SYMPOSIUM U

Ferromagnetic Materials

April 17 – 20, 2001

Chairs

Sara A. Majetich
Dept of Physics
Carnegie Mellon Univ
Wean Hall
Pittsburgh, PA 15213-3890
412-268-3105

John Q. Xiao
Physics and Astronomy Dept
Univ of Delaware
Newark, DE 19716
302-831-6547

Manuel Vazquez
UCM-RENFE-CSIC
Inst de Ciencia de Materiales-Madrid
Cantoblanco (Madrid), 28049 SPAIN
34-91-3349051

Symposium Support
Magnequench International, Inc.

Joint Proceedings with Symposium T/U/V
to be published in both book form and online
(see *ONLINE PUBLICATIONS* at www.mrs.org)
as Volume 674
of the Materials Research Society
Symposium Proceedings Series.

* Invited paper

SESSION U1: SOFT MAGNETIC ALLOYS AND FERRITES
Tuesday Morning, April 17, 2001
Golden Gate B3 (Marriott)

8:30 AM *U1.1
NOVEL PROCESSING OF SOFT MAGNETIC MATERIALS WITH ENHANCED MECHANICAL PROPERTIES. C.L. Chien, Johns Hopkins University, Dept. of Physics and Astronomy, Baltimore, MD; R.C. Cammarata, P.C. Searson, T.P. Weihs, Johns Hopkins University, Dept. of MS&E, Baltimore, MD.

Materials such as FeCo-based alloys have excellent soft magnetic properties, but their inferior mechanical properties at high temperatures have precluded applications in engines and turbines that operate under high stresses and at high temperatures. By controlling the microstructure (grain size, crystallographic texture, and second phase oxide particles) of FeCo-based alloys, we have produced FeCo materials with improved mechanical behavior for soft magnet applications. Through annealing treatments, we have been able to vary the grain size of commercial FeCoV Hiperco alloys from the nanometer scale up to hundreds of microns. This microstructural control has allowed us to produce a nanocrystalline alloy with a unique combination of very large tensile strength (2.3 GPa) and ductility (2.0%) at room temperature, as well as larger grain size material with improved creep strength at elevated temperatures (450 to 600°C). We have also succeeded in developing a novel electrochemical deposition technique that produces FeCo alloys with embedded second phase oxide particles. These materials display enhanced mechanical properties (with minimal magnetic property degradation) owing to oxide dispersion strengthening.

9:00 AM U1.2
THERMAL EVOLUTION OF MAGNETIC PROPERTIES AND CRYSTALLINITY IN Fe-BASED METALLIC GLASSES. Yinyan Luo, Subhash H. Risbud, Univ of California at Davis, Dept of Chemical Engineering and Materials Science, Davis, CA.

The changes in the magnetic properties and crystal structures of melt-spun $Fe_{73.5}Cr_5V_2Mn_{0.5}P_{13}C_5Si_1$ alloys upon heat treatment were investigated. Hysteresis loops and magnetization data were obtained by a vibrating sample magnetometer (VSM). Crystalline phase evolution and microstructure development were monitored by X-ray diffraction (XRD), differential thermal analysis (DTA) and transmission electron microscopy (TEM). The effect of processing on structure and magnetic properties will be discussed.

9:15 AM U1.3
FERROMAGNETISM AND NANOCRYSTALLIZATION BEHAVIOR OF AMORPHOUS $(Fe_{0.99}Mo_{0.01})_{78}Si_9B_{13}$ RIBBONS. Xiang-Cheng Sun, Prog. Simulacion Molecular, Instituto Mexican del Petroleo, D.F. Mexico, MEXICO; S. Galindo, ININ, Carr. Mexico-Toluca, Edo.de Mexico, MEXICO; Wensheng Sun, RSA, Institute of Metal Research, CAS, Shenyang, CHINA.

Ferromagnetic properties and nanocrystallization process of ferromagnetic $(Fe_{0.99}Mo_{0.01})_{78}Si_9B_{13}$ ribbons were extensively studied by in situ transmission electron microscope (TEM), atomic force microscopy (AFM), X-ray Rietveld refinement, Mössbauer spectroscopy (MS), differential scanning calorimeters (DSC) and magnetic moment measurements. The Mössbauer spectrum exhibited an essentially symmetric hyperfine field pattern of 225KOe in as-quenched amorphous state at room temperature. The Curie and crystallization temperature were determined to be T_C = 665K and T_x = 750K, respectively. The T_x value was in good agreement with DSC measurement results. X-ray Rietveld refinement have shown a good reconfirm of mail two metastable phases ((Fe, Mo)$_{23}$B$_6$, (Fe, Mo)$_3$B) have ever occurred under in-situ nanocrystallization process. Which these metastable phases embedded in the amorphous matrix have a significant effects on magnetic behavior. The ultimate nanocrystalline phases of α-Fe (Mo, Si) and Fe(Si)$_2$B at in situ optimum annealing temperature have been observed respectively. It is notable that the magnetization of the amorphous phase decreases more rapidly with increasing temperature than those of nanocrystalline ferromagnetism, suggesting the presence of the distribution of exchange interaction in the amorphous phase or high metalloid contents.

9:30 AM U1.4
FERROMAGNETIC RESONANCE ON METALLIC GLASS RIBBONS. Mircea Chipara, Department of Physics and Astronomy, University of Nebraska, Lincoln, NE; Monica Sorescu, Physics Department, Duquesne University, Pittsburgh, PA; Mariana Toacsen, Institute for Physics and Technology of Materials, Bucharest, ROMANIA.

Metallic glasses are frequently available as ribbons produced by rapid quenching from the melt. They exhibit both metallic and soft magnetic features and present high mechanical strength and hardness. Ferromagnetic resonance (FMR) investigations on some amorphous magnetic ribbons ($Fe_{40}Ni_{38}Mo_4B_{18}$, $Fe_{78}B_{13}Si_9$ and $Fe_{66}Co_{18}B_{15}Si$) have been performed using a JES-ME-3X spectrometer, operating in the X band. No significant effects on the FMR line shape, due to the skin effect, were observed. The FMR spectra were fitted by a superposition of 2 to 3 Lorentzian lines, reflecting the presence of an incipient crystalline phase within the amorphous material. Although the splitting of the resonance line in several components has be ascribed to the presence of magnetic domains [1], the external magnetic field should be sufficiently large to suppose that the sample behaves as a single domain. However, the large number of defects usually present in these amorphous materials may pin the magnetization [2], causing the splitting of the resonance line. The angular dependence of FMR spectra, for the out of plane configuration (the external magnetic field is normal to the plane of the sample) is reported. The dependence of the resonance line position and of the resonance line width on the angle between the external magnetic field and the plane of the ribbon is discussed. The data are analyzed using a thermodynamic approach that takes into account the viscous evolution of the magnetization in the external magnetic field, trough the Landau (Gilbert) damping factor. The main contribution to the angular dependence of the spectra is ascribed to the shape anisotropy.
References:
[1] U. Ebels, P.E. Wigen and K. Ounadjela, J. Mag. Mag. Mat., 177-181, 1239 (1998).
[2] A. Gavrin, J. Unguris, J. Mag. Mag. Mat., 213, 95 (2000).

9:45 AM U1.5
CHARACTERIZATION OF SOFT MAGNETIC THIN LAYERS USING BARKHAUSEN NOISE MICROSCOPY. Jochen Hoffmann, Norbert Meyendorf, Center for Materials Diagnostics, University of Dayton, Dayton, OH; Iris Altpeter, Fraunhofer Institute for nondestructive Testing IZFP, Saarbruecken, GERMANY.

Ferromagnetic materials are essential for data recording devices. For inductive or magnetoresistive (MR) sensors softmagnetic thin layer systems are used. Optimal performance of these layers requires homogeneous magnetic properties, especially a pronounced uniaxial magnetic anisotropy. Microstructural imperfections and residual stresses influence the magnetic structure in the layer system. They are due to non-optimized process conditions, undesired phase transitions or insufficient ductile adaptation to the substrate. Residual stresses deteriorate the signal to noise ratio and thus the sensor sensitivity. The bad ductile adaptation between the substrate and the ferromagnetic layer leads to insufficient workability of the sensoric. Barkhausen noise microscopy offers the possibility of characterizing such thin layers. By cycling the magnetic hysteresis of ferromagnetic material electrical voltages (the Barkhausen noise) are induced in an inductive sensor. Miniaturization of the sensor and the scanning probe technique provides resolution down to few micrometers. Two materials were examined in terms of their structure, thickness, residual stresses and heat treatment condition: Sendust, used in inductive sensors and nanocrystalline NiFe, used in MR-sensors. In quality correlations to Barkhausen noise parameters were found. For a representative sample a quantification of the residual stress distribution could be established employing X-ray stress analysis.

10:30 AM *U1.6
MAGNETIC CORRELATIONS AND MAGNETIZATION PROCESSES IN NANOSTRUCTURED FERROMAGNETS. Jörg F. Löffler, California Institute of Technology, W.M. Keck Laboratory, Pasadena, CA.

In nanostructured ferromagnets, the macroscopic magnetic properties arise from a subtle interplay of microscopic parameters like grain size, intergrain coupling, and anisotropy. At a certain grain size above the onset of superparamagnetism, isolated nanoparticles can be magnetically hard, whereas the same material can turn magnetically soft in the case of intergrain coupling. The relevant magnetic correlations determining the macroscopic properties, such as coercivity, occur on length scales of the order of the grain size. In order to resolve the grain size dependence of these correlations, we have performed magnetic small-angle neutron scattering on nanostructured Fe, Co, and Ni. For small grain sizes we find magnetic correlations extending over several grains, whereas for large grains the correlation length is proportional to the grain size. The crossover between these two regimes is determined by the bulk domain-wall width of the respective material. In Fe, the correlation length shows a minimum at grain sizes of around 30 nm, where the coercive field has a maximum. In order to explain these observations, we propose a generalization of the random-anisotropy model that includes reduced intergrain coupling and allows for domain-wall formation within grains. Magnetization configurations in coupled grains are discussed analytically. Our model allows us to predict the domain size distribution for given grain size distributions, exchange constants, and anisotropy constants, in good agreement with the experimental data.

The evolution of magnetic correlations in increasing magnetic fields was also studied and can be described by the switching of correlated domains via a modified Stoner-Wohlfarth model.

11:00 AM *U1.7
A TUTORIAL ON FERRITE MATERIALS - SPINELS, GARNETS, SUBLATTICES, SUBSTITUTIONS, AND MAGNETIC PROPERTIES. Carl E. Patton, Colorado State Univ, Dept of Physics, Fort Collins, CO.

Ferrites represent one class of magnetic oxide materials with a wide range of magnetic order types from antiferromagnets to "weak ferromagnets", to ferrimagnets. These materials have specific properties such as magnetization, anisotropy, and magnetostriction which can be tuned through various magnetic and nonmagnetic substitutions. The most popular ferrites have cubic or hexagonal structure. This talk will review basic ferrite structure, the role of magnetic sublattices in determining the magnetic properties, and the effect of specific sybstitutions on these properties. Specific examples of ferrite materials for magnetic recording and high frequency applications will be considered.

11:30 AM U1.8
MAGNETIC PERMEABILITY AND RELAXATION FREQUENCY IN HIGH FREQUENCY MAGNETIC MATERIALS. M.I. Rosales, H. Montiel and R. Valenzuela, Institute for Materials Research, National University of Mexico, Mexico, MEXICO.

In many applications (such as switched-mode power supplies, for instance) the performance of the device depends on a magnetic material possessing simultaneously a high magnetic permeability, μ, and a high relaxation frequency, f_x. However, an increase in μ seems to be always associated with a decrease in f_x. In this paper, we measure polycrystalline Ni-Zn ferrites and show that the dominant magnetization process (i.e., the one leading to the highest permeability value in the high-frequency range), is domain wall bulging. We investigate the dependence of both μ and f_x on microstructure (particularly average grain size), and based on the equation of motion for domain walls, we propose an analysis of the relaxation frequency correlation with intrinsic parameters. From these results it was possible to establish a constant, and independent of temperature, wall damping term (β) for samples of same composition and normalized by grain size. Similar results have been reported using different parameters [1] and different experimental techniques[2].
[1].- M.I. Rosales, E. Amano, M.P. Cuautle and R. Valenzuela, Mat. Sci. Eng. B49, 1997, p 221.
[2].- C. Aroca, E. Lopez and P. Sanchez, Phys. Review B, 30(7), 1984, p 4024.

11:45 AM U1.9
A STUDY ON THE MOCVD MECHANISM OF INVERSE SPINEL COPPER FERRITE THIN FILMS. Yuneng Chang, Hsinhua Tsen, Mingyung Chen, Menghsiu Lee Lunghwa Inst. of Tech., Dept of Chemical Engineering, Gueishan, Taoyuan, TAIWAN ROC.

Spinel ferrites (MFe_2O_4) are soft magnetic ceramics, with inverse spinel crystalline structure. For high frequency wireless communication devices operated at several MHz, due to the large resistivity of spinel ferrites, energy loss caused by induced eddy current will be reduced. As future development of ferrite process will be emphasized on thin film, integration within one chip, and compatible to modern deposition technologies; further, ideal soft magnetic thin films should be low stress, fine grain, and thin domain wall. All these goals can be met by using MOCVD, and controlling process parameters such as deposition temperature, and supersaturation ratio. In this project, we have used a horizontal cold wall CVD reactor, using metal acetylacetonates, $Cu(C_5H_7O_2)_2$, $Fe(C_5H_7O_2)_3$, and O_2 as reactants, and deposited $CuFe_2O_4$ thin films at 760 torr, 420°C. As revealed by AES/XPS/XRD results, the $CuFe_2O_4$ primary phases are (311), (440), (400), (222). Few α Fe_2O_3 and CuO crystallites were observed at lower deposition temperature. SQUID data indicated that films were ferrimagnetic, with low coercive field (<10 Oe), saturation magnetization(Ms), 3-14eμ/g, and remanece magnetization(Mr), 0.16eμ/g. SEM showed that deposited $CuFe_2O_4$ crystallites were facetted polyhedrons. The grain size increased sharply as deposition temperature increased. Arrhenius equation was used to estimate the activation energy, Ea, for grain growth. As the derived Ea being above 25 kcal/mole, grain growth was suggested as surface reaction controlled. A gas dynamics model, adopted from molecular beam epitaxy (MBE) theory, considering precursor vapor impingement flux, was used to interpret correlation between CVD film composition and precursor partial pressure. After compared with experimental data, we suggested to put precursor desorption rate into the gas dynamics model, to achieve more realistic results.

SESSION U2: HARD BULK MAGNETS
Tuesday Afternoon, April 17, 2001
Golden Gate B3 (Marriott)

1:30 PM *U2.1
EFFECT OF COMPOSITION AND PROCESSING ON THE MICROSTRUCTURE AND MAGNETIC PROPERTIES OF 2:17 HIGH TEMPERATUE MAGNETS. George C. Hadjipanayis, Department of Physics and Astronomy, Univ of Delaware, Newark, DE.

The $Sm(Co_{bal}Fe_vCu_yZr_x)_z$ magnets represent a complicated system with four compositional variables (x, y, v, z) and five heat treating variables (T_h, t_h, T_{ag}, t_{ag}, dT/dt). The homogenized $Sm(Co,Fe,Cu,Zr)_z$ magnets have a featureless microstructure. A cellular/lamellar microstructure develops after 2-3 hours of aging at 800-850°C, but the coercivity increases only after a subsequent slow cooling to 400°C. During cooling, diffusion takes place and Cu is concentrated in the 1:5 cell boundaries and Fe in the 2:17R cells. This dilutes the magnetic properties of the 1:5 phase and causes domain wall pinning/nucleation at the cell boundaries. Higher ratio z leads to larger cells as expected due to the larger amount of the 2:17 phase. For a fixed Cu content, this translates to a larger amount of Cu in 1:5 cell boundary, and therefore, to a higher coercivity. Magnets without Cu but with Zr have a lamellar and a cellular like microstructure. In Zr free samples, however, a larger amount of Cu is needed to form the cellular microstructure. This cellular microstructure is unstable with prolonged isothermal aging. A uniform and stable cellular/lamellar microstructure is only observed in alloys containing both Cu and Zr. A higher aging temperature T_{ag} also leads to larger cells and higher coercivity because of the reasons explained earlier. The results of all of these studies clearly show that the amount of Cu in the 1:5 cell boundaries controls both the coercivity and its temperature dependence leading to positive and negative temperature coefficients of coercivity in low and high Cu content alloys, respectively.
This work is supported by the Air Force Office of Scientific Research under Grant No. MURI F49620-96-1-0403.

2:00 PM U2.2
PARTITIONING DURING CRYSTALLIZATION AND ITS EFFECTS ON MAGNETIC PROPERTIES IN RARE EARTH PERMANENT MAGNETS. J.E. Shield and B.B. Kappes, Dept. of MS&E, University of Utah, Salt Lake City, UT; J.A. Horton and J. Bentley, Oak Ridge National Laboratory, Oak Ridge, TN; D.J. Branagan, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID.

Nanoscale permanent magnets are routinely produced by annealing overquenched melt spun ribbons. The nanocrystalline structure is formed upon devitrification of the mostly amorphous precursor. It is desirable to have a uniformly glassy material so that devitrification results in a homogeneous microstructure. This often requires alloying additions to improve the 'quenchability'. Additionally, alloying additions are also used to alter the crystallization process to produce smaller grain sizes. The result is most often a complicated multicomponent alloy. The magnetic properties of nanoscale permanent magnets are strongly influenced by microstructural features that affect intergranular exchange interactions, including grain size and the character of the grain boundaries. While alloying elements may aid in refining the grain size, segregation to the grain boundaries may occur, which would inhibit intergranular exchange interactions. We have studied the devitrification process in several Nd-Fe-B-based alloys in order to understand the microstructural evolution and the resultant effects on the magnetic properties. Analytical electron microscopy has been used to examine the chemical profile across growing crystallites in three alloys: Nd-Fe-B, Nd-Fe-B-Ti-C, and Nd-Pr-Dy-Fe-Co-B-C-Ti-Zr. Segregation of Ti to the crystal/amorphous interface was observed in the Ti-bearing alloys. These alloys also showed a depletion of Fe at the interface, while the ternary alloy displayed a uniform composition across the crystal/amorphous interface. The scale of the crystallites in the partially crystallized materials also depended on alloy composition, indicating significant differences in the nucleation and growth characteristics. Vast differences in the transformation kinetics were also observed, again indicating differences in the nucleation and growth characteristics. The effect of these differences in microstructural formation on the magnetic properties, especially with respect to intergranular exchange interactions as determined from recoil measurements, will also be discussed.

2:15 PM U2.3
EFFECT OF IRON SUBSTITUTION ON THE HIGH-TEMPERATURE PROPERTIES OF Sm(Co,Cu,Ti)z PERMANENT MAGNETS. J. Zhou, R. Skomski, and D.J. Sellmyer, Dept of Physics and Astronomy and Ctr of Matls Research and Analysis, Univ of Nebraska, Lincoln, NE; W. Tang and G.C. Hadjipanayis, Dept of Physics and Astronomy, Univ of Delaware, DE.

Recently, Ti-substituted Sm-Co permanent magnets have attracted renewed attention due to their interesting high-temperature coercivity [1]. Our presentation deals with the effect of iron substitutions on the magnetic properties of the materials. X-ray diffraction shows that the investigated Sm(Co,Fe,Cu,Ti)z materials (z = 7.0 - 7.6) are two-phase magnets, consisting of 1:5 and 2:17 regions. The iron content affects both the coercivity and the magnetization. Depending on composition and heat treatment, some samples show a positive temperature coefficient of the coercivity in the temperature range from 22°C to 550°C. Moderate amounts of iron enhance the room-temperature coercivity. For example, the room-temperature coercivity of $Sm(Co_{6.0}Fe-0.4Cu_{0.6}Ti_{0.3})$ is 9.6 kOe, as compared to 7.6 kOe for $Sm(Co_{6.4}Cu_{0.6}Ti_{0.3})$. At high temperatures, the addition of Fe has a deteriorating effect on the coercivity, which is as high as 10.0 kOe at 500 C for $Sm(Co_{6.4}Cu_{0.6}Ti_{0.3})$. The room-temperature magnetization increases on iron substitution, from 78 emu/g for $Sm(Co_{6.4}Cu_{0.6}Ti_{0.3})$ to 82 emu/g for $Sm(Co_{6.0}Fe_{0.4}Cu_{0.6}Ti_{0.3})$. Replacing some of the Ti by Fe yields a further increase in the magnetization but reduces the coercivity. The observed temperature dependence is ascribed to the preferential dumbbell-site occupancy of the Fe atoms. Since Ti has a similar preference for the dumbbell sites, the magnetic properties are a nonlinear function of the Fe and Ti concentrations.
Research supported by ARO, AFOSR, and CMRA.
[1] J. Zhou, R. Skomski, C. Chen, G.C. Hadjipanayis and D.J. Sellmyer, 'Sm-Co-Cu-Ti high-temperature permanent magnets', Appl. Phys. Lett. vol. 77, pp 1514-1516, Sept. 2000.

2:30 PM *U2.4
NANOCRYSTALLINE AND NANOSTRUCTURED HIGH-PERFORMANCE PERMANENT MAGNETS. Dagmar Goll, Wilfried Sigle, Helmut Kronmuller, Max-Planck-Institut fur Metallforschung, Stuttgart, GERMANY; George C. Hadjipanayis, University of Delaware, Newark, DE.

High-performance permanent magnets (pms) are based on compounds with outstanding intrinsic magnetic properties as well as on optimized microstructures. This correlation is demonstrated for two types of RE-TM pms: (i) $Re_2Fe_{14}B$ (RE=Nd,Pr) which is currently regarded to be the highest performance pm material at all and which is well-suited for the newly developed polymer bonded magnets. (ii) Sm_2(Co,Cu,Fe,Zr)17which supplies the highest maximum energy products (BH) max at elevated temperatures (beyond which $RE_2Fe_{14}B$ is no longer viable) therefore being well-suited for high-temperature applications. On the basis of the ternary RE-Fe-B phase diagram three types of nanocrystalline pms have been tailored: (a) Magnets with RE excess where the hard magnetic $RE_2Fe_{14}B$ grains are separated by a paramagnetic RE-rich intergranular film limiting the remanence to J_R eq 0.5 J_S (saturation polarization J_S approx 1.6 T). (b) Stoichiometric magnets, where the hard magnetic grains are exchange coupled leading to an enhancement of the remanence (J_R>0.5 J_S) and therefore of $(BH)_{max}$. (c) Composite magnets with overstoichiometric Fe, in which the remanence enhancing effect can be significantly increased by exchange hardening of small soft magnetic Fe grains. Sm_2(Co,Cu,Fe,Zr)17 magnets are characterized by a complicated nanostructure which develops during a complex annealing procedure. One finds Fe-rich pyramidal 2:17 cells of about 100 nm in size being more or less separated by a Cu-rich 1:5 boundary phase of about 5 -10 nm. Additionally, a Zr-rich platelet phase of 2 -4 nm in width which is oriented perpendicularly to the c-axis is superimposed on the cellular structure. By using high-resolution energy dispersive X-ray analysis the chemical compositions of the three phases involved and their continuous change between the different phases have been determined for various stages of the complex annealing procedure and correlated with the intrinsic magnetic properties clarifying the coercivity mechanism of this material system and the evolution of its characteristic microstructural and magnetic properties unambiguously.

3:30 PM *U2.5
Nd-Fe-B MAGNETS - AN UPDATE. V. Panchanathan, Magnequench, Inc., Anderson, IN.

The Nd-Fe-B market is a significant growing fraction of the total permanent magnet market, and has experienced the fastest growth of any permanent magnet industry. The processing of these magnets has been carried out by two different methods. One is the conventional powder sintering process, and the other is the rapid solidification process. The sintering process produces only fully dense anisotropic magnets. The rapid solidification process makes both bonded and fully dense isotropic and anisotropic magnets. The wide range of application for bonded magnets includes computer storage devices, automotive applications, office automation products, consumer electronics, and hand held power tools. The fully dense magnets find applications in cranking motors, sensors, voice coil motors, speakers, inductrial servo motors, etc. Continuing advances in Nd-Fe-B magnets are expected to increase the demand for these magnets in various applications. The technological developments in Nd-Fe-B magnets and their applications will be discussed.

4:00 PM U2.6
SPATIAL DEPENDENCE OF AMORPHOUS CHARACTER IN CAST NdFeAl FERROMAGNETIC ALLOYS. N.H. Dan, V.H. Ky, N.X. Phuc, Institute for Materials Science, NCST, Hanoi, VIETNAM; N. Chau, N.H. Luong, C.X. Huu, Center for Materials Science, Department of Physics, Hanoi National University, Hanoi, VIETNAM; L.H. Lewis, Energy Sciences and Technology Dept., Brookhaven National Laboratory, Upton, NY; R.W. McCallum, Ames Laboratory, USDOE and Department of MS&E, Iowa State University, Ames, IA.

Bulk magnetic glasses (BMG) of composition $Nd_{60}Fe_{30}Al_{10}$ are of interest due to their reported appreciable coercivity (up to 0.4 T) at room temperature. Reported differences in the coercivities of different forms of the BMG (i.e., melt-spun ribbons vs. cast rods) naturally suggest that the solidification conditions, and attendant nanophase selection, greatly influence the magnetic properties. To clarify the effect of solidification conditions on the magnetic properties of BMG alloys, detailed x-ray diffraction and magnetization studies were systematically performed on regions of suction-cast rods made from $Nd_{60}(Fe,Co)_{30}Al_{10}$ prealloyed in three different routes: Fe and Al were combined and Nd added in later; Nd and Fe were combined and Al alloyed in later; and four elements (Nd, Fe, Al and 10 at% Co) were alloyed simultaneously. The suction-cast rods were of height $z_0 \sim$ 60 mm, width $y_0 \sim$ 10 mm and thicknesses $x_0 \sim$ 1 or 3 mm. It was found that the structural and magnetic hysteresis character vary strongly with the depth along the thickness (x). In all rods the outermost layer shows the existence of micron-sized crystallites within the amorphous matrix. With increasing depth x the amorphous fraction first increases ($0 < x < 1/4x_0$) and then decreases ($1/4x_0 < x < 1/2x_0$). While the amorphous/crystalline material ratio depends very little along the z position, the magnetic hysteresis exhibits a significant dependence on location within the rods. These results indicate that the extent of crystallization and the accompanying magnetic properties are very sensitive to the temperature inhomogeneities present during the casting process.
Research performed under the auspices of the U.S. Dept. of Energy, at Ames Laboratory under Contract No. W-7405-ENG-82 and at Brookhaven National Laboratory under contract No. DE-AC02-98CH10886.
Support from the East Asia and Pacific Program of the Division of International Programs, N.S.F., is gratefully acknowledged.

4:15 PM U2.7
INVESTIGATIONS ON THE MAGNETIC PROPERTIES OF HIGH-COERCIVITY $(Nd_{1-x}Fe_x)_{90}Al_{10}$ BULK AMORPHOUS ALLOYS. Horia Chiriac, Nicoleta Lupu, National Institute of Research and Development for Technical Physics, Iasi, ROMANIA; Akira Takeuchi, Akihisa Inoue, Institute for Materials Research, Tohoku University, Sendai, JAPAN.

Bulk and melt-spun amorphous $(Nd_{1-x}Fe_x)_{90}Al_{10}$- alloys were investigated by the magnetization measurements using a VSM magnetometer in the temperature range 80-800 K and external fields up to 1.6 T. The coercive fields amount to 0.4 T at room temperature for bulk amorphous alloys with x<0.5, and are no larger than 0.05 T for amorphous melt-spun ribbons of the same compositions. The increase of x results in the increase of the coercive field of the melt-spun amorphous ribbons up to 0.35 T. The temperature dependence of the observed coercivity shows a maximum at around 150 K. The large coercive field values for the melt-spun and bulk $(Nd_{1-x}Fe_x)_{90}Al_{10}$ amorphous alloys as well as their cooling rate dependence appears to arise from the very small magnetic clusters embedded in the amorphous matrix. The regular temperature treatments reveal the presence of bifurcation of the zero-field-cooled (M_{ZFC}) and field-cooled (M_{FC}) magnetization curves for melt-spun amorphous ribbons in all range of thicknesses and bulk amorphous rods. The presence of one pronounced cusp on (M_{ZFC}) curves and its displacement towards low temperatures with samples' thickness increase indicate the coexistence of two types of magnetic order: microscopic short-range spin-glass-like order within the magnetic clusters and macroscopic long-range ferromagnetic order. Both magnetic clusters' structure and amorphous matrix are very sensitive to composition, temperature, and preparation conditions and suffer different magnetic transitions. Details about the micromagnetic structure of $(Nd_{1-x}Fe_x)_{90}Al_{10}$ amorphous alloys will be discuss.

4:30 PM *U2.8
THE COERCIVITY - REMANENCE TRADEOFF IN NANO-CRYSTALLINE PERMANENT MAGNETS. Laura H. Lewis and David C. Crew, Materials and Chemical Sciences Division, Energy Sciences and Technology Dept, Brookhaven National Laboratory, Upton, NY.

The energy product $(BH)_{max}$ is a figure of merit quantifying the maximum amount of useful work that can be performed by the magnet. The energy product is determined by the magnetic remanence and the coercivity which, as extrinisic properties, are determined by the magnets' microstructure. Thus, in principle, magnetic material microstructures may be tailored to obtain defined parameters to produce optimal permanent magnets. However, as asserted by the eponymous Murphy, "Nature favors the hidden flaw". While there is still much undeveloped potential in nanomagnetic materials, with relevant length scales on the order of 100$\AA$, accumulating evidence strongly suggests that maximum remanence and maximum coercivity are mutually exclusive in nanocrystalline magnetic materials. Diverse experimental and computational results obtained from nanocrystalline $Nd_2Fe_{14}B$-based magnets produced by melt-spinning techniques and subjected to various degrees of thermomechanical deformation confirm this conclusion. Recent results obtained from temperature-dependent magnetic measurement, magnetic force microscopy and simple micromagnetic modelling will be reviewed and summarized. The results, while somewhat discouraging, do hint at possible materials design routes to sidestep the inherent performance limitations of the magnetic nanostructures. Research performed at Brookhaven National Laboratory under the auspices of the U.S. Dept. of Energy, Division of Materials Sciences, Office of Basic Energy Sciences under contract No. DE-AC02-98CH10886.

SESSION U3/T4: JOINT SESSION HARD FERRITES/COLOSSAL MAGNETO-RESISTANCE MATERIALS

Wednesday Morning, April 18, 2001
Golden Gate B3 (Marriott)

8:30 AM *U3.1/T4.1

ATOMIC AND NANOENGINEERED FERRITE SYSTEMS: NEW HORIZONS IN LOW DIMENSIONS. V.G. Harris, Naval Research Laboratory, Washington, DC.

Spinel ferrites are attractive materials for high frequency (1 MHz $\leq f \leq$ 500 MHz) applications where low core losses are essential. Further, these materials are the only low-loss magnetic materials available for microwave frequency ($f \geq$1 GHz) applications. An essential property of the ferrites is their insulating properties that limit eddy current losses and other forms of conduction losses. Other attractive properties are their high permeability, low anisotropy fields, low FMR linewidths, and low magnetostriction. However, their ferrimagnetic nature limits their intrinsic magnetization. This has the effect of limiting the power loads and efforts to reduce component size at the MHz frequencies, and their broadband utility at the microwave. In recent years, trends in ferrite research have involved processing of ferrite nanoparticles for core fabrication for MHz frequencies, and as films for monolithic magnetic integrated circuits for nonreciprical microwave devices. In both cases the ferrites are processed in low dimensional form where surface phenomena dominate (in nanoparticles), and nonequilibrium processing conditions in films. In this paper, we discuss the nature of nonequilibrium cation inversion (i.e. disorder) in particle and film systems and its effect on the magnetic, electronic and loss characteristics. This discussion will address the challenges associated with the atomic design of ferrite systems, as well as nanoengineering of composites designed to overcome the intrinsic limitations of ferrite systems.

9:00 AM U3.2/T4.2

DIRECT AND REAL-TIME OBSERVATION OF SUB-MICRON DOMAIN DYNAMICS IN MAGNETICALLY BIASED STRONTIUM FERRITE PERMANENT MAGNETS BY ROOM TEMPERATURE SCANNING MICRO-HALL PROBE MICROSCOPY. A. Sandhu, N. Iida, Tokai Univ, Dept of Electrical Engineering, JAPAN; H. Masuda, Toei Kogyo Ltd, Tokyo, JAPAN; A. Oral, Bilkent Univ, Dept of Physics, TURKEY; S.J. Bending, Univ. of Bath, Dept of Physics, UNITED KINGDOM.

The development of ferromagnetic materials for high performance permanent magnets requires a fundamental understanding of the behavior of magnetic domains in external bias fields. We have developed a new room temperature scanning micro-Hall probe microscope (RT-SHPM) system for such purposes and will report on the imaging of domain movement in Sr ferrite permanent magnets (SFM) in external bias fields. The RT-SHPM system enables the highly sensitive, extremely fast, non-invasive, and quantitative measurement of localized surface magnetic fields on the micron-scale. A 0.8 x 0.8 μm GaAs/AlGaAs micro-Hall probe (300K Hall coefficient =0.3Ω/G and field sensitivity=0.04 G/$\sqrt{Hz}$) with an integrated STM tip for precise vertical positioning was used as a magnetic field sensor. External bias fields (Hex) of up to 3000 Oe were applied in steps of 400 Oe parallel to the easy and hard axes of carefully polished 400 μm thick thermally demagnetized Sr ferrite permanent magnets (Hc=2570 Oe; Br=2870 G). 50x50 μm areas were imaged at a height of 0.3 μm above the SFM surface for each Hex, with scan speeds of $\sim$1 frame/second enabling almost real-time imaging in synchronization with bias field changes. RT-SHPM imaging for Hex applied along the easy axis of SFMs showed (i) the existence of 8-15 μm sized domains with a surface magnetic field of $\pm$226G at Hex=0; (2) domains to move only above a critical bias field of $\pm$700 Oe; (3) the measured surface magnetic field to decrease with increasing bias fields to a value of 170 G at Hex=3000 Oe. The details and physical interpretation of these and related results for bias fields along the hard direction and imaging during demagnetization of the SFM from the remanent state will be discussed. Our results demonstrate the RT-SHPM system to be a valuable tool for the quantitative study of micro-magnetic phenomena in ferromagnetic materials.

9:15 AM U3.3/T4.3

ADVANCES IN THE LOW TEMPERATURE PREPARATION OF LANTHANUM STRONTIUM MANGANITE POWDERS. Sophie Guillemet-Fritsch, Herve Coradin, Patricia Baradat, Philippe Tailhades, Abel Rousset, CIRIMAT/LCMIE, Universite Paul Sabatier, Toulouse, FRANCE.

In recent years, the doped perovskite lanthanum strontium manganites have attracted much attention due to the colossal magnetoresistance (CMR) properties. It has been shown that the microstructure, and especially the grain size, plays a significant role on the intrinsic CMR properties. So the synthesis methods are very important for obtaining polycrystalline materials with special microstructure. In the present work perovskite-type compounds of general formula $La_{1-x}Sr_xMnO_3$ were prepared by the thermal decomposition of precursor powders. Two different kinds of precursors, carbonates and citrates have been prepared by low temperature, i.e. "Chimie douce" technique. The careful control of the chemical and the hydrodynamic parameters during the synthesis process allows to obtain small particles (30 nm for citrates)and narrow size distribution. A pure perovskite phase is observed after a low temperature thermal treatment, starting from 550°C. The structure is a function of the strontium content and the temperature. Moreover it depends also on the nature of the precursors used. It has been suggested that this behavior results from the different atmosphere due to the release of CO_2, CO and H_2O species during the decomposition process. The "Chimie douce" technique is a powerful tool to control the particle size and the surface area but also to a certain extent the structure of such perovskite materials.

9:30 AM U3.4/T4.4

Abstract Withdrawn.

9:45 AM U3.5/T4.5

CRYSTAL STRUCTURE AND MAGNETIC PROPERTIES OF THE DOUBLE PEROVSKITE $(Sr_{2-x}Ca_x)FeMoO_6$. Ting-Shan Chan[1], Ru-Shi Liu*,[1], Chih-Hung Shen [1], Ravi Gundakaram[1], Jauyn Grace Lin[2], Chao-Yuan Huang[3], Jin-Ming Chen[4], Ling-Yun Jang[4]. [1]Department of Chemistry, National Taiwan University, Taipei, TAIWAN. [2]Center for Condensed Matter Sciences, National Taiwan University, Taipei, TAIWAN. [3]Center for Condensed Matter Sciences, Department of Physics and Department of Electrical Engineering, National Taiwan University, Taipei, TAIWAN. [4]Synchrotron Radiation Research Center, Hsinchu, TAIWAN.

A new series of ordered double perovskite oxides $(Sr_{2-x}Ca_x)FeMoO_6$ displaying colossal magnetoresistance has been synthesized by solid state reaction. A monotonous decrease of the lattice constants (*a* and *c*) has been found with increasing x, which arises from the variation of chemical pressure in the compounds. This result is consistent with the fact that the Ca^{2+} ion is smaller than the Sr^{2+} ion. The resistivity decreases with increasing x, showing that the hole concentration may increase due to the application of chemical pressure. Moreover, the growth of the particle size with increasing Ca doping has also been observed. The valence states of Fe and Mo was determined by the X-ray absorption near-edge structure (XANES) and extended fine structure (EXAFS) spectroscopies at the Fe and Mo edges. The results compared to the standard samples show that the valence states of Fe ($3d^5$) and Mo ($4d^1$) are $^{3+}$ and $^{5+}$ respectively. Based on our studies, we can understand that the chemical pressure is an important factor in controlling the colossal magnetoresistance in the new ordered double perovskite oxide series $(Sr_{2-x}Ca_x)FeMoO_6$.

10:30 AM *U3.6/T4.6

CRITICAL-STATE PHASE-CONTROL IN COLOSSAL MAGNETORESISTANCE MATERIALS. Y. Tokura, Tsuoshi Kimura, Department of Applied Physics, University of Tokyo, Tokyo, JAPAN, and Joint Research Center for Atom Technology (JRCAT) and Correlated Electron Research Center (CERC), Tsukuba, JAPAN.

Control of electronic parameters via modifications of composition, structure, and lattice strain in perovskite type manganese oxides

produces novel magnetoelectronic properties, including colossal magnetoresistance (CMR). Close interplay among spin, charge, orbital, and lattice is responsible for this, producing rich and complex electronic/magnetic/orbital phases. With use of order-disorder phenomena in the charge and orbital sectors, unconventional phase control is also possible, such as photo- and current-induced insulator-metal and/or antiferromagnetic-ferromagnetic transitions. Recent results of such an study on single crystals and thin films of CMR oxides are presented.

11:00 AM U3.7/T4.7
THE INFLUENCE OF SINGLE GRAIN BOUNDARY JUNCTIONS ON THE MAGNETORESISTANCE IN GRANULAR PEROVSKITE MANGANITE FILMS. Robert Gunnarsson, Zdravko Ivanov, Chalmers Univ of Technology, Dept of Microelectronics and Nanoscience, Gothenburg, SWEDEN; Roland Mathieu, Peter Svedlindh, Dept of Materials Science, Uppsala Univ, Uppsala, SWEDEN.

We have examined single grain boundary junctions (GBJs) as well as GBJ arrays in Sr-doped (33%) lanthanum-manganite thin films. The films were deposited by pulsed laser deposition (PLD) on symmetric bi-crystals with 8.8o, 18.4° and 45° misorientation angles. Microbridges, with a width of a few hundred nanometers and crossing the artificial grain boundary of the bi-crystal, were patterned by Ar-ion milling through a resistive mask. Magnetoresistance and noise measurements of the GBJ were performed in a wide range of temperatures and magnetic fields. The measurements on single GBJ reveal a switching, i.e. steps in the magnetoresistance near the coercive field. We show that the switching originates from the magnetic domain structure of the bridge at the bi-crystal interface. With a multi-domain model the magnetoresistive behaviour of a single junction can be described. The noise measurements show that the grain boundary noise, which has a Debye-Lorentzian frequency-dependence, is additional to the normal 1/f-noise seen in bulk perovskite manganites.

11:15 AM *U3.8/T4.8
ANISOTROPIC MAGNETOCALERIC EFFECT IN NANO STRUCTURED MAGNETIC CLUSTERS. X.X. Zhang, Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, CHINA.

We have systematically studied the magnetic entropy change, -DSM (H,T), in the Fe8 molecular crystals in a wide temperature range. Since the Fe8 crystals are composed of a huge number of (Avogadros constant) identical, non-interacting, aligned, anisotropic magnetic clusters with spin 20mB, it is a model system for the study of the fundamental properties of the nanostructured magnetic materials. The isothermal magnetization curves have been measured at the different angles between the applied magnetic field and the magnetic easy axes of the clusters. From the isothermal magnetization data, the temperature and field dependence of the magnetic entropy change or magnetocaloric effect (MCE) have been obtained. It is found that the magnetic anisotropy ploys a very important role in the determination of the magnetocaloric effect.
The maximum and minimum MCE are observed when the applied magnetic fields are parallel and perpendicular to the easy axis respectively in the whole temperature range. The magnetic entropy change and other properties of a system composed of isotropic magnetic clusters have been obtained by the numerical methods in order to illustrate the magnetic anisotropy effect.

11:45 AM U3.9/T4.9
NANOSCALE MAGNETIC DOMAIN STRUCTURE IN COLOSSAL MAGNETORESISTANCE MATERIALS ISLANDS. Yan Wu and Yuri Suzuki, Department of MS&E, Cornell University, Ithaca, NY.

The doped perovskite manganites have received an enormous amount of attention recently because they exhibit colossal magnetoresistance (CMR) and may be half metallic, with complete spin polarization at the Fermi level. The magnetic and magnetoresistive responses are extremely sensitive to lattice strain and thus to structural distortion. As a result many groups have studied partially and fully strained CMR films. We have chosen to study the effects of strain in CMR islands where we can tune the strain state through variation of island aspect ratio. We have fabricated sub-micron sized islands of $La_{0.7}Sr_{0.3}MnO_3$. Magnetization loops indicate a characteristic field that reflects shape anisotropy effects. We have used magnetic force microscopy to image the magnetic domain states of these individual islands in zero field after saturation in different directions. The stripe magnetic domain states that we observe are a result of the competition among shape anisotropy, strain anisotropy, magnetocrystalline anisotropy and magnetostatic energies. The evolution of domains in a magnetic field reveals the importance of shape anisotropy as well as magnetostriction in determining the micromagnetics in such small CMR structures. Our understanding of the micromagnetics provides a foundation for the analysis and implementation of thin film magnetoresistive devices made of this class of materials.

SESSION U4: MAGNETIC NANOPARTICLES, NANOWIRES AND ARRAYS
Wednesday Afternoon, April 18, 2001
Golden Gate B3 (Marriott)

1:30 PM *U4.1
FIELD-INDUCED 3D AND 2D CRYSTALS OF FERRO-MAGNETICALLY COATED MICROSPHERES. Ping Sheng, Weijia Wen, Lingyun Zhang, C.T. Chan, Wing Yim Tam, HKUST, Dept. of Physics, Clear Water Bay, Kowloon, Hong Kong, CHINA.

We have fabricated uniform-sized, ferromagnetically coated microspheres ranging from 1-50 microns in diameter, each consisting of a glassy core with an outer Ni layer of adjustable thickness. An additional insulating coating of TiO_2 or PZT is optional. The magnetic moment of each microsphere is easily tunable by controlling the Ni coating thickness. By dispersing the magnetic spheres in liquid, we show that the electric and/or magnetic field(s) can induce 3D crystalline arrangements of the microspheres. In addition, 2D magnetic colloidal crystals are formed by floating the microspheres on a liquid meniscus. Under a magnetic field, the balance between the repulsive magnetic interaction and the "attractive" interaction, due to the weight of the particles projected along the surface tangent, yields not only the triangular lattice with a variable lattice constant, but also all the other planar crystal symmetries such as the oblique, centered-rectangular, rectangular, and square lattices. By using two different sized magnetic microspheres, local formations of 2D quasicrystallites with fivefold symmetry were also observed.

2:00 PM U4.2
AC SUSCEPTIBILITY OF MONODISPERSE IRON NANO-PARTICLES. Keith D. Humfeld, Anit K. Giri, and Sara A. Majetich, Physics Dept., Carnegie Mellon University, Pittsburgh, PA; Eugene L. Venturini, Sandia National Laboratories, Albuquerque, NM.

We have synthesized highly monodisperse, unoxidized iron nanoparticles and measured their susceptibility as a function of frequency and temperature. 7 nm α-Fe nanoparticles were prepared using water-free inverse micelles, and via thermal decomposition of iron pentacarbonyl in an organic solvent. A 0.1 vol.% solution was sealed in an ampoule to facilitate the study of the magnetic properties of non-interacting nanoparticles. The sample was frozen to prevent free rotation of the particles. The real and imaginary parts of the susceptibility were measured between 0.1 and 1000 Hz for temperatures between 10 and 150 K. The sinusoidal applied field had an amplitude of 5 Oe. The peak in the imaginary part of the susceptibility χ"(f) for a given temperature was designated as the characteristic frequency, f_c. /*chi*"(f) for different temperatures was normalized to a single curve by plotting it as a function of f/f_c. The real part of the susceptibility /*chi*'(f) could not be normalized to a single curve due to the temperature dependence of the magnetization, $M(T) \approx M_s{}^2 HV/kT$. However the /*chi*'T scaled to a single curve when plotted as a function of f/f_c. While in nanocomposites $\ln(f_c)$ increased slowly and linearly with temperature T, for the nanoparticles $\ln(f_c)$ rose linearly with ln(T), and changed dramatically over a small temperature range. Though the nanoparticles are monodisperse, they may have differing energy barriers for coherent rotation due to weak interparticle interactions and varying orientations of the easy axes. To differentiate these effects, and to better understand the reason for the temperature dependence of f_c, magnetic viscosity is measured for magnetically aligned and unaligned samples. The unaligned particles exhibit a magnetic viscosity S as per $M(t) = M_0 - S\ln(t)$. The aligned particles exhibit a narrower distribution of energy barriers.

2:15 PM U4.3
SYNTHESIS OF NANOSTRUCTURED COLLOIDAL MAGNETIC PARTICLES AND MAGNETIC NANOCRYSTAL SUPER-LATTICES. Michael Hilgendorff, Nelly Sobal, Michael Giersig, HMI, Dept of Solar Energie Science, Berlin, GERMANY.

The preparation of low-dimensional well ordered layers of nanocrystalline, size-controlled, and monodisperse magnetic particles are of interest to a wide range of technological applications such as memory devices. It is known that the deposition of monodisperse non-aggregated colloids may lead to self assembled layers and superlattices. The quality of the ordering of magnetic particles can be improved using a magnetic field during the deposition, i. e. during the solvent evaporation. To make the preparation of well ordered layers of nanocrystalline particles attractive for technological applications it is necessary to find easy ways for the preparation of non-aggregated, monodisperse colloids as well as for the preparation of well ordered layers (considering the necessity of different properties to apply different deposition technics). Our approach is to find central and cheap synthesis routes to prepare nanocrystalline particles in solution which can be easily modified to get non-aggregated, size-controlled, and monodisperse colloids in water as well as in hydrophobic solvents. We are also interested to alloy and/or coat the nanocrystalline particles with nobel metals to change their magnetic properties, to preserve the particles for oxidation and to control the distance between the particles of a well ordered deposited Layer. We will report some simple routes to monodisperse non-aggregated magnetic particles in hydrophobic solutions, their nanostructuring and the preparation of more-dimensional ordered nanocrystalline layers using a magnetophoretic deposition technique. Actual successes and problems will be discussed.

2:30 PM U4.4
MAGNETIC NANOPARTICLE ARRAYS. Dorothy Farrell, Sara Majetich, Anit K. Giri, Keith Humfeld, Mihaela Tanase, Saeki Yamamuro, Carnegie Mellon University, Dept of Physics, Pittsburgh, PA.

Solvent evaporation from suspensions of surfactant coated 4-12 nm Fe or FePt particles in hexane can cause self-assembly of the particles into mono- and multilayer arrays. The particles are formed by dissolving platinum acetonylacetonate in octyl ether in the presence of a reducing agent and heating. Iron pentacarbonyl is added at elevated temperature, and the molar ratio of Fe to Pt determines whether FePt or Pt seeded Fe is formed. Surfactants are added to the system to coat the particles, which are then washed and dispersed in hexane. When the suspension dries on a flat surface, the hexane evaporates and the suspension forms a thin film. Solvent evaporation from the film gives rise to immersion capillary forces, which bring the particles together. These forces and particle interactions balance, resulting in monolayer array formation. Solvent flows into the array from the rest of the suspension to replace the evaporated hexane, carrying more particles with it. These particles are added to the growing crystal edge; when the contact angle between solvent and crystal surpasses a critical angle, multilayers of varying structure and orientation are formed. Transmission electron microscopy images are used to quantify and explain the lattice structures. The array structures should have unique magnetic properties. SQUID magnetometry reveals the coercive and magnetization behavior of the arrays, while Lorentz mode TEM reveals the magnetic structure. Unfortunately, the as formed FePt particles have a face centered cubic internal structure, and are only weakly magnetic. The arrays can be annealed, however, to transform the particles to the higher anisotropy tetragonal phase. For both the Fe and FePt arrays, the magnetic properties can be enhanced by crystallographic alignment of the particles. Growing and annealing the arrays in large magnetic fields is a promising avenue for this alignment that we have been pursuing.

2:45 PM U4.5
LOW TEMPERATURE STUDY OF MAGNETIZATION REVERSAL AND MAGNETIC ANISOTROPY IN Fe, Ni, AND Co NANOWIRES. Michael Kröll, Physics Department, Trinity College Dublin, IRELAND; Jos de Jongh, Fernando Luis, Peter Paulus, Kamerlingh Onnes Laboratorium, Universiteit Leiden, THE NETHERLANDS; Günter Schmid, Institut für Anorganische Chemie, Universität Essen, GERMANY.

Iron, Nickel and Cobalt nanowires are prepared by an AC plating procedure using nanoporous alumina membranes as a matrix material. The pore diameter and therefore the diameter of the wires can easily be controlled within a range of 5 to 200 nm. A study of the magnetic reversal mechanism for Iron and Nickel nanowires with diameters down to 5 nm, i.e. smaller than the domain wall width, is presented. The coercive field at 5 K is a factor of three lower than the prediction for rotation in unison. We also observe that the activation energy associated with the reversal process is proportional to the cross-section of the wires and nearly independent of the wire length. From the temperature dependence of the coercive field and the magnetic viscosity we can conclude that magnetization reversal takes place via a nucleation of a small magnetic domain, probably at the end of the wire, followed by the movement of the domain wall. For Cobalt wires, we observe a different behavior that is dominated by the competition between the shape anisotropy and the temperature dependent magnetocrystalline anisotropy. This competition is partly due to a competition between hcp-Co and fcc-Co. The amount of fcc-Co increases with decreasing wire diameter causing a different magnetic behavior. Structural studies (EXAFS, WAXS) support this statement.

3:30 PM *U4.6
STABILITY OF MAGNETIC STATES IN PATTERNED MATERIALS. Martha Pardavi-Horvath, George Washington University, Dept. of ECE, Washington, DC.

The interest in regular two-dimensional arrays of small magnetic particles is motivated by their potential as the next generation high density magnetic recording medium. The stability of a 2D patterned magnetic system is an important practical problem with interesting fundamental aspects. The elements of a 2D array are single domain particles, switching by incoherent rotation, and interacting magnetostatically. The stability of the magnetic state of the elements and the system is determined by material parameters, shape and size, statistics, and reversal mode. The role of the shape and size in switching of individual elements, and the statistical distribution of the switching fields is one of the determining factors in the stability of the system. Another factor is the interaction between elements. Its mean value depends on the total magnetization of the system, however, its standard deviation depends not only on the statistical errors in the geometry of the array, but it depends also on the total magnetization of the system. This means, that for a 2D magnetic recording medium, the stability of the recorded information depends on the information itself. The stability against thermal excitation depends on the details of the magnetization process. The magnetization process in film and bulk materials involves both low energy barrier domain wall motion and high energy rotational processes. However, the thermal stability of single domain particles, switching by rotation, is much higher than for a continuous medium with a much broader switching barrier distribution, ranging from the domain wall motion coercivity up to the anisotropy field. Experimental data for a model 2D square array of single crystalline, strongly uniaxial, single domain garnet particles illustrate the effects on stability of shape, statistics, and magnetization process.

4:00 PM U4.7
SYNTHESIS AND SELF ASSEMBLY OF FILMS CONTAINING FeCoPt NANOPARTICLES. Min Chen, Dawai Zhang and David E. Nikles, University of Alabama-Tuscaloosa, AL.

$Fe_{49}Co_7Pt_{44}$ nanoparticles were synthesized by simultaneous chemical reduction of platinum acetylacetonate and cobalt acetylacetone and thermal decomposition of iron pentacarbonyl. As-prepared the particles had a disordered face-centered cubic lattice with an average diameter of 3 nm and were superparamagnetic. The particles were dispersed in a hydrocarbon solvent and deposited onto a silica coated Cu TEM grid. After drying, the particles assembled into parallel arrays of chains. The particles were deposited onto a single crystal Si (100) substrate and annealed at 700°C for 30 minutes. The particles transformed to the face-centered tetragonal phase with the (111) direction oriented in the plane of the film. The film became ferromagnetic with a in-plane coercivity of 8700 Oe and a squareness of 0.75.

4:15 PM U4.8
EFFECT OF SUBSTRATE ON THE SELF-ASSEMBLY OF FePT NANOPARTICLES. Min Chen, Dawei Zhang and David E. Nikles, Center for Materials for Information Technology, The University of Alabama, Tuscaloosa, Tuscaloosa, AL.

Spherical $Fe_{48}Pt_{52}$ nanoparticles were synthesized by simultaneous chemical reduction of platinum acetylacetonate and thermal decomposition of iron pentacarbonyl using the procedure of Sun, et al. (S. Sun, C.B. Murray, D. Weller, L. Folks and A. Moser, Science, Vol 287, 1989 (2000)). As-prepared the particles had a disordered face-centered cubic lattice with an average diameter of 3 nm and a polydispersity of less than 5%. The particles were superparamagnetic. The particles were dispersed in a 50/50 mixture of hexane and octane and deposited onto different substrates. When deposited onto a carbon coated Cu TEM grid the particles assembled into the form of hexagonal two-dimensional array. When deposited onto a silica coated Cu TEM grid the particles formed a square, closed-packed two-dimensional array. The particles were deposited onto a single crystal Si (100) substrate and annealed at 700°C for 30 minutes. After annealing the particles transformed to the face-centered tetragonal phase with the particle 111 planes oriented in the plane of the films. The film became ferromagnetic with an in-plane coercivity greater than 11,000 Oe and a squareness of 0.70.

4:30 PM *U4.9
DOMAIN WALL STRUCTURE IN EPITAXIALLY GROWN MAGNETIC WIRES AND DOTS. K. Ounadjela, L. Prejbeanu, L. Buda and U. Ebels, IPCMS (UMR 7504 CNRS-ULP), FRANCE.

Advances in materials growth and characterization have, over the past ten years, made possible the investigation of basic physical processes in new 'artificial' materials. These materials are artificial in the sense that the geometry and composition are controlled during growth on micrometer and nanometer length scales. This results in macroscopic behaviour that can be dramatically different from that of a material in its bulk form. Magnetic order and reversal processes which have been extensively studied since the turn of the century have now to be

reexamined for nanostructured materials. The results on domain structure in submicron magnetic dots, rings and wires presented here exemplify current state-of-the-art growth and imaging technologies. Equally important, the reported results of intricate domains in submicronic magnetic structures demonstrate the potential for precise control of micromagnetic behaviour in patterned materials. For instance, the recent observation of a domain wall magnetoresistance effect in magnetic nanowires exhibiting a head to head wall structure[1] was recently interpreted in terms of spin dependent scattering and spin accumulation at the domain walls. In this interpretation the domain wall width plays a crucial role, making a precise knowledge of the domain wall structure a primary concern. Here, a detailed investigation on the domain wall structure is presented in epitaxial Co nanowires which form perfect model systems for such investigations. Wires and dots were patterned, from an initially epitaxially grown 10 to 80nm thick Co film. We have established experimentally the boundaries between the ground states and the metastable states which strongly depend on the lateral width and height of the nanostructured material. We will discuss furthermore the existence of metastable configurations induced following specific magnetization histories.
[1]U. Ebels, A. Radulescu, Y. Henry, L. Piraux, K. Ounadjela, Phys. Rev. Lett. **84**, 983 (2000).

SESSION U5: MAGNETIC MICRO- AND NANOCOMPOSITES
Thursday Morning, April 19, 2001
Golden Gate B3 (Marriott)

8:30 AM *U5.1
THE ROLE OF DISORDER IN NANOSTRUCTURED MAGNETIC ALLOYS. Diandra L. Leslie-Pelecky, L. Yue, R. Sabirianov, E. Kirkpatrick, University of Nebraska - Lincoln, Department of Physics & Astronomy and Center for Materials Research & Analysis, Lincoln, NE; Paul Shand, Department of Physics, University of Northern Iowa, Cedar Falls IA; T. Pekarek, Department of Natural Sciences, University of North Florida, Jacksonville, FL.

Low-energy, randomly oriented crystalline regions in a nanostructure interact with each other through non-crystalline interphase regions. Atoms in the interphase - which can comprise as much as 50% of the sample when the grain size is on the order of 5 nm - experience a different structural and magnetic environment than the bulk atoms. Understanding the effect of different types of structural disorder on the magnetic properties of ferromagnetic alloys is critical to our ability to produce materials for specific applications. This talk will focus on the effects of disorder in three magnetic alloys. $SmCo_5$, a hard magnetic material, can be made harder via mechanical milling. The factor-of-two change in the coercivity with as little as two hours of milling is shown by aging studies to be due to defects and not simply grain size. The metastable Ni_3C phase is predicted by Linear-Muffin-Tin-Orbital calculations to be nonferromagnetic; however, mechanically alloyed Ni_3C has a 70 Oe coercivity at room temperature. Subsequent LMTO calculations demonstrate that locally disordered Ni_3C regions can indeed support ferromagnetism. Crystalline $GdAl_2$ is a ferromagnet with a Curie temperature of ~175 K, while amorphous $GdAl_2$ is a spin glass with a freezing temperature of 16 K. Nanostructured $GdAl_2$ has spin-glass-like features, but with a freezing temperature near 65 K. The effects of structural changes on the nature of the magnetic ground state have been investigated using linear and non-linear susceptibility measurements. Scaling theory is used to determine the magnetic phase diagram as a function of the order of the alloy.

9:00 AM U5.2
EXCHANGE COUPLING AND THE AC MAGNETIC PROPERTIES OF FeCo NANOCOMPOSITES. Keith D. Humfeld, Anit K. Giri, Saeki Yamamuro, and Sara A. Majetich, Physics Dept., Carnegie Mellon University Pittsburgh, PA.

The AC magnetic properties of compacted FeCo nanocomposites are explained quantitatively in terms of the random anisotropy mode with two types of exchange coupled regions. These nanocomposites were formed by the compaction of monodisperse but in many cases multigrained nanoparticles, which have a thin carbonaceous coating. Our previous measurements of the permeability, coercivity, and power loss have suggested that there are two distinct components contributing with different AC magnetic properties. Here these components are identified, showing consistency with the random anisotropy model and with our microstructural AC model. The temperature dependence of the anisotropy was found from that of the magnetization. Using the anisotropy K_1 and the average grain size found from Scherrer analysis V_{gr}, plus the random anisotropy model, these quantities can be related to the effective anisotropy K* and the volume of the exchange coupled region V*. A second equation involving these quantities has been found from AC simulations and the experimental cutoff frequencies. Together they are used to obtain the temperature dependence of K* and $V^*=L_{ex}^3$. The exchange coupled volumes are comparable to or smaller than V_{gr}. These small regions are associated with the cutoff frequencies, and currently limit the useful frequency range of the nanocomposites. At lower frequencies a second type of exchange coupled region dominates. Here the anisotropy K' is estimated from the low frequency coercivity and saturation magnetization, to within a temperature-independent constant α. Using the random anisotropy model with K_1, V_{gr}, and K', the exchange coupled region V can be estimated. Fresnel Lorentz microscopy shows domain walls around regions 100-200 nm in diameter, suggesting $\alpha \approx 0.5$. This dimension is comparable to the diameter of the particles used to form the nanocomposite.

9:15 AM U5.3
ELECTROCHEMICAL DEPOSITION OF FeCo ALLOYS AND $FeCo/TiO_2$ NANOCOMPOSITES. Ingrid Shao, P.M. Vereecken, P.C. Searson, R.C. Cammarata, Johns Hopkins Univ, Dept of MS&E, Baltimore, MD; C.L. Chien, Johns Hopkins Univ, Dept of Physics and Astronomy, Baltimore, MD.

Iron-cobalt alloys near the equiatomic composition have superior soft magnetic properties with a very high saturation magnetization (24 kG), high D.C. permeability, low D.C. coercivity and low A.C. core loss. The ability to produce soft magnetic materials in thin film form has many technological applications, such as hard disk drives, microactuators and microinductors. Electrochemical deposition is an important processing technology for microfabrication due to its low cost, high yield, low energy requirements, and capability for generating high-aspect-ratio features. However, electrochemical deposition of FeCo alloys has been problematic over the years. We have successfully produced high quality $Fe_{50}Co_{50}$ films from an aqueous sulfamate electrolyte with a rotating disk electrode. Samples (7 mm in diameter and about 25 μm in thickness) were deposited at constant current densities between -5 and -400 mA/cm^2 and at a temperature of 50°C. Knoop hardness, magnetic hysteresis loops, resistivity, microstructure, and composition of these films were characterized. A saturation magnetization about 21 to 22 kG was typical for these as-deposited films. Bulk FeCo alloys are primarily used in the manufacture of rotor and stator laminations in motors and generators for aircraft power generation applications. The inferior mechanical properties of these alloys, including low yield strength, low creep resistance and poor ductility, has hampered their use in technological applications. We have utilized electrochemical codeposition from an electrolyte containing a suspension of TiO_2 particles (25 nm in diameter) to produce oxide dispersion strengthened $FeCo/TiO_2$ nanocomposites. Large grain sizes of about 10 μm were observed for all these $FeCo/TiO_2$ films. An average hardness enhancement of 50% was observed for the electrodeposited $FeCo/TiO_2$ (1 to 2 vol.% particles) nanocomposites compared to cast FeCo alloys with similar grain sizes. Magnetic properties were slightly degraded due to the incorporation of nanoparticles.

9:30 AM U5.4
HIGH STRENGTH MAGNETIC COMPOSITES. A. Gorea, M.M. Corte-Real, R.H. Yu, and John Q. Xiao, University of Delaware, Department of Physics and Astronomy, Newark, DE; L. Ren, Azar Parvizi-Majidi, University of Delaware, Department of Mechanical Engineering, Newark, DE.

There has been an increasing demand in high temperature soft magnetic materials with much better mechanical properties than existing commercial materials such as FeCo alloys. We have designed new magnetic composites by reinforcing FeCo alloys with high strength tungsten or carbon fibers. Several methods including electrodeposition, slurry infiltration, and high pressure compaction were employed to achieve bulk alloys. In general, as-deposited composites show a relatively high Hc and low magnetic permeability m, because of induced strain during the fabrication. After appropriate thermal annealing, the composites show good soft magnetic properties comparable to bulk commercial alloys. However the saturation induction is reduced due to nonmagnetic fibers inclusions. The composites also show significant enhancements in yield strength and tensile strength that increase linearly with fiber volume fraction as seen in other common composite materials. In addition near zero creep is observed at 600°C under a stress of 600 MPa. The mechanical properties can be further improved by co-depositing soft magnet and Al_2O_3 nanopowder onto fibers. An approximate linear relationship was observed between Hc and the volume fraction of Al_2O_3 particles. The hardness of the composites nearly doubled with about 10% vol. concentration of Al_2O_3 particles. The square root relationship has also been observed between the hardness and Al_2O_3 particle concentration.

9:45 AM U5.5
MAGNETIC PROPERTIES OF TRANSITION METAL-DENDRIMER NANOCOMPOSITES. Richard A. Fry, R.D. Shull, National Institute of Standards and Technology, Gaithersburg, MD; S.

Uppuluri, and L. Balogh, University of Michigan, Center for Biologic Nanotechnology, Ann Arbor, MI.

Magnetic nanocomposites have been successfully prepared by encapsulating nanosized entities of iron, cobalt, and nickel compounds in hydrophobic poly(amidoamine) (PAMAM) dendrimer hosts. Problems related to the instability of the magnetic structures [1] under the influence of an external electromagnetic field have been overcome by using a solid polystyrene matrix to embed the dendrimer hosts containing the magnetic guests. SQUID magnetometry measurements on these nanocomposites showed that after subtraction of the diamagnetic polymer background, at 300 K all samples exhibited paramagnetic behavior, with susceptibilities of 1.14, 1.68, and 0.70 $\times 10^{-6}$ m^3/kg for Fe-, Co-, and Ni-containing samples respectively. The temperature dependence for T<300 K showed typical paramagnetic behavior, with the susceptibility increasing for decreasing temperature. Curie-Weiss (1/M vs. T) graphs displayed a linear behavior at high temperatures, with temperature axis intercepts (θ) occurring at -139 K (Fe), -16 K (Co), and 0 K (Ni). Negative deviations from Curie-Weiss behavior occurred at T<175 K for the Fe and T<25 K for the Co samples, which indicated that the susceptibility increased at a faster rate with decreasing temperature than the Weiss molecular field model would dictate. Magnetic moments calculated from the high temperature Curie constant indicated that Fe, Co, and Ni possessed effective moments of 4.4, 4.4, and $2.8\mu_B$ under the assumption that these species were present in metallic form. The negative intercepts and the fact that these moments are larger than those expected for metallic transition metals is indicative that these species are probably present in an oxidized form. The low-temperature behavior showed curved isotherms with approach to saturation [76, 132, and 123 A$\cdot$m^2/kg (i.e., emu/g) at 5 K and 5 T for Fe, Co, and Ni respectively at fields >30 kOe indicating either superparamagnetic or soft ferromagnetic behavior. Detailed structural characterization of the nanomagnets is presently under investigation.

[1] R.D. Shull, L. Balogh. D.R. Swanson, and D. Tomalia, presented at Fall Meeting of the American Chemical Society, Boston, MA (1998).

10:30 AM *U5.6

FERROMAGNETIC AND SUPERAPARAMAGNETIC PARTICLE COMPOSITES STRUCTURED BY UNIAXIAL AND BIAXIAL FIELDS. James E. Martin, Judy Odinek, Eugene Venturini and Robert A. Anderson, Sandia National Laboratories Albuquerque, NM.

We will discuss the synthesis and properties of anisotropic composites of ferromagnetic and superparamagnetic particles. The former we refer to as Field-Structured Composites (FSCs), and these consist of ferromagnetic particles suspended in a polymeric resin and structured into chain or sheet-like aggregates by applied uniaxial or biaxial fields. The formation of chains in a uniaxial field is familiar, and occurs because of induced dipolar interactions. The formation of sheets in a biaxial field, such as a rotating field, is less familiar, and occurs because of negative induced dipolar interactions. FSCs exhibit highly anisotropic magnetic, optical and transport properties, and are promising materials for such applications as actuators, chemical sensors, and current-limiting thermistors. Recently, we have begun to investigate the properties of structured composites of super-paramagnetic particles, which we call Dipolar Nanocomposites (DPNs), to emphasize the permanent particle dipoles. Uniaxial DPNs are easily made in a static applied field, but producing biaxial composites in a rotating field is challenging, due to the high field frequencies and strengths required. This was ultimately accomplished by designing an audio frequency, Resonant Biaxial Helmholtz Coil that employs a fractal capacitor bank essentially continuously tunable over three decades of capacitance. The strong collective dipolar interactions in DPNs significantly alter their magnetism, producing anisotropic suseptibilities, shifts in the blocking temperature, and shifts in the temperature dependence of the AC susceptibility. Finally, both the structure of these materials and their magnetic properties are accounted for by simple Langevin dynamics codes.

11:00 AM U5.7

NANOCOMPOSITE WITH NON-SPHERICAL GRANULES - LOGARITHMIC FIELD DEPENDENCE OF GIANT MAGNETORESISTANCE. E. Meilikhov, Russian Research Center Kurchatov Institute, Moscow, RUSSIA; B. Raquet, Laboratoire de Physique de la Matiere Condensee de Toulouse, Toulouse, FRANCE.

In the present paper, we consider the giant magnetoresistance of the nanocomposite $Fe_x(SiO_2)_{1-x}$ which is the granular ferromagnetic metal in the insulator matrix with x$\sim$0.6 (that corresponds to the state close to the percolation transition metal-insulator). Experiments show that at high enough magnetic fields, the resistance of the system depends logarithmically on the magnetic field. Such a dependence does not fall into the framework of the known theory of the giant magnetoresistance of ferromagnetic nanocomposites. We relate this unusual feature to the fact that the "traditional" theory is applied to systems with spherical granules, while real nanocomposites consist most commonly of non-spherical ones. Moreover, as a rule, there are granules of diverse non-sphericity in the system - from the strongly prolate to the strongly oblate ones. This paper examines the giant magnetoresistance of such a system in terms of a simple model where the non-ordinary semilogarithmic magnetic field dependence of nanocomposite magnetoresistance is related to the non-spherical granules distribution over their shapes.

11:15 AM *U5.8

SYNTHESIS AND PROPERTIES OF HYBRID HIGH-TEMPERATURE NANOSTRUCTURED MAGNETS. D.J. Sellmyer, J. Zhou, H. Tang, R. Skomski, Behlen Lab of Physics and Ctr for Materials Research and Analysis, Univ of Nebraska, Lincoln, NE.

We report studies of novel Sm-Co-based nanostructured magnets with excellent high-temperature properties. Two classes of materials have been synthesized. The first is Sm-Co-Cu-Ti hybrid magnets which are two-phase mixtures of 2:17 Sm-Co-Ti grains surrounded by 1:5 Sm-Co-Cu inter-granular regions [1]. The typical dimensions of the main and boundary phases are 70 nm and 10 nm, respectively. A positive temperature dependence of the coercivity H_c is observed with maxima in the 400-500°C region. H_c values to 12.3 kOe at 500°C have been observed, the largest known values at this high temperature. A theoretical model involving wall pinning provides a qualitative understanding of the unusual H_c(T) behavior. The second class of material reported is mechanically milled $Sm(CoZr)_7$ magnets with grain sizes in the 10-20 nm region and with the disordered $TbCu_7$ structure [2]. The Zr stabilizes and refines the nanostructure leading to H_c values up to 21 kOe and $(BH)_{max}$ values up to 13 MGOe at room temperature. Zr addition provides enhanced hard magnetic properties through both increased anisotropy and intergranular exchange coupling.

Research supported by DOE under grant DE-FG-03-98ER45703, DARPA/ARO under grant DAAG55-98-1-0268, and AFOSR under grant F49620-98-1-0098.

[1] J. Zhou, R. Skomski, C. Chen, G.C. Hadjipanayis and D.J. Sellmyer, Appl. Phys. Lett. **77**, 1514 (2000).
[2] H. Tang, Y. Liu, J. Zhou, D.J. Sellmyer (submitted).

SESSION U6/Y7: JOINT SESSION
MAGNETIC PROPERTIES OF NANOMATERIALS
Chairs: James E. Hutchison and Franziska Groehn
Thursday Afternoon, April 19, 2001
Metropolitan II (Argent)

1:30 PM *U6.1/Y7.1

MAGNETISM IN THE NANOTECHNOLOGY WORLD. Robert D. Shull, Magnetic Materials Group, National Institute of Standards and Technology, Gaithersburg, MD.

The National Nanotechnology Initiative (NNI) in the United States this year has caused renewed attention to the area of nanometer length-scale materials and devices, even internationally. Why all the interest? And where does magnetism fit into this flurry of activity? Here, a description will be presented of the properties and applications of materials possessing nanometer-thick films, particles, or crystals of a ferromagnet intimately mixed with magnetically-dissimilar materials. Such nanoscale morphology has been found to result in novel magnetic behavior. Why does this occur and how will it impact your present and future lives? Particular attention will be devoted to the fabrication and use of magnetic "nanocomposites" for magnetic recording. In this application, use is made of a novel phenomenon called the "Giant Magnetoresistance (GMR) Effect" which derives from nanometer-thick layering of dissimilar materials. The reasons for our group's world leading magnetic "spin valve" structures and behind the unusual magnetic switching behavior of certain key elements in these "spin valve" structures (using the GMR effect) will also be included. Mention will be made of the first successful preparation of magnetic dendrimers, very attractive nanocomposites for targeted drug delivery and magnetic imaging contrast, along with how nanocomposites can play a role in the development of advanced high energy density permanent magnets, or even of the "softest" soft ferromagnets. If time permits, a description will also be provided on how nanolayering can be used to develop very large magnetic anisotropies and on how magnetism can be used to develop high efficiency refrigerators, using the "Giant Magnetocaloric Effect" in magnetic nanocomposites, applications also pioneered at NIST. As a result of this presentation, it should become obvious what makes magnetism a particularly special case for nanotechnology excitement.

2:00 PM U6.2/Y7.2

SUPERPARAMAGNETISM AND MICROSTRUCTURAL PROPERTIES OF CARBON ENCAPSULATED Ni NANO-PARTICLE ASSEMBLIES. Xiang-Cheng Sun, J.A. Toledo, Prog.

Simulación Molecular, Instituto Mexicano del Petróleo, México, MÉXICO; M.J. Yacaman, ININ, México, MÉXICO.

Superparamagnetism is a unique and important features of magnetic nanoparticles. Novel carbon encapsulated Ni nanoparticles offer us great opportunities for studying the mechanism of superparamagnetic properties.
Carbon encapsulated Ni nanoparticles were synthesized by modified arc-discharge reactor under methane atmosphere. The presence of carbon encapsulation was identified by HR-TEM lattice imaging, nano-diffraction and X-ray microanalysis. The grain size is typically 10-3 nm with spherical shape, neither gaps nor intermediate phases were observed between the outer carbon layers and the core metallic Ni nanocrystals. The intimate and contiguous carbon fringes around these Ni nanocrystal particles is good evidence for complete encapsulation by carbon shell layers.
Superparamagnetic properties studies for an assembly of carbon encapsulated Ni nanoparticles using DC-SQUID magnetometer. The field-cooled (FC) and zero-field-cooled (ZFC) magnetization measurements display a divergence below the blocking temperature at a certain applied magnetic field. The blocking temperature (T_B) is determined to around 115K at 1000Gs applied field. Below T_B, the temperature dependence of the coercivity is given by $H_c = H_{ci}[1-(T/T_B)^{1/2}]$, with $H_{ci} \approx$ 500Oe. Above T_B, the magnetization M(H,T) can be described by the standard Langevin function L using the relation, $M/M_s(T=0)$ = cloth(μH/kT)- kT/μH. The particle size can be inferred from Langevin Fit (particle moment μ) and blocking temperature theory (T_B), which values are bigger than HR-TEM observations. It is suggested, this assemblies of carbon encapsulated Ni nanoparticles have been showed typical single-domain, field-dependent superparamagnetic relaxation properties; and these typical superparamagnetic behaviors are consistent with the Stoner-Wohlfarth theory on single-domain particles.
These interesting superparamagnetic properties studies indicates, this novel carbon encapsulated Ni nanoparticles have many potentials for application such as ferrofluids, magnetocaloric refrigeration, and magnetic resonance imaging (MRI) enhancement.

2:15 PM U6.3/Y7.3
NANOSTRUCTURES WITH VARIABLE MAGNETIC PROPERTIES. Igor P. Suzdalev, Yuri V. Maksimov, Vladimir N. Buravtsev, Vladimir K. Imshennik, Sergey V. Novichikhin, Institute of Chemical Physics, Russian Academy of Sciences, Moscow, RUSSIA.

An assembling of nanocluster systems causes new properties of the matter that can be varied by means of cluster organization and interfacial interactions. This work deals with novel type of magnetic and structural phase transitions in iron oxide nanocluster systems induced by interface and strain effects. New nanostructure systems composed of alfa, gamma-iron oxide nanoclusters with sizes of 20-50 nm were synthesized by solid-state chemical reaction. The systems were loaded by shear stress (250 grade) under high pressure (up to 20 Kbar) as well as by the stresses combined with polymerization in acrylamide. The nanostructures were found to compose of nanoclusters that strong interact with each other and matrix. The magnetic properties of systems were determined by intercluster interaction, by density of defects in clusters and by intercluster strain. We observed new type of magnetic phase transition: jump-like first order magnetic phase transition at which the magnetization and magnetic order disappeared by jump with temperature at Tcc$\sim$120-300K (Tc for the bulk is $\sim$900K). The studied nanostructers showed collective transition into the unusual twin structure just above the Morin temperature, Tm, typical of a-ferric oxide. The values of TM were found to vary from 120 to 260K depending on intercluster interaction. An action of shear stress under high pressure leads to change Tcc and the character of magnetic phase transition (first or second order phase transition) depending on the presence or absence of polymeric matrix. For nanoclusters of 20-30 nm in size the character of magnetic phase transitions and variation of the Curie or Neel points were treated and explained by the thermodynamic model of magnetic phase transition with regard for intercluster strain effects, intercluster interaction and density of defects.

2:30 PM U6.4/Y7.4
PRODUCTION OF MAGNETIC-ORDERED SPIN SYSTEMS BY THE FORMATION OF TWO - DIMENSIONAL OXIDE NANOSTRUCTURES OF VARIOUS TOPOLOGY ON THE SILICA SURFACE. Vladimir M. Smirnov, Igor V. Murin, St. Petersburg State University, Dep. of Chemistry, St. Petersburg, RUSSIA.

Theoretical bases and experimental data confirmed a possibility of a synthesis of ordered spin systems are discussed in the communication. Chemical designing of specified steric arrangement of surface atoms in the matrix of two-dimensional nanostructure (nanolayer) is considered as the base of the procedure. In the instance of oxide nanostructures we evaluate a possibility to use the resources of modern precision synthesis for the dissolving of the production problem of solid chemical compounds with various steric distribution of atoms (structural topology) within the high order artificial substance like oxide superlattice. The phenomenon of two-dimensional ferromagnetism which was discovered by us is discussed.
Two-dimensional magnetization area is supposed to arise from aggregation of certain amount of Fe^{3+} - O group on the surface of diamagnetic support. Problems of production of high ordered spin systems are considered in the relation to magnetic properties of two samples series: i) two-dimensional oxide nanostructures containing in the plane of two-component monolayer various element-oxygen groups with their designed ratio (Fe^{2+} - O and Fe^{3+} - O, Fe^{3+} - O and Ni^{2+} - O, Fe^{3+} - O and Ti^{4+} - O etc.); ii) two-dimensional oxide nanostructures containing alternating element-oxygen monolayers of various chemical composition (Fe^{2+} - O and Fe^{3+} - O, Fe^{3+} - O and Ni^{2+} - O, Fe^{3+} - O and Zn^{2+} - O etc.), the monolayers are deposited in the designed order.
The data obtained confirm a possibility to control vigorously the ordered spin states (states of magnetic moments) within given oxide nanostructures. Work is supported by RFBR (RUSSIA) under the Grant No 99-03-32010.

2:45 PM U6.5/Y7.5
NANOCRYSTALLINE Co NEEDLES MADE BY NON-AQUEOUS ELECTRODEPOSITION. C.-S. Yang, A. Sokolov, J.R. Jennings, J. Redepenning, B. Doudin Dept. of Physics and Astronomy, Dept. of Chemistry, University of Nebraska Lincoln, Lincoln, NE.

This research investigates the synthesis and properties of magnetic materials made by electrodeposition in non-aqueous solvents. Very little is known on this synthesis method, mostly because aqueous deposition is easy. However, the use of non-aqueous solvent has been found to be of primordial importance when plating over a thin oxide for the purpose of making tunnel junction by electrochemical methods. Our initial research concentrates on the magnetic properties of nanometer-sized wires, of diamters down 30 nm, obtained by template synthesis in filtering membranes. Wires have the ideal needle-type geometry for which the shape contribution of the magnetic anisotropy energy is dominant. Our results show surprisingly small crystallite size when using different solvents. Wires of Co plated in an ethylene glycol solvent show properties similar to those observed with aqueous solvents. However, a decrease in magnetization and coercive force for the other solvents is evident. Electron microscopy studies show that the crystallites size is not exceeding 3 nm for the DMF produced Co, and even lower for the acetonitrile bath. Non-aqueous plating offers a unique possibility to make ferromagnetic materials with very low crystallites dimensions. The decrease of the saturation magnetization is more likely due to an increasing number of Co surface atoms. A model of chain-of-grains become more accurate to explain the magnetic properties of low-crystallinity samples.

3:30 PM *U6.6/Y7.6
FROM NEAR-SURFACE AND INTERFACE MAGNETISM TO THE MAGNETISM IN SMALL PARTICLES. B. Stahl, M. Ghafari, H. Hahn, Darmstadt University of Technology, Institute of Materials Science, Darmstadt, GERAMANY.

To understand magnetic phenomena in small particles not seen in bulk materials, especially in the vicinity of critical points, surface, interface, shape, volume and structural effects have to be taken into account. Experiments on different particle sizes in order to distinguish between these effects have to start with infinite large particles, i.e. the near-surface region of single crystals and interfaces of layered structures. These near-surface and interfaces properties give a significant contribution to the magnetic properties of particles in the nanometer range. From this it is clear that the experimental methods have to cope with this scaling with respect to depth resolution, magnetic and structural characterisation. This gives the field a largely interdisciplinary character, especially if one aims at applications as is the case for instance in magneto-resistance devices. Experiments on the near-surface magnetism of single crystals as well as on nano-structured materials will be presented, laying special attention on a surface sensitive and depth resolved Moessbauer technique.

4:00 PM U6.7/Y7.7
SIZE-DEPENDENCE OF MAGNETIC PROPERTIES OF BISMUTH FERRITE NANOPOWDERS. H. He, J. Li, Lanzhou Univ, Dept of Materials Science, Lanzhou, CHINA.

$BiFeO_3$ is a magnetoelectric material in which antiferromagnetic and ferroelectric orderings coexist. $BiFeO_3$ has a cycloidal spiral modulated magnetic structure with an abnormal long period of 62 nm. So it would be interesting if the crystal dimension decreases to nanometer scale, especially below 62 nm. $BiFeO_3$ nanopowders with average grain sizes from 20 to 60 nm are supposed to be single-crystal particles and have narrow size distributions. The cell edge increases markedly and the axis angle deviates increasingly from 60° as the particle size decreases. The change of magnetic susceptibility with temperature is characteristic of antiferromagnetic ordering. However, its high magnitude is indicative of weak ferromagnetism. The magnetization and magnetic susceptibility increase with decreasing particle size. Mössbauer studies reveal that the spin canting angles in the smaller particles are bigger and have a wider distribution. The magnetic structure in these particles is an uncompensated antiferromagnetic spin ordering. Therefore, as the particle size decreases, the lattice distortion, the spin canting and the weak ferromagnetism of the $BiFeO_3$ nanopowders increase.

4:15 PM U6.8/Y7.8

MAGNETIC BEHAVIOUR OF INTERACTING SUPER-PARAMAGNETIC IRON OXIDE NANOPARTICLES IN FERROFLUIDS. Wolfgang Voit, Royal Institute of Technology, Engineering Materials Physics Division, Stockholm, SWEDEN and XaarJet AB, Jarfalla, SWEDEN; Do Kyung Kim, Mamoun Muhammed, Royal Institute of Technology, Materials Chemistry Division, Stockholm, SWEDEN; Werner Zapka, XaarJet AB, Jarfalla, SWEDEN; K.V. Rao, Royal Institute of Technology, Engineering Materials Physics Division, Stockholm, SWEDEN.

We present a magnetic study of ferrofluids containing super-paramagnetic magnetite (Fe_3O_4) particles in a size range from 6 to 10 nm. The iron oxide particles were produced using a controlled co-precipitation technique, preventing undesirable oxidation of Fe^{2+}. After coating with sodium oleate or PVA, the nanoparticles were dispersed in a water-based solution forming a stable ferrofluid. The magnetic properties of ferrofluids with different particle concentration were studied using SQUID magnetometry and AC-susceptibility, and compared to the magnetic properties of the solid iron oxide nanoparticles. The measurements reveal a dependency of the blocking temperature on the particle concentration. In addition, the dc-susceptibility for the zero-field-cooled and field-cooled magnetisation show irregularities near the transition point from the frozen to the liquid state for ferrofluids, due to different relaxation mechanisms (Néel relaxation and Brownian relaxation). The AC-susceptibilty measurements in the frequency range from 10 Hz to 4 kHz complement this study. A correlation of the magnetic properties to the chemical environment around the particles is investigated. Recent results of these studies will be presented.

4:30 PM *U6.9/Y7.9

MAGNETIC PROPERTIES OF SINGLE MOLECULE MAGNETS. Andrew D. Kent, Louisa Bokacheva, Dept of Physics and Marc Walters, Dept of Chemistry, New York University.

Single molecule magnets (SMM) are a new type of magnetic nanostructure that consist of a core of strongly exchange-coupled transition metal ions with a large collective magnetic moment per molecule, thus far up to about 20 μ_B. Their molecular nature enables experimental studies of monodisperse ensembles of nanomagnets with well-defined size, shape, chemical composition, and magnetic anisotropy. Such materials are of interest for investigations of the interplay between classical and quantum effects in nanomagnets, as well as potential applications in quantum computing. This talk will present results of our recent magnetic studies of the crossover between thermal activation (superparamagnetism) and quantum tunneling of the magnetization in the prototype SMM Mn_{12}-acetate [1]. Some open questions in magnetic quantum tunneling in SMMs and perspectives for new SMM materials will also be discussed.

[1] L. Bokacheva, A.D. Kent and M. Walters, Phys. Rev. Lett. **85**, 4803 (2000).

SESSION U7: MAGNETOSTRICTION
Friday Morning, April 20, 2001
Golden Gate B3 (Marriott)

8:30 AM *U7.1

MAGNETIC FIELD INDUCED 6% STRAIN IN Ni-Mn-Ga CRYSTALS: EXPERIMENTAL RESULTS AND MODELING. R.C. O'Handley, S.M. Allen, S.J. Murray[a], M. Marioni and P.G. Tello, Massachusetts Institute of Technology, Cambridge, MA. [a]Midé Technology Corporation, Cambridge, MA.

Very large field-induced strains (e $\approx$ 6%) have been reported for Ni-Mn-Ga single-crystal ferromagnetic shape memory alloys (FSMAs) at room temperature [1]. While these materials show the conventional thermoelastic shape memory effect upon transformation to the high-temperature phase, the magnetic field-induced strain occurs fully within the low-temperature, martensitic phase. Fields of 320 to 400 kA/m (4 to 5 kOe) are sufficient to produce the maximum strain under opposing stresses of order 1 MPa. The blocking stress (stress at which field-induced strain is zero) observed here is aproximately 2 Mpa but can be up to 10 MPa. These strains are not magnetostrictive in origin but arise rather from field-induced motion of twin boundaries in the martensitic phase [2]. A thermodynamic model for field-induced twin-boundary motion is described [3]. It includes terms for Zeeman energy, magnetocrystalline anisotropy, external stress, demagnetizing energy, coercivity, as well as the elasticity and pseudo-elasticity of the martensite. In the infinite anisotropy case, the twin boundary motion is driven solely by the Zeeman energy difference, muo del(Ms).H, between the adjacent twin variants. For finite anisotropy, twin boundary motion is driven by the sum of the Zeeman and anisotropy energy differences. The effects of each class of terms on the strain versus field behavior are illustrated. The field dependence and stress dependence of the strain are reasonably well accounted for by the model. All parameters for the model can be measured from stress-versus-strain curves and magnetization-versus-field curves.

9:00 AM U7.2

SPONTANEOUS AC FIELD INDUCED MECHANICAL ROTATION IN MAGNETOSTRICTIVE AMORPHOUS FeSiB WIRES SUBJECTED TO THERMAL TREATMENT. V. Raposo[1], A. Mitra[1,2] and M. Vázquez[1]. [1]Instituto de Ciencia de Materiales de Madrid (C.S.I.C.) and Instituto de Magnetismo Aplicado UCM-RENFE, Madrid, SPAIN. [2]National Metallurgical Laboratory, Jamshedpur, INDIA.

An astonishing new phenomenon has been recently observed in magnetostrictive amorphous and polycrystalline wires [1,2]. It consists of the spontaneous rotation of the wires when submitted to an AC axial field. The rotation, observed at certain amplitudes and frequencies of the applied field, is believed to appear due to interaction between the eddy currents and magnetoelastic standing waves. In the present work rotational characteristics of amorphous $Fe_{77.5}Si_{7.5}B_{15}$ wires in their as cast and heat-treated state has been investigated. The experimental results on the as-cast state indicate that spontaneous rotation occurred at 5.5kHz magnetizing frequency at constant amplitude of the magnetic field of 0.7kA/m. The maximum rotational speed of the as-cast wire was 80Hz and observed at the magnetizing frequency of 21kHz. In the 700K annealed wire, the rotational speed increased and rotation of the wire was observed at more applied frequencies than the as-cast one. In fact it appeared to be a continuum with respect to the applied frequency with variation in rotational speed of the wire. The maximum rotational speed in annealed samples was 90Hz and observed at 22kHz applied field. Applied magnetic field amplitude dependence of the rotational characteristic was also investigated using 17kHz magnetizing field. Rotation of as-cast wire started at critical applied field of 0.36kA/m and the speed was 40Hz. Critical applied field decreased to 0.26kA/m when the sample was annealed at 700K. The change in rotational characteristics of the wire is due to the relaxation of quenched-in internal stresses by annealing.

[1] F.J. Castaño, M. Vázquez, D.-X. Chen, C. Prados, E. Pina, A. Hernando, and G. Rivero, Appl. Phys. Lett. 75 (1999) 2117.
[2] V. Raposo, M. Vázquez and T.-A. Ovári to be published in IEEE Transaction on Magnetics.

9:15 AM U7.3

EFFECTIVE MAGNETOSTRICTION OF NANOCRYSTALLINE MAGNETIC MATERIALS: INTERFACIAL EFFECT. C.-W. Nan, Department of MS&E, Tsinghua University, Beijing, CHINA; G.J. Weng, Department of Mechanical and Aerospace Engineering, Rutgers University, New Brunswick, NJ.

Recently, nanocrystalline Fe-based alloys, such as FeZrBCu nanocrystalline alloys, consisting of nanosized crystallites grown in their amorphous precursors, show excellent soft magnetic properties which are considered to be attributed to the absence (or very small value) of magnetostriction due to nanostructure effect. An effective-medium type method is developed for the effective magnetostriction of nanocrystalline magnetic alloys based on the successful Green's function technique. A more general, explicit relation for determining the effective magnetostriction of nanocrystalline alloys is derived, and it recovers those previous Reuss-type approximations in the special cases. For illustration and comparison, calculations for the effective magnetostriction of nanocrystalline $Fe_{85}Zr_7B_6Cu_2$ alloy are given. The effective-medium type formula is more applicable to consider the interfacial effect.

9:30 AM U7.4

OBSERVATION OF PATTERNS BY MAGNETIC FORCE MICROCOPY IN Fe-ALLOYS WITH SHAPE MEMORY EFFECT. M.I.N. da Silva, J.C. González, North Carolina State University, Analytical Instrumentation Facility, Raleigh, NC; M.S. Andrade Laboratório de Nanoscopia, Setor de Tecnologia Metalúrgica - CETEC, Av. José Candido da Silveira, Belo Horizonte-MG, BRAZIL.

In this work we make a study of the magnetic domain in a FeMnSiNiCr stainless steel sample using the MFM technique. We compared the patterns obtained by scanning the sample with three different coated tip: standard MFM, LM (low magnetization), and LC (low coercivity). The tip-surface separation was varied from 25 to 300 nm in order to quantify the magnetic microstructure of the sample, using a simple domain model. This model showed that the average maximum frequency decreasing with the tip-surface separation, for the three tips and that the frequency's intensity is stronger for standard MFM and decrease for LM and LC tips. Using X ray diffraction we have identified only two phases in the sample: γ phase (paramagnetic phase) and α phase (magnetic phase) and that the patterns seen in MFM image are due the sample's magnetic phase.

9:45 AM U7.5
TAILORING OF MAGNETIC PROPERTIES OF GLASS COATED MICROWIRES. Arcady P. Zhukov, Donostia International Physics Centre, San Sebastian, SPAIN; J. Gonzalez, Departamento de Fisica de Materiales, Facultad de Quimica, San Sebastian, SPAIN; V. Zhukova, J.M. Blanco, Dpto. Fisica Aplicada I, EUITI, Univ. Pais Vasco, San Sebastian, SPAIN.

The Taylor-Ulitovski technique has been employed for fabrication of tiny ferromagnetic amorphous and nanocrystalline metallic wires covered by an insulating glass coating with magnetic properties of great technological interest. A single and large Barkhausen jump is observed for Fe-rich microwires with positive magnetostriction. Negative Co-rich magnetostriction microwires exhibit almost unhysteretic behaviour with an easy axis transverse to the wire axis. Enhanced magnetic softness (initial permeability to 14000) and Giant Magneto-impedance effect (GMI) (up to 140% at 10 MHz) was observed in amorphous Co-based microwires with nearly zero magnetostriction after adequate heat treatment. Large sensitivity of GMI and magnetic characteristics on external tensile stresses has been observed. The effect of conventional furnace and DC current annealing under DC axial magnetic field or without it on the magnetic properties of Co and Fe-based glass coated microwires has been studied. Such thermal treatment modifies the magnetic parameters owing to the internal stresses relaxation process and induction of magnetic anisotropy. In particular, annealing under applied magnetic field (field annealing) can improve significantly such magnetic parameters as coercivity or magnetic permeability. Such phenomenology can be interpreted considering the noticeable magnetic anisotropy induced by the combined effects of the applied magnetic field and internal stresses originated from the coating during the annealing. Upon heat treatment, FeSiBCuNb amorphous microwires devitrificate into nanocrystalline structure with enhanced magnetic softness. Such nanocrystallization process depends on internal stresses induced by the glass coating and on chemical composition. The magnetic bistability has been observed even after the second crystallization process in particular cases. The switching field can increase up to 5.5 kA/m for first or second crystallization processes. Hard magnetic materials with coercivity up to 60 kA/m were also obtained as a result of decomposition of metastable phases in Co-Ni-Cu and Fe-Ni-Cu.

10:30 AM *U7.6
MAGNETOSTRICTIVE MULTILAYERS FOR SENSOR AND ACTUATOR APPLICATIONS. Eckhard Quandt, Markus Loehndorf, Alfred Ludwig, Michael Tewes, Center of Advanced European Studies and Research, Bonn, GERMANY.

Magnetostrictive thin films are an attractive class of materials to realize micro-sensors or actuators since they offer the possibility of wire-less, high frequency operation, simple designs, and a cost-effective manufacturing technique using magnetron sputtering. An essential development is related with the preparation of layered magnetic thin film materials, which allows e.g. the control of the magnetic and electric properties as well as the microstructure in a wide range by combining different materials. In the case of micro-actuators e.g. for microfluidic devices, ultrasonic motors, or laser scanners, multilayers consisting of amorphous giant magnetostrictive Tb-Fe layers with positive magnetostriction and nanocrystalline soft magnetic Fe-Co layers having a very high magnetization present a spring-magnet-type system which shows very high magnetoelastic energies at low fields. E.g., the saturation field of these multilayers can be reduced compared to single layer materials due to the increased magnetization and the reduced anisotropy while keeping relatively large values of the magnetostriction. In general, applications of these materials require a well-defined uniaxial in-plane anisotropy, which can be obtained by a magnetic bias field during deposition or by annealing under a magnetic field. In the case of micro-sensors for mechanical quantities like torque the magnetostrictive thin film materials are used as a core in a microinductor or in combination with the giant magneto-impendance effect. With either techniques it is possible to detect mechanical stresses over large distances by a radio-link, preferable at a frequency of 2.5 GHz. Co-B/Fe-Co multilayers were found to be a suitable candidate for the magnetostrictive film material due to their high permeability, their high magnetic polarisation, their small coercive field, and their high magnetic anisotropy resulting in a cut-off frequency in extent of 2.5 GHz. The magnetic properties (magnetization, magnetostriction, magnetoresistivity, rf permeability) of both types of magnetostrictive multilayers will be discussed in view of possible applications as micro-actuators or sensors.

11:00 AM U7.7
DOMAIN STRUCTURE OF 'THICK' AMORPHOUS MICROWIRES WITH NEARLY ZERO MAGNETOSTRICTION. Horia Chiriac, Tibor-Adrian Ovari, National Institute of Research and Development for Technical Physics, Iasi, ROMANIA; Minoru Takajo, Nishinippon Institute of Technology, Dept of Electrical Engineering, Kanda, JAPAN; Jiro Yamasaki, Kyushu Institute of Technology, Dept of Electrical Engineering, Tobata, JAPAN.

Nearly zero magnetostrictive glass-coated amorphous microwires (λ = -1 $\times$ 10^{-7}) are suitable materials for sensor applications. Samples with metallic core diameters below 25 μm exhibit a typical hysteresis loop for soft magnetic materials, that was related to the existence of a domain structure with circumferential easy axis. The magnetic behavior of these microwires is changing drastically when the metallic core diameter increases over 25 μm, i.e. they display a bistable magnetic behavior at low fields, that is a one step magnetization reversal at a certain value of the applied field, called switching field. In this paper, results on the direct domain observation in nearly zero magnetostrictive $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ glass-coated amorphous microwires by means of Kerr microscopy are reported for the first time. Samples of different transverse dimensions, but with the metallic core diameter over 25 μm, and fixed length (7 cm), have been investigated. The effect of glass removal on the domain structure has been also studied. AC hysteresis loop measurements have been employed to establish a correlation between domain structure and magnetic behavior. Glass-coated microwires exhibit a single domain configuration with the magnetization pointing mostly to the wire axis. The domain structure does not change qualitatively with glass removal, but the parameters of the squared hysteresis loops are modified. The remanence to saturation ratio increases after glass removal, while the switching field decreases. For a microwire with the metallic core diameter of 34 μm and the glass thickness of 33.5 μm, the remanence to saturation ratio increases from 0.68 to 0.88 after glass removal, while the switching field decreases from 31.5 mOe to 27.7 mOe. The obtained results are of interest for sensor applications, and show that the metallic core diameter is a dimensional factor that contributes to important changes in the domain structure of such microwires.

11:15 AM U7.8
MAGNETIC SHAPE MEMORY EFFECTS INDUCED BY NANO SCALE COLUMNAR GRAIN. Yoshitake Nishi, Hiromasa Yabe, Haru-Hisa. Uchida, Yoshito Matsumura and Hirohisa Uchida, Tokai University, Shonan Campus, Hiratsuka, JAPAN.

Rapid vapor deposition often formed the orientated directional texture. In order to obtain giant magnetostriction, a Fe-Pd magnetic shape memory alloy were prepared by magnetron sputtering process to form the thin film of the fine nano scale columnar structure, which shows anisotropy of crystal orientation. The fine nano scale columnar grain below 100 nm was observed near eutectoid point. The reversible relationship was obtained between magnetostriction and applied magnetic field. Since the magnetostrictive susceptibility was higher than that of $Tb_{0.3}Dy_{0.7}Fe_2$ thin film, the highest magnetostrictive susceptibility for thin film was detected at low magnetic field at room temperature.

11:30 AM U7.9
X-RAY MAGNETIC LINEAR DICHROISM OF Fe-Ni ALLOYS ON Cu(111). Tracey F. Johnson, S. Chiang, Y. Sato, J.D. Shine, J.A. Giacomo, G.E. Thayer, X.D. Zhu, University of California Davis, Dept of Physics, Davis, CA; D.P. Land, University of California, Davis, Dept of Chemistry, Davis, CA; D.A. Arena, M. Hochstrasser, J.G. Tobin, Lawrence Livermore National Laboratory, Livermore; S.A. Morton, University of Missouri, Rolla, MO.

We are studying layer-by-layer synthesis of ultra-thin metal films by controlling at monolayer level the composition and structure of these films, including the interfacial region. We have prepared $Ni_{1-x}Fe_x$ multilayers on Cu(111) in order to better understand the giant magnetoresistive (GMR) effect in NiFe/Cu which are relevant to magnetic disk drive heads. Using Undulator Beamline 7.0 and the Spectromicroscopy Facility (7.0.1.2) at the Advanced Light Source, we have measured x-ray magnetic linear dichroism (XMLD) signals for five different thin Ni-Fe alloy films on Cu(111) with Fe composition ranging from 34% to 76%. The Curie temperature for all of these samples was in the range -25°C to -130°C, which is considerably lower than we previously seen for such films deposited on Cu(100). Further work is in progress to measure the magnetic asymmetry as a function of film thickness in addition to composition. We also plan to compare the XMLD and SQUID measurements of the magnetic moments of these alloy films.

11:45 AM U7.10

INDUCED SPIN POLARIZATION IN ANTIMONY OVERLAYERS.

Takashi Komesu, C.N. Borca, Hae-Kyung Jeong, R. Skomski, P.A. Dowben, University of Nebraska-Lincoln, NE; Delia Ristoiu, J.P. Nozieres, CNRS, Laboratoire Louis Neel, Grenoble, FRANCE.

We have investigated the induced magnetization of paramagnetic Sb overlayers on the Heusler alloy NiMnSb. From combined X-ray absorption spectroscopy (XAS) and spin-polarized inverse photoemission spectroscopy (SPIPES) [1], we can assign some of the unoccupied states of the Heusler alloy NiMnSb. With increasing thickness of the Sb overlayer, there is a decline in the density of states near the Fermi energy, as expected for a semimetal overlayer on a metallic substrate and explained in context of a spin-dependent envelope-function approximation (SEDFA) [2]. While the Sb is polarized by the ferromagnetic NiMnSb substrate, consistent with the expectations of mean field theory, the polarization at the center of the surface/overlayer Brillouin zone cannot be easily related to the induced magnetization. The NiMnSb acts as a magnetic perturbation and induces a spin polarization in the semimetallic Sb overlayer. Due to the small numbers of carrier electrons and holes, the perturbation propagates deep into the overlayer and can be described by SEDFA [2]. It is argued that range of the injection depth decreases with increasing temperature and obeys a $1/(T)^{1/2}$ law at high temperatures, i.e. well above room temperature. In addition, the magnetic behavior of the overlayer is mapped onto a Ginzburg-Landau theory whose parameters are both band-structure and temperature dependent.

[1] Takashi Komesu, C.N. Borca, Hae-Kyung Jeong, P.A. Dowben, Delia Ristoiu, J.P. Nozieres, Shane Stadler and Y.U. Idzerda, Physics Letters A 245-251 273 (2000).

[2] R. Skomski, Takashi Komesu, C.N. Borca, Hae-Kyung Jeong, P.A. Dowben, Delia Ristoiu, and J.P. Nozieres, submitted to J. Appl. Phys.