at ambient T. Msat maintains its high value up to the melting T of the solvent matrix and scales as predicted by the Langevin equation. The effects of various surface passivators and molecular O2 on the magentic response is discussed as well as experiments to grow both homo- and heteroatomic (core/shell) clusters on these monodisperse "seeds". The origin of the dramatic increase 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 since the size and ideal superparamagnetic 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-AC04-94AL8500. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the US Department of Energy.

3:00 PM R2.4
G FACTOR FOR Fe_xPt_{1-x} NANOPARTICLES ASSEMBLY. Magdalena Ulmeanu, Gerhard-Mercator-Universitaet Duisburg, Exp. Tieftemperaturphysik, GERMANY; Carolin Antoniak, Technishe Universitaet Carolo Wilhelmina Braunschweig, GERMANY; Ulf Wiedwald, Gerhard-Mercator-Universitaet Duisburg, Exp. Tieftemperaturphysik, GERMANY; Shouseng Sun, IBM T.J. Watson Research Center, Yorktown Heights, NY; Michael Farle, Gerhard-Mercator-Universitaet Duisburg, Exp. Tieftemperaturphysik, GERMANY.

Chemically produced Fe_xPt_{1-x} nanoparticles with various compositions (x = 38, 56, 70) have been deposited on different substrates: Si_3N_4, quartz and Si. Low resolution Transmission Electron Microscopy (TEM) pictures show that the as prepared Fe_xPt_{1-x} consist of round shape nanoparticles with a mean size diameter of 2.6 nm and 3.5 nm, depending of the composition. Ferromagnetic Magnetic Resonance (FMR) spectra at 9.829, 24.121 and 79.344 GHz frequencies have been recorded at room temperature. The g-factors = 2.104, 2.070, 2.041 for x = 38, 56 and 70 respectively were determined. The g-factor deviates from the bulk bcc Fe 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 PM R2.5
ANOMALOUS MAGNETIC BEHAVIOUR OF NANOGRANULAR COBALT FILMS DEPOSITED BY MOCVD. Peter Haycock, Feodor Ogrin, Mariana Chioncel, Brian Ruthven, Anthony Wright, Jonathon Starling, 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 samples have been produced by metal-organic 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 native oxide layer. 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 PM R2.6
MAGNETIC PROPERTIES AND SPIN-TRANSPORT IN MAGNETITE NANOPARTICLES. Kai Liu, L. Zhao, P. Klavins, Physics Department, University of California, Davis, CA; Frank E. Osterloh, and H. Hiramatsu, Chemistry Department, University of California, Davis, CA.

Nanoparticles of magnetite (Fe_3O_4) 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 displays superparamagnetic behavior above 150 K over a 30 *s* time scale. The blocking behavior is modified by the packing density, or the average inter-particle distance, of the particle assembly. Comparing to bulk magnetite, 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 form, the electron transport is by tunneling through adjacent 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 FE-PT NANOPARTICLES. Sonja Stappert, Bernd Rellinghaus, Mehmet Acet, and Eberhard F. Wassermann, Exp. Tieftemperaturphysik, Gerhard-Mercator-Universität, Duisburg, GERMANY.

Stoichiometric FePt nanoparticles in the chemically ordered $L1_0$ phase have a large magneto-crystalline anisotropy, which makes them attractive for future high density magnetic data storage media. However, independent of the preparation method employed, a thermal annealing step is mandatory in order to obtain this phase. We have, therefore, studied the thermal sintering of gas-phase prepared FePt nanoparticles and its impact on their magnetic properties. $Fe_{62}Pt_{38}$ particles are prepared by DC sputtering in an Ar/He gas mixture. Prior to their deposition, the particles are sintered in-flight at temperatures of up to $T_S = 1273K$. 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_S. At temperatures $293K \leq T_S \leq 873K$, inter-particle coalescence occurs. Below $T_S = 673K$, we observe neck growth between the primary particles. Above this temperature, the agglomerates are compacted, and the primary particles grow from $d_P \simeq 5nm$ at $T_S = 673K$ to $d_P \simeq 7nm$ at $T_S = 1073K$. From the variation of d_P with T_S, we estimate an activation energy for this growth process of roughly $E_a \simeq 60kJmole^{-1}$ indicating that surface diffusion and/or grain boundary diffusion are the predominant sintering mechanisms in this temperature range. At $T_S \leq 1073K$, we observe the onset of intra-particle recrystallization, which leads to an increasing amount of single crystals and the formation of $L1_0$ 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 $L1_0$ ordered particles, both the effective magnetic anisotropy constant and the coercivity $H_{C0} = H_C(T = 0)$ increase from $K_{eff} = 3.6 \times 10^5 Jm^{-3}$ at $T_S = 293K$ to $K_{eff} = 7.7 \times 10^5 Jm^{-3}$ at $T_S = 1273K$ and from $H_{C0} = 1.48kOe$ at $T_S = 293K$ to $H_{C0} = 4.65kOe$ at $T_S = 1273K$, respectively.

4:00 PM R2.8
STRUCTURAL AND MAGNETIC PROPERTIES OF SELF-ORGANIZED Co CLUSTERS. F. Luis, L.M. Garcia, J.M. Torres, F. Bartolome, J. Bartolome, ICMA, CSIC-Universidad de Zaragoza, Zaragoza, SPAIN; F. Petroff, J.-L. Maurice, A. Vaurës, UMP CNRS/Thales and Universite Paris-Sud, Orsay, FRANCE; D. Babonneau, LMP-Universite 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 mean sizes (0.5 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 can be clearly linked to the distribution of the particle's surfaces rather than the volume distribution. We will also show that Co/Al_2O_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, evolving from a 2D layer to a 3D behavior which 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 Fe AND Ni NANOPARTICLES. D. Kumar, Department of Mechanical Enginering, North Carolina A&T State University, Greensboro, NC; S.J. Pennycook, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN; J. Sankar, Department of Mechanical Enginering, 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 a nonmagnetic oxide (such as alumina) or nitride (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, structural phases, morphology, microstructure 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 the competition between the thermodynamic instability and kinetic effects. The studies of magnetic properties was focused around (a) size effect (b) shape, crystal, and surface anisotropy, and (c) core-shell morphology of the nanomagnetic particles. Investigation using scanning transmission electron microscopy with atomic number contrast (STEM-Z) and atomic resolution electron energy loss spectroscopy (EELS) have indicated that 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
CHARACTERIZATION OF CORE/SHELL MAGNETIC NANOPARTICLES BY X-RAY ABSORPTION SPECTROSCOPY. S. Calvin, E.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 power supplies and filters operating in the MHz range. In addition, they hold promise in the fields of targeted drug delivery and biological sensors. In this study, nanoparticles with iron cores and oxide shells were synthesized using the reverse micellar method. TEM confirmed a core/shell structure with approximate diameter 10 nanometers. 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: when a mixture of NP-5 and NP-9 (both nonionic) 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 (at 10 K) saturation moments of approximately 90 emu/g for the amorphous core samples and as much as 170 emu/g for the samples with the partially nanocrystalline cores. In keeping with the small 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. Ghazali, Groupe de Physique des Solides, UMR7588-CNRS, Universités Paris 6 et Paris 7, Paris, FRANCE.

Confined or non confined 2D-self-assembling 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 are arranged in vortices as obtained in 2D spin lattice simulations [2]. The interaction between neighboring chains is rather weak. This explains numerous inhomogeneities in the particle assembly. At higher

densities magnetic arrangements in vortices is confirmed. The vortices' centers are located at vacancies. This saves magnetic energy. Applying an in-plane field always leads to an arrangement of parallel chains, while an out-of-plane field always leads to an amorphous organization of separate particles. When no out-of-plane field is applied, the weak coupling of particle chains at all densities is expected to lead to a viscous behavior and to a delayed response to an external excitation. A comparison with available experimental results will be given.
[1] R.W. Chantrell *etal.*, J. Phys. A **13**, L119 (1980); R.E. Rosenweig, *Ferrohydrodynamics*, Dover (1997).
[2] E.Y. Vedmedenko, A. Ghazali and J.-C.S. Lévy, Phys. Rev. B **59**, 3329 (1999).

SESSION R3: NANOMAGNETS - CHARACTERIZATION
Chairs: Marcos Grimsditch and James G. Tobin
Wednesday Morning, April 23, 2003
Golden Gate C3 (Marriott)

8:30 AM *R3.1
MICROMAGNETICS AT THE NANOSCALE. George Skidmore, Andrew Kunz, Charles Campbell, and E. Dan Dahlberg, Magnetic Microscopy Center, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN.

There has been a renaissance in magnetism in the last decade or so. In the area of micromagnetics (although in the modern context it should be nanomagnetics), major breakthroughs have resulted from the development of new magnetic imaging techniques. A powerful magnetic microscope is the magnetic force microscope (MFM), a variant of the atomic force microscope. One of the frontiers in magnetism being pushed back is to understand the domain structure and the magnetization reversal in nanometer sized particles. We have combined high resolution MFM (30 nm) with Landau Lifschitz Gilbert (LLG) simulations to investigate the magnetic domain structure in Ni dots with diameters ranging from 40nm to 1700nm. The Ni dots were prepared with a perpendicular anisotropy energy. In unpatterned films the perpendicular anisotropy induced stripe domains with a period on the order of 200 nm. The statistics of the allowed states in the dots was determined using the MFM data from over 3000 images. The comparison of the MFM images with the LLG simulations provide confidence that the magnetic structure beyond the MFM resolution MFM resolution is accurate.

9:00 AM *R3.2
SCANNING FORCE MICROSCOPY FOR MAGNETIC IMAGING IN THE PRESENCE OF A MAGNETIC FIELD. Alexander Volodin, Dieter Buntinx, Chris Van Haesendonck, Katholieke Universiteit Leuven, Laboratorium voor Vaste-Stoffysica en Magnetisme, Leuven, BELGIUM.

During the last few years magnetic force microscopy (MFM) has emerged as a convenient tool for imaging the ferromagnetic domain structure with submicrometer resolution. When compared to other magnetic imaging techniques, including scanning Hall probe microscopy, scanning SQUID microscopy, magneto-optical imaging and electron microscopy based techniques, MFM suffers from its invasive character which offsets its rather good spatial resolution (of the order of 10 nm). This invasive character, resulting from the magnetic interaction between tip and sample, can be reduced by decreasing the magnetic charge on the MFM tip and can be taken into account by micromagnetic simulations. On the other hand, there is a clear need to perform MFM measurements in a magnetic field without affecting the magnetic state of the tip. We built an MFM based on piezoresistive detection which operates in an external magnetic field down to liquid helium temperatures. The cryogenic system is able to simultaneously monitor the magnetoresistance of the sample, allowing to directly link changes in the magnetoresistance to specific changes in the magnetic domain structure. Such changes are induced by the stray field of the tip when the tip comes sufficiently close to the surface. The excellent and reproducible force sensitivity of the MFM operation is confirmed by measurements with microfabricated magnetic coils and by measurements of the Abrikosov flux line lattice in niobium diselenide crystals. The measurements clearly demonstrate a major advantage of MFM when compared to other imaging techniques: By changing the distance between the MFM tip and the sample surface it is possible to obtain topographic as well as magnetic information at the same location.

9:30 AM *R3.3
NOVEL INSIGHT INTO NANOMAGNETISM BY SPIN-POLARIZED SCANNING TUNNELING SPECTROSCOPY. Roland Wiesendanger, University of Hamburg, Institute of Applied Physics and Microstructure Advanced Research Center Hamburg (MARCH), Hamburg, GERMANY.

To gain fundamental insight into spin-dependent properties at the nano- or even down to the atomic scale we have combined the scanning tunneling microscope (STM) with spin-sensitivity. This is achieved by the use of ferro- and antiferromagnetically coated probe tips offering a high degree of spin-polarization of the electronic states involved in the tunneling process. Magnetic domain imaging with sub-nanometer-scale spatial resolution has been demonstrated for magnetic transition metal as well as rare earth metal films. Ultra-sharp domain walls were discovered in ultra-thin iron films while for antiferromagnetic samples, the different orientation of magnetic moments could directly be made visible at the atomic level. The phenomenon of magnetic hysteresis was observed for the first time at the nanometer length scale and has directly been correlated with microscopic processes of domain nucleation and domain wall motion. We also studied magnetic vortex structures in nano-scale ferromagnetic islands as well as in frustrated antiferromagnetic systems. Magnetic switching phenomena of ultra-small magnetic islands and nanoparticles were studied by time-dependent spin-sensitive STM imaging. It will be shown that granular thin films exhibit a complex magnetic switching behaviour due to the statistical distribution of grain sizes, grain shapes and inter-grain spacings. Finally, we will discuss the application of spin-sensitive STM measurements to individual atoms and molecules.

10:30 AM *R3.4
CHARATERIZATION OF MAGNETIC NANOSTRUCTURES USING SYNCHROTRON X-RAY AND NEUTRON SCATTERING. Sunil K. Sinha, University of California, San Diego, CA and Los Alamos National Laboratory, Los Alamos, NM; M. Fitzsimmons, Los Alamos National Laboratory, Los Alamos, NM; D.R. Lee and S. Stepanov, Argonne National Laboratory, Argonne, IL; R. M. Osgood III, Lincoln Laboratories, MIT, Cambridge, MA; V. Metlushko, University of Illinois, Chicago, IL.

The properties of thin magnetic films have assumed increased importance in recent years owing to their importance for magnetic storage and recording technologies. It is generally accepted that the chemical and magnetic structure at the interfaces plays a central role in determining their magnetic and transport properties. Neutron and resonant magnetic x-ray scattering via the techniques of specular reflectivity and off-specular diffuse scattering can be extremely valuable tools in elucidating the nature of the chemical structure and morphology and the magnetic structure of these interfaces and in studying the statistical properties of the domains. We shall illustrate with examples from recent experiments on magnetic thin films. Examples will also be given of studies of so-called patterned magnetic films, involving arrays of magnetic dots or holes, which can also be studied with grazing incidence techniques.

11:00 AM *R3.5
X-RAY IMAGING OF MAGNETIC NANOSTRUCTURES AND THEIR DYNAMICS. Joachim Stöhr, Stanford Synchrotron Radiation Laboratory, Stanford, CA.

We discuss the use of soft x-rays to image magnetic domains present in magnetic thin films or coupled multilayer systems, as well as in lithographically made nanostructures. Special emphasis is given to exchange biased systems, magnetic multilayers, and to nanostructures fabricated to study magnetic switching by spin injection. Results will be reported for imaging ground state domain configurations in coupled thin films and at interfaces, and for new static magnetic configurations created after field excitation. In addition, we report time dependent measurements with 100 ps resolution of the dynamical processes in nanostructures that follow excitation by Oersted fields created by current flow through wires, and switching processes originating from exchange fields created by spin injection.

11:30 AM R3.6
NEW POSSIBILITY OF LORENTZ TEM IN THE CHARACTERIZATION OF MICROMAGNETIC FEATURES OF THIN FILMS. Jeff. Th. M. de Hosson, Department of Applied Physics, Materials Science Centre and Netherlands Institute for Metals Research, University of Groningen, Groningen, THE NETHERLANDS; and Nicolai G. Chechenin, Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, RUSSIAN FEDERATION.

Previously we have shown [1] that micromagnetic ripples can strongly influence the FMR frequency, diminishing the electromagnetic response at high frequencies. To characterize the micromagnetic ripple, we have employed Lorentz transmission electron microscopy (LTEM). The longitudinal oscillation of the transversal component of the magnetization causes ripple fringes, which are oriented perpendicular to the magnetization. In this presentation we show that in the LTEM images of ultra-soft magnetic films, besides the commonly observed ripple fringes, the contrast also oscillates along

the fringes. The observed features are analyzed based on a model where in addition to the longitudinal oscillation of the transversal component of magnetization, there is also a transversal 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 magnitude of the magnetization due to the nanocrystalline structure of the film. 1. N.G. Chechenin, C.B. Craus, A.R. Chezan, T. Vystavel, D.O. Boerma, Th. M. de Hosson and L. Niesen, 2002 MRS Spring meeting: Symposium H: Materials Issues for Tunable RF and Microwave Devices III; p.H3.14; Jeff Th.M. De Hosson, Nicolai G. Chechenin, Daan Hein Alsem, Tomas Vystavel, Bart Kooi, Antoni Chezan, Dik Boerma, Microscopy and Microanalysis 8, 274-287, 2002.

11:45 AM R3.7
ATOMIC RESOLUTION MAGNETIC RESONANCE DIFFRACTION. Mladen Barbic and Axel Scherer, Departments of Applied Physics and Electrical Engineering, Caltech 200-36, Pasadena, CA.

We will 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 of 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 relaxes 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]. [1] M. Barbic J. Appl. Phys. 91, 9987 (2002). [2] M. Barbic and A. Scherer J. Appl. Phys. (in press 2002). [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: Yvan B. Bruynseraede
Wednesday Afternoon, April 23, 2003
Golden Gate C3 (Marriott)

1:30 PM *R4.1
EPITAXIAL NANOSTRUCTURED FERROMAGNETIC TUNNEL JUNCTIONS. J.L. Costa-Krämer, J. Anguita, J.I. Martín, C. Martínez-Boubeta, A. Cebollada, and F. Briones, Instituto de Microelectrónica de Madrid, CNM-CSIC, Madrid, SPAIN.

The magnetic properties of planar 10 nm Fe/ x nm MgO / 10 nm Fe (x=1, 2, 5 & 7 nm) epitaxial ferromagnetic square-shaped elements 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 $\sim$4 μm lateral size. The field ranges where magnetic switching occurs agree 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 placed closer 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 neighbour's positions. The same argument implies that the junction electrodes retain their single domain character down to smaller sizes than single layer Fe tiles. For the thinnest barrier, 1nm MgO, patterning reduces the ratio of exchange coupled junctions in the array. The effect of patterning in rectangular shaped epitaxial junctions is also discussed

2:00 PM *R4.2
MAGNETIZATION STABILIZATION IN ARRAYS OF Fe NANODOTS WITH EXCHANGE BIAS. Igor V. Roshchin, 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 size, offers a great potential for new physics. Advancement of technology demands techniques capable of producing nanometer-sized structures over large areas. Using self-assembled nanopores in anodized alumina as a shadow mask [1], magnetic sub-100 nm dots covering over 1 cm^2 area are deposited by electron-beam evaporation. This method provides a good control over dot size and separation. Samples with Fe and Fe/FeF_2 nanodots as well as continuous Fe and Fe/FeF_2 films are simultaneously grown on the same substrate. Typically 15-20 nm of Fe and 20-90 nm of FeF_2 are used, and the samples are capped with a 5-8 nm-thick Al layer to preserve Fe from oxidation. Comparative studies of magnetic properties of these samples in a wide range of temperatures are presented. All samples are cooled from 150 K in an applied 2 kOe field. Improved squareness of the magnetization loops for Fe nanodots with the FeF_2 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 FM nanodots by coupling to an AF layer is discussed.
Work is supported by AFOSR.
[1] Kai Liu et al., Applied Physics Letters, 81 (2002), H. Masuda and K. Fukuda, Science 268, 1466 (1995).

2:30 PM R4.3
MAGNETO-RESISTANCE IN PATTERNED NANO-BRIDGES ON EPITAXIAL Ni FILMS. R. Alejandra Lukaszew, University of Toledo, Physics and Astronomy Department, Toledo, OH; Antonio Zambano, Physics and Astronomy Department, Michigan State University, E. Lansing, MI.

The latest results on BMR research have shown surprising ballistic magnetoresistance with values over 3000% in Ni nano-contacts at room temperature. [1] It has been postulated that the ballistic magnetoresistive effect arises from non-adiabatic spin scattering across very narrow (atomic scale) magnetic domain walls trapped at nano-sized constrictions. [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 publish data so far, is still poorly understood. In an attempt to clarify some of the possible processes present in the observed phenomena 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 favor ballistic regime provided that the nano-contact is small enough. Thus we have patterned nanobridges with a similar T geometry to that utilized by Chopra and Garcia. [1,3] Thus, the combined shape and magnetocrystalline anisotropies provide the required two states for the magnetization at each side of the constriction. Our preliminary results indicate that domain walls 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]. B.D. Chopra and S.Z. Hua, Phys. Rev. B. 66, 020403(R), 2002. [2]. P. Bruno, Phys. Rev. Lett. 83, 2425 (1999) [3]. N. Garcia, M. Munioz, V.V. Osipov, E.V. Ponizovskaya, G.G. Quian, I.G. Saveliev and Y.-W. Zhao, J. Magn. Magn. Mater. 240, 92 (2002).

3:15 PM R4.4
SPIN DEPENDENT TRANSPORT IN Co NANOSTRUCTURES. M.I. Montero, R. Dumas, O.M. Stoll, University of California San Diego, Physics Department, La Jolla, CA; W.A.A. Macedo, 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 nanocontacts, magnetoresistance values of up to 3000% have been reported recently [1,2]. We have developed a method to prepare magnetic nanocontacts using standard e-beam lithography and dry etching techniques. The process allows us to fabricate mechanically stable nanocontacts with different widths on a single sample. The nanocontact widths are in the range of 20 to 100 nm. The transport properties of Co nanocontacts on top of different semiconducting substrates, prepared 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 nanocontacts. 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.

Simultaneously, our fabrication process allows us to prepare semiconducting nanogaps, 30 to 300 nm wide, on the same sample. We propose that these semiconducting nanogaps can be used for the demonstration of spin injection into semiconductors by means of an electric transport experiments. Work supported by DOE. References [1] H.D. Chopra and S.Z. Hua, Phys. Rev. B 66, 020403R (2002). [2] N. Garcia, M. Munoz, G.G. Qian, H. Rohrer, I.G. Saveliev and Y.-W. Zhao, Appl. Phys. Lett. 79, 4550 (2001). [3] K. Miyake, K. Shigeto, K. Mibu, T. Shinjo and T. Ono, J. Appl. Phys. 91, 3468 (2002). [4] B. Hausmanns, T.P. Krome, G. Dumpich, E.F. Wassermann, D. Hinzke, U. Nowak and K.D. Usadel, J. Mag. Mag. Mat. 240, 297 (2002).

3:30 PM R4.5
TUNING THE MAGNETIC PROPERTIES OF SINGLE ELEMENT AND MULTILAYERED NANOWIRES. Ryan Cobian 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) texturing 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 were influenced similar to the plain Co wires. This allows some control over the magnetic anisotropy of individual layers in a GMR structure. Third, we fabricated 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 R4.6
ARRAYS OF TOUCHING MAGNETIC RING ELEMENTS. V. Metlushko, University of Illinois at Chicago, Chicago, IL; U. Welp, V. Vlasko-Vlasov, G. Crabtree, M. Grimsditch, V. Novosad, J. Hiller, N. Zaluzec, Materials Science Division, Argonne National Laboratory, Argonne, IL; B. Ilic, Cornell University, Ithaca, NY; J. Bekaert, V.V. Moshchalkov, and Y. Bruynseraede, Laboratorium voor Vaste-Stoffysika en Magnetisme, Katholieke Universiteit Leuven, BELGIUM.

Recent studies show that the narrow ring-shaped magnetic elements exhibit two different stable "onion" states at remanence in addition to the vortex state. Those two onion states, forward or reverse magnetized, realized at 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 totally 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 STEM to determine the magnetic patterns inside the rings, and 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 W-31-109-ENG-38, at UIC by the U.S. NSF, grant #ECS-0202780 and U.S. Dept. of Energy Grant #DE-FG02-97ER45653.

4:00 PM R4.7
INTERMEDIATE METASTABLE STATES DURING MAGNETIZATION REVERSAL IN SQUARE RINGS. M. Grimsditch and V. Novosad, Materials Science Division, Argonne National Laboratory, Argonne IL; P. Vavassori, INFM, National Research Center on NanoStructures and Biosystems at Surfaces (S^3)-Dipartimento di Fisica, Università di Ferrara, ITALY; V. Metlushko, Dep. of Electrical and Computer Engineering, University of Illinois at Chicago, Chicago, IL; and B. Ilic, School of App. and Eng. Physics, Cornell University, Ithaca, NY.

Magnetization reversal in permalloy square rings has been investigated using diffraction Magneto-optic Kerr effect combined with numerical micromagnetic simulations and MFM imaging. Diffracted MOKE loops show a two-step switching process for external fields along both the ring edge and diagonal. However, hysterisis loops calculated from micromagnetic simulations show that switching in 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 asymmetry must be introduced in the ring shape. In slightly asymmetric square rings a metastable intermediate state appears during the switching, and the calculated hysteresis loops reproduce the experimentally measured ones. When the external field is applied along the rings edge the intermediate state is a new bi-domain state, which we term the horseshoe state. For the external field applied along the ring's diagonal the intermediate state is a vortex state. These states have been quenched and imaged with MFM techniques. P.V. gratefully acknowledge financial support from INFM, under the "MAGDOT" PAIS research program as well as from MURST- COFIN 2000. Work at ANL was supported by US Department of Energy, BES Materials Sciences under contract W-31-109-ENG-38. and V.M. at UIC by the U.S. NSF, grant #ECS-0202780.

4:15 PM R4.8
IMAGING OF SPIN DYNAMICS IN CLOSURE DOMAIN AND VORTEX STRUCTURES. Jooho Park, Peter Eames, Dave Engebretson, Jesse Berezovsky, 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 of $Ni_{0.81}Fe_{0.19}$ films sputtered on GaAs (100) substrates. Squares of thickness 18 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 disk is a vortex with a singularity at the center. The higher frequency mode observed in the vortices is due to precession of magnetization about the azimuthally symmetric 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 phase of the response at different positions. 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 in 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 [Guslienko *et al.*, J. Appl. Phys. **91**, 8037 (2002).] This work was supported by NSF DMR 99-83777, the Research Corporation, the Alfred P. Sloan Foundation, the University of Minnesota MRSEC (DMR-0212302), and the Minnesota Supercomputing Institute.

4:30 PM R4.9
MAGNETISATION REVERSAL STUDIES IN NANOELEMENTS 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 mechanisms of small elements by in-situ experimentation in the transmission electron microscope. Here we describe two recent sets of experiments involving permalloy elements with lengths 1000 nm and widths down to 150 nm. In the first we show how the field at which the magnetisation reverses can be reduced by gently curving the ends of an otherwise 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 carry out such experiments effectively, the electron optical configuration should not change during the course of a magnetising experiment. If it does, attention needs to focus on the instrument rather than on what is happening to the small elements themselves. Many of the results referred to above were obtained using a new 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, how 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 maze- and bubble-like magnetic domain structures have been observed under ambient conditions in $La_{0.67}Sr_{0.33}MnO_3$ films by magnetic force microscopy (MFM) for films grown on a compressive (LaAlO3) two 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 substrate-induced stress in this soft magnetic material appears to be a necessary but not sufficient condition 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 Montero
Wednesday Evening, April 23, 2003
8:00 PM
Salon 1-7 (Marriott)

R5.1
Abstract Withdrawn.

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

Nano-meter FeNi particles were prepared by the hydrogen plasma-metal reaction method. Structural analysis of x-ray diffraction (XRD), transmission electron microscopy (TEM), electron diffraction (SAED) and energy dispersive spectroscopy (EDS) showed that particle size was about 10-25 nm in spherical shape; the nanophase was identified as mainly fcc γ-FeNi. Nano-EDS indicated an average value of $Fe_{48}Ni_{52}$ in this fcc γ-FeNi particles. Superconducting quantum interference device (SQUID) magnetometer and vibrating sample magnetometer (VSM) measurements indicated that the saturation magnetization (M_S) and coercivity (H_c) were than that of the bulk FeNi materials due to their nano-metre particle nature. Hyperfine fields (H_{hf}) values that from Mssbauer 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 magnetocrystalline anisotropy was the dominant factor under magnetization process.

R5.3
GROWTH AND CHARACTERIZATION OF NICKEL NANOSTRUCTURES IN ANODIC ALUMINUM OXIDE TEMPLATE. Jin-Seung Jung, Seung-Lim Oh, Eun-mi Kim, Kangnung National University, Dept of Chemistry, Kangnung, KOREA; Jin-Kyu Lee, Seoul National University, Dept of Chemistry, Seoul, KOREA; Lesezk Malkinski and Charles J. O'Connor, AMRI/Dept of Chemistry, New Orleans, LA.

Magnetic propeties of Ni nanostructrues electrodeposited into cylindrical porous alumina arrays 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 alumites 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_w/d_w (wire length divided by wire diameter), increasing from 300oe at l_w/d_w=1(spherical form) to 2000 Oe at l_w/d_w=100(nanowire form).

R5.4
PREPARATION AND TRANSFORMATION OF FERRO-MAGNETIC Fe AND Fe-Co NANOPARTICLES SYNTHESIZED BY CHEMICAL VAPOR CONDENSATION. Chul-Jin Choi and Byoung-Kee Kim, Korea Institute of Machinery and Materials, Changwon, Kyungnam, KOREA; Oleg Tolochko, State Technical University, Politechnicheskaya, Saint-Petersburg, RUSSIA.

Ferromagnetic Fe and Fe-Co nanoparticles were synthesized by Chemical Vapor Condensation (CVC) Process using the precursor of Fe(CO)5 and Co2(CO)8. We investigated the microstructures, magnetic properties of the nanoparticles and their oxidation behavior during annealing systematically by means of HRTEM, DTA-TGA, Moesbauer 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 shells, the slow oxidation of particles was achieved by exposure of iron nanoparticles in the inert atmosphere with controlled oxygen 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 epitaxial 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-GEL PREPARED ALUMINA: HYDROGENATION OF CO/H_2 AND CO_2 /H_2 MIXTURES. Seetala V. Naidu, Akundi N. Murty, Joseph Leonard and Charlene Jones, Department of Physics, Grambling State University, Grambling, LA; Upali Siriwardane, Srivani Naga Vegesna, Sireesha Vudatha, Ramkiran Goduguchinta, Buddy G. Barnett, Edwin Everett, Sheba Anderson, Karen Luurtsema, Laura Holeman, and Andrew Emge, Department of Chemistry and IfM, Louisiana Tech University, Ruston, LA.

The alumina granules, containing metal oxide nano-particles, CoO, Fe_2O_3, and CoO/Fe_2O_3, were prepared by sol-gel/oil-drop methods. Synthesis was carried out using both aluminum tri-sec-butoxide (ALTSB) and aluminum tri-iso-propoxide (ALTIP). The optimum calcinations-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 dissorption. They were in the mesoporus range of 200-400 m^2/g. These catalysts were examined by powder X-diffraction and the results showed that the metal oxides are in the nano-particle range. The particle sizes and metal loading of granules were studies by scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) analysis. The metal loading results were used to optimize the synthesis process to obtain consistent metal compositions. The catalytic activities of Fe, Co, and Co/Fe on alumina for the conversion of $CO/H_2/N_2$ and $CO_2/H_2/N_2$ mixtures were investigated. Both, slurry phase batch and continuous flow gas phase reactors were used. The catalytic activity of Fe/Co mixed metal catalyst has grater activity compared to Co and Fe catalysts. Vibrating sample magnetometer (VSM) was used to study the magnetic characteristics of as prepared, reduced, and post-reaction catalysts. 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-reaction 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
XAS STUDIES OF SUPERPARAMNETIC NANOPARTICLS IN COLLOIDAL SUSPENSIONS FOR BIOMEDICAL APPLICATIONS. M. Croft, Rutgers Univ, Physics Dept, Piscataway, NJ; M. Dasilva, S. Wolbach, T. Tsakalakos, Rutgers Univ, Department of Ceramics, Piscataway, NJ; P. Ansari, Seton Hall Univ, Physics Dept, S. Orange, NJ; D. Kim, M. Mikhailova, T. Toprak, Z. Zhang, Royal Institute of Technology, Materials Chemistry Division, Stockholm, SWEDEN; B. Bjelke, Karolinska Institute, MRI-Center, Experimental Unit, Stockholm, SWEDEN; J. Kehr, Karolinska Institute, Division of Cellular and Molecular Neurochemistry, Stockholm, SWEDEN; M. Muhammed, 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 as building blocks for assembly of 2D or 3D structures. Bio-active 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 suspension of the size-controlled nanopaticles into a ferrofluid. The specific fluid used will depend on the application. The encapsulation of the SPION by gold and/or fictionalizing molecules is also used, either to interact selectively with biochemicals or provide a passivation layer for transport through a biomembrane. By virtue of the small nanopartical size (<10nm), their amorphous character, the encapsulation and the suspension in fluid characterization of the particules structure by x-ray diffraction is not possible. X-ray absorption spectroscopy (XAS) provides a microscopic structural and electronic state probe of these particles, and their interactions with the suspending fluid and encapsulated/fictionalized particles while in the fluid. We will present Fe-K and Au-$L_{2,3}$ edge XAS results on a wide range of nanoparticles in their fluid suspensions. Comparison to standard materials will be used to identify the local structure and to probe for chemical modifications in processing.

R5.7

NANO-SIZED SUPERCONDUCTING PARTICLES AND MAGNETIC PROPERTIES. Fang Li, Cumaraswamy Vipulanandan, University of Houston, Materials Engineering Laboratory (TCSAM), College of Engineering, Houston, TX.

Nanoparticles were synthesized by the water-in-oil microemulsion method. Conductivity measurement was used to investigate the role of each chemical component in the microemulsion system in order to optimize its performance. In this study, yitrrium-barium-copper-oxide nanoparticles were synthesized and the particles were characterized by using the X-Ray Diffraction (XRD), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM) and Dynamic Light Scattering (DLS) techniques. The average diameter of the nanoparticles varied based on the composition of the microemulsion systems. Sintering temperature of the nanoparticles was much lower than the regular superconducting powder with particle size in the range of fraction of a millimeter. The XRD results confirmed the formation of orthorhombic superconducting phase in the nanoparticles at a temperature below 800°C, which was more than 100°C lower than the sintering temperature needed to sinter regular superconducting powder. Magnetization measurements of the superconducting nanoparticles were made with a superconducting-quantum-interference-device (SQUID) magnetometer, and the relationship between the magnetic moment and the temperature has been determined. The difference in behavior between the normal size superconductor powder and the nano-sized superconducting particles are compared and analyzed. The gradual transition behavior observed in the nano-sized particles was not observed with the normal size particles indicating the size effect phenomena on the behavior.

R5.8

STRUCTURAL AND MAGNETIC PROPERTIES OF NANO-STRUCTURED $NiFe_2O_4$. Heng Zhang, Shihui Ge, Mingzhong Wu, and Y.D. Zhang, Inframat Corporation, Farmington, CT.

Commercially available $NiFe_2O_4$ possesses a very high cut-off frequency (> 100 MHz) among the ferrite family due to its ultra high resistivity; while its initial permeability is too low (13-15). In an effort to explore innovative approaches for fabricating ferrite materials with improved performance, a study of fabricating nanostructured $NiFe_2O_4$ magnetic core using wet chemistry followed by low temperature consolidation has been carried out in this work. The $NiFe_2O_4$ nanoparticle was synthesized by wet chemistry; the nanopowder was consolidated using hot press approach at different temperatures and with various pressures. The nanostructure of the consolidated sample was identified using x-ray diffraction and transmission electron microscopy. The static magnetic properties were studied using a SQUID magnetometer. The initial permeability and its frequency response were determined using an impedance meter. It was found that the phase stoichiometry, packing density, resistivity and magnetic properties of the consolidated material are intimately dependent on the powder synthesis parameters and consolidation conditions. Our results show that through the use of the nanostructuring approach, the initial permeability of $NiFe_2O_4$ can be significantly improved.

R5.9

FABRICATION OF NANO PATTERNED FILMS ON THE ANODIC ALUMINUM OXIDE TEMPLATES AND THEIR MAGNETIC PROPERTIES. Mun Ja Kim, Jong Hyung Choi, Jong Bae Park, Jin Seung Lee, Seong Kyu Kim, and Ji-Beom Yoo, Chong-Yun Park Center for Nanotubes and Nanostructured Composites, Sungkyun-kwan University, Suwon, KOREA; T.S. Oh, Department of Materials Science and Engineering, HongIk University, Seoul, KOREA.

Controlling magnetic properties of the magnetic materials such as Ni, Co, and Fe gives us much interest because of the applications in permanent magnet, magnetic random access memory (MRAM), magnetic storage media, and new materials development in medical science. The stability and magnetic properties of crystal depend on its structure and size. We focused on the effect of size and shape of magnetic materials on the magnetic properties. So far, the study of the property changes of magnetic materials in nano-scale has been limited to nanowire and multilayers. We formed the nano-sphere, nano-honeycomb and nano-double ring patterns of Ni, Co and Fe on the anodic 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 FePd ($L1_0$)-BASE FERROMAGNETIC ALLOYS. H. Okumura[a], S. Saha, H. Heinrich[b], J.M.K. Wiezorek, J.A. Barnard, and W.A. Soffa, Department of Materials Science and Engineering, University of Pittsburgh, Pittsburgh, PA. [a]Now at Carnegie-Mellon University, Department of Materials Science and Engineering [b]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 constituent hard and soft phases comprising these multiphase aggregates. The Fe-Pd alloy system characterized by the FePd ($L1_0$) uniaxial, ferromagnetic intermetallic 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 Fe-Pd system over a range of compositions. Enhanced coercivities compared to bulk 50Fe-50Pd alloys have been achieved in an off-stoichiometric Fe-34Pd alloy utilizing non-equilibrium decomposition of the parent austenite phase. The magnetic hardening will be discussed in terms of the microstructural evolution and attendant 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. Leonard Spinu, Leonard Spinu, Advanced Materials Research Institute & Physics Department, University of New Orleans, New Orleans, LA; Alexandru Stancu, Faculty of Physics, "Al. I. Cuza" University, Iasi ROMANIA; Le Duc Tung, Jiye Fang, 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 Delta-M curves. As it is very well known, in order to determine the regular Delta-M curves we need to start from an ac demagnetizing state. When the relaxation phenomena are not very important, this procedure can be performed easily at room temperature. In the case of nanoparticle systems, in order to obtain regular Delta-M plot one would need to obtain the initial ac demagnetizing state at low temperatures, which experimentally it is not trivial. That it is why there were attempts to obtain the regular Delta-M plots substituting the ac demagnetizing state with a thermal demagnetization one. However, this approach was proven to be gravely misleading for the interpretation of the classical Delta-M curves. In this study we propose a generalization of the Delta-M curves to evaluate the interactions that overcomes the experimental difficulties generated by the presence of the combined effect of interaction and magnetic relaxation in the case of nanoparticle systems. The experimental curves we are using for interactions evaluation, the Integral Generalized Delta-M plots, are constructed based on the classical DC demagnetized (DCD) curve and a number of Isothermal Remanent Magnetization (IRM)-type curves, referred as forward IRM curves, starting from remanent states on the DCD curve. 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 average particle 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 IGDM 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.

Cobalt ferrite / silica (CoFe2O4)1-x(SiO2)x, (2 < x < 20%) nanocomposite thin films have been prepared by spin coating method from a new sol-gel system. The influences of sol-gel composition, substrate 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. Takuya Kinoshita, Satoshi Seino, Youhei Otome, Hiroki Maruyama, Takashi Nakagawa, and Takao A. Yamamoto, Osaka Univ, Dept of Nuclear Engineering, Osaka, JAPAN; Tadachika Nakayama, Osaka Univ, ISIR, Osaka, JAPAN; Okitsu Kenji, Japan Society for the Promotion of Science, Tokyo, JAPAN.

Nanocomposite powder materials composed of single-nanosized 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 nano-sized metallic gold colloids was checked by monitoring the absorption band due to the plasmon with an UV-VIS spectrophotometer and XRD. The X-ray absorption near edge structure indicated that iron was of Fe_3O_4. The average grain size and size distribution determined from TEM micrographs were in a range of 4 – 7 nm and 1.27 or more in terms of geometric standard deviation, respectively. The magnetization data set measured with a SQUID magnetometer indicated occurrence of superparamagnetism at temperatures 80 K or above. This result indicated that magnetic moments of the Fe_3O_4 grains were well-isolated 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 = 2:1 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.

R5.14
INVESTIGATION OF MAGNETIC MICROSTRUCTURES USING PHOTOEMISSION ELECTRON MICROSCOPE. D.H. Wei and Y.J. Hsu, Synchrotron Radiation Research Center, Hsinchu, TAIWAN; J.Y. Ou, J.C. Wu, National Changhua University of Education, Dept of Physics, Changhua, TAIWAN.

The magnetic properties of artificial structures with finite dimensions are scientific interesting and technological important subjects that have attracted much attention recently accompanied with the advance of nanotechnology. Interesting phenomenon such as the pinning of magnetic domain and enhanced exchange field observed in patterned structures is one example showing the impact of dimension 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 micron-sized structures; NiFe and NiO/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.

R5.15
AMORPHOUS MAGNETIC NANOWIRE ARRAYS. H. Chiriac, A.-E. Moga, M. Urse, I. Paduraru, and N. Lupu, National Institute of Research and Development for Technical Physics, Iasi, ROMANIA.

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 electrodeposion were reported. This paper focuses on the preparation conditions, structure characterization and magnetic properties of amorphous NiP nanowires. It is important to point out that such kind of materials were prepared for the first time as nanowires in our group. The nanowires were obtained by electrochemical deposition into the nanopores of alumina and polycarbonate membranes in a two-electrode chemical cell. The influence of the bath composition, pH value and the temperature of the solution on the nanowire composition is presented in detail. Structural investigations by XRD show the presence of only broad peaks characteristic to the amorphous phase. Saturation magnetization 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 amorphous nanowires will be presented. The ferromagnetic resonance studies results will be also discussed. [1] A. Fert and L. Piraux, J. Magn. Magn. Mater. 222 (1999) 338.

R5.16
GROWTH OF Cu NANOPARTICLES IN AMORPHOUS SiC MATRIX FOR APPLICATION IN NOVEL CPP GMR SPIN VALVES. Dong-Woon Shin, Shan 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 structures. Small resistance-area (RA) product has been one of the most serious drawbacks in the applications of current-perpendicular-to-plane (CPP) GMR spin valve, opposite to that of magnetic tunnel 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 ΔRA will increase simultaneously. 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 UHV. 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 amorphous matrix to isolate the Cu particles. Both plan view and cross-sectional transmission electron microscope (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 valves based on IrMnRh/CoFe/SiC/Cu/SiC/CoFe/NiFe system were fabricated. All layers were deposited in-situ by DC magnetron sputtering and ion beam deposition under UHV conditions. Junctions of 4-81 μm^2 area were fabricated using liftoff process. Magnetoresistance was measured in four-point geometry configuration to remove resistances incorporated in lead lines. MR data showed that ΔRA was 43 mΩ μm^2 at room temperature.

R5.17
PREPARATION AND CHARACTERIZATION OF FIBROUS ELECTROMAGNETIC WAVE ABSORBER USING FERRITE COMPOSITES. Joong-Hee Nam, Byoung Gil Ahn and Nam-Pal Hur[a], Korea Institute of Ceramic Engineering and Technology, Seoul, KOREA. [a]MUE Industry, Hwasung, KOREA.

Ferrite has been widely used as an electromagnetic wave absorber(EWA) at high freqeucny range. EWA properties of ferrites are mainly determined by its magnetic permeability, thickness of specimen and dielectric constants. We have developed materials processing based on improved polymer composites techniques for preparation of fibrous EWA. These materials consist of cohesively mixed and bonded polymer fibers filled with ferrite encapsulated by polymer of ferrite-containing non-woven composites. The development of effective and cheap EWA composites processed 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 fillers 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 inverstigated that ferrite powders as fillers and composites including multilayered 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. Xiaoyuan Qi, Bethanie J.H. Stadler, Randall Victora 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, as grain growth inhibitors. We chose to use Si 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 much lighter element. The multlayers were deposited by DC magnetron sputtering in a high vacuum system with background pressures of 8x10-8 Torr and target-to-substrate distances of 5.5 inches. The growth sequence was 2nm-ITO seedlayer, 2nm-Pd adhesion layer, and multilayers of 13 layers of [Co(0.26nm)/Si(0.05nm)Pd(1nm)] or [Co(0.26nm)Si(0.05nm)/Pd(1nm)]. The Si-doped multilayers static magnetic properties were very promising as measured by vibrating sample magnetometry: Hc=5400Oe, Ms=2000emu and a = 4pdM/dH = 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 sent to IBM for X-ray grain and cluster size studies, see [1] 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 B-doped samples. In addition, Si-doped multilayers that were spin tested at IBM showed an increase in signal-to-noise ratio of a striking 5dB compared to high-performing B-doped samples. [1] E. Fullerton et al. IEEE Trans. Mag. 38, 1693 (2002).

R5.19
MAGNETIC PROPERTIESTHICKNESS DEPENDENCE IN NANO-CLUSTERED $Nd_{90-x}Fe_xAl_{10}$ MELT-SPUN RIBBONS. N. Lupu, H. Chiriac, National Institute of Research and Development for Technical Physics, Iasi, ROMANIA; A. Takeuchi, A. Inoue, Institute for Materials Research, Tohoku University, Sendai, JAPAN.

Extensive structural and magnetic studies on $Nd_{90-x}Fe_xAl_{10}$ melt-spun ribbons with 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 magnetization remains almost unchanged for a given composition. It is important to point out that the mechanism that determines large coercivities in thick ribbons seems to be different than that one which 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 Fe-Nd magnetic clusters, whose size approaches a single magnetic domain, dispersed in the amorphous matrix. The microstructure is more homogenous 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 2-3 nm and their composition approaches $Fe_{77.2}Nd_{22.8}$.

R5.20
ELECTRIC CURRENT CONTROL OF MAGNETIZATION IN MAGNETIC NANOSTRUCTURES. V.K. Dugaev, Inst for Problems of Materials Science, Chernovtsy, UKRAINE; J. Barnaś, Dept of Physics, A. Mickiewicz, Univ, Poznań, POLAND; M. Vieira, 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 results of our theoretical study of the magnetic torque responsible for this phenomenon. The 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 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 thin magnetic layers with different orientations of the magnetic moments.

R5.21
SPIN STATES OF Mn and M IN NANOCRYSTALLINE $LaMn_{0.5}M_{0.5}O_3$ (M = Co, Ni). V.L. Joseph Joly, P.A. Joy, S.K. Date, Physical and Materials Chemistry Division, National Chemical Laboratory, Pune, INDIA.

The nanometer sized polycrystalline ferromagnetic oxides, $LaMn_{0.5}M_{0.5}O_3$ (M = Co, Ni), synthesized by a low-temperature technique, exhibits interesting magnetic behavior. A lower ferromagnetic transition temperature observed for the nanomaterial was found to be associated with different spin 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
Chairs: Vitali V. Metlushko and K. V. Rao
Thursday Morning, April 24, 2003
Golden Gate C3 (Marriott)

8:30 AM *R6.1
MAGNETISM IN $LaFeO_3$ EXCHANGE BIASED SYSTEMS. Jean-Pierre Locquet, IBM Research Division, Zurich Research Laboratory, Rueschlikon, SWITZERLAND.

Epitaxial films of the antiferromagnetic $LaFeO_3$ grown by MBE have recently opened several exciting avenues to explore the properties of exchange biased systems. First the observation of the magnetic signature of large antiferromagnetic domains using PEEM was reported. Next it was demonstrated that these antiferromagnet domains are exchange coupled with an subsequently deposited ferromagnetic film. With the same technique, it was also 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 NiF_2 FILMS. Hongtao Shi and D. Lederman, Physics Department, West Virginia University, Morgantown, WV; K.V. O'Donovan and J.A. Borchers, National Institute of Standards and Technology, Gaithersburg, MD.

(110)-oriented thin NiF_2 films were deposited on single crystal (110)-MgF_2 substrates via molecular beam epitaxy, followed by 18 nm thick Co layers. Neutron diffraction revealed that the Néel temperature (T_N) in single NiF_2 film (60 nm thick) and NiF_2 / Co bilayer was enhanced to ~80 K, compared to T_N = 73.2 K[1] in bulk single crystal NiF_2. Exchange bias (H_E) after cooling the bilayer sample in a magnetic field of 2 kOe in the film plane perpendicular to the c-axis of NiF_2 showed the blocking temperature (T_B), at which H_E vanishes coincided with the T_N of the film. Such enhancement is attributed to the strain in NiF_2 film due to the small lattice mismatch between the film and the substrate. H_E and T_B dependence on the thickness of NiF_2 will be presented. [1]J.W. Stout and E. Catalano, J. Chem. Phys. 23, 2013 (1955).

9:15 AM R6.3
ON THE MAGNETIC INSTABILITY OF Fe(x)Ni(1-x) PSEUDOMORPHIC THIN FILMS EXHIBITING THE INVAR EFFECT. J.G. Tobin, M. Hochstrasser, S.A. Morton, Lawrence Livermore National Laboratory, Livermore, CA; G.D. Waddill, University of Missouri-Rolla, Rolla, MO; N.A.R. Gilman, R.F. Willis, Pennsylvania State University, University Park, PA.

At a critical concentration of around 65% Fe, bulk FeNi alloys exhibit the "Invar effect", a sudden arresting of the Wigner-Seitz cell volume and a zero expansion coefficient. Previously, we studied this effect in ultrathin films of NiFe/ Cu(001). [1] We are extending this earlier work, using high resolution spectroscopy of the sp states near the Fermi energy, spin resolved studies of the 3d states and XMCD-Absorption of the 2p levels. [2] 1. F.O. Schumann et al, Phys. Rev. Lett. 79, 5166 (1997). 2. M. Hochstrasser et al, Phys. Rev. B 60, 17030 (1999).

9:30 AM R6.4
EFFECT OF Cu DIFFUSION ON MICROSTRUCTURE AND MAGNETIC PROPERTIES OF L10 FePt (001) FILMS AT LOW DEPOSITION TEMPERATURE. J.P. Wang, MINT & Electrical and Computer Engineering Department, University of Minnesota, 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 1Tbit/in2. L10 FePt films with perpendicular [1] and longitudinal [2] anisotropy has been prepared on Cr90Ru10/glass at substrate temperature 400°C or below by dc magnetron sputtering. Effect of Ru pinning layer in FePt films has been explored 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 4nm was deposited on the FePt layer at the temperature 350°C. The XRD results indicate that with 2 and 4 nm Cu top layer, the FePt-fcc phase was reduced. The rocking curve and grazing x-ray diffraction show that the FePt (001) orientation start to deteriorate when the Cu top layer is above 4 nm. The c/a, which is not dependent on the Cu top layer, is 0.96 and fct-FePt phase is fully ordered. The coercivity of the films increases from 3.1 kOe to 7.8 kOe. The slope at Hc decreases to about 1 after the introduction of Cu top layer, which indicate a well exchange-decoupling. The increase in the coercivity is assumed to the change in reversal mechanism of magnetization from domain wall motion to uniform rotation mode. The diffusion of Cu investigated by XPS and TEM will be reported in full paper. [1]. Y.F. Xu, J.S. Chen, and J.P. Wang, Appl. Phys. Lett. 80, 3325 (2002). [2] J.S. Chen, B.C. Lim and J.P. Wang, Appl. Phys. Lett, 81,1848 (2002) [3] Z.L. Zhao, J.P. Wang, J.S. Chen and J. Ding, Appl. Phys. Lett. 81, 3612 (2002).**9:45 AM R6.5**
Transferred to R4.10

10:30 AM R6.6
INTERFACIAL TRANSITION LAYERS PROBED BY SOFT-X-RAY RESONANT MAGNETIC SCATTERING. Bryan M. Barnes, John J.G. Kelly IV, Don Savage, Eric Wiedemann, and Max G. Lagally, 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 (XRMS) provides element-specific information about both the magnetization and structure/morphology of a magnetic material. Specifically, specular XRMS measurements provide a depth profile of the magnetization of thin films while the diffusely scattered component of XRMS (DXRMS) provides information about 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 anisotropy, or interface moments could become decoupled from the bulk moments. We perform XRMS on ultra-thin 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 de-coupled 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 that for Co films less than 10nm thick, the top and bottom transition layers meet so 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
PROBING THE BIAS FIELD IN SPRING MAGNETS WITH A FIRST ORDER REVERSAL CURVE METHOD. L. Zhao, C.R. Pike, H.G. Katzgraber, R.T. Scalettar, K.L. Verosub, G.T. Zimányi, and Kai Liu, University of California, Davis, CA; O. Hellwig, and E.E. Fullerton, IBM Almaden Research Center, San Jose, CA.

A first order reversal curve (FORC) technique[1] has been used to investigate details of the magnetization reversal processes in a series of exchange-spring magnet films[2] of FePt (20 nm) / FeNi (5-80 nm). We have directly observed a microscopic bias field that mirrors the exchange field in such films. After measuring a family of 100 reversal curves along the major hysteresis loop, we transform the second order mixed derivative of the magnetization relative to the reversal field and the applied field to map out the distribution of coercivity and exchange field in a FORC diagram. For the series of samples studied, the coercivity distribution is 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 samples, even though the major loop is centered about zero field. Furthermore, with decreasing FeNi layer thickness, the coercivity distribution monotonically shifts toward higher values, while the bias distribution first increases and then eventually decreases at the smallest FeNi thickness. The thickness-dependent behavior can be explained in terms of a (partial) domain wall inside FeNi that is parallel to the FePt/FeNi interface.
*This work is supported by NSF and UC Davis. [1]C.R. Pike, A.P. Roberts, and K.L. Verosub, J. Appl. Phys. **85**, 6660 (1999). [2]O. Hellwig, J.B. Kortright, K. Takano, and E.E. Fullerton, Phys. Rev. B **62**, 11694 (2000).

11:00 AM R6.8
MAGNETIZATION REVERSAL DETAILS IN EXCHANGE BIASED Fe/FeF_2. Kai Liu, H.G. Katzgraber, C.R. Pike, L. Zhao, R.T. Scalettar, K.L. Verosub, G.T. Zimányi, University of California, Davis, CA; Ivan K. Schuller, 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[1] in an exchange biased Fe (27 nm) / FeF_2 (20 nm) thin film. After measuring a family of 100 reversal curves along the major hysteresis loop, we transform the second order mixed derivative of the magnetization relative to the reversal field and the applied field to map out the distribution of coercivity and exchange field in a FORC diagram. At 100 K, above the FeF_2 Néel temperature of 80 K, the FORC diagram shows a narrow distribution of coercivity with zero bias, centered at the value obtained from the major loop. However, there is a small tail in the FORC diagram due to regions in the sample with higher coercivity. This corresponds to a tail-like feature in the major loop near saturation. After an exchange bias is established, at 50 K, the FORC diagram shows a distribution of coercivity and exchange field that are consistent with the major-loop values. Surprisingly, the tail of higher coercivity regions bends toward *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. [1]C.R. Pike, A.P. Roberts, and K.L. Verosub, J. Appl. Phys. **85**, 6660 (1999).

11:15 AM R6.9
THE QUANTIZATION CONDITION OF QUANTUM-WELL STATES IN Cu/Co(001). J.M. An and E. Rotenberg, Advanced Light Source, LBNL, Berkeley, CA; D. Raczkowski, M. Leung, L.-W. Wang, A. Canning, Computational Research Division, LBNL, Berkeley, CA; Michel A. Van Hove, Advanced Light Source, Materials Sciences Division, LBNL, Berkeley, CA, and Physics, UC Davis, CA; Z.-Q. Qiu and Y.Z. Wu, Materials Sciences Division, LBNL, Physics, UC Berkeley, CA.

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 sample fabrication at beamline 7.0.1.2 to reach a level that we now can observe QWS from discrete atomic layers in Cu/Co/Cu(100) system. Such improvement gives a precise 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 phase accumulation model (PAM) in which the phase 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 phase accumulation model. This may 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 to identify the phase deviation from the PAM model through a more sophisticated microscopic wavefunction fitting procedure. This procedure provides the phases at the interface and surface whose potential geometry is strongly influenced by local atomic environments, unlike simple step-like potential wells. The calculated total phases are compared with the experimental values, and our calculated QWS reproduce the correct Cu sp-dispersion curve within known LDA/GGA error margins. The quantization condition of QWS appears to hold true for our calculated potentials, although its constituent phases are strongly influenced by the local potential geometry.

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 (110) sapphire 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. Surface roughening starts at 450°C, and increases 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.

J. Bentley and N.D. Evans, Oak Ridge National Laboratory, Metals and Ceramics Division, Oak Ridge, TN; J.E. Wittig and J.F. Al-Sharab, Vanderbilt University, Nashville, TN.

High-spatial-resolution analytical electron microscopy (AEM) characterization has been performed on several sets of nanoscale multilayer reference and model materials for perpendicular magnetic recording, such as CoCrPt/CrTa/NiAl/CoZrNb/NiAl and (FeTaN/IrMn) multilayers. The main techniques employed were spectrum imaging and spectrum profiling of cross-sectioned specimens by simultaneous energy-dispersive X-ray (EDS) and electron energy-loss spectroscopies (EELS) in the scanning transmission electron microscopy (STEM) mode on a Philips CM200FEG AEM equipped with an Emispec 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. AEM has revealed some unexpected and interesting compositional profiles. However, the data rarely yield composition profiles simply or easily because of potential artifacts arising from specimen preparation, limited spatial resolution from probe-size and beam spreading, and complications in analysis of the spectra due to 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 overcome, resulting in improved confidence in compositional data. Research at the ORNL SHaRE Collaborative Research Center was sponsored by the Division of Materials Science and Engineering, Office of Basic Energy Sciences, Office of Science, 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 DYNAMICS

Chairs: Samuel D. Bader and Jean-Pierre Locquet
Thursday Afternoon, April 24, 2003
Golden Gate C3 (Marriott)

1:30 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-V's has allowed integration of magnetic cooperative phenomena with III-V heterostructures. I will review a number of new structures and phenomena that have been explored and demonstrated using ferromagnetic III-V structures, including isothermal and reversible electric field control of ferromagnetism.

2:00 PM *R7.2
NANOMAGNETICS 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 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 nano-scale dimensions in the device structures and full control over the properties at that scale. Further, the improved understanding of nano-scale 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 appealing. In case these latter devices, currrently fabricated with micron-size dimensions, endaevor to challenge the mature advanced electronic components in the future, nano-scale 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/circuit 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 nano-scale magnets 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. For the latter, the author acknowledges the contributions of W. Van Roy, P. Van Dorpe, V. Motsnyi, Z. Liu, W. Hiebert, L. Lagae, J. Das, W. Eckmans, J. Bekaert, R. Wirix-Speetjens, J.L. Primus and G. Borghs.

2:30 PM *R7.3
A NEW ROOM TEMPERATURE FULLERENE-BASED ORGANIC FERROMAGNET. K.V.Rao, Lioubov Belova, Wolfgang Voit, Department of Materials Science-Tmfy-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 C_{60} and the paramagnetic organic molecule 2,2,6,6 tetramethyl-4 oxy-piperidinooxy (TMOP). Samples containing approximately 10 weight percent of the magnetic phase, determined by superconducting quantum interference device (SQUID) magnetometry measurements, have been obtained by mixing nominal 1:1 molar ratios of C_{60} 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 C_{60} based ferromagnets on various substrates will also be presented.

3:30 PM *R7.4
EXCHANGE BIAS SYSTEMS: EFFECT OF NANOPATTERNING AND MAGNETIZATION REVERSAL. Michael Fraune, Andrea Tillmanns, Ulrich Rüdiger[a], Bernd Beschoten, S. Cardoso[b], Paolo Freitas[b], Gernot Güntherodt, II. Physikal. Institut, RWTH Aachen, Aachen, GERMANY; [a]Fachbereich Physik, Universität Konstanz, Konstanz, GERMANY, [b]INESC, Lisboa, PORTUGAL.

The domain state model for exchange bias (EB) presented recently [1,2,3] 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 test 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 Ni/NiO 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 5 K. 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 ion milling vs. reactive ion etching processes. The magnetization reversal in exchange bias systems has been measured by means of a magnetooptic Kerr setup using both longitudinal and transverse configurations. The asymmetry of the hysteresis loops, i.e. coherent rotation of the magnetization vs. 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 nanopatterning of exchange bias systems on the asymmetric vs. symmetric magnetization reversal will be discussed. Work supported by Deutsche Forschungsgemeinschaft through SPP 1133, grant no. BE 2441/2-1 and by EC RTN Networks SUBMAGDEV and NEXBIAS. [1] P. Miltenyi, J. Keller, B. Beschoten, G. Güntherodt, U. Nowak, K.D. Usadel, Phys. Rev. Lett. 84, 4224 (2000) [2] U. Nowak, K.D. Usadel, P. Miltenyi, J. Keller, B. Beschoten, G. Güntherodt, Phys. Rev. B 66, 14430/1-9 (2002) [3] J. Keller, P. Miltenyi, B. Beschoten, G. Güntherodt, U. Nowak, K.D. Usadel, Phys. Rev. B 66, 14431/1-11 (2002) [4] M. Fraune, U. Rüdiger, G. Güntherodt, S. Cardoso, P. Freitas, Appl. Phys. Lett. 77, 3815 (2000) [5] Work in cooperation with I.K. Schuller, C. Leighton, J. Eisenmenger, M.R. Fitzsimmons [6] M.R. Fitzsimmons, P. Yashar, C. Leighton, I.K. Schuller, J. Nogues, C.F. Majkrzak, J.A. Dura, Phys. Rev. Lett. 84, 3986 (2000).

4:00 PM R7.5
MULTIBAND TIGHT-BINDING MODEL OF LOCAL MAGNETISM IN $Ga_{1-x}Mn_xAs$. Jian-Ming Tang, 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 sp^3 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 nearby 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 S.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 (Ristoiu 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 half-metallic 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$\sim$.45 has been explored via sputtering MTJs using CoFe as a counter-electrode, and by spin polarized tunneling into superconductors. MnSb shows a tunneling spin polarization of 30%, and a tunneling magneto-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 $Ni_{81}Fe_{19}$ USING DILUTE Eu IMPURITIES. Lili Cheng, William E. Bailey, Sean G. Reidy, 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 50nm $Ni_{81}Fe_{19}$ can boost the precessional frequency of the system by over 400 MHz without effect on Gilbert magnetic damping parameter α. 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. Kittle plot analysis shows that the $g_{eff}{}^2M_{sat}$ 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. Pufall, W.H. Rippard, 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. Slonczewski and Berger attribute this step to the onset of coherent, high-frequency (10-100 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 nanopillars [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 $Ni_{40}Fe_{10}Cu_{50}$/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 Slonczewski 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 resistance 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**, 9353 (1996) [2] J.C. Slonczewski, 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).