SYMPOSIUM R
Nanomagnetism
April 22 – 24, 2003

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*Invited paper
SESSION R1: NANO MAGNETS PREPARATION I
Chairs: Dieter Weller and Kai Liu
Today's Morning, April 29th
Golden Gate CS (Marrick)

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

Arrays of magnetic nanowires and nanowire devices were fabricated using nanorod templates derived from self-assembling diblock copolymer fluid growth of magneto-chemical (Fe, Co) diblock copolymers as porous templates that were used to fabricate hexagonal arrays of vertical nanowires with densities exceeding 1x10^7 per square inch. Electrodeposition within the template produces highly oriented nanowires with a wide variety of potential uses. This work is supported by the National Science Foundation.

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

Arrays of small magnetic particles have been proposed for use in various magnetic electronic 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-10 nm magnetic particles made by interference and block copolymer lithography techniques. The sizes, shapes, compositions, and two-dimensional arrangement of the particles on the substrate can be controlled, enabling a wide variety of different magnetic behaviors to be obtained. In particular, we will describe the thermal stability of closely spaced 30 nm diameter Ni and Co particles made using a block copolymer as a template, and the behavior of multilayered Co/Ni/NiFe rectangular pseudo-spin-valve bars made by block copolymer lithography. We will also discuss the magnetic properties of ringshaped thin film elements in which interesting domain configurations can be observed.

10:00 AM R1.3
NANOPATTERNING OF MAGNETIC NANOSTRUCTURES OF BARUUM FERRITE VIA DIP-PEN NOLITHOGRAPHY (DPN) AND A SOL-GEL PROCESS. Lei Fu and Vinayak P. Desai, Department of Materials Science and Engineering and Institute for Nanotechnology, Northwestern University, Evanston, IL; Xiongwen 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 on the example of fabrication of "hard" magnetic barium hexaferrite (BaFe) nanostructures. By combining 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 BaFe 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, X-ray photoelectron spectroscopy (XPS), and x-ray photoelectron spectroscopy (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 FERRIBYDRITE MAGNETIC NANOPARTICLES ANCHORED IN A SOL-GEL DERIVED ORGANIC-INORGANIC HYBRID MATRIX. N.J.O. Silva, V.S. Amural and I.D. Carlos, Departamento de Fisica e CICECO, Universidade de Aveiro, PORTUGAL; V. de Zena Bermudez, Departamento de Quimica, UTAD, Vila Real, PORTUGAL.

Nanostructured Ferribydrate (R=OH, R2H2O) particles formed within an organic-inorganic hybrid matrix were obtained by the sol-gel process. In the present work, it was attempted to observe the formation of magnetic ferrites at the atomic level by electron microscopy techniques. The hybrid matrix here reported, classified as glass-ceramic, is composed of poly(ethylene oxide) chains grafted to form small groups by means of cross-links [1-4]. PMMA and silicate copolymers as poros templates that were used to fabricate hexagonal arrays of vertical nanowires with densities exceeding 1x10^7 per square inch. Electrodeposition within the template produces highly oriented nanowires with a wide variety of potential uses. This work is supported by the National Science Foundation.

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

CoCrPt thin films are attracting widespread interest for applications to high-density magnetic recording media and head 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 patterning otherwise inaccessible by lithographic procedures. In this work, we have investigated magnetic properties of Co50Cr40Pt10 thin films deposited on nanopatterned PS2000(styrene)-PVP150vinyl pyridine) diblock copolymer. The PS-PVP diblock copolymer were coated on Si(100) surface with a sputtering rate of 20 nm/second (s) diblock copolymer formation 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 middle 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 similar to the PS-PVP template. Magnetic property of CoCrPt films were measured by magneto-optical microscope magnetometer and temperature dependence. The perpendicular magnetic anisotropy (PMA) of CoCrPt films strongly enhanced when we deposited the films on nanopatterned PS-PVP template. The coercivity, defined as the remnant Kerr rotation angle divided by the saturation one, increased from 0.3 to 0.85 for the samples of 200Ax CoCrPt/PS-PVP/Si(100) and 200Ax CoCrPt/Si(100), respectively. The coercivity is also increased dramatically 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 - BARUUM FERRITE NANO COMPOSITES. Mireia Chipaun, Indiana University Cyclotron Facility, Bloomington, IN; Diandra Leslie Peckley, David Sellmeyer, Amy Bender, and Luming Yue, Dept of Physics, University of Nebraska, Lincoln, NE.

Magnetic nanocomposites have been obtained by dispersing various amounts of barium ferrite (BaFe12O19) 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 3h. The magnetic nanoparticles were obtained by mechanical milling. Their average grain size has been estimated to be 10 nm, from the X-Ray diffractometric lines. Vitrifying salt 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 $M = M_0(1 - A H/R H^2)$, after extracting a linear contribution due to the diamagnetic and paramagnetic contributions. $M_0$ is the magnetization at saturation and $R$ is related to the magnetocrystalline anisotropy. A matrix effect was observed, the temperature dependence of $M_0$ and $R$ being close to the glass transition temperature of the polystyrene phase and confirmed by the temperature dependence of the magnetic properties in a composite-based on vinyl and Fe$_3$O$_4$. The result suggests that the magnetic nanocomposites have 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. Segmented melts exhibit several relaxation times characterized by persistency 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 the nearest free volume cluster, a jump of the nanoparticle, eventually accompanied by its reorientation, occurs. The competition between the dynamics of magnetic nanoparticles and the spin reorientation is analyzed in detail. Reference: 1. M. Chipara, Physica B, 234-236, 265-265, 1997.

11:00 AM R1.4 SYNTHESIS AND CHARACTERIZATION OF MONODISPERS MAGNETITE AND COBALT FERRITE NANOPARTICLES. Hao Zheng and Shouheng Sun, IBM T.J. Watson Research Center, Yorktown Heights, NY.

Fe$_3$O$_4$ and CoFe$_3$O$_4$ 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 particle sizes can be tuned from 4 nm to 16 nm. These nanoparticles are spherical, monodisperse and single crystalline, allowing them to self-assemble into three-dimensional superlattices. The as-synthesized magnetic nanoparticles are superparamagnetic at lower concentrations. The blocking temperature increases with increasing magnetic nanoparticle concentration. This could be attributed to Verwey transition in magnetic magnetite systems. The CoFe$_3$O$_4$ is synthesized with $x = 2$, 1.5, 1 and 0.6, respectively, where $x$ is defined by the amount of the Co(acac)$_2$ precursor under constant amount of Fe(acac)$_3$. 3 nm CoFe$_2$O$_4$ and 1.5 nm CoFe$_3$O$_4$ mononano particles show large coercivity at low temperatures (above 12 K Oe at 10 K), while blocking temperature decreases above 170 K. These are consistent with the large magnetic moment anisotropy and high coercivity of the ferrites. The iron oxide based nanoparticles and their self-assembled structures may have potential in microwave and biological applications.

11:15 AM R1.8 COOPERATIVE MAGNETISM IN DIPOLE NANOCOMPOSITES. Eugene Venturini, James Martin, Dale Huber and Paula Prowenca, Sandia National Laboratories, Albuquerque, NM.

We present experimental data and detailed numerical simulations demonstrating large changes in the magnetic response arising from cooperative dipolar interactions among 7 nm iron nanoparticles in non-nanocrystalline arrays. The isolated particles, synthesized by iron carbynyl decomposition in diethyl ether, exhibit approximately half the saturation magnetization of bulk iron and have a superparamagnetic blocking temperature near 60 K. These particles, suspended in a supercooled solvent, form self-assembled 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 structures exhibit greater than 10$^3$ 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 spin giant monodipole magnetic moment.

The blocking temperature in the nanocomposites is raised by the dipolar interactions, and, at temperatures well below blocking, the interactions provide additional rotational anisotropy that leads to a doubling in the remanence coercivity an increase 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-GLASS PROCESS. Nely Dellas Santana Mohalen, Luciana Moreira Senna, Dept. of Chemistry, UFMG, Belo Horizonte, BRAZIL.

Nanostructured oxide thin films have potential technological use for their high surface/volume ratio, which leads 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, by self-coffing 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 the nearest free volume cluster, a jump of the nanoparticle, eventually accompanied by its reorientation, occurs. The competition between the dynamics of magnetic nanoparticles and the spin reorientation is analyzed in detail. Reference: 1. M. Chipara, Physica B, 234-236, 265-265, 1997.

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

Organic-inorganic hybrid materials can provide very useful properties by coupling together the characteristics of the individual organics (e.g. plasticity, efficient luminescence) and inorganics (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$_{3}$H$_{6}$(H$_{2}$)$_{4}$N$_{3}$)$_{2}$MoCl$_{6}$ (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 Cmcm), while SQUID magnetometry has probed the transition to an antiferromagnetic state at low temperatures (<4 K).

We note that their magnetic behaviour is marginally affected by the varying $d$ of the organic double-layer spacer ($d$ = 1.1-4.5 nm). Utilizing the chemical activity and structural flexibility of the organic cations, polycrystalline perovskite nanoparticles 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$_{3}$H$_{6}$(H$_{2}$)$_{4}$N$_{3}$)$_{2}$MoCl$_{6}$/THF slurry with cross-linked PDMS at 30 000 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 to one another within the polymer matrix. The inorganic perovskite phases afford contrast in the electron microscope, allowing for the observation of individual perovskite nanoparticles and their distribution throughout the matrix. 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 magnetic interactions or solitons prevail in a similar fashion to that in the parent hybrid perovskite systems, however, at reduced transition temperatures. We suggest that changing the mechanical attributes (e.g. by applied stress) of the polymeric matrix can be modified the magnetic behavior of the system.

SESSION R2: NANO-MAGNETIC PREPARATION II

Chair: Mark Thurnmen and David Lederman

Tuesday Afternoon, April 22, 2008

Golden Gate C3 (Marriott)
1:30 PM R2.1

FERROMAGNETIC NANOWIRE ARRAYS IN POROUS ALUMINA FROM 3D-POLYCRYSTALLINE TOWARDS SINGLE CRYSTAL ARRANGEMENT. Korinella Nielsch*, Ralf B. Wehrspohn, Jinsub Choi, Ricardo Hertel, and Ulrich Gosele, Max Planck Institute of Microstructure Physics, Halle, Germany. "Current Address: MIT, Department of Materials Science and Engineering, Cambridge, MA.

Nanowire arrays have recently attracted scientific interest due to their potential application as patterned perpendicular magnetic storage media. Using interference lithography large scale arrays of nickel columns with aspect ratios of up to h/Dp = 2.5 [1] (ratio of wire length to diameter Dp) have been achieved by C.A. Ross et al. In order to obtain magnetic columns with larger aspect ratios (h/Dp > 1), self-ordered porous alumina is based on the approach of Masuda et al. [2] is a suitable template. Currently, highly-ordered nanomagnetic nanowire arrays exhibit a 3D-poly-crystalline arrangement with a deposition density of 4x10^9 cm^-2. The fabrication of Ni nanowire arrays on imprint lithography will be presented, which show a perfect hexagonal arrangement on a cm^-2-scale and ∆ Dp /Dp ≈ 5%. Additionally, we will analyze experimentally as well as theoretically the influence of the degree of order of the Ni nanowires on their 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 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 Aragon, the Technical University of Vienna, and the National University of Singapore.


2:00 PM R2.2

USING TRIAXIAL MAGNETIC FIELD TO CREATE HIGH MAGNETIC 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 radio-frequency magnetic fields to particle/resin dispersions along three orthogonal directions. The magnetic fields create particle dipole moments that arose 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 heterodisperse and/or for modulation to create all manner of oscillating structures, and during resin polymerization these fibrate into highly organized composites, such as cellular honeycombs and three-dimensional particle foams. This structure should evolve by slow diffusion, 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 susceptibilities in ferromagnetics can be created through modest field amplitude imbalances.

2:15 PM R2.3

ENHANCED MAGNETIC RESPONSE OF DILUTE COBALT NANO PARTICLES IN AN ORGANIC MATRIX. J.P. Wilkson, E.L. Venturini, and P. Prevencio.

We report studies of the magnetic response of nanocrystallites of extremely small, D=1.5 and 1.9 nm dilute Co particles in frozen organic matrices. An air and water-free inverse micelle synthesis is described and the observation of the magnetic response is found to increase from 1%20% of the bulk saturation magnetism. One day after synthesis to a value exceeding that of the bulk HCP martenite after a 30 day aging period in a saturated air environment. Maintains its high value after a 15 min heating of T of the current matrix medium as predicted by the Langevin equation. The effects of various surface passivators and molecular O2 on the magnetic response is discussed as well as experiments to grow both homo- and heteroatomic [core/shell] clusters. The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds". The origin of the "Nanoscale Seeds".


3:00 PM R2.4

G FACTOR FOR Fe, Fe1-x, NANO PARTICLES ASSEMBLY. Magdalena Ulmennu, Gerhard-Mercator-Universität Duisburg, Exp. Tiefenlentespektroskopie, GERMANY; Carolin Antoniuk, Technische Universität Carolo Wilhelmum Braunschweig, GERMANY; Ulf Wald, Gerhard-Mercator-Universität Duisburg, Exp. Tiefenlentespektroskopie, GERMANY; Shouang Sun, IBM T.J. Watson Research Center, Yorktown Heights, NY; Michael Forle, Gerhard-Mercator-Universität Duisburg, Exp. Tiefenlentespektroskopie, GERMANY.

Chemically produced Fe1-x, Fe nanoparticles with various compositions (x = 38, 56, 70) have been deposited on different substrates: Si, Au, quartz and Si. Low resolution Transmission Electron Microscopy (TEM) pictures show that the as-prepared Fe1-x consist of round shape nanoparticles with a mean size diameter of 2.6 nm and 3.5 nm, depending on the composition. From magnetic Magnetic Resonance (FMR) spectra, at 9.8 GHz, 9.12 GHz and 79.34 GHz frequencies have been recorded at room temperature. The g-factors are 2.104, 2.070, 2.04 for x = 38, 56 and 70 respectively were determined. The g-factor deviates from the bulk one Fe value (g = 2.00) in respect with the Fe contents in the nanoparticles. Moreover it is to be mentioned that the contribution of 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 NANOGRAINED COBALT FILMS DEPOSITED BY MOCV. Peter Haycock, Fedor Ogrin, Miriam Chiancol, Brian Rathven, Anthony Wright, Jonathan Stirling, Keele Univ, School of Chemistry and Physics, Keele, Staffordshire, UNITED KINGDOM; Steve Hoon, Manchester Metropolitan Univ, Dept of Environmental and Geographical Sciences, Manchester, UNITED KINGDOM; Sarah Thompson, York Uni, 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 magnetisation 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, which have been produced by metastable chemical vapour deposition, which is a particular 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 magnetisation 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 TRANSFER IN MAGNETITE NANO PARTICLES. Kui Li, L. Zhao, P. Khivs, Physics Department, University of California, Davis, CA; Frank E. Osterloh, and H. Rimmer, Chemistry Department, University of California, Davis, CA.

Nanoparticles of magnetite (Fe3O4) have been synthesized using an aqueous precipitation technique. The particles are spherical in shape, with an average size of 8-9 nm and a small size distribution, revealed by transmission electron microscopy and atomic force microscopy. X-ray diffraction and chemical titration confirm a single cubic spinel phase with expected stoichiometry. Dispersed nanoparticles display superparamagnetic behavior above 150 K over a 30 at a scale. The blocking behavior is modified by the packing density, or the average particle distance, of the particle assembly. A critical buckling of the particles in nanometer bundles decreases the saturation magnetization in nanoparticles decreases
faster with increasing temperatures, still according to $T^{-1/2}$, due to enhanced contributions from surface magnetizations. In a compressed pellet from mixture of Ni, P, and Fe, the transport is by mobile particles. Negative magnetoresistance, $-8.9 \%$ at $200 \, \text{K}$ and $-5.9 \%$ at $300 \, \text{K}$, has been observed. This is due to the field-induced alignment of the nanoparticles magnetization directions.

3:45 PM P2.7
THE EFFECT OF THERMAL SINTERING ON THE MAGNETISM OF FePt-NANOPARTICLES. Sonja Stecker, Bernhard Bellinghaus, Michael Schieber, Arndt Götze, and Wolf-Dietrich Götze, TiefTemperaturphysik, Gerhard-Mercator-Universität, Duisburg, Germany.

 Stoichiometric FePt nanoparticles in the chemically ordered L1$_0$ phase have a large magnetic moment, which makes them attractive for future high density magnetic data storage media. However, independent of the preparation method employed, a thermal annealing treatment is necessary in order to obtain nanocrystals, therefore, we studied the thermal sintering of gas-phase prepared FePt nanoparticles and their impact on their magnetic properties. Fe$_x$Pt$_{1-x}$ 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 $T_s = 1273 \, \text{K}$. The influence of the sintering process on the particle morphology and crystal structure and the magnetic properties are investigated by means of (HR)TEM and SQUID magnetometry, respectively. The gas-phase preparation results in the formation of particle agglomerates which are increasingly compacted to single particles with increasing sintering temperatures $T_s$. At temperatures $293 \, \text{K} < T_s < 873 \, \text{K}$, inter-particle coalescence occurs. Below $T_s = 723 \, \text{K}$, we observe neck growth between the primary particles. Above this temperature, the agglomerates are compacted, and the primary particles grow from $d_p \approx 50 \mu \text{m}$ at $T_s = 293 \, \text{K}$ to $d_p \approx 1 \mu \text{m}$ from the variation of $d_p$ with $T_s$. We estimate an activation energy for this growth process of roughly $E_a \approx 6 \times 10^4 \text{Jmol}^{-1} \text{K}^{-1}$ indicating that surface diffusion and/or grain boundary diffusion are the predominant sintering mechanisms in this temperature range. TEM measurements confirm this finding. The temperature range $T_s = 723 \, \text{K}$ to $T_s = 1273 \, \text{K}$ and from the variation of $d_p$ with $T_s$, 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 range, 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 $H_C = H_{K} (T = 0)$ increase from $K_{eff} = 2 \times 10^3 \, \text{Jm}^{-3}$ at $T_s = 293 \, \text{K}$ to $K_{eff} = 7 \times 10^3 \, \text{Jm}^{-3}$ at $T_s = 1273 \, \text{K}$ and from $H_C = 1.8 \, \text{kOe}$ at $T_s = 293 \, \text{K}$ to $H_C = 4.6 \, \text{kOe}$ at $T_s = 1273 \, \text{K}$, respectively.

4:00 PM P2.8
STRUCTURAL AND MAGNETIC PROPERTIES OF SELF-ORGANIZED Co CLUSTERS. F. Luis, L. M Garcia, J. M. Torres, F. Bartolome, J. Bartolome, ICMa, CSIC-UAM Universidad de Zaragoza, Zaragoza, Spain; F. De Fauw, IMEP, UMP CNRS/Thales and Université Paris-Sud, Orsay, France; D. Buchmann, LMP-Université de Poitiers, Futuroscope Chasseneuil, FRANCE.

We have fabricated granular multilayers consisting of successive planes of nanocrystalline cobalt clusters separated by alumina along the growth direction. Combining growing-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 ($0.5 \, \text{nm}$) 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 appears to be closely linked to the distribution of the particles, i.e., the surfaces rather than the volume distribution. We will also show that Co/Al$_2$O$_3$ granular multilayers appear as a model system to study the effect of dipole-dipole interactions between magnetic nanoparticles and its influence on their relaxation times. Our data clearly demonstrate that magnetic relaxation becomes slower as the degree of interactions increases. The blocking temperature and the effective activation energy increase almost linearly with the number of nearest neighbor clusters, starting from a $3 \times 3$ lattice in 2D 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 P2.9
PULSED LASER DEPOSITION ASSISTED SELF-ASSEMBLED GROWTH OF Pd AND Ni NANOPARTICLES. D. Komar, Department of Electrical Engineering, North Carolina State University, Greensboro, NC, S.J. Pennycott, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN; J. Smink, Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC.

The present study focuses on developing pulsed laser deposition (PLD) assisted self-organized growth of uniform magnetic nanoparticles (islands) within matrices of aluminum or 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, particle sizes, functional groups and configuration, 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 determines the number density of arriving ablations on substrate surface, and pressure of the gas ambient. The uniformity in particle size distribution was monitored by the competition between 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) 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 Pd particles.

4:30 PM P2.10
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 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 confirms a core-shell structure with an approximate diameter 10 nm. X-ray absorption spectra of these samples were collected at the National Synchrotron Light Source, and subjected to a variety of methods of analysis. The ratio of core to shell was determined by comparing the x-ray absorption near edge structure (XANES) to metal and mixed-oxide standards, with the results indicating about 60% of the iron atoms reside in the metallic core. This information was then used to constrain a fit of the extended x-ray absorption fine structure (EXAFS). Successful EXAFS fits to the data were obtained for a model consisting of amorphous iron oxide, nanocrystalline iron, and amorphous close-packed iron. The structure of the core was strongly dependent on the surfactant used to form the micelles. REM confirmed the presence of iron in the core. Magnetic measurements performed with a superconducting quantum interference device (SQUID) and a vibrating sample magnetometer (VSM) are consistent with the structural interpretation, yielding a 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 partially crystalline cores. In keeping with the small size of the particles, coercivities are less than 100 Oe in both cases.

4:45 PM P2.11
SELF-ORGANIZATION OF MAGNETIC PARTICLES IN 2D. J.-C.S. Lévy, Laboratoire de Physique théorique de la Matière Condensée, Université Paris 7, FRANCE; A. Giselmi, Groupe de Physique des Solides, UMR 7688-CNRS, Université Paris 6 et Paris 7, 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 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 randomly arranged in vortices as seen from lattice simulations [2]. The interaction between neighboring chains is rather weak. This explains numerous inhomogeneities in the particle assembly. At higher
To gain fundamental insight into spin-dependent properties at the nanoscale, 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 the LTEM images of ultra-thin magnetic films, besides the commonly observed ripple fringes, the contrast also reveals along...
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. Advancements of technology demand technical control of producing nanometer-sized structures over large areas. Using self-assembled monolayers in nanoresonator structures as a low loss [1] magnetic sub-100 nm dots covering over 1 cm² area are deposited by electron-beam evaporation. This method provides a good control over dot size and separation. Samples with Fe and Fe/Co films as well as continuous Fe and Fe/Co films are simultaneously grown on the same substrate. Typically 15-20 nm of Fe and 20-30 nm of Fe₂ are used, and the samples are capped with a 5×10 nm-thick Al layer to prevent Fe from oxidation. Comparative studies of magnetic properties of these nanoresonators in a wide range of frequencies are performed. All samples are cooled from 150 K in an applied 2 kOe field. Improved squareness of the magnetization loops for Fe nanodots with Fe₂ 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 Fe₂ nanodots by coupling to an AF layer is discussed.

Work is supported by AFOSR.


3:30 PM R4.3 MAGNETORESISTANCE IN PATTERNED NANO-BRIDGES ON EPITAXIAL Ni FILMS. R. A. Aleksandarov, University of Toledo, Physics and Astronomy Department, Toledo, OH; Antonio Zambrano, Physics and Astronomy Department, Michigan State University, East Lansing, MI.

The latest results on BMR research have shown surprising ballistic magnetoresistance values with over 3000% in Ni nano-contacts at room temperature. 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 constriction. [2] The reported BMR effect has been observed in room temperature and low magnetic field in Ni nano-contacts electrodeposited between Ni wires. Much of the published data so far, is still poorly understood. In an attempt to clarify some of the possible processes present in the observed 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 have ballistic regime provided that the nano-contact is small enough. Thus we have patterned nano-bridges with a similar T geometry to that utilized by Choppa and Garcia. [1,3] Then the combined shape and magnetocrystalline anisotropies provide the required two states for the magnetization at each side of the nano-contact. Our preliminary results indicate that the key results indicate that the key results suggest that the BMR effect may play a role in the magnetoresistance of these nano-bridges but the order of magnitude of the observed effect is considerably smaller than the reported observations. In addition, we have explored the magnetoconductivity of these nano-contacts. The nano-contact resistance above 10 kΩ is low enough for comparison with other devices.

3:30 PM R4.5

MAGNETIC PROPERTIES OF SINGLE ELEMENT AND MULTILAYERED NANOWIRES
Ryan Cohain and Bethanie Studler, 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/NaNi multilayered nanowires using metal sputtered electrodes 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 a 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 GM structure. Third, we fabricated Ni/Ni multilayered nanowires in the presence of an applied field to influence the exchange between the ferromagnetic Ni layer and the antiferromagnetic Ni layer. Creating Ni/NaNi multilayered nanowires with good exchange coupling is the first step towards creating Ni/Co/Cu/NaNi spin valve structured nanowires.

3:45 PM R4.6

AIRYS OF TOUCHING MAGNETIC RING ELEMENTS
V. Metlushko, University of Illinois at Chicago, Chicago, IL; U. Welp, V. Vishik, G. Crabtree, M. Grimsditch, V. Novosad, J. Hille, N. Zakwicz, Materials Science Division, Argonne National Laboratory, Argonne, IL; and S. Mielczarek, University of York, UK; and V.V. Moshchalkov, and V. Brune, University of Namur, Belgium.

Recent studies show that the narrow ring-shaped magnetic elements exhibit different static magnetic binding or remanence in addition to the vortex state. Those two states, forward or reverse domains, and their magnetic properties, 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 TEM to determine the magnetic properties. In addition, the magnetic moment analysis with magneto optical imaging to visualize the moment reversal process during a magnetization cycle, will presented. Work at ANL is supported by US Department of Energy, BES Materials Sciences under contract #DE-AC02-06CH11357. This work was supported by NSF DMR-0723577.

4:15 PM R4.8

IMAGING OF SPIN DYNAMICS IN CLOSED DOMAIN AND VORTEX STRUCTURES
Joshua Park, Peter Ennes, Dave Englebrenson, Jesse Berensky, Paul A. Crowell, Univ of Minnesota, Dept of Physics, Minneapolis, MN.

We have studied spin dynamics in closed 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 techniques and films sputtered on GaN (100) substrates. Structures 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 remanent state of each vortex with a singularity at the center. The higher frequency mode observed in the vortices is due to precession of the azimuthal magnetic field component, 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 inhomogeneous 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 (Galshenko et al., J. Appl. Phys. 91, 8337 (2002)). This work was supported by NSF DMR-0723577, the Research Corporation, the Freed P. Bower Foundation, the University of Minnesota MSEC (DMR-0921309), and the Minnesota Supercomputing Institute.

4:30 PM R4.9

MAGNETIZATION 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 magnetization reversal mechanisms of small elements by in-situ experimentation in the transmission electron microscope. Two recent experiments performed at the same time on the magnetization process of single permalloy elements with lengths 1000 nm and widths down to 150 nm. In the first we show how the field at which the magnetization 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 magnetization rotation, are dominant. To carry out such experiments, the Magnetic Spectroscopy Division, Argonne National Laboratory, Argonne, IL; and P. Wenzelstr, FMP, National Research Center on Nanostructures and Bio-systems at Interfaces (S3)-Dipartimento di Fisica, Universita di Ferrara, ITALY; V. Mielczarek, and V. Brune, University of Namur, Belgium.
particularly suited to experiments in which the specimen is subjected to (repeated) pulsed fields and has application not only in the study of switching processes but also to how, for example, the properties of multilayer films change on repeated cycling.

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

Preferably, nong and bubble-like magnetic domain structures have been observed under ambient conditions in La$_2$Cu$_3$Sr$_2$Mn$_2$O$_8$ films by magnetic force microscopy (MFM) for films grown on a compressive (La$_2$A03) two percent lattice-mismatched substrate and a direct correlation was seen between growth temperature, grain size, and coercivity. X-ray diffraction confirmed approximately one percent distortion of the lattice parameter resulting in out-of-plane magnetic structure. The substrate-induced stress in this soft magnetic material appears to be responsible for the appearance of these structures. In order to better understand these magnetic structures, we have examined films grown by pulsed-laser deposition at 750°C and 800°C by magnetic force microscopy as a function of temperature to study the behavior of the domain structures. Since the average transition temperature for these films was about 350°C, they are 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 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: Martin Inselo Montoro
Wednesday Evening, April 23, 2003
8:00 PM
Salon 1.7 (Merriott)

R5.1
Abstract Withdrawn.

R5.2
MAGNETIC AND STRUCTURAL PROPERTIES OF NANO-METER Fe$_3$O$_4$ Particles. Xingzhong Sun and D.E. Nikles, Center for Materials for Information Technology (MINT), The University of Alabama, Tuscaloosa, AL.

Nano-meter Fe$_3$O$_4$ 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 electron dispersive spectroscopy (EDS) showed that particle size was about 15-25 nm in spherical shape; the nanosphere was identified as mainly γ-Fe$_3$O$_4$. NanoEDS indicated an average value of Fe$_3$O$_4$ in this Fe-γFe$_3$O$_4$ particles. Superconducting quantum interference device (SQUID) magnetometer and vibrating sample magnetometric (VSM) measurements indicated that the saturation magnetization (Ms) and coercivity (Hc) were less than that of the bulk Fe$_3$O$_4$ materials due to their nano-metre particle size. Hyperfine fields (H_{hf}) values that from Mössbauer spectra at room temperature confirmed this FCC γ-Fe$_3$O$_4$ nanosphere. SQUID, VSM and Mössbauer spectra suggested that these Fe$_3$O$_4$ nano-meter particles exhibited ferromagnetic behavior at room temperature, no superparamagnetic properties. And magneto-crystalline 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, Kangnam Kogaku University, Dept of Chemistry, Kangnam, KOREA; Jin-Kyu Lee, Seoul National University, Dept of Chemistry, Seoul, KOREA; Lee Seok-Mo, Kangnam University, Dept of Chemistry, Kangnam, KOREA; and Charles J. O'Connor, AMRI/Dept. of Chemistry, New Orleans, LA.

Magnetic properties of Ni nanostructures deposited into cylindrical vapor grown alumina seras have been investigated. Usually magnetic properties vary with the wire diameter, length and wire distribution. In this work we observed the size and shape effect on the magnetic properties of Ni nanostructures deposited in alumina for different lengths of time. The physical and chemical properties of obtained nanostructures have been investigated by XRD, SEM, TEM, AFM and SQUID. The coercivity of Ni nanostructures was found to depend on aspect ratio, L/dw (wire length divided by wire diameter), increasing from 30 Oe at 1L/dw (spherical form) to 2000 Oe at 1L/dw=100 (nanowire form).

R5.4
PREPARATION AND TRANSFORMATION OF FERROMAGNETIC Fe$_3$O$_4$ AND Fe-Co NANO PARTICLES SYNTHESIZED BY CHEMICAL VAPOR CONDENSATION. Chul Min Chei and Byung-Kee Kim, Korea Institute of Machinery and Materials, Changwon, Kyungnam, KOREA; Oleg Tolochko, State Technical University, Politechnicheskaya, Saint-Petersburg, RUSSIA.

Ferromagnetic Fe$_3$O$_4$ and Fe-Co nanoparticles were synthesized by Chemical Vapor Condensation (CVC) Process using the precursor of Fe$_3$O$_4$ and Co$_2$O$_3$. We investigated the magnetic properties of the nanoparticles and their oxidation behavior during annealing systematically by means of HREM, DTA-TGA, X-ray 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 6-25 nm comprise of the metal core and oxide shell. To form oxide shell, the slow oxidation of particles was achieved by exposure of iron nanoparticles in the inert atmosphere with controlled 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 optical 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. Sotero V. Nishi, Akuni N. Ito, and Charlene Jones, Department of Physics, University of Alaba, U.K.

The aluminas granules, containing metal oxide nanoparticles, CoO, Fe$_3$O$_4$, and Co$_3$O$_4$, were prepared by solgel/solid methods. Synthesis was carried out using both aluminum tri-sec-butoxide (AlTB) and aluminum tri-propoxide (AlTP). 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 desorption. They were in the mesoporous range of 200-400 m$^2$/g. These catalysts were examined by powder X-ray diffraction and the results showed that the metal oxides are in the nanoparticle range. The particle sizes and metal loading of catalysis were studied 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$_3$O$_4$ on the hydrogenation of CO/H$_2$ and CO$_2$/H$_2$ were investigated. Both, a steady phase batch and continuous flow gas phase reactors were used. The catalytic activity of Fe-Co mixed metal catalyst had greater activity compared to Co and Fe catalysts. Vibrating sample magnetomter (VSM) was used to study the magnetic characteristics of as-received and reduced powder 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 of cobalt and the changes in metal centers during catalytic reactions. Magnetic studies of post-reduction Co and Fe nano-catalysts showed that the formation of carbides is higher for iron compared to cobalt. In the Fe-Co mixed catalyst it is observed that the presence of iron enhances the cobalt oxide reduction. We have correlated the catalytic activities with the magnetic characteristics. • Work supported from Department of Energy.

R5.6
XAFS STUDIES OF SUPERPARAMAGNETIC NANO PARTICLES IN COLLOIDAL SUSPENSIONS FOR BIOMEDICAL APPLICATIONS. M. Croft, Rutgers Univ, Phys. Dept, Piscataway, NJ; Dale S. Doty, S. Wollscheid, T. Tsvinskafos, Rutgers Univ, Department of Chemical, Piscataway, NJ; P. Ansari, Seton Hall Univ, Physics Dept, S. Ornage, NJ; D. Kim, M. Perkovic, T. Togasaki, Z. Zhang, Royal Institute of Technology, Materials Chemistry Division, Stockholm, SWEDEN; B. Bjelke, Karolinska Institute, MBL Center, Experimental Unit, Stockholm, SWEDEN; K. Jemil, Karolinska Institute, Division of Cellular and Molecular Neurochemistry, Stockholm, SWEDEN, M. Maciejewski, Royal Institute of Technology, Materials Chemistry Division, Stockholm, SWEDEN.
Superparamagnetic iron oxide nanoparticles SPION have been of great interest in recent years for potential biomedical applications and for use in building blocks for assembly of three-dimensional (3D) structures of bioactive 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 selective control of the size and shape of magnetic materials in the magnetic properties of the magnetic particles such as Ni, Co, and Fe because of the application of permanent magnetic, 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 size and shape. We focus on the size and shape of magnetic materials on the magnetic properties in the magnetic properties. So far, the study of the property changes of magnetic materials in nano-scale has been limited to nanowires and multilayers. We formed the nano-sphere, nano-honeycomb and nano-double ring patterns of NPs on the modic 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.


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 Fe-Pd (L12) uniaxial ferromagnetic phase offers promise as a basis for producing nano-composite hard magnets through solid state transformation in off-stoichiometric compositions. This paper reports on the recent studies of the evolution of microstructure and two-phase alloys produced through phase transformations in the R-Pd system over a range of compositions. Enhanced coercivities compared to bulk 50Fe-50Pd alloys have been achieved in an off-stoichiometric Fe-24Pd alloy utilizing non-equilibrium decomposition of the parent austenite phase. The magnetic hardening will be discussed in terms of the microstructural evolution and interdiffusion 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 Spina, Leonard Spina, 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 Thoig, Jang Fong, 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 is performed even at low temperature. In the case of nanometric systems, in order to obtain regular Delta M plots one would need to obtain the initial ac demagnetizing state at low temperatures, which experimentally it is not trivial. Thus 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 provide a theoretical framework for the interpretation 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 nanometric systems. The experimentally obtained Delta M curves, based on the classical DC demagnetized (DCD) curve and a number of Isothermal Remanent Magnetization (IRM) curves, reflect for the first time the information contained in the DCD curve. In order to investigate the role of the interactions, we performed experiments on various temperatures on samples of Co nanoparticles, dispersed in different concentrations in wax matrix. The degree of dilution in the wax controls the distance and therefore the strength of interactions. Two samples were considered for this study: a sample of CV=0.11 volume fraction of Co nanoparticles dispersed in wax and a sample containing only Co nanoparticles. The experimentally obtained IRM curves are analyzed with a Generalized M-Moving Periesch 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 (CoFe$_2$O$_4$)/x-SiO$_2$) in [2 < x < 20%] nanocomposite thin films have been prepared by spin coating method from a new solvent-based 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 Kinoshi, Shunchi Seino, Yohei Otome, Hironori Maruyama, Takashi Nakagawa, and Tokuo A. Yamamoto, Osaka Univ, Dept of Nuclear Engineering, Osaka, JAPAN; Tadashi Nakamura, Osaka Univ, ISHR, Osaka, JAPAN; Ositka Kenji, Japan Society for the Promotion of Science, Tokyo, JAPAN.

Nanocomposite powder materials composed of spinel-type nanocrystalline 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-irradiation. Formation of a nonmagnetic metallic gold colloids was checked by monitoring the absorption band due to the plasmon resonance with an UV-VIS spectrophotometer and XRD. The X-ray absorption near edge structure indicated that iron was of Fe$_3$O$_4$. The average grain size and size distribution determined from TEM micrographs were in a range of 1 to 2 nm 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$_3$O$_4$ grains were well defined 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 Chianghua University of Education, Dept of Physics, Chianghua, TAIWAN.

The magnetic properties of artificial structures with finite dimensions are of great interest and technological important subjects that have attracted much attention recently accompanied with the advance of nanotechnology. Interesting phenomena such as the pinning of magnetic domain walls and novel structures observed in patterned structures is one example showing the impact of dimensions on spatially confined systems. In this study, the X-ray Photoemission Electron Microscope (X-PEEM) coupled with the XMCD effect is utilized to acquire magnetic image of two series of patterned structures, NiFe and 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. Mogo, M. Urs, I. Popescu, 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, NiCo polycrystalline magnetic nanowires prepared by chemical electrophoresis were reported. This paper focuses on the preparation conditions, structure characterization and magnetic properties of amorphous NiFe nanowires. It is essential 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 nanoscleres of 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. Susceptibility 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 NiFe 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) 238.

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

We report the first successful growth of Cu nanoparticles embedded in insulating SiC matrix for applications in novel spin valve devices. Small resistance-area (RA) product has been one of the most drawback in the applications of current-perpendicular-to-plane (CPP) GMRI spin valves to that of magnetic tunnel junctions. One way to increase RA product is to insert nanoxide layer (NOL) in the CPP elements, decreasing the effective area for the current paths. However, this approach will not increase the RA product itself since RA and AR 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 AR 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 5 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 together with Cu nanoparticles. Both TEM and cross-sectional transmission electron microscopy (TEM) images confirmed the presence of nanocrystalline Cu particles imbedded in an amorphous matrix. The sizes of the particles range between 5 to 10 nm in diameter. Finally, CPP spin valve devices based on IrMnRh/CoFe/Cu/SiC/Cu/SiC/CoFe/NiFe system were fabricated. All layers were deposited in-situ by DC magnetron sputtering and ion beam deposition under UHV conditions. Samples of 481 µm$^2$ area were fabricated using liftoff process. Magnetic resistance was measured in four-point geometry configuration to remove resistances incorporated in lead lines. MR data showed that RA was 43 mΩ$^2$ µm$^2$ at room temperature.

R5.17  
PREPARATION AND CHARACTERIZATION OF FIBROUS ELECTROMAGNETIC WAVE ABSORBER USING FERRITE COMPOSITES. Jeong-Hee Nien, Byoung Gil Ahn and Nam-Pal Hur*, Korea Institute of Ceramic Engineering and Technology, Seoul, KOREA. *MIE Industry, Hwaseong, KOREA.

Ferrite has been widely used as an electromagnetic wave absorber (EWA) at high frequency range. EWA properties of ferrites are mainly determined by its magnetic permeability, thickness of specimen and dielectric constants. We have developed materials processing based on improvement in these parameters 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-magnetic composites. The development of effective and cheap EWA composites prepared 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 investigated that ferrite powders as fillers and composites including multi-phase nanocoating with magnetic particles were prepared to form EWA at high frequency range of GHz.

R5.18  
SiDOPING OF Co/Pd MULTILAYERS FOR IMPROVED SIGNAL-TO-NOISE IN PERPENDICULAR MAGNETIC RECORDING MEDIA. Xiaoying Qiao, Bethanne J.J. Stanley, Randall Victoria and Jack Judy. University of Minnesota, Department of Electrical and Computer Engineering, Minneapolis, MN.

Co/Pd-based multilayers were Si-doped in order to enhance their potential for perpendicular magnetic recording (PMR) media. Co/Pd multilayers have high interfacial-induced perpendicular anisotropy, high coercivity and high squirmness, all of which make them excellent candidates for PMR. Doping elements can be utilized to reduce grain size as well as to reduce magnetic coupling between grains via compositional segregation to the grain boundaries. Ta, Cr, C, O, and especially B have all been used in longitudinal media, and to some extent in perpendicular media, with inhibitory effects. The results we present here demonstrate that Si as a dopant because the change 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 multi-layer films were deposited by D.C. magnetron sputtering in a high vacuum system with background pressures of ~10⁻⁸ Torr and target-substrate distances of 5.5 inches. The growth sequence was 2um-ITO seedlayer, 2um-Pd adhesion layer, and multilayer of 10 layers of [Co(0.26nm)/Si(0.08nm)/Pd(1nm)] or [Co(0.26nm)/Si(0.08nm)/Pd(1nm)]. The S-doped multilayer static magnetic properties were very promising as measured by vibrating sample magnetometry. Hc=6000Oe. Ms=2000emu and n = 4pm/TH = 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 generated for X-ray and magnetooptical 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 8nm clusters in our previous B-doped samples. In addition, S-doped multilayers that were spin tested at IBM showed an increase in signal-to-noise ratio of a striking 50% when tested at the highest level of performance. [1] E. Fullerton et al. IEEE Trans. Mag. 38, 1653 (2002).

R5.19

MAGNETIC PROPERTIES, THICKNESS DEPENDENCE IN NANO-CLUSTERED Nd₀.₅₋ₓFeₓAl₀.₅ MELT-SPUN RIBBONS. N. Iapu, I. Gherciu, National Institute of Research and Development for Technical Physics, Iasi, ROMANIA; A. Tokeschi, A. Inoue, Institute for Materials Research, Tohoku University, Sendai, JAPAN.

Extensive structural and magnetic studies on Nd₀.₅₋ₓFeₓAl₀.₅ melt-spin ribbons with different thicknesses (20 to 200 μm) were performed for understanding the specific magnetic behavior of ternary Nd₅-Fe-Al amorphous alloys. Large coercive fields at room temperature up to 3 T depending on ribbons thickness were obtained, whereas the magnetic remanence 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 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 permeability in comparison with the thin ones, as proved by the HRTEM images and neutron diffusion measurements. The dimensions of the magnetic clusters is about 3-3 nm and their composition approaches Fe₂₁₀Nd₂₁₀.

R5.20

ELECTRONIC CURRENT CONTROL OF MAGNETIZATION IN MAGNETIC NANOSTRUCTURES. V.K. Doganov, Inst. for Problems of Materials Science, Chernovata, UKRAINE; J. Barnd, Dept. of Physics, A. Mickiewicz, Univ. Poznan, POLAND; M. Vieria, Dept. of Electronics and Communications, INEL, 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 nanostuctures, contrary to the existing theories based on quasiclassical methods which are applicable rather to thick magnetic layers. We present the results of numerical and analytical 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 Fe IN NONCRYSTALLINE LaMnₓFe₂₋ₓO₄ (M = Co, Ni). V.I. Josephy, J.A. Jolly, P.A. Jolly, S.K. Date, Physical and Materials Chemistry Division, National Chemical Laboratory, Pune, INDIA.

The nanometer sized polycrystalline ferromagnetic oxides, LaMnₓFe₂₋ₓO₄ (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 consistent with different layers of CoMnFe oxide, M when compared to the spin states of these ions in the bulk material and not due to the decrease in the particle size. The nanocrystalline materials form a different phase of these oxides. The interesting structural and magnetic behavior of these nanocrystalline ferromagnetic oxides will be discussed.

SESSION R6: MAGNETIC THIN FILMS
Chair: Vitali V. Meshchko and K. V. Rao
Thursday Morning, April 24, 2003
Golden Gate C3 (Murriett)

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

Epitaxial films of the antiferromagnetic LaFeO₃ grown by MBE have recently opened several exciting avenues to explore the properties of exchange biased systems and the observation of the magnetization signature of large antiferromagnetic domains using PEEM was reported. Next it was demonstrated that these antiferromagnet domains are exchange coupled with an simultaneously deposited ferromagnetic film. With the same technique, it was also demonstrated that the AFM layer 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 reflectivity 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 ANTI-FERROMAGNETIC NiFe₂ FILMS. Hongbo Shi and D. Lederman, Physics Department, West Virginia University, Morgantown, WV; K.V. O'Donnell and J.A. Borchers, Institute of Standards and Technology, Gaithersburg, MD.

The (110)-oriented thin NiFe₂ films were deposited on single crystal [110]MgO substrates via molecular beam epitaxy, followed by 18 nm thick Co layers. Neutron diffraction revealed that the Néel temperature (TN) in single NiFe₂ film (60 nm thick) and NiFe₂/Co bilayer was enhanced to ~80 K, compared to TN = 73 K in bulk single crystal NiFe₂. Exchange bias in the bilayer was measured using in situ sample in a magnetic field of 24 Oe in the film plane perpendicular to the c-axis of NiFe₂ showed the blocking temperature (TB) at which HEB vanishes coincided with the TN of the film. Such enhancement is attributed to the strain in NiFe₂ film due to the small lattice mismatch between the film and the substrate. HEB and TB dependence on the thickness of NiFe₂ will be presented.


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. Monteiro, Livermore National Laboratory, Livermore, CA; G.D. Wadsworth, University of Missouri-Rolla, Rolla, MO; N.R. Gilman, R.F. Willis, Pennsylvania State University, University Park, PA.


9:30 AM R6.4
EFFECT OF Co DIFFUSION ON MICROSTRUCTURE AND MAGNETIC PROPERTIES OF L1₀ Feₐ Coₐ 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 Feₐ films with high magnetic anisotropy have been studied due to their high potential for use as recording media at ultrahigh densities approaching 1 Tbit/in². L1₀ Feₐ 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 Feₐ 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, Co top layer with the
thickness from 0 to 4 nm was deposited on the FePt layer at the temperature 360°C. The XRD results indicate that with 2 and 4 nm Co top layer, the film is amorphous. The rocking curve and grazing x-ray diffraction show that the FePt (011) orientation starts to deteriorate when the Cu top layer is above 4 nm. The c/n value, which is not dependent on the Cu top layer, is 1.986 and for-FePt layer is fully ordered. The coercivity of the films increases from 3.1 kOe to 7.8 kOe. The slope at He decreases to about 1 after the introduction of Cu top layer, which indicates a well exchange-coupling. The increase in the coercivity is assumed to change in the reversal mechanism of magnetization. The results show that the magnetic moment of the FePt layer is lower than that of the Co layer.


10:30 AM R6.6
INTERFACIAL TRANSITION LAYERS PROBED BY SOFT-X-RAY RESONANT MAGNETIC SCATTERING, Bryan M. Barnes, John J. Kelly IV, Don Scagne, Eric Wiedmann, and Marc 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 (XRMSc) provides element-specific information about both the magnetization and structural/morphological properties of magnetic materials. Specifically, the XRMSc measurements provide a depth profile of the magnetization of thin films while the coherently scattered component of the XRMSc 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 in the non-magnetic material, implying a non-magnetic transition layer near the interface. Two models can explain the existence of a transition layer that is magnetic in nature or less active than the bulk of the film. Interface moments could be pinned out-of-plane by surface microrot, or interface moments could become decoupled from the bulk moments.

We perform XRMSc on ultrathin Co films to determine aspects of the physics of transition layers. By examining bare and capped Co films on both smooth and rough substrates, we find that spins that are decoupled from bulk moments, and can move more or less free 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 15 nm thick, the top and bottom transition layers meet so that the film exhibits no magnetism. We show the dependence of these results on interface roughness.

Research supported by ONR and Seagate Technologies, Inc.

10:45 AM R6.7

A first order reversal curve (FORC) technique has been used to investigate the effective magnetic moment in a series of exchange-spring magnet films 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. The FORC diagram, for the set 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 shifts toward higher values, while the bias distribution first increases and then eventually decreases as 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.

11:00 AM R6.8

Details of the magnetization reversal processes have been investigated by a first order reversal curve (FORC) technique in an exchange biased Fe (27 nm)/FeFb (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 FeFb Néel temperature of 80 K, the FORC diagram shows a narrow distribution of coercivity and exchange field that are consistent with the major-loop values. Surprisingly, the tail of the high 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. C.R. Pike, A.P. Roberts, and K.L. Verbous, J. Appl. Phys. 85, 6660 (1999).

11:15 AM R6.9

Quantum well states (QWS) in metallic ultrathin films play an important role in many phenomena such as the oscillatory magnetic interlayer coupling in magnetic multilayers. Photomission provides the 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/Cu/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 is calculated by assuming a step function of the potential well. With our recent photomission data, we can determine the phase value in experiment. We found that the experiment phase value is different from the phase value of the accumulation model. This may be due to the nature of the Co energy gap which results from the hybridization of the d electrons, thereby changing the local potential geometry at the interface. First-principle calculations were performed to verify the phase determined by the PAM. We also perform 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 up-dispersion curve within LDA/GGA error margins. The quantization condition of QWS appears to hold true for our calculated potentials, although their 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 Espano, Hongtao Shi, and David Leducman, 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) silicon at 315°C via MBE and magnetron sputtering. As-grown films had a surface roughness of approximately 0.7 nm. Images were acquired in-situ at temperatures ranging between room temperature and 600°C. The surface roughness increases as the temperature increases, 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.
High-spatial-resolution analytical electron microscopy (AFM) has been performed on several samples of nanoscale magnetic thin films and model materials for perpendicular magnetic recording, such as CoCrPt/CoCrTa/NiAl/CoZrNb/NiAl and (FeCoNiFe)/FeMn multilayers. The main techniques employed were spectrum imaging and spectrum profiling of cross-sectioned specimens by using focused ion-beam laser interference microscopy (FELIS) in the scanning transmission electron microscopy (STEM) mode on a Philips CM200FEG AEM equipped with an ENEVI Vision integrated data acquisition system. Elemental mapping by energy-filtered transmission electron microscopy (EFTEM) has also been performed on some samples. An important issue in structure-property correlations for such materials is the degree of chemical mixing at the interfaces between the various layers. AFM has revealed some unexpected and interesting compositional profiles. However, the data rarely yield composition profiles simply or easily because of potential artifacts arising from specimen preparation, limited spectral resolution from probe-size and beam spreading, and complications in analysis of the spectra due to a severe peak overlap and background fitting. With carefully controlled data acquisition, advanced spectral processing methods, and care in specimen preparation, many of the artifacts or limitations can be minimized or completely avoided in improved compositional data.

The domain state model for exchange bias (EB) presented recently [1,2] considers defects at the magnetic sites in the volume of the antiferromagnet (AFM), thus stabilizing volume domains in the AFM. This domain state in the volume of the AFM carries after field cooling a saturation magnetization. These uncompensated, invariably 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 one should 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 walls and sizes we have chosen NiO. In the Ni$_2$O$_3$ system the exchange bias field at room temperature is reduced by a factor of four in going from the continuous layer system to wires of minimum width 120 nm [4]. This decrease is consistent with the domain state model. No such reduction is found at 5K. The reduction in the EB field at room temperature is paralleled by an increase in the coercive field proportional to the inverse wire width. The effect of etching on the exchange bias field and the coercivity will be discussed by comparing iron milling vs. reactive ion etching processes. The magnetization reversal in exchange bias systems has been measured by means of a magnetooptic Kerr setup both using longitudinal and transverse configurations. The asymmetry of the hysteresis loops, i.e. coherent rotation of the magnetization is domain mediated 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 be clearly identified by the transverse Kerr component. The effect of patterning of exchange bias wires on the asymmetric vs. symmetric magnetization reversal will be discussed. Work supported by Deutsche Forschungsgemeinschaft through SPP 1130, grant no. DE 244/1-3 and by EC RTN Networks SUBMAGDEV and NEXHAAS.

This research was supported in part by the National Science Foundation (NSF) and the U.S. Department of Energy (DOE).

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SESSION R7: UNCONVENTIONAL MAGNETS AND DYNAMICS

Chair: Samuel B. Bozorth and Jean-Pierre Loget

Thursday Afternoon, April 30, 2003

Golden Gate C3 (Marriott)

1:30 PM **R7.1**

**MAGNETISM OF FERROMAGNETIC SEMICONDUCTOR STRUCTURES**

Doro Oho, Lab. for Electron. Intelligent Systems, Res. Inst. of Electrical Commun., Tohoku University, Sendai, JAPAN.

Carrier-induced ferromagnetism in magnetic III-Vs has allowed the integration of magnetic cooperative phenomena in 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 isostructural and reversible electric field control of ferromagnetism.

2:00 PM **R7.2**

**NANOMAGNETIC APPLICATIONS**

De Bech, 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, currently fabricated with micron-size dimensions, endeavor 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 magneto/electronic / spintronic characteristics. Many of these requirements lead straight back to the nano-scale material that will be at the heart of these applications. The views and challenges will be illustrated by examples from the recent literature, illustrated further by results from our own research activity. For this purpose the author acknowledges the contributions of W. Van Roy, P. Van Dorpe, V. Moons, Z. Liu, W. Hebert, L. Lagae, J. Deconinck, J. Beketta, R. Wirix-Speeckens, J. Pullum and G. Borghs.
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 nearest 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. Panchal, Christian Kaiser,
Stuart P. Parkin, IBM Almaden Research Center and Stanford
University.

Surface studies show that thin films of NiMnSb, a proposed
halfmetal, can suffer from surface segregation of Mn and Sb. [Risticu
et al. Appl. Phys. Lett. 76 (2000) 2899.] This segregation at the
electrode-barrier interface in magnetic tunnel junctions (MTJs) has
the potential to destroy the halfmetallic behavior. 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$_{1-x}$)$_2$ for $x = 0.45$ has been explored via spattering 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 magnetoresistance of about 18%. These results are
compared to reported data on NiMnSb. [Takanak et al J Appl. Phys
86 (1999) 6399.] and support the theory that surface segregation of Mn
and Sb affects the spin transport.

4:30 PM R7.7
LOSSLESS ENHANCEMENT OF GHz PRECESSIONAL
FREQUENCY IN Ni$_x$Fe$_{1-x}$ USING DILUTE Fe 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 5nm Ni$_x$Fe$_{1-x}$ can
boost the precessional frequency of the system by over 400 MHz
without effect on Gilbert magnetic damping parameter $a$. This is
equivalent to a dynamic anisotropy field of over 9 Oe “stiffening” the
system. The source of the effect is under investigation. Comparison of
microwave inductive measurements and MOKE magnetometry
indicates that static and dynamic anisotropy do not correlate well for
the doped films. Kettle plot analysis shows that the $K_{eff}/M_{sat}$
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. Pufahl, 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. Skoniewski 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
cut-off-plane fields [3], or in patterned Co/Cu nanowires [4].
Subsequent work has extended these results, but again using
the Co/Cu system. Using point contact spectroscopy, we found these
excitations to occur for both in- and cut-off-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$_x$Fe$_{1-x}$/Cu. For all systems, the excitations were of similar
dependence, with the critical onset current $I$ 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 Skoniewski
theory, and are found to be in the range expected for the polarization
dependence 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,