SYMPOSIUM I

Fabrication and New Applications of Nanomagnetic Structures

November 28 - December 1, 2004

Chairs

Jian-Ping Wang
Electrical & Computer Engineering Dept
University of Minnesota
MINT
EE/CSi 6-153 200 Union St. SE
Minneapolis, MN 55455
612-625-9509

Pat J. Ryan
Advanced Transducer Development
Seagate Technology-LLC
M.S. NRW102
7801 Computer Ave.
Bloomington, MN 55435
952-402-7530

Kornelius Nielsch
Experimental Dept. 2
Max-Planck-Inst Microstr Physics
Weinberg 2
Halle, 6120 Germany
49-345-5582-902

Zhao-hua Cheng
State Key Laboratory for Magnetism
Chinese Academy of Sciences
Institute of Physics
Beijing, 100080 China
86-10-8264-9282

Symposium Support
Heraeus, Inc.

Proceedings to be published online
(see *ONLINE PUBLICATIONS* at www.mrs.org)
as volume 853E
of the Materials Research Society
Symposium Proceedings Series.

* Invited paper

TUTORIAL

FT I: Nanomagnetic Fabrication and New Findings
Sunday November 28, 2004
1:30 PM - 5:00 PM
Room 204 (Hynes)

I. Fabrication and Use of Spin-Valve and Magnetic-Tunnel-Junction Nanopillar Devices for Spin-Transfer Research

The first part of the tutorial will introduce the phenomenon of spin transfer, where the torque from a spin-polarized current can be employed to reversibly switch the magnetic moment of a thin-film nanomagnet or, depending upon the bias condition, excite the nanomagnet into high-frequency microwave oscillations. The tutorial will also present an overview of the thin-film processing and nanofabrication techniques that have been successfully employed to make magnetic nanostructures suitable for the study of spin-transfer effects, and will discuss some of the materials challenges associated with the fabrication of improved spin-transfer devices. The objective of the tutorial is to provide attendees with a basic understanding of spin transfer and its potential for technological applications. A perspective on some of the materials science and physics challenges that need to be addressed for further advances in the field, both for expanded scientific understanding and for the development of significant applications, will be presented.

II. Nanostructured Media for Future Magnetic Recording Applications at Areal Densities Beyond 1 Terabit/in2

The second part of the tutorial will outline various materials and fabrication challenges of future nanostructured magnetic recording media. Going much beyond Terabit/in2 will likely require drastic changes to conventional media sputter-fabrication processes, where simultaneous grain growth and nucleation limit the achievable physical and magnetic dispersions. So-called "self-organized magnetic arrays" (SOMA) of chemically synthesized 3-4 nm Fe-Pt nanoparticles have promising properties and are being explored as alternatives. Since these nanoparticles are almost spherical and nonmagnetic during the self-organization process, however, it is most challenging to control their magnetic orientation in this bottom-up nanofabrication approach. Top-down approaches based on nano-imprinting or block copolymer templates, on the other hand, start with continuous, magnetically well-behaved films into which the final structure is etched. The tutorial will cover recent developments in both top-down and bottom-up nanofabrication approaches and will review their respective potential for future magnetic-recording media and other applications.

Instructor:
Robert A. Buhrman
Cornell University

SESSION I1: Patterned Magnetic Film
Chair: Eckhard Quandt
Monday Morning, November 29, 2004
Independence W (Sheraton)

8:30 AM *I1.1
Fabrication of FePt Dot Arrays Using Block Copolymer Templates. Hiroyuki Hieda, Yoshiyuki Kamata, Katsuyuki Naito and Akira Kikitsu; Corporate Research & Developement Center, Toshiba Corporation, Kawasaki, Japan.

Heat-assisted recording with near-field optics and high magnetic anisotropy media, such as FePt alloys are attractive for high-density magnetic storage with sufficient thermal stability. Patterned media, which have regularly aligned preformed magnetic dots with an isolated single magnetic domain for each dot will possibly reduce transition noise on recorded mark. FePt alloys with patterned structures are expected to generate a high density of 1 Tbpsi or more. We demonstrated the fabrication of highly dense FePt dot arrays using block copolymer templates. Patterns of microphase separated block copolymer films were transferred to SOG island patterns, which were used as etching masks. The SOG island patterns were transferred by Ar ion milling to FePt films underneath. After etching, an increase of Hc in the out-of-plane direction and a decrease of Hc in the in-plane direction were observed. This suggests that the magnetic shape anisotropy increased as a result of the change of shape from plane film to columnar dots. Guided self-assembly of the block copolymer was also done to fabricate the circumferentially aligned dot structure. The applicability of this fabrication method to a 1 Tbpsi dot density was also investigated. FePt dot arrays with a 30 nm dot pitch and a 15 nm dot diameter were successfully fabricated. Sectional TEM images revealed that the dots were conical with a height of 20 nm. No significant damage on the etched surfaces or the sidewalls of the dots were observed. This implies that our methods will possibly be applicable to the fabrication of 1 Tbpsi dot arrays for magnetic media. This work was supported by OITDA project "Terabyte optical storage technology" being conducted under contract for the Ministry of Economy, Trade and Industry of Japan and the New Energy and Industrial Technology Development Organization.

9:00 AM *I1.2
Fabrication of Magnetic Tubes, Rings and Dots using Novel Processes. Caroline A Ross, F.J. Castano, W. Jung, D. Morecroft, Joy Y. Cheng, F. Ilievski, M. Shnayderman, K. Nielsch, R. Krishnan, J.W.A. Robinson and Henry I. Smith; Massachusetts Institute of Technology, Cambridge, Massachusetts.

New applications in nanomagnetics and spintronics require the development of new methods for the fabrication of magnetic nanostructures. Here we discuss the use of several processes, based on both self-assembling systems and conventional lithography, for the fabrication of magnetic structures with a range of geometries and properties. Electron-beam lithography or zone-plate array lithography (ZPAL) may be used to form complex planar thin film structures such as magnetic multilayer rings. These can show a variety of stable and metastable remanent states, containing different types of domain walls, and may be suitable for applications in magnetic random access memories where several bits may be stored in each ring. Electron-beam lithography is limited in area, but ZPAL can be used to produce ring arrays over large areas suitable for magnetometry. Properties of exchange-biased and pseudo-spin valve circular and elliptical rings will be described. Self-assembled block copolymer thin films may be used as templates to form arrays of nanostructures with sub-50 nm dimensions over large substrate areas. These 2D arrays have good short-range order, but lack long range order. However, long-range order can be imposed by guiding the phase-separation of the block copolymer using topographical substrate features, and the resulting ordered arrays may be useful in applications such as patterned media. Three-dimensional structures such as hollow magnetic tubes can be created by templating the growth of metal films inside porous alumina. By infiltrating a polymer containing cobalt carbonyl into the pores in an anodic alumina film, followed by thermal decomposition of the carbonyl, a thin-walled tube of cobalt can be formed inside each pore, which can be subsequently released by dissolving the alumina template. These structures may have applications in drug delivery or magnetoelectronic devices. In this presentation we will describe the capabilities of these traditional and non-traditional fabrication methods, and the properties and possible applications of the resulting magnetic nanostructures.

9:30 AM I1.3
Nanomagnetic Structures Fabricated by Block Co-Polymer Pattern Transfer. Filip Ilievski, Caroline A. Ross and Joy Y. Cheng; Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Magnetic nanodot arrays have recently drawn significant attention both for fundamental studies of magnetic phenomena as well as for applications in high-density patterned magnetic media. We have shown that nanoscale structures can be manufactured by pattern transfer from a self-assembled polymer layer. We have applied this technique to fabricate close-packed magnetic dot arrays of 5 - 20 nm thick Co and NiFe with periodicity of 56 nm and dot diameters of 34 nm. To produce these samples, the Co or NiFe films were evaporated, then coated with hard mask layers of W and SiO_2, then a solution of polystyrene-polyferrocenyldimethylsilane (PS-PFS) block copolymer was spincoated on top. The PS-PFS was annealed at 140°C to cause phase segregation, resulting in a 2D close-packed array of PFS spheres in a PS matrix. The PS-PFS block copolymer has a molecular weight of 91k for the PS and 21k for the PFS, leading to a periodicity of 56 nm for the sphere array. The PS matrix was removed, then the PFS sphere pattern was transferred into the SiO_2 layer and the W layer by reactive ion etching. Finally, the W pattern was transferred down into the magnetic layer by Ne ion milling. The resulting dot arrays have an in-plane magnetization direction and coercivities of up to 228 Oe for the Co and 160 Oe for NiFe arrays. Magnetic characterization showed strong magnetostatic interactions between the dots, for example the switching volume of the samples was 2 - 6 times the physical volume suggesting that several dots switch collectively (Cheng et al. Phys. Rev. B, in press (2004)), and the delta-M is negative. These samples therefore behave as arrays of strongly-interacting single-domain particles with in-plane magnetization, which makes them unsuitable for patterned media applications. To develop arrays more suitable for recording, we also patterned thin films with perpendicular magnetic anisotropy. The starting material was a thin film of perpendicular Co 66 at% Cr 22at% Pt (CoCrPt) deposited on a seed layer of Ti using RF-magnetron sputtering in an ultra-high vacuum at room

temperature. Structures as thin as 5nm Ti / 20nm CoCrPt exhibit perpendicular magnetic crystalline anisotropy due to preferential growth of the c-axis of the CoCrPt layer perpendicular to the sample plane, as shown by x-ray diffraction. The coercivity of the film was 134 Oe. The PS-PFS polymer used to pattern the Ti/CoCrPt has a lower molecular weight and produced a 2D array of PFS spheres with a periodicity of 49 nm and sphere diameter of 25 nm. We will describe the magnetic properties of the resulting arrays, which consist of 25 nm diameter CoCrPt dots with a range of film thicknesses, and will include an analysis of the interactions between the dots. We will also describe how long-range order can be imposed on the 2D dot array over large areas by the use of topographic substrate features, making the structures promising candidates for patterned media and other applications.

9:45 AM I1.4
Design and Synthesis of Core-Shell Magnetic Nanoparticles and the Application of Nanoparticles in the Fabrication of Arrays of Magnetic Rings. Hong Yang[1,2], Xiaowei Teng[1] and Qijie Guo[1]; [1]Chemical Engineering, University of Rochester, Rochester, New York; [2]LLE, University of Rochester, Rochester, New York.

Multi-component nanomaterials often possess unique magnetic properties that do not exist in single-phased magnets. The precise control of both composition and structure at nanometer length scale is essential for the realization of the properties; those involve magnetic exchange coupling/bias in particular. In this context, core-shell nanoparticles are important precursors, as they can be used for creating multiphased nanoparticles and nanocomposites with predetermined elements and designed nanostructures. I will discuss in this presentation the design and synthesis of platinum-iron oxide core-shell nanoparticles with the overall diameters between 4 and 20 nm in diameter. By using the sequential synthetic method [1], we were able to decouple the formation of core-shell nanoparticles one component at a time. The core-shell nanoparticles made thus can have different core diameters and shell thicknesses. These core-shell nanoparticles can be converted into various single-phased or core-shell nanoparticles that contain various FePt alloys at the elevated temperatures [2]. The platinum-iron oxide core-shell nanoparticles have further been used as precursors for making magnetic nanocomposites , in which exchange behaviors can be observed. The approach developed can extend to magnetic nanoparticles of other types of materials. Such platinum-iron oxide core-shell nanoparticles can be used in making arrays of magnetic rings by using combined patterned Langmuir-Blodgett (pLB) [3] and contact printing techniques. The materials and structures of single nanoparticle and nanocomposites have been studied by transmission electron microscopy (TEM), atomic force microscopy (AFM), electron diffraction (ED), powder X-ray diffraction (PXRD), energy disperse X-ray (EDX), electron energy-loss spectroscopy (EELS), X-ray photoelectron spectroscopy (XPS), superconducting quantum interference device (SQUID) magnetometer, and magnetic force microscopy (MFM). [1] X. Teng, D. Black, N. J. Watkins, Y. Gao, H. Yang, Nano Lett., 2003, 3, 261. [2] X. Teng, H. Yang, J. Am. Chem. Soc., 2003, 125, 14559. [3] Q. Guo, X. Teng, S. Rahman, H. Yang, J. Am. Chem. Soc., 2003, 125, 630.

SESSION I2: Magnetic Multilayer Films and Nanocomposite Materials
Chair: Caroline Ross
Monday Morning, November 29, 2004
Independence W (Sheraton)

10:30 AM I2.1
(FeCo/Cu/Ni) GMR Trilayer or Multilayer Systems as Strain Gauges. Stefani Dokupil, Maik-Thomas Bootsmann, Simon Stein, Markus Loehndorf and Eckhard Quandt; caesar, Bonn, Germany.

Recently, highly sensitive strain gauges were developed, which are based on TMR (tunnel magnetoresistance) or GMR (giant magnetoresistance) effects combined with the inverse magnetostriction [1, 2]. GMR and TMR structures generally possess a symmetrical characteristic which reflects the switching fields of the soft and hard layers, respectively. This characteristic can be changed by a stress field if the soft layer is replaced by a suitable magnetostrictive layer leading to a stress induced rotation of the magnetostrictive layer with respect to the reference layer. Alternatively, both magnetic layers can be soft magnetic, one being positive, the other negative magnetostrictive. In this case a stress applied on the stack leads to a reverse rotation of both layers due to the different sign in magnetostriction. This new approach is especially attractive since no reference layer is required which allows multilayering for GMR effect enhancement. This talk will present and interpret the stress biased characteristics of this (FeCo/Cu/Ni) GMR trilayer and multilayer systems in which the positive magnetostrictive FeCo and the negative magnetostrictive Ni replace the sensing and reference layer of a conventional GMR stack. The results will be compared to GMR/TMR strain sensors using a fixed reference layer and either FeCo or Ni as a magnetostrictive sensing layer. [1] Loehndorf, M.; Duenas-Lockwood, T.; Tewes, M.; Quandt; E., Ruehrig, R.; Wecker, J.: Highly sensitive strain sensors based on magnetic tunneling junctions (MTJs). Appl. Phys. Lett., 81 (2002), 313 [2] Loehndorf, M.; Dokupil, S.; Wecker, J.; Ruehrig, R.; Quandt; E.: Characterization of magnetic tunnel junctions (MTJ) with magnetostrictive free layer materials. J. Magn. Magn. Mater., 272/276 (2004), 2023

10:45 AM I2.2
GMR/TMR Sensors with Perpendicular Magnetic Anisotropy. Yunfei Ding, Jack Judy and Jian-Ping Wang; Electrical and computer engineering, University of Minnesota, Minneapolis, Minnesota.

Conventional magnetic thin film sensors using giant magneto resistance (GMR) and tunneling magneto resistance (TMR) mostly have in-plane magnetic anisotropy. We have developed three GMR/TMR structures in which either one or both of the free and pinned layers have perpendicular magnetic anisotropies. In the first structure, the easy axes of free and pinned layers are both perpendicular to the film plane. A perpendicular magnetic field can switch the film between high resistance and low resistance states. This structure can be used in a two-state perpendicular field sensor or in a magnetic memory. In the second structure only the pinned layer has perpendicular easy axis. The perpendicular anisotropy of the free layer is slightly smaller than its demagnetizing field(4PiMs). A sensor with this structure has a linear response to a magnetic field perpendicular to the film plane. In the third structure the free layer has a perpendicular easy axis while the pinned layer has an in-plane easy axis. A sensor with this structure has a linear response to an in-plane magnetic field. Comparing to the conventional configuration, now the free layer and pinned layer magnetizations are naturally perpendicular to each other, therefore a maximum and linear response to the in-plane field can be achieved without using a bias field. In conventional GMR or TMR sensors the magnetizations are confined inside film plane by the large demagnetizing field, so only in-plane magnetic field can be detected. When the device is fabricated into sub-micron scale one has to deal with the problems caused by the magnetostatic field. Perpendicular anisotropy can avoid these problems, and also opens a window to more flexible sensor designs. However in order to achieve favorable properties, such as high sensitivity and proper operating field range, the materials for the layers with perpendicular anisotropy have to be optimized. In this study the layers with perpendicular anisotropies are CoFe coupled with [CoFe/Pt]n multilayers. In this presentation the GMR and/or TMR sensors with the above three designs will be demonstrated, the optimizations of the [CoFe/Pt]n multilayers for each design will be discussed.

11:00 AM I2.3
Properties of Exchange-biased Elliptical Magnetic Rings Fabricated Using Zone-Plate-Array Lithography. Wonjoon Jung[1], Fernando Castano[1], Deborah Morecroft[1], Rajesh Menon[2], Henry I. Smith[2] and C. A. Ross[1]; [1]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Ring-shaped thin film magnetic structures have been of interest due to their unique magnetic 'onion' (bidomain), 'vortex' (flux-closed), and 'twisted' (i.e. containing a 360 degree wall) remanent states [1], which could potentially be used for storing data bits in magnetic random access memories (MRAMs) or for performing magnetic logic. Considerable research has been carried out on investigating the effect of shape, dimensions, and material of single-magnetic-layer rings on their magnetic states and switching behavior. However, the magnetic characteristics of multilayered rings have not yet been systematically studied. In this work we describe the fabrication of exchange-biased rings and explore the effect of exchange bias on the magnetic reversal of the rings. Large (4.5 x 2.4 mm) elliptical-ring arrays were fabricated using zone-plate-array lithography (ZPAL) and a lift-off process. ZPAL is a maskless optical lithography technique using an array of high-numerical-aperture-diffractive lenses to generate arbitrary patterns on the surface of a photoresist-coated substrate. Single ferromagnetic layers and exchange-biased thin film structures, where FeMn was employed as an antiferromagnetic material, were deposited using dc-triode magnetron sputtering on elliptical-ring patterns of different widths. The films were deposited in a magnetic field resulting in exchange pinning parallel to the long axis of the ellipses. Magnetic measurements were conducted using an alternating gradient magnetometer (AGM) and magnetic force microscopy (MFM). As an example, 3 micron major diameter, 1.7 micron minor diameter, 600 nm wide exchange-biased elliptical ring arrays fabricated from a 20 nm NiFe/ 10 nm FeMn thin film bilayer

exhibited asymmetric two-step hysteresis. After the elliptical-rings were saturated opposite to the pinning direction, the first switching from an onion to a vortex state occurred at 5 Oe before the field reached zero, producing a vortex state at remanence. However, saturation parallel to the pinning direction leads to an onion state at remanence, and the vortex state does not form until a reverse field of 80 Oe is applied. MFM, which was carried out at remanence, confirms this behavior and shows remanent vortex states in the first case and remanent onion states in the second case. The 'reverse onion' state, which is not favored by the exchange bias, was not found in any MFM images for all field histories explored, neither was the twisted state. Minor hysteresis loops and remanence curves of the ring arrays also confirm this asymmetric switching. For comparison, 20 nm thick NiFe elliptical rings of similar dimensions show symmetrical hysteresis loops with both onion states stable at remanence depending on the saturating field direction. Exchange-pinned and single-layer ring results will be compared, and micromagnetic simulation results will be discussed. [1] F J. Castano et al., Physical Review B, 67 (2003) 184425

11:15 AM I2.4
Investigation of Exchange Coupling in Thickness Gradient Fe/Sm-Co and Co/Sm-Co Magnetic Bilayers. Minghui Yu[1,2], J. Hattrick-Simpers[1], H. Ohguchi[1], I. Takeuchi[1], J. P. Liu[2], S. E. Lofland[3], J. W. Freeland[4], L. A. Bendersky[5] and D. Josell[5]; [1]Materials Science and Engineering, University of Maryland, College Park, Maryland; [2]Department of Physcis, University of Texas at Arlington, Arlington, Texas; [3]Department of Physcis, Rowan University, Glassboro, New Jersey; [4]Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois; [5]Materials science and Engineering Laboratory, National Institute of Standard and Technology, Gaithersburg, Maryland.

Exchange-coupled nanocomposite soft/hard magnet systems can achieve high energy product by combining the high magnetization of the soft magnet and the high magnetocrystalline anisotropy of the hard magnet. We have fabricated Fe/Sm-Co and Co/Sm-Co bilayers with gradient thickness of Co and Fe layers in order to systematically study the dependence of exchange coupling on the thickness of the soft layer. The films were deposited in a combinatorial magnetron-sputtering chamber, where the Fe and Co thickness wedges are created by the natural thickness gradient due to the deposition geometry. The soft layer was deposited at two different temperatures (150 °C and 300 °C) in order to study the effect of deposition temperature on the exchange coupling. Rapid magnetic property screening techniques using the magneto-optical Kerr effect (MOKE) and the x-ray magnetic circular dichroism (XMCD) have been employed to systematically characterize the gradient thickness exchange-coupled magnetic bilayers. The trend of the enhanced pinning of the soft layer by the hard layer with the decreasing soft layer thickness is clearly demonstrated by the MOKE measurement. The deposition of the soft layer at the higher temperature (300 °C) was found to enhance the interlayer exchange coupling between Fe and Sm-Co. The single-phase-like magnetization reversal exchange length increases from 12 nm for Fe deposited at 150 °C to 24 nm for Fe deposited at 300 °C. This might be an indication of the better contact and stronger binding resulting in a more coherent interface between Fe and Sm-Co layers. Separate exchange couplings of the soft layer with Co and Sm in the hard layer are revealed through measuring the elemental demagnetization curves using the XMCD technique. Results from bilayer libraries made by a combinatorial electron-beam evaporation system with FePt as the hard layer will also be presented.

11:30 AM I2.5
Characterization of the Distribution of Fe Particles Included in Carbon Nanotubes by SQUID Measurements.
Cheol Eui Lee[1], Jae Won Jang[1], Kyu Won Lee[1] and Cheol Jin Lee[2]; [1]Physics, Korea Univ., Seoul, South Korea; [2]Nanotechnology, Hanyang University, Seoul, South Korea.

We have controlled the Fe catalyst particle distribution in multiwalled carbon nanotubes (MWNTs) by means of vapor phase growth at 950 °C with constant Ar carrier gas flow rate and varying CO reaction gas flow rates. Magnetic properties of the MWNTs with various growing conditions were characterized by means of SQUID measurements in which superparamagnetic behaviors were observed. Control of the size and number of the Fe particles included in MWNTs was discussed in view of the change of the average magnetic moment, the coercive field, and the remanent magnetization of Fe particles with changing Fe concentration.

11:45 AM I2.6
Magnetic Properties of FeCo Nanoparticles Dispersed in Alumina Aerogel Matrix. Andrea Falqui, Maria Francesca Casula, Anna Corrias and Sergio Marras; Chemical Science, University of Cagliari, Cagliari, Italy.

Recently nanocomposites constituted of FeCo alloy nanoparticles dispersed into amorphous sol-gel matrix were obtained in the form of xerogel, aerogel and films. These materials are of interest since FeCo alloys have attractive size-dependent magnetic properties which can be strongly affected by interparticle interactions; moreover, FeCo supported particles can be exploited for catalytic applications. In this work, nanocrystalline γ-Al_2O_3 and FeCo-Al_2O_3 nanocomposite aerogels with high surface areas and pore volumes were prepared by high temperature supercritical drying of alcogels obtained by a fast sol-gel procedure. A complete investigation of morphological and structural properties of the these materials was performed by means of conventional and high resolution transmission electron microscopy, X-ray diffraction and X-ray absorption spectroscopy, the magnetic properties were investigated by means of static zero field cooled (ZFC) and field cooled (FC) magnetization, measured both by fixing the external magnetic field and varying the temperature and by fixing temperature and varying the external magnetic field (ZFC and FC hysteresis cycles). The formation of γ-Al_2O_3 occurs via a sequence of stages: in the parent aerogel an alkyl derivative of boehmite is observed, whose calcination gives rise to a disordered phase and finally to γ-Al_2O_3 which is stable up to 1000 °C. In the presence of iron and cobalt, calcination of the aerogel gives rise to a spinel phase similar to γ-Al_2O_3 where metal ions partially fill the vacancies. Nanocomposites constituted of FeCo alloy nanoparticles dispersed into γ-Al_2O_3 matrix are obtained via reduction in hydrogen flow of the aerogels containing iron and cobalt. The amount and average size of the nanoparticles depends both on the temperature and time of the reduction treatment and affects the resulting magnetic properties. All the calcined aerogels show pure paramagnetic behavior, while reduced aerogels show superparamagnetic behavior, but the collective magnetic properties are strongly dependent on the amount and mean size of the alloy nanoparticles. Increasing time and temperature of the reduction treatment causes the increase of the mean value and width distribution of size of the alloy nanoparticles dispersed in the crystalline alumina matrix. Moreover, a first effect of such an increase is observed on the collective magnetic behavior: the strength of dipolar interaction increases, as expected, with the nanoparticles size, leading to a magnetic blocked state still at room temperature for the samples with nanoparticles size larger than 15 nm. Furthermore the appearance of core-shell antiferromagnetic-ferromagnetic exchange interaction is observed for the sample containing the largest particles.

SESSION I3: Spintronics
Chairs: Yiming Huai and Jian-Ping Wang
Monday Afternoon, November 29, 2004
Independence W (Sheraton)

1:30 PM *I3.1
Spin-Transfer Effects in Magnetic Multilayer Nanostructures.
Robert Buhrman, Center for Nanoscale Systems, Cornell University, Ithaca, New York.

A spin-polarized current can exert a substantial torque on the moment of a thin film nanomagnet onto which it impinges through the direct transfer of spin angular momentum from the conduction electrons to the ferromagnetic moment. This spin transfer can give rise to dynamic effects that depend upon the magnetic field and current bias applied to the nanomagnet. At low fields, spin transfer can drive reversible magnetic switching of the nanomagnet, while at high fields spin transfer from a DC current can excite the nanomagnet into steady-state magnetic oscillation, with the frequency of this microwave oscillation being tunable by the field and current bias. This spin transfer effect is providing a new means of studying ferromagnetic behavior and magnetic dynamics at the nanoscale. It is also opening up the possibility of both direct-current-switched, non-volatile, dense magnetic memory and of nanoscale microwave oscillators for information processing and communications applications. In this presentation I will describe some recent experiments that have investigated spin-transfer effects both in spin-valve nanopillar structures and in nanoscale magnetic tunnel junctions with very thin tunnel barrier layers. I will discuss the phase diagram based on the modified Landau-Lifshitz-Gilbert equation that appears to successfully describe much of the behavior of a nanomagnet under magnetic field and spin current bias, and recent experiments and simulations that have examined the effect of thermal fluctuations on the spin-transfer behavior. These include temperature-dependent measurements of thermally-activated telegraph noise fluctuations in regimes of the phase diagram that are thermally bi-stable, as well as measurements of nanomagnet dynamics in both the GHz frequency (steady state response), and nanosecond time (pulse response) regimes. I will also discuss some current progress towards reducing the critical current density for the reversible spin-transfer switching of a thermally stable nanomagnet and towards narrowing the linewidth and enhancing the phase stability of a nanomagnet microwave oscillator. I will conclude with a brief discussion of some of the challenges and opportunities that may

impact further developments in this rapidly advancing field.

2:00 PM *I3.2
Nanomagnetic logic devices. Russell Cowburn, Physics Department, Durham University, Durham, United Kingdom.

We demonstrate a complete nanomagnetic logic architecture in which the various logic elements are fully integrated and operational. The architecture is based on planar ferromagnetic nanowires that are lithographically-defined to create the circuit. Typical nanowires are made from Permalloy (Ni80Fe20) and are 5 nm thick and 100 to 200 nm wide. Under the action of an in-plane rotating magnetic field, domain walls propagate through the nanowires to various nanowire junctions, where logic functions are performed. This allows successive logic elements to be simply and directly connected together with no intermediate conversion stage. The logical NOT function we have reported previously [1] is now complemented with logical AND/OR nanowire junctions and additional elements for signal fan-out and signal cross-over. We demonstrate a working nanowire logic circuit in which all four of these basic logic element types are shown to operate together. [1] Allwood et al. Science 296, 2003 (2002)

2:30 PM I3.3
Programmable spintronics logic device based on a single magnetic tunnel junction element. Jianguo Wang, Hao Meng and Jian-Ping Wang; ECE department, University of Minnesota, Minneapolis, Minnesota.

Programmable Spintronics Logic Devices have absorbed more attentions due to its/ many potential advantages compared with semiconductor logic devices, such as non-volatile, rapidly un-limited re-configurable variations, high integration density etc. So far, based on a single MR element with pinned structure, maximum four logic functions (AND, OR, NAND, NOR) can be realized [1]. A novel programmable spintronics logic device is designed and fabricated base on a single magnetic tunnel junction element (MTJ). By introducing a novel current input line passing through MTJ element itself and using thermally assisting switching for the pinned layer magnetization with other two separated input current lines, full logic functions (AND, OR, NAND, NOR, XOR and XNOR) can realized based on a normal pinned and a synthetic pinned structure MTJ element. The XNOR gate is proposed for the first time. A Weston-bridge was designed and fabricated to read this one MTJ elements logic device. MTJ elements with 1μm^2 size and normal pinned structure: (Ta30Å / NiFe40Å / MnIr35Å / CoFe30Å / (Al 7Å) + oxidation / CoFe30Å / NiFe40Å / Ta200Å), have low resistance of 6.3 Ω and high resistance of 7.2 Ω, which gives the MR ratio 14%. The operation of logic device is performed in two steps. First step is named //SET// that sets MTJ element to an initial logic gate state, and second step is named //Logic// that the MTJ element output depends on these inputs. The programmable spintronics logic device chip picture is shown, each die of chip has four same logic devices. The operation of the XOR and OR logic function //Set// and //Logic// are discussed, and about 3 mV output differences is obtained between logical 1 and 0. The output can be improved by increasing MTJ resistance and MR ratio. [1]. A.Ney, C.Pampuch, R.Koch and K.H.Ploog. "Programmable computing with a single magnetoresistive element," Nature, 425, 485-487, 2 Oct. (2003).

2:45 PM I3.4
Magnetic Vortex Core Switching Studied by Spatially Resolved Ferromagnetic Resonance. Hermann Stoll[1], Bartel Van Waeyenberge[1], Aleksandar Puzic[1], Tolek Tyliszczak[2], Hubert Brueckl[3] and Karsten Rott[3]; [1]MPI for Metals Research, Stuttgart, Germany; [2]Chemical Sciences Division, LBNL, Berkeley, California; [3]Fakultaet fuer Physik, Universitaet Bielefeld, Bielefeld, Germany.

Studies are presented on in-plane magnetic vortex dynamics in micron-sized Permalloy patterns and on deliberate switching of the orientation of the out-of-plane vortex core. Sub-ns time-resolved measurements were performed for the first time at a Scanning Transmission X-ray Microscope (STXM). The ferromagnetic domain patterns were excited by a "spatially resolved ferromagnetic resonance" (SR-FMR) technique which was occasionally used in optical Kerr microscopy /1/. The vortex movement of the magnetic Landau structure of a 1 micron x 1 micron Permalloy pattern (50 nm thick) was excited by a continuous external in-plane ac magnetic field at a frequency close to that of an eigen-mode of the vortex movement (250 MHz in the present experiment). The time and position resolved response of the magnetization of the sample was observed by a stroboscopic XMCD measurement at the STXM (ALS, BL 11). A spatial resolution of 20-40 nm (given by the STXM) and a time resolution of about 70 ps (given by the inherent time structure of the synchrotron radiation) were achieved. The time-dependence of the in-plane precessional motion of the vortex core was observed and compared with micromagnetic simulations. The chirality (handedness) of the magnetization dynamics was measured. The chirality in our Permalloy samples is determined by the orientation of the out-of-plane vortex core (it is of nanometer size) which can be either "up" or "down". Our SR-FMR measurements are consistent with PEEM results /2/ where similar samples have been excited by short in-plane magnetic pulses (stroboscopic "pump-and-probe" experiments). The advantages and disadvantages of our novel frequency-domain "spatially resolved FMR" technique are discussed in comparison to time-domain "pump and probe" experiments /2,3/. Surprisingly the chirality of the magnetic vortex movement observed in our sample could be deliberately switched by adjusting the amplitude of the 250 MHz magnetic ac excitation field. A sharp threshold was observed: A change of the excitation field by 10 percent at the threshold level produced a well defined repeatable change in the chirality of the magnetic vortex movement, indicating a switching of the orientation of the vortex core from the "up" to the "down" position and vice versa. Trajectories of the two different modes of vortex movements were derived from our measured data. The nanometer-scale vortex core orientation can be detected by "spatially resolved FMR" measurements at the STXM. In addition, FMR excitation allows deliberate and reproducible switching of the vortex core orientation as a step forward for using the orientation of the vortex core, e.g., for data storage purposes. /1/ S. Tamaru and J.A. Bain, J. Appl. Phys, 91, 8034, 2002 /2/ S.-B. Choe et al., Science, 304, 420, 2004 /3/ H. Stoll et al., Appl. Phys. Lett., 84, 3328, 2004

3:30 PM *I3.5
Trends in Nano-Scaled Magnetic Reader Transducer Song S Xue, Patrick J Ryan Advanced Transducer Development, Seagate Recording Head, Minnepolis, MN 55435. Song Xue and Patrick Ryan; Seagate Technology, Minneapolis, Minnesota.

For the past 50 years or so, the area density in magnetic recording has increased by almost 8 orders of magnitude. Today, the advanced magnetic reader typically has a reader width less than 100 nm. As the reader width continues to shrink, trade-off among performance, magnetic stability, and reliability poses serious challenges for further increasing area density. We will review process technologies to fabricate nano-scale magnetic reader sensor. We will also discuss a few reader device options available to us; there are Current-In-Plane Spin Valve (CIP SV), Tunnel Magetoresistive Valve (TMR), and Current Perpendicular to Plane Spin Valve (CPP SV). Scaling limits in those reader transducers will also be discussed.

4:00 PM I3.6
Avalanche Spin-valve Transistor. Kasey Joe Russell[1], Ian Appelbaum[1], Wei Yi[1], Douwe Monsma[1], Federico Capasso[1], Charles Marcus[1], Venkatesh Narayanamurti[1], Micah Hanson[2] and Arthur Gossard[2]; [1]Harvard University, Cambridge, Massachusetts; [2]Materials, University of California, Santa Barbara, California.

Despite their high magnetoresistance, spin-valve transistors have not seen much commercial development, partly as a result of their low collector current. Here, a spin-valve transistor with a GaAs/AlGaAs avalanche-multiplying collector is demonstrated, and greater than 1000% magnetocurrent variation is obtained at 35x multiplication. This indicates that the intrinsic amplification of the magnetic-field sensitive collector current should allow for fabrication of spin-valve transistors with high gain in a variety of materials. For devices limited by receiver sensitivity, this avalanche multiplication can increase the total signal-to-noise ratio of the system, increasing the commercial viability of the spin-valve transistor.

4:15 PM I3.7
A Novel Method for Fabrication of Magnetic Spin Valves. Shashi Paul, Alokik Kanwal and Manish Chhowalla; Ceramic & Materials Engineering, Rutgers University, Piscataway, New Jersey.

In the currently topical field of Spintronics, it is the spin of the electron, rather than the charge, that is invoked to characterize device behavior. There is active interest in the search for new materials in which charge carriers can be injected with preferential spin orientation that can be maintained in the material. Recently, the use of ?-conjugate organic semi-conductors [1,2] has been reported in this context. In both these reports the used material is Manganite, which is a ferromagnetic material with a 100% spin polarization. The polymer and Manganite, acting in concert, have been observed to enhance the magnetoresistance by 30% to 40%. A model explaining the use of polymer as a spacer layer has been proposed by Xie et. al [3]. In this work, it is suggested that by adjusting the relative chemical potential of the contact between the magnetic material and the polymer, spin polarized electrons can be transferred into the polymer from the magnetic layer through the interfacial coupling. These electrons can retain the initial spin orientation up to a certain length in the polymer. Encouraged by such reports, we attempt to observe an increase in the magnetoresistance in a Chromium Dioxide system, using a novel procedure. Chromium Dioxide is ferromagnetic in nature and has already been extensively used in the recording

applications. In this work, we prepare a blend of poly-vinyl-phenol (PVP) and CrO_2 particles to use as a spin valve; the size of the CrO_2 particles is around 1μm. A thick film of a PVP and the CrO_2 blend is prepared by drop casting on Aluminum covered glass. The top contact was made by evaporating the Al through a shadow mask. Magnetoresistance data shows a significant increase in the resistance. We have investigated a wide range of the composition parameters of the PVP and CrO_2 blend to improve the magnetoresistance properties of our spin valve devices. 1. V Dediu, M. Murgia, F.C. Matacotta, C. Taliani, S. Barbanera, Solid State Communications, 181, 122 (2002) . 2. Z.H. Xiaong, Di Wu, Z. Valy Vardney, and Jing Shi, Nature, 821, 427 (2004) 3. S.J. Xie, K.H. Ahn, D.L. Smith, A.R. Bishop, and A. Saxena, Phys. Rev. B, 125202, 67 (2003)

4:30 PM I3.8 TRANSFERRED TO I3.4

SESSION I4: Poster Session
Chairs: Randy Cheng and Kornelius Nielsch
Monday Evening, November 29, 2004
8:00 PM
Exhibition Hall D (Hynes)

I4.1
Effective Magnetoviscosity of Ferrofluids Planar-Couette Flow. Xiaowei He and Markus Zahn; EECS, MIT, Cambridge, Massachusetts.

Ferrofluids are suspensions of permanently magnetized colloidal particles immersed in a suitably chosen carrier fluid. Ferrofluids are of increasing interest in the design of magneto-responsive colloidal extractants, micro fluidic pumps and actuators driven by alternating or rotating magnetic fields, and in biological applications such as drug delivery vectors, magnetic cell sorting schemes, and magnetocytolysis treatment of localized tumors. These new ferrofluid applications involve ferrohydrodynamic properties of ferrofluids. Ferrofluid spin velocity, shear stress, and magnetoviscosity are calculated for a planar- Couette ferrofluid flow, with applied uniform DC magnetic fields parallel and transverse to the duct axis using Shliomis' first magnetization relaxation equation, generally valid for low magnetic fields. For simplicity, we take the ferrofluid to be linearly magnetizable with constant magnetic susceptibility . With the assumption of incompressible flow and the symmetry of the geometry, the solution for the axial flow is a linear function of position within the channel while the spin velocity is spatially constant, where both the spin velocity and the change in viscosity, , due to the magnetic field obey a 5th order algebraic torque equation. This analysis describes the conditions for multi-value effective magnetoviscosity and spin velocity.

I4.2
Permanently Linked Rigid Superparamagnetic Chains. Harpreet Singh[1], T. Alan Hatton[1] and Paul E. Laibinis[2]; [1]Chemical Engg., Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Department of Chemical Engg., Rice University, Houston, Texas.

Magnetorheological (MR) fluids are suspensions of paramagnetic colloidal particles that self-assemble to form chains under the application of an external magnetic field. This aggregation is reversible and, owing to Brownian motion, the colloidal particles return to their freely dispersed state once the magnetic field is removed. Such chaining of MR fluids in the presence of an external magnetic field has a significant effect on the fluid rheology, including inducing a finite yield stress. Permanently linked chains of these polarizable particles have several interesting potential applications since their suspensions have a dynamic structure both in the presence and absence of a magnetic field. Sol-gel chemistry is used to bond superparamagnetic beads aligned in a microchannel of a fixed height to form rigid chains of defined length and diameter. These superparamagnetic beads were prepared by adsorbing magnetic nanoparticles on the surface of the polystyrene beads modified by the layer-by-layer technique. The dynamic response of these chains to an external applied magnetic field was also modeled.

I4.3
Structural and magnetic properties of $Al_2O_3/Ni_{81}Fe_{19}$ thin films: From superparamagnetic nanoparticles to ferromagnetic multilayers. Inna L. Soroka[1], Bjorgvin Hjorvarsson[1], Victor Stanciu[2], Per Nordblad[2] and Jun Lu[2]; [1]Physics, Uppsala University, Uppsala, Sweden; [2]Material Science, Uppsala University, Uppsala, Sweden.

$[Al_2O_3(18\text{Å})/Ni_{81}Fe_{19}(8\text{-}30\text{Å})]_{10}$ films were deposited by dc and rf magnetron sputtering on thermally oxidized Si(001) substrates. It has been shown that by changing the thickness of NiFe layer it is possible to vary the magnetic and structural properties of the films from superparamagnetic nanoclusters in amorphous matrix to ferromagnetic multilayers with well-defined layered structures. The saturation magnetization is found to decrease with decreasing NiFe layer thickness indicating the presence of magnetically inactive layer at the interfaces. The thickness of this layer corresponds to 0.6 monolayer for the flat continues film and 2.1 monolayer for the film which consists of magnetic nanoclusters.

I4.4
Synthesis of Near-Monodisperse Iron Oxide Nanocrystals by Thermal Decomposition of Iron Carboxylate Salts. William W. Yu, Joshua C. Falkner, Cafer T. Yavuz and Vicki L. Colvin; Department of Chemistry, Rice University, Houston, Texas.

Iron oxide (magnetite) nanocrystals were synthesized in non-coordinating solvents by thermal decomposition of iron (III) carboxylate salts. This approach produces highly monodisperse materials (? = 5-15%) in sizes ranging from 6 to 30nm. The attractive features of this approach are that (a) large amounts of iron oxide nanocrystals were easily obtained by scaling up the starting materials, and (b) the continuously tunable size range covers the ideal sizes for magnetic separation/ferrofluids applications. The as-prepared iron oxide nanocrystals were very stable in both solution and solid state forms, and no particle aggregation was observed over a two month period. This method may become a general strategy for the synthesis of high quality metal oxide nanocrystals.

I4.5
Water-Dispersible FePt Nanoparticles Having ω-Mercapto-α-carboxylic Acid Ligands. David Eugene Nikles[1,2], Janis K. Mabry[1,2], Laura Beth Tackett[1], Hitesh G. Bagaria[1], Xiangcheng Sun[1], Earl T. Ada[1], Mohammad Shamsuzzoha[1], Kai Sun[3], Lu-min Wang[3] and Duane T. Johnson[1]; [1]Center for Materials for Information Technology, The University of Alabama, Tuscaloosa, Alabama; [2]Department of Chemistry, The University of Alabama, Tuscaloosa, Alabama; [3]Department of Nuclear Engineering and Radiological Sciences, The University of Michigan, Ann Arbor, Michigan.

FePt nanoparticles, 2nm in diameter, were prepared by the polyol reduction of platinum(II) acetylacetonate and iron(III) acetylacetonate in the presence of oleyl amine and oleic acid surfactants. The particles were dispersed in hexane and the dispersion added to a solution of 11-mercaptoundecanoic acid in cyclohexanone. As the 11-mercaptoundecanoic acid ligands replaced the oleic acid ligands, the particles precipitated. The particles could be dispersed in basic water, made basic either with sodium hydroxide or ammonium hydroxide. X-ray photoelectron spectra showed a peak near 164 eV, sulfur (2p) confirming the presence of the thiol ligand. Similarly, the oleic acid ligands were replaced with either 3-mercaptopropionic acid or 16-mercaptohexadecanoic acid to give FePt particles that could be dispersed in water. Dispersions made with FePt nanoparticles having 11-mercaptoundeacnoic acid ligands and ammonium counter ions were dried on TEM grids to give highly ordered films consisting of close-packed arrays of FePt nanoparticles. When the counter ion was sodium, the particles tended to aggregate, instead of forming ordered arrays.

I4.6
Synthesis and Characterization of Magnetic Spinel Core-Shell Nanoparticles. Ombretta Masala and Ram Seshadri; Materials, UCSB, Santa Barbara, California.

Metal ferrite nanoparticles show great interest because of their potential applications in technology, ranging from materials for recording media devices, magnetic targets for drug delivery and contrast-enhancement agents for magnetic resonance imaging. The creation of heterostructures in which metal ferrites alternate in a layer-type architecture offers the possibility of tuning their magnetic and electronic properties which make them desirable materials for such applications. In this work, we present the synthesis and characterization of core/shell $CoFe_2O_4$ /$ZnFe_2O_4$ nanoparticles. The spinel oxides $CoFe_2O_4$ and $ZnFe_2O_4$ are both ferrimagnets with the difference that $CoFe_2O_4$ is a hard ferrimagnet with high coercive fields and $ZnFe_2O_4$ is a soft ferrimagnet with no coercivity. It is interesting to study how such differences affect the magnetic properties of the resulting core/shell nanoparticles. The nanoparticles were synthesized through the high-temperature decomposition of the correspondent metal acetylacetonates in the presence of oleic acid and oleylamine as capping agents [1]. Characterization by XRD and TEM showed that the particles are highly crystalline and monodispersed. Their magnetic properties were measured with a SQUID instrument at different temperatures and magnetic fields. Magnetic measurements showed that the nanoparticles displayed a dramatic exchange biased-behavior resulting from the interaction of the magnetic spins at the interface between the soft and hard layers. Hysteresis data suggested that as the field is reversed after saturation, the spins of

$ZnFe_2O_4$ farthest away from the $CoFe_2O_4/ZnFe_2O_4$ interface reoriented first, while the spins of $ZnFe_2O_4$ closest to the interface remained pinned by the adjacent $CoFe_2O_4$ layer until the coercive field of the hard layer was finally reached. Thus, the soft magnet is the first to be demagnetized. This behavior has been previously observed in epitaxial thin ferrite films [2] and is reported here for the first time in soluble spinel nanoparticles. [1] S. Sun, H. Zeng, D. B. Robinson, S. Raoux, P. M. Rice, S. X. Wang and G. Li, *J.Am.Chem.Soc.*, 126 (2004) 273. [2] Y. Suzuki, *Annu.Rev.Mater.Res.*, 31 (2003) 265.

I4.7

Self-Assembly of Magnetic FePt and FePt(M) Nanoparticles. Xiangcheng Sun[1], David E. Nikles[2], Kai Sun[3] and Lumin Wang[3]; [1]Chemistry Depart., Rutgers, The State University of New Jersey, Piscataway, New Jersey; [2]Center for Materials for Information Technology (MINT), The University of Alabama, Tuscaloosa, Alabama; [3]Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, Michigan.

Controlled self-assembly of magnetic nanoparticles has stimulated great interest recently as it may offer a convenient tool for magnetic nanodevice fabrication [1, 2]. In this study, a series of FePt or FePt(M) nanoparticles has been synthesized by chemically polyol or superhydride reduction in the presence of stabilizers oleic acid and oleyl amine. The observed TEM grids samples were obtained by dropping dilute solutions of monodispersive FePt or FePt(M) nanopartclies onto carbon-coated copper TEM grids, and the solvent was allowed to evaporate at room temperature [3]. As-prepared particles have a chemically disordered face-centered cubic lattice with average diameter of 4-8 nm and are superparamagnetic. These magnetic particles were well dispersed in hydrocarbon solvents and self-assembled into particles arrays with a variety of close-packing arrangements. Larger domains of monolayer (2D), two layers and more than five layers of particles (3D) particles arrays were also revealed. The orientation of the lattice planes for the nearly spherical nanocrystals on the TEM grids was random. EDS profile also revealed non-uniform composition variations, which is in agreement with our earlier particle composition works. Actually, van der Waals forces, magnetic dipoles and steric repulsion among magnetic particles have been responsible for the 2-D or 3-D self-assembly process. It is crucial to prepare the controlled magnetic with uniform size and composition distributions. References [1] S. H. Sun et al., Science 287 (2000)1989. [2] H. Zeng et al., Nature, 420 (2002) 395. [3] X. C. Sun et al., J. Appl. Phys. 93 (2003) 7337.

I4.8

Optimization of Fe/Co Nano-Particles Composite for RF Application. Philippe Renaud[1], Celine Desvaux[1], Peter Fejes[2], Catherine Amiens[3] and Bruno Chaudret[3]; [1]TSO, Freescale Semiconductor, Toulouse, France; [2]TSO, Freescale Semiconductor, Tempe, Arizona; [3]LCC, CNRS, Toulouse, France.

Recent progress on iron and iron-cobalt nanoparticle synthesis led to dramatic improvement of the structural and organizational properties and their implication in magneto-static and AC characteristic. In this paper, we report results on Fe/Co nanoparticles synthesized using organometallic precursors, where optimized process conditions led to elemental redistribution within particles and 3D organization into densely packed supercrystals. Microscopic observations were carried out thanks to a SEM-FEG down to few nanometers resolution to evidence 2D-3D organization. Structural characterizations were carried out using HRTEM, EELS, EDX, with spectral imaging to investigate elemental distributions within the particles and inter particles medium. Static magnetic properties were performed using SQUID magnetometer and AC permeabilities up to 18GHz were drawn using a HP8510 network analyzer. Chemical synthesis of monodispersed 15nm FeCo nanoparticles results from the mixed decomposition of Co(h3-C8H13)(h4-C8H12) and Fe(CO)5 under 3 bar H2 in toluene at 150C in the presence of a mixture of oleic acid and hexadecylamine. Observation by HRTEM reveals that the as synthesized particles appear to have a core-shell configuration, with iron located in the core and cobalt in the shell. The nanoparticles are almost amorphous, with only occasional signs of crystallinity. Very little trace of oxidation can be detected at particles edges. A subsequent annealing process under inert atmosphere for 30 minutes at 500C induces a redistribution of the elements within the particles, with no impact on the particles shape, size and organization. Even if the particles are packed in very dense clusters, no coalescence is detected; moreover, ligand carbonation leads to the formation of a carbon coating resulting in a perfect surface passivation and a 91% metal weight fraction. Hence the measured saturation magnetization of 2.23T corresponding to 91% of that of Bulk FeCo remains unchanged after a long period of air-exposure. To preserve the dielectric nature of the composite, a controlled particle surface oxidation was carried out in-situ right after the decomposition reaction by injecting a small amount of dioxygen into the reaction bottle; thus avoiding particle-to-particle electrical conduction due the carbon shell. RF characterization of the final product shows that the material exhibits a ferromagnetic resonance between 5GHz en 11GHz depending on sample preparation and composition.

I4.9

Preparation and Magnetic Properties of Hollow Nano-Spheres of Cobalt and Cobalt Oxide. Hirofumi Yoshikawa[1], Kenta Hayashida[1], Yasuharu Kozuka[1], Asami Horiguchi[1], Kunio Awaga[1], Shunji Bandow[2] and Sumio Iijima[2]; [1]Department of Chemistry, Graduate school of Science, Nagoya University, Nagoya, Japan; [2]Department of Materials Science and Engineering, Meijo University, Nagoya, Japan.

The study of nano-scale morphology is especially interesting in the case of magnetic materials, because their properties are governed by their shape and texture. The preparation of magnetic hollow nano-spheres is a promising approach for developing new magnetic phenomena. In the present work, we prepared magnetic hollow nano-spheres of cobalt and cobalt oxide with diameter 500 nm and thickness 40 nm using polystyrene-bead templates, and carried out magnetic measurements on the obtained materials. To prepare the hollow spheres of cobalt and cobalt oxide, at first, the 600nm PS beads were coated with basic cobalt carbonate (1) by a controlled hydrolysis of urea. Hollow spheres of cobalt oxide (2) were prepared from 1 by calcination at 500 degree centigrade for 3 h in air, and, further, metallic cobalt hollow particles (3) were obtained from 2 by calcination at 500 degree centigrade for 4 h under a 1:1 mixed gas of H2 and N2. SEM and TEM images of 2 and 3 confirm that the spherical shapes were maintained even after calcinations and the inside is empty. The mean diameters of 1-3 were estimated to be 680, 500 and 500 nm with a thickness of 40 nm from the SEM images. The XRD patterns for 2 and 3 agreed well with those of Co3O4 and fcc-cobalt, respectively. Magnetizations of 2 were measured in an applied field of 50 Oe, heating from 2 K, after cooling in zero field (ZFC) or after cooling (FC) under 0.05, 0.1, 0.5, 1, 3, 5 and 50 kOe. The ZFC magnetizations shows a broad maximum at 30 K. This feature is consistent with the magnetic property of bulk Co3O4, which is an antiferromagnet with TN=30 K. Below this temperature, however, there is a drastic enhancement of the FC magnetization, suggesting the presence of spontaneous magnetization. Stronger the applied field upon cooling, larger the magnetization remained below TN. It is believe that the remnant magnetization below TN is due to imbalance between the magnetizations on different sublattices and the field-dependence is caused by spin readjustments within the walls of immobile antiferromagnetic domains. The magnetization curve for 3 at 2 K shows that the material is a very soft ferromagnet, like bulk fcc cobalt.

I4.10

PSS-encapsulated Fe3O4 nanoparticles prepared from a functional surfactant-mediated system. Haiso Yen Lee[2], Wang Leeyih[1] and Syang-Peng Rwei[2]; [1]Center for Condensed Matter Sciences, National Taiwan University, Taipei, Taiwan, Taipei, Taiwan; [2]Institute of Organic & Polymer Materials, National Taipei University of Technology, Taipei, Taiwan, Taipei, Taiwan.

The synthesis of polymer-encapsulated Fe3O4 nanoparticles was demonstrated. Fe3O4 particles were prepared from Fe(II) and Fe(III) salts in a 28% of ammonium hydroxide aqueous solution at a stirring rate of 3000 rpm at room temperature. These nanoparticles were then surface-capped with a series of surfactant-like molecules that contain a 2-bromoisobutyryloxy hydrophobic tail and a phosphonic acid group acting as the binding head for grafting metal oxide. In turn, the functional tails on the particle surface were utilized as multifunctional initiators for growing polystyrene chain via controlled free-radical polymerization techniques, followed by the sulfonation of benzene ring with acetyl sulfate. This synthetic method ensures that each core-shell particle contains only one magnetic particle and that the polymer shell evenly encapsulates the core. The thus-prepared materials were characterized by TEM, dynamic light scattering, UV-Vis, AFM and XRD methods.

I4.11

Nanoparticle Structure and Magnetic Correlations in Granular Cosputtered $Ag_{100-X}Fe_X$ Films Determined by Magnetotransport Measurements and AFM. Elena Olivetti[1], Paolo Allia[1], Federica Celegato[1], Marco Coisson[2], Paola Tiberto[2], Franco Vinai[2], Franco Ronconi[3] and Federico Spizzo[3]; [1]Physics, Politecnico di Torino and INFM, Torino, Italy; [2]Materials, IEN Galileo Ferraris and INFM, Torino, Italy; [3]University of Ferrara and INFM, Ferrara, Italy.

Granular films of composition $Ag_{100-x}Fe_x$ (x: 10, 14, 20, 26, 30) and nominal thickness 250 nm were prepared by dc plasma sputtering deposition in Ar atmosphere on Si substrates covered with naturally grown oxide. The in-plane film magnetization was measured between 4 K and 270 K using either a SQUID magnetometer (x = 10, 14, 20)

or an extraction magnetometer (x = 26, 30); maximum applied field: 50 kOe in both cases. The magnetoresistance was measured by the four-contact method. AFM images of the film surfaces were obtained at room temperature by a DI Nanoscope workstation. The films with $x \leq 14$ can be pictured as interacting superparamagnets [1], with Fe particle size of the order of 2 nm, while the films with $x \geq 26$ magnetize through coherent magnetic ordering of large regions, possibly composed of many correlated Fe particles. All films exhibit negative magnetoresistance (MR), whose intensity decreases monotonically with temperature. The MR displays no apparent saturation up to 50kOe. When plotted vs. reduced magnetization, the MR curves of the systems richer in Fe ($x \geq 26$) exhibit a box-like behavior distinctive of the proximity magnetoresistance proper of concentrated magnetic systems with competing interactions [2]. On the other hand, the systems richer in Ag ($x \leq 14$) display a nearly parabolic behavior, typical of almost uncorrelated moments. The ratio of the magnetic coherence length to the electron mean free path is obtained by applying a simple model [2]. Such a ratio turns out to be much larger than unity at all temperatures for $x \geq 26$ (indicating a frustrated ferromagnetic behavior with ultrashort magnetic coherence length), while is of the order of unity for $x \leq 14$ (indicating a nearly complete loss of correlation among single particle moments). The change from an interacting superparamagnetic behavior to a disordered ferromagnetic phase is described by the growth of the magnetic correlation length, and takes place gradually with increasing x. AFM observations point to a similar granular structure in all films, possibly induced by the preparing conditions with average particle size of 50 nm. Each of these large, smooth particles contains smaller Fe particles, evidenced by magnetic measurements, and embedded in the Ag matrix. [1] P. Allia et al., Phys. Rev. B64, 144420 (2001) [2] P.Allia et al., Phys. Rev. B67, 174412 (2003)

I4.12

Iron Oxide, Gallium Arsenide and Composite Nanoparticles.

Lingyan Wang, Jin Luo, Mathew M. Maye, Li Han, Jordan Peck, Jian Q. Wang and Chuan-Jian Zhong; Chemistry, SUNY-Binghamton, Binghamton.edu, New York.

Semiconducting and magnetic nanoparticles are attracting increasing interests for information storage, drug delivery, medical imaging, catalysis, and sensors. The ability to control the size and surface composition of such nanoparticles is particularly important for these applications. In this presentation, we will describe recent results of an investigation of the synthesis of gallium arsenide, iron oxide nanoparticles and their composite nanoparticles, which contains gold and other metals in core-shell type nanostructures. Superparamagnetic gama-Fe2O3 and Fe3O4 nanoparticles in 2-20 nm size range have been prepared. By controlling the reaction temperatures and manipulating the capping agent properties and solution compositions, the size, shape, composition, and monodispersity can be tailored. The nanoparticles are characterized by an array of techniques, including TEM, ED, DCP, XPS, XRD, FTIR, TGA, and SQUID techniques. The measured magnetic properties were fitted by a Langevin function approach in superparamagnetic region, and independently by fitting to Curie-Weiss law. The particle sizes calculated from magnetic measurements were in good agreement with TEM data. Preliminary results of the study of catalytic activities and sensory properties of the composite nanoparticles will also be discussed.

I4.13

Magneto-Transport Properties in Patterned Cobalt Wires.

Weilie Zhou, Chen Chen, Lesley J. Campbell, Volodymyr O. Golub, Andriy Ya Vovk and Leszek Malkinski; AMRI, University of New Orleans, New Orleans, Louisiana.

Single Cobalt zigzag wires with different width have been patterned by the e-beam lithography. The wires are connected with four gold electrodes. The gold electrodes with contact pads of 1 square millimeter are fabricated by photolithography. The electrical resistances versus magnetic field of the cobalt wires are measured by Physical Property Measurement System (PPMS) at temperatures 5K to 300K, at magnetic field orientation of 0, 45 and 90 degrees respect with the zigzag wire length direction. There are 2 peaks on the magneto-resistance curve corresponding to the magnetic field at 200 and -200 Oersted; and the peak positions chang at different orientations. The magneto-resistance behaviors are discussed based on domain wall properties.

I4.14

Single Crystal Calcium Hexaboride Nanowires: Synthesis and Characterization.

Terry Xu[1], Jian-Guo Zheng[2], Alan Nicholls[3], Sasha Stankovich[1], Richard Piner[1] and Rod Ruoff[1]; [1]Mechanical Engineering, Northwestern University, Evanston, Illinois; [2]NUANCE center, Northwestern University, Evanston, Illinois; [3]Research Resource Center, University of Illinois at Chicago, Chicago, Illinois.

Catalyst-assisted growth of single crystal calcium hexaboride (CaB6) nanowires was achieved by pyrolysis of diborane (B2H6) over calcium oxide (CaO) powder at 860-900 degree C and 155 mTorr in a quartz tube furnace. Nickel (Ni) and Platinum/Palladium (Pt/Pd) alloy are effective catalyst. TEM electron diffraction and Raman spectroscopy indicate that the nanowires are single crystal CaB6 and have a preferred [001] growth direction. Analysis of TEM/EDX/EELS data proves the nanowires consist of CaB6 cores and thin (1-2nm) amorphous oxide shell material. The CaB6 nanowires have diameter of 15-40 nm, and length of 1-10 um. Such CaB6 nanowires have potential applications in nanocomposites and nanoelectronics. Moreover, they can be used to investigate the currently controversial magnetic and electrical properties of CaB6, but on nanoscle samples. We appreciate the support of the National Science Foundation (grant EEC-0210120), and the Office of Naval Research grant (No. N000140210870).

I4.15

Highly Magnetic Nickel Nanostrands Fabrication of a new High Aspect Ratio Nanoparticle.

George Hansen[2], Matt Pettit[2] and Max D. Alexander[1]; [1]Polymer Branch, Air Force Research Laboratory, Dayton, Ohio; [2]Metal Matrix Composites, Heber City, Utah.

A new form of small diameter, high aspect ratio nickel, know as nickel nanostrands, has been created and evaluated. Theses nanostrands are strands of pure nickel, and can be controllably mass produced in sizes ranging from about 50nm in diameter by 5 microns long to a few microns in diameter by several 1000 microns long. These materials are readily processable in a variety of host resin systems, and can be easily aligned into patterns by controlling the magnetic field applied to the specimens during the processing. Here we will illustrate the various morphological and electrical properties of the nickel nanostrands obtained by different growth mechanisms and their utility in a variety of electronic applications.

I4.16

The Use of Hexagonal Mesoporous Silica Matrices for the Preparation of Controlled-Anisotropy Iron Nanowires.

Andrei Anatolievich Eliseev[1], Kirill Sergeevich Napolskii[1], Irina Valerievna Kolesnik[1], Alexey Viktorovich Lukashin[1], Yuri Dmitrievich Tretyakov[1], Peter Goernert[2], Natalia Anatolievna Grigorieva[3], Sergei Grigoriev[4,5] and Alexey Vorobiev[5,4]; [1]Department of Materials Science, Moscow State University, Moscow, Russian Federation; [2]INNOVENT e.V., Jena, Germany; [3]St-Petersburg State University, St-Petersburg, Russian Federation; [4]St-Petersburg Nuclear Physics Institute, Gatchina, St.Petersburg, Russian Federation; [5]Institute Laue-Langevin, Grenoble, France.

Modern information technologies require development of novel high-density data storage devices due to colossal growth of digital information volume. Today, no other technology can compete with magnetic information carriers in storage density and access rate. However, usually very small (10-1000 nm^3) magnetic nanoparticles shows para- or superparamagnetic properties, with very low blocking temperatures and no coercitivity at normal conditions. One possible solution of this problem is preparation of highly anisotropic nanostructures. From the other hand, the use of purely nanocrystalline systems is limited because of low stability and tendency to form aggregates. These problems could be solved by encapsulation of nanoparticles in an inert matrix. One of promising matrices for preparation of highly anisotropic magnetic nanoparticles is mesoporous silica. One can expect that the pore system of mesoporous silica is a perfect reactor for synthesis of nanocomposites due to the limitation of reaction zone by the pore walls. Here we suggest a novel variant of synthesis of ordered magnetic nanowires in the mesoporous silica matrix, based on the introduction of a hydrophobic metal compound, into the hydrophobic part of silica-surfactant composite. Hexagonal mesoporous matrices with different pore diameters (3-8 nm) were used for preparation of iron nanowires. Incorporation of metal ions was studied by chemical analysis TEM, ED, SAXS, SANS, BET and magnetic measurements. It was showed that particles shape and size are in good agreement with that of the pores. Particles are uniform and well ordered in the silica matrix. The anisotropy parameters of the magnetic wires were determined using two non-correlated methods: temperature dependence of magnetic susceptibility and small angle polarized neutron scattering. It was found that the particle length increases with the increasing of the thermal treatment temperature. Obviously it deals with crystallization and growth of metal particles inside the pores at constant diameter of single particle. It was found that the anisotropy factor of iron nanowires attain the value of 40. Such wires represent high coercive force up to 460 Oe (at 300K) and saturation magnetization of 3 emu/g, which is nearly enough for modern information storage. Besides the control over diameter of the pores enables us to define the anisotropy parameters of nanowires. Thus, our approach leads to functional materials with nanosized active elements in the matrices, which could find an application in various

fields of engineering and technology. This work is supported by RFBR (03-03-32182) and INTAS (01-204).

I4.17
Synthesis and Characterization of $BiFeO_3$ Nanotubes.
Tae-Jin Park[1], Yuanbing Mao[1] and Stanislaus S. Wong[1,2]; [1]Chemistry, SUNY at Stony Brook, Stony Brook, New York; [2]Materials and Chemical Sciences, Brookhaven National Laboratory, Upton, New York.

Polycrystalline bismuth ferrite ($BiFeO_3$) multiferroic nanotubes have been fabricated using a modified sol-gel technique. As-synthesized $BiFeO_3$ nanotubes generated from alumina membranes with 200 nm diameter pores as a template show smooth surface morphology with diameters in range of 240 nm to 300 nm and lengths ranging from several microns to even up to 50 μm. The aspect ratios of these $BiFeO_3$ nanotubes reach larger than 150 : 1. $BiFeO_3$ nanotubes obtained from a template having 100 nm diameter pores show relatively rough surface, diameters in range of 140 nm to 180 nm, and lengths of up to several microns. $BiFeO_3$ materials have been characterized by X-ray diffraction measurement (XRD), transmission electron microscopy (TEM), scanning electron microscopy (SEM), and high-resolution TEM (HRTEM) coupled with the energy dispersion X-ray spectroscopy (EDX) as well as the selected area electron diffraction measurement (SAED).

I4.18
Production and Characterization of Ferromagnetic Alloyed-Nanowires inside Carbon Nanotubes.
Ana Laura Elias A.[1], Julio A. Rodriguez Manzo[1], Adalberto Zamudio[1], Samuel Baltazar Rojas[1], Florentino Lopez Urias[1], Emilio Munoz Sandoval[1], Humberto Terrones[1], Mauricio Terrones[1,3], M. R. McCartney[2], David J. Smith[2], Dmitri Golberg[3], Chengchun Tang[3] and Yoshio Bando[3]; [1]Advanced Materials Department, IPICyT, San Luis Potosi, S.L.P., Mexico; [2]Department of Physics and Astronomy, Arizona State University, Tempe, Arizona; [3]International Center for Young Scientists, National Institute for Materials Science, Tsukuba, Ibaraki, Japan.

We describe the production of aligned multi-walled carbon nanotubes filled with Fe-Co alloys. The method involves the aerosol thermolysis of toluene-ferrocene-cobaltocene solutions at temperatures ranging from 650 to 800 °C in an inert atmosphere. The materials have been carefully characterized using state-of-the-art high-resolution transmission electron microscopy (HRTEM), energy electron loss spectroscopy (EELS), scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX), electron diffraction, HREELS-STM elemental mapping, X-ray powder diffraction and SQUID magnetometry. The results indicate that different stoichiometries of Fe_xCo_y alloys could be produced at different temperatures. We noted that the formation of FeCo alloys only occurs at relatively low pyrolytic temperatures (e.g. 650 - 750 °C). Above this temperature, segregation of Co and Fe domains start to occur. The alloy nanowires (5-30 nm OD; 1 micron long) are monocrystalline and always exhibit the FeCo (110) parallel to the carbon nanotube axis. The Fe_xCo_y nanomaterial has shown unusual ferromagnetism and large coercive fields at room temperature (e.g. 1500 Oe). We envisage that these aligned ferromagnetic nanowires could be used in the fabrication of high-density magnetic storage devices.

I4.19
Magnetic Nanostructures with GMR for the Detection of Movement of MEMS Microgears. Neamtu G. Jenica[1] and Marius Volmer[1]; [1]Micro&Nanostructured magnetic Materials, ICPE-CA, Advanced Research Institute for Electrical Engineering, Bucharest, Romania; [2]Physics, Transilvania University, Brasov, Romania.

Magnetic nanostructures with Giant Magneto-Resistance have higher sensitivity than AMR sensors to detect the magnetic field and field gradient. The movement of small devices, as microgears, processed with standard Integrated Circuit (IC) techniques can be sensed with GMR nanostructures, deposited onto IC system. We have deposited GMR nanostructures (FM/NM/FM) onto patterned MEMS structures. Here, FM denotes NiFe (Permalloy=Py), Co layers or combination using Py-Co layers. As NM we have deposited Cu or Al2O3 layers. In order to study the magnetic sensitivity we made GMR and Hall effect measurements for the Py/Cu/Py/FeMn, Py/Al2O3/Py/FeMn, Py/Co/Cu/Co/Py/FeMn and Py/Co/Al2O3/Co/Py/FeMn multilayer structures. When the magnetic field lies in the film plane the measured voltage is produced by the Planar Hall Effect (PHE) which, basically, is an Anisotropic Magnetoresistance Effect (AMR). In this work, PHE measurements were employed to evaluate the magnetization reversal processes and the coupling between the magnetic layers. Also, we made tunnel experiments on the structures with Al2O3 as NM layer. Because the conduction electrons in ferromagnetic metals are spin polarized, Julliere model for FM/I/FM tunneling structures predicts that the tunnel junction magnetoresistance is dependent on the relative orientation of the magnetization vectors in the adjacent magnetic layers separated by an insulator, I. The saturation fields obtained when the magnetic field is applied normal to the film plane are less than the values predicted from the shape anisotropy and give us information regarding the films roughness. Due to a very shape change of resistance with magnetic field obtained for a small area of the magnetic nanostructures are attractive candidates for use as movement microsensors.

I4.20
Synthesis of Magnetic Cu-Co Alloys through Metastable Liquid Phase Separation. Surasak Wannaparhun and Reza Abbaschian; Materials Science and Engineering, University of Florida, Gainesville, Florida.

The Cu-Co system has been widely investigated because it exhibits several promising multifunctional properties for structural, catalytical and magneto-electronic applications. Bulk supercooling of Cu-Co liquids could lead to metastable liquid phase separation (MLPS) resulting in dispersion of one liquid in another. In the present study, an electromagnetic levitation complimented with splat quenching apparatus was utilized for the synthesis of such alloys. It was found that rapid solidification immediately after the MLPS resulted in a homogeneously distributed sub-micron size spherical Co-droplets within a copper matrix. The hysteresis curves of magnetic Cu-Co alloys with various microstructures will also be discussed.

I4.21
Structure and Magnetic Properties of Shock Consolidated Bulk Exchange-Coupled Nanocomposite Hard Magnets.
Zhiqiang Jin[1,2], J. Ping Liu[2] and Naresh N. Thadhani[1]; [1]School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia; [2]Department of Physics, University of Texas at Arlington, Arlington, Texas.

Consolidation of powders using high-pressure shock waves is a potentially important method for the synthesis and processing of bulk nanocrystalline materials. In this work, hard magnetic $Pr_2Fe_{14}B/\alpha$-Fe bulk nanocomposites were produced by dynamic consolidation using various gas-gun and explosive loading approaches. The structural and magnetic properties of consolidated and post-shock heat-treated samples were investigated. Nearly fully dense compacts with solid-state interparticle bonding were obtained, with retention and even refinement of the nano-scale grain sizes of the soft and hard phases. Reduction in nanocrystalline grain size was observed to be caused by generation of shear bands during shock-compression which in addition to truncating pre-existing 25 nm size grains also contained 10 nm size grains. Optimal magnetic properties, similar to those of the starting materials, but higher than those of commercial bonded magnets, were obtained in the recovered bulk exchange-coupled nanocomposites. Post-shock heat treatments resulted in the improvement of coercive field, which is related directly to the dependence of effective anisotropy on the grain size. In this paper, the unique attributes of the shock-densification process in forming and retaining the nanocrystalline structure, and therefore leading to improved and optimized magnetic properties, via control of starting powder characteristics, shock consolidation conditions, and post-shock annealing treatments are described. This work was supported by US DoD/DARPA through ARO under grant No. DAAD19-03-1-0038.

I4.22
Size effect on the exchange-bias behavior in ferromagnetic La0.67Sr0.33MnO3 / SrRuO3 bilayers. Xianglin Ke[1], Land Belenky[1], Chang-Beom Eom[1], Mark Rzchowski[1], Dmitry Ruzmetov[2] and Venkat Chandrasekhar[2]; [1]University of Wisconsin, Madison, Wisconsin; [2]Northwestern University, Evanston, Illinois.

Epitaxial La0.67Sr0.33MnO3 (LSMO)/ SrRuO3 (SRO) ferromagnetic bilayer has been grown on SrTiO3 (STO) substrates by pulsed laser deposition with atomic layer control. By magnetization measurements, the exchange-bias behavior has been extensively studied when both LSMO and SRO are ferromagnetic. We have interpreted the exchange-bias behavior by the existence of an antiferromagnetic exchange coupling between the ferromagnetic LSMO layer and the ferromagnetic SRO layer[1,2]. Using metal as mask, by means of e-beam lithography and ion milling process, we have patterned the bilayers into sub-micro dots with different size. Size dependence of exchange-bias of ferromagnetic bilayers will be discussed. References: [1] X. Ke, M. S. Rzchowski, L. J. Belenky, C. B. Eom, to appear on June 28th in Appl. Phys. Lett. [2] X. Ke, M. S. Rzchowski, L. J. Belenky, C. B. Eom, to be submitted.

I4.23
Magnetic and Transport Properties of Nanocomposite $Fe/Fe_{3-\delta}O_4$ and $Fe_{3-\delta}O_4$ Films Prepared by Plasma Deposition. Jinbo Yang[1,2], S. K. Malik[4], Xiaodong Zhou[1], W. J.

James[1,3] and W. B. Yelon[1,3]; [1]Materials Research Center, University of Missouri-Rolla, Rolla, Missouri; [2]Department of Physics, University of Missouri-Rolla, Rolla, Missouri; [3]Department of Chemistry, University of Missouri-Rolla, Rolla, Missouri; [4]Tata Institute of Fundamental Research, Colaba, Mumbai, India.

Reflective, pinhole-free, Fe/Fe_3O_4 and $Fe_{3-\delta}O_4/Fe_2O_3$ nanocomposite films were obtained by reacting iron pentacarbonyl, $Fe(CO)_5$, in an inductively-coupled radio frequency (rf) glow discharge reactor. The conductivity of the $Fe_x/(Fe_3O_4)_{1-x}$ (x> 7%) composite film shows metal characteristics, and the conductivity decreases as the α-Fe content decreases. The metal to Insulator transition (MIT)temperature of the $Fe_x/(Fe_3O_4)_{1-x}$(x=0.07)) films shifts to a higher temperature as compared to $Fe_{3-\delta}O_4$, due to the increased conductivity from α-Fe. The magnetization versus temperature(M-T) curves show the Verwey transition temperature ranging from 95 to 136 K, and decreasing as the Fe/O ratio decreases. The $Fe_{3-\delta}O_4$ film has a negative magnetoresistance (MR) of about 4% and 8% at room temperature and 80 K, respectively.

I4.24
Magnetic and Transport Properties of Ferromagnetic-PEEK Polymer Nanocomposite Prepared via Ion-implantation. Kartik C. Ghosh[1], T. Kehl[1], T. Kassim[1], S. Mishra[2], R. Patel[1], M. Curry[1] and R. E. Giedd[1]; [1]Physics, Astronomy and Materials Science, Southwest Missouri State University, Springfield, Missouri; [2]Physics, University of Memphis, Memphis, Tennessee.

Recently, research interest in the field of nanocomposite materials is growing rapidly due to their size-dependent interesting electronic, magnetic, and optical properties that have many potential applications. Ion implantation is a versatile technique that can create nanocomposite materials. Currently, we have prepared magnetic (Ni, Fe and Ni-Fe perm alloys)-PEEK polymer nanocomposite thin films using ion-implantation. The films were prepared via bombarding nitrogen ions on a polymer poly ether ether ketone (PEEK) sheet pre-deposited with different thickness of magnetic thin film. The microstructure of nanoparticles was studied by scanning electron microscope, transmission electron microscope, and magnetic force microscopy. The structural evaluation of the composite via TEM suggests the presence of very fine nanoparticles in the rage of 10-20 nm embedded in polymer matrix. The particle size depends on the ion dose and the thickness of the pre-deposited magnetic thin films. Characterizations such as electrical conductivity, magneto-transport and Hall magnetometery have been performed on the samples. Room temperature magneto-transport measurement indicates negative magnetoresistance at low magnetic field. Thus, magnetotransport properties suggest presence of spin-dependent tunneling between magnetic nanoparticles. Hall magnetometery shows that as the particle size decreases the behavior of the sample changes from ferromagnetic to superparamagnetic. In this presentation many of unique electrical and magnetic properties of magnetic nanocomposite thin films produced by ion implantation will be discussed in detail.

I4.25
Ferromagnetism in Fe-doped β-Ga_2O_3 Prepared by a Solid State Reaction. Hajime Hojo, Koji Fujita, Katsuhisa Tanaka and Kazuyuki Hirao; Material Chemistry, Kyoto University, Kyoto, Japan.

Since magnetic semiconductors with Curie temperature (T_c) above room temperature are greatly demanding for the development of spintronic devices, diluted magnetic semiconductors (DMS/s) and wide-band gap semiconductors have attracted many research groups. Great interest has recently stemmed due to high temperature ferromagnetism in oxide such as ZnO with Co or Mn doping, TiO_2 with Co and SnO_2 with Mn or Fe. Equally important is the fundamental issue of the origin and the nature of ferromagnetism in these low carrier density systems. While carrier-induced interaction between the magnetic ions is suggested as the important factor of ferromagnetism in DMS/s, the precise mechanism is still controversial and is being actively debated in their papers. β-Ga_2O_3 is intrinsically an insulator with a band gap of 4.8eV. It becomes an n-type semiconductor when Sn^{4+} or oxygen defects are introduced. Great advantage is expected if one could achieve ferromagnetic DMS based on this conducting wide-band gap oxide, but there has been no report of its use as the host semiconductor for DMS, to our knowledge. In this study, we have fabricated Fe-doped β-Ga_2O_3, $(Ga_{1-x}Fe_x)_2O_3$, by a solid-state reaction. The behavior of ferromagnetic ordering was observed at room temperature in the samples sintered at low temperatures below 900°C using Ga_2O_3 powder and iron nitrate, $Fe(NO_3)_3{\cdot}9H_2O$, as the starting materials, while the sintering above 900°C led to the paramagnetic behavior. Magnetization as a function of temperature showed spin-glass-like behavior, meaning that long-range ferromagnetic ordering does not exist. When the sample was sintered at 500°C, the single phase of β-Ga_2O_3 was obtained up to x=0.08 with no trace of secondary phase or other impurity according to X-ray diffraction measurements. For the samples with x>0.08, α-Fe_2O_3 (hematite) phase appeared, which is known to show canted spin magnetism. The hematite phase seems to have nothing to do with the magnetic behavior of this system because the magnetization per total iron atom was decreased when the hematite phase was present. On the other hand, starting with Fe_2O_3 powder as iron source, α-Fe_2O_3 phase in addition to β-Ga_2O_3 phase was precipitated when the low-temperature sintering was performed. The result indicates that the sintering at low temperatures using iron nitrate as the starting materials is crucial in realizing the ferromagnetic behavior in Fe-doped β-Ga_2O_3. The reason for spin ordering in this system is now unclear. It is, however, expected that this finding will help to elucidate the underlying mechanism for room-temperature ferromagnetism in the DMS/s as in the recent report by Coey and coworkers, in which ferromagnetic coupling of ferric ions via an electron trapped in a bridging F center is proposed to explain the high Curie temperature. New mechanism of inducing ferromagnetism may be developed through this study.

I4.26
Effects of Defects on the Electrical and Magnetic Properties of $Ga_{1-x}Mn_xAs$ Layer. Dongwan Koh[1,4], Jin-Bum Park[1], Young Ju Park[1], Jeoung Il Lee[1], Chanjin Park[2], Hoonyoung Cho[2], Young Mi Kim[3], Il-Woo Park[3] and Kwan Soo Chung[4]; [1]Nano Device Research Center, Korea institute of Science and Technology, Seoul, South Korea; [2]Dep. of Physics, Dongguk University, Seoul, South Korea; [3]Seoul Branch, Korea Basic Science Institute, Korea University, Seoul, South Korea; [4]Dep. of Electronic Engineering, Kyung Hee University, Young-In, South Korea.

We investigated the effects of V/III flux ratios on the Curie temperature, T_C, in $Ga_{1-x}Mn_xAs$ layers with various Mn mole fractions of x = 0.03 and 0.07. GaMnAs epilayer was grown on semi-insulating GaAs (001) substrates using molecular beam epitaxy (MBE) method. A 70 nm thick GaMnAs layer was grown at the temperature of 250 °C with various V/III flux ratios of 25 34. The structural, optical and magnetic properties of GaMnAs epilayer were evaluated by double crystal X-ray diffraction, Hall measurement, photoluminescence measurement, superconducting quantum interference device magnetometer and deep level transient spectroscopy (DLTS). The changes of T_C are observed by varying V/III flux ratio with a fixed Mn mole fraction. The T_C in the sample grown with a lower V/III flux ratio of 25 is found to be higher comparing to that with higher V/III flux ratio of 34 at a fixed high Mn concentration (x = 0.05). Although the Mn concentration increases, the T_C is not much changed when the V/III flux ratio is high of 34. The changes of T_C with various V/III flux ratios are explained by the existence of low temperature grown defects, which are clarified by the deep level transient spectroscopy measurement. The prime species of defects are found to be As_{Ga} and Mn_I etc.

I4.27 TRANSFERRRED TO I8.4

I4.28
Nanomagnetic Structures in (Ga,Cr)As. Abdellah Dakhama, Phillip Crider, Nathan E. Israeloff and Don Heiman; Physics, Northeastern University, Boston, Massachusetts.

Alloys of GaAs with chromium have been shown to form nanomagnetic structures,[1] in addition to having high Curie temperatures. (Ga,Cr)As grown by MBE exhibits unusual magnetic, transport and structural properties. At low temperatures the magnetization increases rapidly with increasing field due to the alignment of ferromagnetic units (nanomagnets or polarons) having large dipole moments of order 10-100 Bohr magnetons. A standard model of superparamagnetism is inadequate for describing both the field and temperature dependence of the magnetization M(B,T). In order to explain M(B) at low temperatures we employ a *distributedmagneticmoment* (DMM) model in which cooperating ions are grouped in clusters having a distribution of moments. The magnitude of the magnetic moments indicates an average dimension of 3 nm. STM images also show structures of similar size which are aligned in rows. The resistivity increases rapidly for decreasing temperature below room temperature, and becomes strongly insulating at low temperatures. The conductivity follows $exp[-1/T^{1/2}]$ over a range of conductivity of eight orders of magnitude, characteristic of tunneling between nanomagnetic structures. Supported by NSF Grant DMR-0305360. [1] A. Dakhama, B. Lakshmi, and D. Heiman, Phys. Rev. B **67**, 115204 (2003).

I4.29
TEM studies of Magnetically Phase Separated $La_{1-x}Sr_xCoO_3$. Ryan S. Thompson, Chris Leighton, Jing Wu and C. Barry Carter; Dept. of Chem. Eng. & Mat. Sci., University of Minnesota, Minneapolis, Minnesota.

The doped perovskite Cobaltites display a very clear form of magnetic phase separation where nanoscale ferromagnetic clusters form in a

hole-poor non-ferromagnetic matrix. This magnetic phase separation is a general phenomenon that plays a key role in the understanding of colossal magnetoresistance in Manganites and high temperature superconductivity in Cuprates. We have studied the magnetic inhomogeneity in Cobaltites by conventional magnetometry, magnetotransport, Co NMR, and small angle neutron scattering, but the key open questions remains; is the magnetic inhomogeneity purely electronic or is it due to local variations in Sr content? In this work we have applied high-resolution transmission electron microscopy (with energy filtering) to address this key question.

I4.30
Magnetic Dissipation of Single Submicron Magnets Characterized by Cantilever Magnetometry. Tse Nga Ng, Neil Jenkins and John Marohn; Chemistry and Chemical Biology, Cornell University, Ithaca, New York.

Recent work in magnetic resonance force microscopy (MRFM) suggests that magnetic fluctuations in a microcantilever's tip could be a potent source of deleterious sample spin relaxation. We have measured thermomagnetic fluctuations in submicron nickel magnets using ultrasensitive cantilever frequency shift magnetometry and have compared the effect of magnet material, shape, and temperature on fluctuations. Magnets with high aspect ratio of length to width (l/w > 10) had smaller dissipation at 77K than at 4.2K. Surprisingly, applying the static magnetic field along the short axis of oblong magnets (l/w > 2.5) showed decreasing dissipation as magnetic field is increased. Compared to cobalt magnets of similar size (Stipe et al. Phys. Rev. Lett.86 2874 (2001)), our nickel magnets showed 20 × less dissipation and we conclude that they will be suitable for use in MRFM on nuclear spins.

I4.31
Modification of Magnetic Properties of FeCo Thin Films by Rare Earth Ion Implantation. Alfred Ludwig[2], Helmut Karl[1] and Bernd Stritzker[1]; [1]Institut fuer Physik, Univ. Augsburg, D-86135 Augsburg, Germany; [2]CAESAR, D-53175 Bonn, Germany.

The modification of magnetic properties induced by high dose Sm ion implantion into magnetron-sputtered $Fe_{50}Co_{50}$ thin films on Silicon substrates has been investigated. For this, a combinatorial materials synthesis approach was applied in order to screen a wide range of implantation doses and thin film thicknesses (60 - 100 nm). The magnetic properties of FeCo are altered by introduction of a nanoscopic inhomogeneous concentration distribution of Sm perpendicular to the thin film surface. Subsequent annealing could lead to the formation of nanomagnetic structures like embedded Fe-Sm-Co precipitations. The magnetic hysteresis loops of samples from materials libraries on 4inch silicon wafers implanted with Sm stripes of doses ranging from $4x10^{15}$ cm^{-2} up to $1.6x10^{17}cm^{-2}$, i.e. nearly two orders of magnitude, were measured by VSM (Vibrating Sample Magnetometer) at room temperature after different annealing treatments. The coercitivity shows strong dependence on the Sm dose with local maxima and in-plane anisotropy. In addition the sheet resistance was screened, revealing a continuous increase with implantation dose. The relevant samples were characterized by XRD, Rutherford Backscattering Spectroscopy and dynamic Secondary Ion Mass Spectrometry depth profiles. The structural properties will be correlated to the magnetic properties and electrical resistivity.

I4.32
Magnetic Phase Boundaries in Ferromagnetic Nanostructures. Scott Whittenburg[1,2] and Patrick Nichols[1,2]; [1]Chemistry Dept., University of New Orleans, New Orleans, Louisiana; [2]Advanced Materials Research Institute, University of New Orleans, New Orleans, Louisiana.

The magnetic phase for single domain ferromagnetic nanostructures is known to be dependent on geometrical factors. In this work, the most stable magnetic phase is determined for several geometries (rhombohedra, squares, triangles, and circular dots) using numerical micromagnetic methods. In particular, the boundary between phases for each of these shapes is found as a function of the thickness and aspect ratios. The primary focus will be on Co and permalloy nanostructures.

I4.33
Probing Magnetization Reversal in Novel Magnetic Nanostructured Materials. Cosmin Radu[1], Andrew Dugue[2], Juliano Denardin[2] and Leonard Spinu[1]; [1]Department of Physics and Advanced Materials Research Institute (AMRI), University of New Orleans, New Orleans, Louisiana; [2]AMRI, University of New Orleans, New Orleans, Louisiana.

Magnetization dynamics is one of the key issues of magnetic materials that are part of new data storage devices. For two-dimensional (2D) devices used in magnetic random access memories (MRAM), the magnetization dynamics is determined by the 2D magnetization switching properties as the MRAM cells require that the magnetic field be applied in two dimensions in the plane of the device. Therefore, it is important to study the response of such magnetic systems to fields applied along different directions with respect to easy- and hard-axes. Moreover, study of two-dimensional magnetic switching enables us to determine the critical curve which constitutes the fingerprint of the switching behavior and provides information about micromagnetic and structural properties of magnetic systems. A new sensitive method for critical curve determination of 2D magnetic systems was proposed. It was shown that this method, based on reversible susceptibility's singularities detection, is general and can be applied independent of the expression free energy describing the magnetic system under study. Moreover, the method we propose has the advantage that it does not require a special sample preparation as in the case of anisotropic magnetoresistance measurements where sample contacts are required. Experimentally, the method has been used to investigate the magnetization reversal of a wide range of systems that include magnetic nanostructured materials with different dimensionalities as nanoparticles arrays, thin films, and magnetic multilayers. It is found that depending on the morphology and structure of the magnetic system other mechanisms than coherent rotation govern the dynamics of their magnetization reversal. We gratefully acknowledge support from DARPA grant No. MDA972-02-1-0012

I4.34
In-Situ Magnetic Field Induced Structure and Properties of Epitaxial Spinel Ferrite Thin Films Prepared by Pulsed Laser Deposition (PLD) (Dynamic Aurora PLD Method). Naoki Wakiya[1], Toyokazu Nagamune[1], Takanori Kiguchi[2], Kazuo Shinozaki[1] and Nobuyasu Mizutani[1,2]; [1]Department of Metallurgy and Ceramics Science, Tokyo Institute of Technology, Tokyo, Japan; [2]Center for Advanced Materials Analysis, Tokyo Institute of Technology, Tokyo, Japan.

Pulsed laser deposition (PLD) is widely used for thin film preparation. In the literature, PLD in the magnetic field was reported by several authors[1,2]. In these reports, permanent magnets such as (Sm-Co alloy) were used to generate magnetic field during deposition. In the permanent magnet system, it is impossible to change the magnitude of magnetic field. It is also difficult to raise the substrate temperature during deposition since permanent magnets are heat-sensitive. Therefore, this system can be regarded as a kind of "Static Aurora PLD". To overcome these difficulties, we created a novel PLD system that a solenoid is installed between target and substrate. Using this system, up to around 440 G of magnetic field is obtained on the surface of substrate, and substrate temperature up to 800oC is realized. We named this system as "Dynamic Aurora PLD". (001)epitaxially grown ferrite films with spinel structure ((Ni,Zn)Fe2O4, CoFe2O4, and etc.) were prepared on SrTiO3(001) and (MgO-Al2O3)/CeO2/YSZ-buffered Si(001) substrate [3] using the Dynamic Aurora PLD apparatus. Magnetic field during deposition causes a shrinkage of plasma plume; therefore, deposition rate was increased with magnetic field. In addition, lowering of crystallization temperature, improvement of crystallinity, and increase of magnetization were observed with in-situ magnetic field. Detailed effect of in-situ magnetic field during deposition on the crystal structure, microstructure, and magnetic properties will be clarified. [1] T. Kobayashi, et al., Jpn. J. Appl. Phys., 39 (2000) 1817. [2] H. Agura, et al., Thin Solid Films, 445 (2003) 263. [3] N. Wakiya, et al., Jpn. J. Appl. Phys., 41 (2002) 7242.

I4.35
Nanostructure Control Made Dramatic Improvement in Characteristics of Magnetic Field of $REBa_2Cu_3O_y$ at 77 K. Miryala Muralidhar[1], Sakai Naomichi[1], Murakami Masato[1] and Koshizuka Naomi[2,1]; [1]Superconductivity Research Laboratory, ISTEC-SRL, Morioka, Iwate, Japan. [2]Superconducting Materials Laboratory, Shibaura Institute of Technology, Tokyo, Tokyo, Japan.

Melt processed high Tc superconductors have been developed for more than 10 years and are now close to a commercial employment. The future applications range from small lossless bearings or superconducting motors up to big magnets used in magnetic separation technology, medical diagnostic equipments, superconducting energy storage etc. For a problem-free function and a further extension of the application potential, effective pinning media are essential. This review reports on two new nanometer scale pinning media and the ways of their creation. Microstructure analysis by transmission electron microscopy (TEM) and scanning tunneling microscopy (STM) results are able to recognize the nanometer size pinning defects, to show their shapes and dispersion and help to identify the key structural features responsible for the improved superconducting performance. The two new pinning agents extend the use of $LREBa_2Cu_3O_y$ composites both towards high magnetic fields

and high temperatures.

SESSION I5: Magnetic Nanoparticles
Chairs: Kornelius Nielsch and Jean-Eric Wegrowe
Tuesday Morning, November 30, 2004
Independence W (Sheraton)

8:30 AM *I5.1
Fabrication of FePt/M (M=C, Ag) Nanoparticulate Thin Films With Perpendicular Magnetic Anisotropy. G. C. Hadjipanayis[1], J. Wan[1], Y. Zhang[1], Yunhe Huang[1] and Dieter Weller[2]; [1]Department of Physics, University of Delaware, Newark, Delaware; [2]Seagate Technology, Newark, Delaware.

Magnetic nanoparticles with perpendicular anisotropy are attractive for application in high-density recording media. For these applications, it is highly desirable to have particles with a size below 8 nm, a uniform size distribution, and a reduced ordering temperature to avoid unwanted particle agglomeration upon the required heat treatment to obtain the fct structure. In this work, FePt nanoparticles embedded in non-magnetic matrices M (M=C, Ag) have been fabricated by sputtering FePt and M multilayered thin films onto single crystal MgO [100] substrates at elevated temperatures up to 650°C. The transformation from the disordered fcc to the ordered L10 phase in FePt nanoparticles was observed at temperatures as low as 300°C. Besides the reduced transformation temperature, the deposited material showed an improved [001] texture for FePt/Ag thin films as compared to FePt/C due to a matching lattice parameter between Ag and FePt. As the deposition temperature increases, the degree of atomic ordering approaches that of the fully ordered phase as indicated by the shift in the [002] XRD peak. The magnetic and microstructural properties can be easily tailored by varying the thickness of sputtered FePt film with a maximum coercivity of 33 kOe obtained when the FePt layer thickness is around 4 nm in FePt/C. TEM images showed that isolated particles with smaller average particle size (down to a few nanometers) were formed when the thickness of sputtered film is less than 4 nm. However, with a further increase of thickness of sputtered FePt film, a continuous layer of FePt particles was observed and the coercivity decreased rapidly due to domain wall motion mechanism. Work supported by NSF DMR-0302544 and Seagate Technology.

9:00 AM I5.2
C-Axis Oriented L10-FePt Magnetic Nanoparticles Formed by Coupling Local-Epitaxy with Non-Epitaxy. Suguru Noda, Yoshiko Tsuji, Akira Sugiyama, Fumio Okada and Hiroshi Komiyama; Department of Chemical System Engineering, The University of Tokyo, Tokyo, Tokyo, Japan.

FePt is a promising candidate for high density perpendicular magnetic recording [1]. To be practically used, FePt should have chemically ordered L10 structure, c-axis orientation, a-few-nanometer particle size, inter-particle spacing, and inch-scale homogeneity. Various fabrication methods have been proposed and examined including epitaxial growth on monocrystalline MgO substrates [2], vapor-deposition on polycrystalline MgO seed layers [3], isolation of nanoparticles within matrices [4], and self-assembly of chemically synthesized colloidal nanoparticles [5]. However, these methods lack a concept to satisfy those structural requirements simultaneously. In this work, we propose a new concept, "local epitaxy on non-epitaxial films", satisfying all of those requirements. Non-epitaxial, polycrystalline films having preferred orientation not in in-plane but in out-of-plane directions are used as template. Disorder in in-plane orientation of template expectedly yields single FePt nanoparticles on single template grains whereas order in out-of-plane orientation of templates expectedly yields out-of-plane oriented FePt nanoparticles. Rock-salt crystals tend to have (100) out-of-plane orientation to minimize surface energy, which plane have the same symmetry as that of (001) plane of face-centered-tetragonal (fct) FePt. TiN was firstly introduced as template, and c-axis oriented fct-FePt nanoparticles were successfully formed by magnetron sputtering. Cross-sectional transmission electron microscopy (TEM) confirmed that single FePt nanoparticles were on single template TiN grains, which were locally epitaxial with each other. Super-conducting quantum inference device (SQUID) showed that the FePt nanoparticles had out-of-plane coercivity of 6.2 kOe. This approach opens a new route to form nanoparticles on arbitrary substrates with good structural controllability. [1] D. Weller, A. Moser, L. Folks, M. E. Best, W. Lee, M. F. Toney, M. Schwickert, J.-U. Thiele and M. F. Doerner, IEEE Trans. Magn. 36, 10 (2000). [2] T. Shima, K. Takanashi, Y. K. Takahashi and K. Hono, Appl. Phys. Lett. 81, 1050 (2002). [3] Z. G. Zhang, K. Kang and T. Suzuki, Appl. Phys. Lett. 83, 1689 (2003). [4] J. A. Christodoulides, Y. Huang, Y. Zhang, G. C. Hadjipanayis, I. Panagiotopoulos and D. Niarchos, J. Appl. Phys. 87, 6938 (2000). [5] S. Sun, Ch. Murray, D. Weller, L. Folks and A. Moser, Science 287, 1989 (2000).

9:15 AM I5.3
Spontaneous embedment and self-organization of metallic nanoparticles in phospholipid multilayers.
Bernd F. Rellinghaus[1], Annegret Terheiden[2], Christian Mayer[2], Olga Dmitrieva[3] and Mehmet Acet[3]; [1]Institute for Metallic Materials, Dept. Metastable and Nanostructured Materials, IFW Dresden, Dresden, Germany; [2]Phyiscal Chemistry, University Duisburg-Essen, Duisburg, Germany; [3]Experimental Physics, AG Farle, University Duisburg-Essen, Duisburg, Germany.

Recently, we have shown that the deposition of gas-phase prepared metallic nanoparticles onto multilayers of phospholipid molecules leads to the formation of two-dimensional positional order of the particles. This arrangement of particles into ordered patches of local hexagonal symmetry is due to the self-organized coating from the lipid reservoir film [1,2]. In general, this approach has the opportunity of combining the advantages of gas phase based and colloidal chemistry based preparation techniques, since it allows for both the thermal treatment of the nanoparticles prior to their deposition and the supply of an organic ligand shell around the particle core, which is mandatory to provide a sufficiently large lateral mobility on the substrate. In the present contribution, we report on the effect of different phase states of the lipid multilayer and post-treatments on the quality of the particle arrangements. For this, monodisperse, superparamagnetic FePt nanoparticles from the gas phase were deposited onto multilayers of phospholipids in the liquid crystalline, the intermediate, and the gel phase supported by silicon substrates. After the particle deposition, the samples were subjected to different moderate thermal treatments: (a) 2 hours at T = 35°C under different moisture conditions, (b) irradiation with UV light and subsequent storage at T = 35°C under different moisture conditions. The results were studied by atomic force microscopy (AFM) and scanning electron microscopy (SEM). AFM images reveal an increasing degree of lateral mobility and embedding of the particles in the lipid multilayer going from the gel phase to the liquid crystalline phase. At the same time, SEM data show the increase of inter-particle distances consistent with the formation of a lipid double layer between the particles. The thermal post-treatment leads to a thinning of the separating layer, probably formed by phospholipid molecules with interdigitating aliphatic chains, accompanied by the formation of a self-organized hexagonal lattice. An alternative route to self-organization could be induced by repulsive forces between adjacent particles: latest results show that the application of a homogeneous magnetic field perpendicular to the layer may lead to particle arrangement under preservation of the full double layer. This effect is attributed to the dipolar repulsion of neighbouring particles with parallel alignment of their magnetic moments as enforced by virtue of the external field. The effect of varying both the polar head groups and the aliphatic chains of the phospholipids is discussed. The work is supported by the Deutsche Forschungsgemeinschaft within SFB 445. [1] A. Terheiden, Ch. Mayer, K. Moh, B. Stahlmecke, S. Stappert, M. Acet, and B. Rellinghaus, Appl. Phys. Lett. 84 (2004) 3891. [2] A. Terheiden, B. Rellinghaus, S. Stappert, M. Acet, and Ch. Mayer, J. Chem. Phys. 121 (2004), 510.

9:30 AM I5.4
Ternary Alloy Nanoparticles of FePt and the Influence of the Third Element on the Ability of the Particles to Transform to the $L1_0$ Phase. David Eugene Nikles[1,2], Zhiyong Jia[1,3], Shishou Kang[1], Xiangcheng Sun[1] and J. W. Harrell[1,3]; [1]Center for Materials for Information Technology, The University of Alabama, Tuscaloosa, Alabama; [2]Department of Chemistry, The University of Alabama, Tuscaloosa, Alabama; [3]Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, Alabama.

Heating films of FePt nanoparticles to temperatures required for transformation from the as-prepared fcc phase to the ferromagnetic $L1_0$ phase also results in undesirable particle agglomeration and grain-growth. FCC FePtX ternary alloy nanoparticles, where X is Cu, Ag, or Au, where prepared by the diol reduction of platinum(II) acetylacetonate and a source of the third element (i.e. silver acetate), while thermally decomposing iron carbonyl. Heating self-assembled films of the particles transformed them to the $L1_0$ phase. For the case of FePtCu nanoparticles the Cu remained in the particles after heating, substituting for Fe and the resultant films had a mixture of fcc and $L1_0$ phases. There was no lowering of the temperature required for the phase transformation, relative to that required to transform FePt. When films containing Ag or Au were heated, the Ag or Au left the particles and the temperature required to transform the particles to the $L1_0$ phase was substantially lower. This suggests that the vacancies arising when the Ag or Au left the particles allowed the Fe and Pt atoms to moreve to their $L1_0$ lattice positions at lower temperature. However, careful examination of the x-ray diffraction curves showed considerable increase in crystallite size for the case of FePtAg and FePtAu, even at these lower temperatures, but less sintering for FePtCu nanoparticles. This suggests that additive Ag

and Au may also lower the temperature required for grain-growth.

9:45 AM I5.5
Synthesis of FePt/Fe3O4 and CoPt/CoFe2O4 Core-Shell Nanoparticles with Tunable Core Size and Shell Thickness. Min Chen[1,2], Shouheng Sun[1], J. Ping Liu[2], R. L. Sandstrom[1] and C. B. Murray[1]; [1]Nanomaterials and Devices, IBM Watson Research Center, Yorktown Heights, New York; [2]Department of Physics, University of Texas at Arlington, Arlington, Texas.

FePt and CoPt nanoparticles are a class of hard magnetic nanoparticles that are chemically stable. They have great potential for applications in ultrahigh density magnetic recording media, highly sensitive magnetic sensors and advanced nanocomposite permanent magnets. Synthesis of spherical 2-4 nm FePt nanoparticles has been well established, and elongated CoPt nanoparticles with a diameter of 2 nm and a length of 8 nm has recently been reported. However, the small size of the 2-4 nm in dimension of the both FePt and CoPt nanoparticles is close to the their critical size for superparamagnetism, leading to magnetic thermal instability of these particles. We report our improved one-step synthesis of FePt/Fe3O4 and CoPt/ CoFe2O4 core-shell nanoparticles with core tunable from 3 to 8 nm (in diameter), shell from 1 to 5 nm (in thickness). The synthesis also leads to controlled particle shape in either sphere or cube. The core/shell particles can be easily dispersed in hydrocarbon solvent, facilitating their self-assembly into nanoparticle superlattices. The phase ordering temperature of the particles from fcc to fct is found to decrease significantly for the larger sized particles, and the particles annealed under inert gas have a coercivity up to 1.7 Tesla. Annealing under inert atmosphere indicates that the presence of oxides shell nanoparticles retards the core particles sintering at high temperature (up to 650 degrees). Structure and magnetic properties at different annealing conditions will also be discussed.
Acknowledgement: Research is supported in part by DARPA/ARO under grant DAAD 19-03-1-0038.

10:30 AM *I5.6
Organometallic Approach to Magnetic Metal Nanoparticles of Controlled Shape and Organization. Bruno Chaudret, Laboratoire de Chimie de Coordination, CNRS, Toulouse, France.

The use of organometallic precursors allows the synthesis in mild conditions of metal nanoparticles displaying a controlled size, shape and surface environment. This method has been extended to the synthesis of bimetallic magnetic nanoparticles of controlled anisotropy. We have furthermore evidenced recently the ability of these particles to change their size or shape according to the properties of the surface ligands present. The lecture will focus on the synthesis of the particles and the demonstration of the presence and role of the different ligands in the chemistry of the particles. In a second step, the lecture will describe the physical properties of the particles and the role of Coordination Chemistry to orientate the growth of the particles to control their monodispersity and their shape (spheres, rods, cubes, wires). A special point will be devoted to the self-organization of the particles and to the formation of 2D super-lattices of nanorods and 3D super-lattices of nanospheres and nanocubes, a true crystallization process. Some applications in physics and microelectronics will finally be described. References : 1) F. Dumestre, B. Chaudret, C. Amiens, P. Renaud, P. Fejes Science, 2004, 303, 821. 2) K. Philippot, B. Chaudret Dendrimeres et Nanosciences (D. Astruc Ed), Compte-Rendus Acad Sciences 2003, 6, 1019. 3) K. Soulantica, A. Maisonnat, M.-C. Fromen M.-J. Casanove, B. Chaudret, Angew. Chem. (Int Ed) 2003, 42, 1945 4) F. Dumestre, B. Chaudret, C. Amiens, M. Respaud, P. Fejes, P. Renaud, P. Zurcher, Angew. Chem. (Int Ed) 2003, 42, 5213. 5) D. Zitoun, M. Respaud, M.-C. Fromen, M.-J. Casanove, P. Lecante, C. Amiens and B. Chaudret Phys. Rev. Lett., 2002, 89, 37203. 6) E. Snoeck, R. E. Dunin Borkowski, F. Dumestre, P. Renaud, C. Amiens, B. Chaudret, P. Zurcher App. Phys. Lett., 2003, 82, 88.

11:00 AM I5.7
Exchange Biasing and Magnetic Properties of Co, Co/CoO and CoO Colloidal Nanoparticles. Joseph B. Tracy, Dirk N. Weiss, Dmitry P. Dinega and Moungi G. Bawendi; Chemistry, MIT, Cambridge, Massachusetts.

Colloidal magnetic nanoparticles (NPs) have many applications in magnetic recording, separations and biochemistry. After partially oxidizing Co NPs, their magnetic thermal stability is enhanced through exchange biasing. Oxidized Co NPs have been used as a prototype for studying exchange biasing, but many previous studies were of limited usefulness because they used polydisperse or agglomerated NPs or had poor structural characterization. Our Co NPs are relatively monodisperse with a mean diameter of 10 nm and have been well-characterized using TEM and HRTEM. By choosing this system, we have investigated exchange biasing for finite-thickness antiferromagnets coupled to finite-thickness ferromagnets in a spherical geometry. We systematically studied the magnetic properties of pure Co, Co/CoO and pure CoO NPs through temperature- and field-dependent SQUID measurements. Co/CoO NPs have increased thermal stability and exhibit exchange fields of more than 3000 Oe. At temperatures below 50 K, the magnetization versus field curve is shifted along the magnetization axis due to pinned spins, and the exchange field is suppressed. This magnetization shift and the exchange field can be controlled independently of each other. The origin of these effects will be discussed.

11:15 AM I5.8
Magnetic Properties of Iron Nanoparticles of New Crystal Structure. Catherine Amiens[1], Olivier Margeat[1], Bruno Chaudret[1], Pierre Lecante[2] and Marc Respaud[3]; [1]LCC, CNRS, Toulouse, France; [2]CEMES, CNRS, Toulouse, France; [3]LNMO, INSA, Toulouse, France.

The synthesis of non oxidized iron nanoparticles of a few nanometers is very challenging given the high oxidability of this element and the very few precursors available. Fe(N(SiMe3)2)2 was recently demonstrated to cleanly produce alpha-iron nanoparticles of cubic shape when decomposed under dihydrogen in a solution of hexadecylamine and oleic acid.(1) These particles were in the size range 7-11nm and self-assembled into strongly magnetically coupled cubic super-crystals. Here we report that isolated iron nanoparticles with sizes below 3nm with a very narrow size distribution can also be synthesized from this amido complex. Independent nanoparticles have been obtained in an organic polymer matrix, namely poly(2,6-dimethyl-1,4-phenyleneoxide) via solution phase synthesis. The nanoparticles have been characterized by TEM, WAXS and Moessbauer spectroscopy and magnetic measurements on a SQuID magnetometer. WAXS measurements evidence a crystallographic structure different from the structures reported so far for iron. Octahedral sites are not present, which leads to a less dense structure resembling the e-phase or polytetrahedral arrangements described recently for cobalt.(2),(3) Moessbauer spectra and magnetic measurements show non oxidized iron nanoparticles. As expected for Fe nanoparticles with less than 500 atoms, the magnetization is enhanced as compare to pure bulk material, reaching the value of 2.58 (0.1) Bohr magneton per Fe atom for n around 200-250 atoms, close to those previously reported for gas phase clusters.(4) A large increase of the effective magnetic anisotropy has been evidenced, approximately 8 times the bulk value. The magnetic properties illustrate the major role played in Fe nanoparticles by the surface, which regulates both the magnetization and the anisotropy of the nanoparticles. (1) Dumestre, F.; Chaudret, B.; Amiens, C.; Renaud, P.; Fejes, P. Science 2004, 303, 821. (2) Dinega, D. P.; Bawendi, M. G. Angew. Chem. Int. Ed. 1999, 38, 1788. (3) Dassenoy, F.; Casanove, M. J.; Lecante, P.; Verelst, M.; Snoeck, E.; Mosset, A.; Ely, T. O.; Amiens, C.; Chaudret, B. J Chem Phys 2000, 112, 8137-8145. (4) Billas, I. M.; Chatelain, A.; Heer, W. A. d. Science 1994, 265, 1682-1684.

11:30 AM I5.9
Manipulation of Nickel Nanoparticles Deposited on HOPG. Massood Atashbar[1], Valery Bliznyuk[2], Deep Banerji[1] and Srikanth Singamaneni[1]; [1]Electrical and Computer Engineering, Western Michigan University, Kalamazoo, Michigan; [2]Material Science and Engineering Department, Western Michigan University, Kalamazoo, Michigan.

In this paper, we describe the deposition of nickel nanoparticles and nanowires on the surface of Highly Oriented Pyrolytic Graphite (HOPG). Freshly cleaved surface of HOPG is a very active surface with a number of broken chemical bonds promoting nucleation of the metal being deposited on top of it. These active sites for nucleation are V shaped grooves. HOPG was exposed to an aqueous plating solution of 1mM $Ni_2SO_4.6H_2O$ (Sigma Aldrich) and 0.1 M Na_2SO_4. Nickel nanoparticles were electrochemically deposited by cyclic voltametry. The deposition of nanoparticles on the graphite surface was done in an analytical glass cell filled with the plating solution. The deposition of Ni occurred in the form of grains and followed the grooves of HOPG and hence the grains deposited on adjacent grooves were parallel with respect to each other. By altering deposition parameters we were able to fabricate particles of different sizes ranging from 8nm to 20nm. The morphology of the deposited nanoparticles was studied using an Atomic Force Microscope (AFM) in non-contact mode. When deposited with optimum parameters the grains have sufficient size to be interlinked with each other hence forming continuous nanowires. To obtain continuous and parallel nanowires the experimental parameters applied were: starting and final voltages of -1.0 V and -0.4 V respectively, scan rate of 4000 mV per sec with deposition time of 7 minutes. The magnetic field distribution in nanoscale was studied using Magnetic Force Microscopy (MFM). MFM is a special mode of AFM that gives a simultaneous mapping of the topography and the magnetic field strength of the surface under study. Morphological changes and the redistribution of the nanoparticles were observed when they were subjected to magnetic fields of varying strengths. There was an appreciable change in the distribution of the particles on the surface.

MFM was employed to establish correlation between the redistribution of magnetized nanoparticles and their magnetic field. The critical forces required to overcome various inter-molecular interactions (e.g. frictional and Vander Waal) in order to redistribute the nanoparticles was estimated to be 12 nN with help of AFM tip nanomanipulation. Detail of the experimental results will be reported.

11:45 AM I5.10
A Novel Fabrication Technique for Interacting Ferromagnetic-metal Nanoparticle Systems: Fine-tuning of Particle Diameter and Interparticle Spacing. Satoshi Tomita[1], Kensuke Akamatsu[2], Hiroyuki Shinkai[2], Shingo Ikeda[2], Hidemi Nawafune[2], Chiharu Mitsumata[3], Takanari Kashiwagi[4,5] and Masayuki Hagiwara[4,5]; [1]Japan Science and Technology Agency, Saitama, Japan; [2]Konan Univ., Kobe, Japan; [3]Hitachi Metals Ltd., Saitama, Japan; [4]RIKEN, Saitama, Japan; [5]Yokohama City Univ., Yokohama, Japan.

Macroscopic properties of interacting ferromagnetic-metal nanoparticle systems are strongly affected by two microstructural parameters; the diameter of particles (d) and their spacing (r). Therefore, these parameters must be fine-tuned in order to design and realize a system for a specific purpose or application, e.g., ultra-high density magnetic recording media and left-handed materials. Nevertheless, independent and precise modification of the d and r at the level of several nanometers still remains a challenge. In this contribution, we demonstrate a novel fabrication technique for interacting nickel nanoparticle systems, in which the d and r can be fine-tuned. Metallic nickel nanoparticles were embedded in organic polymer, called polyimide (PI), films by applying a chemical surface modification technique. The technique involved a simple alkali treatment of the PI films, an ion exchange reaction, and thermal annealing. The structure of the films was characterized using transmission electron microscopy (TEM). The TEM study showed that the shrinkage of the PI matrices during the annealing brings about a decrease in the spacing r among nickel nanoparticles having an almost identical diameter d. We have found that the d and r can be fine-tuned independently by controlling the conditions of the alkali treatment and the annealing. Electron magnetic resonance study combined with theoretical considerations clearly indicated that tuning of d and r leads to a tuning of the magnetic dipolar interaction among nickel nanoparticles. The present technique allows us to open a new way to realize tailor-made nanomagnetic structures.

SESSION I6: Magnetic Nanowires and Nanotubes
Chairs: Bernd Rellinghaus and David J. Sellmyer
Tuesday Afternoon, November 30, 2004
Independence W (Sheraton)

1:30 PM *I6.1
Nanomagnetic Structures: Fabrication and Interactions. David J. Sellmyer, M.L. Yan, Y.F. Xu, K. D. Sorge, Y.C. Sui and R. Skomski; Department of Physics & Astronomy, CMRA and NSF-MRSEC, University of Nebraska, Lincoln, Nebraska.

This talk is focused on several novel synthetic methods for producing nanomagnetic structures with controlled properties. The systems considered have significant potential for future information or other magnetic technologies. Topics covered may include: (1) High-anisotropy nanocluster films for extremely high density perpendicular recording. These are $L1_0$ FePt-type clusters embedded in nanomagnetic matrices such as C or Ag and they are grown by a multilayering process that achieves perpendicular magnetic anisotropy *without* epitaxial growth [1,2]. (2) Nanocluster-assembled magnets produced by a cluster deposition system leading to nearly monodispersed $L1_0$ clusters with $d_{av} \cong 5$ nm and rms deviation $\sigma/d_{av} \cong 0.1$. [3,4]. (3) Nanotube and nanoparticle composite magnets produced in alumina nanochannels by a hydrogen reduction process. Both hard and soft systems, FePt and Fe_3O_4, respectively, and hard FePt:C nanocomposites have been synthesized [5,6]. (4) Interactions and switching behavior of soft magnetic dots formed by focused-ion-beam milling [7]. This work is related to elementary magnetic information processing devices. The experimental studies are coupled to analytical and/or simulational work, focused on basic interactions, that will be discussed as well. This research is supported by NSF-MRSEC, INSIC, W.M. Keck Foundation, DOE, ARO and NRI. 1. M.L. Yan, X.Z. Li, L. Gao, S.H. Liou, and D.J. Sellmyer, Fabrication of Nonepitaxially Grown, Double-Layered FePt:C/FeCoNi Thin Films for Perpendicular Recording, Appl. Phys. Lett. 83, 3332 (2003). 2. M.L. Yan, R. Skomski, A. Kashyap, L. Gao, S.H. Liou, D.J. Sellmyer, Hysteresis of Granular FePt:Ag Films with Perpendicular Anisotropy, IEEE Trans. Mag. (in press). 3. Y.F. Xu, Z.G. Sun, Y. Qiang, D.J. Sellmyer, Preparation and Properties of CoPt and CoPt:Ag Nanocluster Films, J. Magn. Magn. Mater. 266, 164-170 (2003). 4. Y.F. Xu, Z.G. Sun, Y. Qiang, D.J. Sellmyer, Magnetic Properties of $L1_0$ FePt and FePt:Ag Nanocluster Films, J. Appl. Phys. 93, 8289-8291 (2003). 5. Y.C. Sui, R. Skomski, K.D. Sorge, D.J. Sellmyer, Nanotube Magnetism, Appl. Phys. Lett. 84, 1525 (2004). 6. Y.C. Sui, J. Zhou, X.Z. Li, R. Skomski, D.J. Sellmyer, Growth and Magnetism of FePt:C Composites In Nanoscale Channels, J. Appl. Phys. 95, 6741 (2004). 7. K.D. Sorge, A. Kashyap, R. Skomski, L. Yue, L. Gao, R.D. Kirby, S.H. Liou, D.J. Sellmyer, Interactions and Switching Behavior of Anisotropic Magnetic Dots, J. Appl. Phys. 95, 7414 (2004).

2:00 PM I6.2
Spin Injection Induced Magnetization Reversal in Electrodeposited Nanostructures. Jean-Eric Wegrowe and Travis Wade; LSI, Ecole Polytechnique, Palaiseau, France.

Current-induced magnetization reversal was studied under current injection in metallic nanostructures of various morphologies. The comparison between the results obtained with homogeneous Ni and Co nanowires and Co(10 nm)/Cu (10 nm)/Co(30 nm) nanometric pillars (40 nm diameter) was performed. The time resolved experiments show that the response of the magnetization exhibits typical activation processes and two level fluctuations [1,2,3,4]. The variation of the activation energy (or equivalently, the effective temperature) of a ferromagnetic layer under current injection is measured with various experimental protocols. The measured energy is about 0.2 eV (2400 K) for Co/Cu/Co nano-pillars and 2.5 eV (30 000K) in Ni nanowires, for a current of typically 10^7 A/cm^2 [1]. Such huge energies are far beyond the Curie temperature, and beyond the energy of spin-wave excitations. The response of the magnetization is also studied as a function of the asymmetry of the interfaces. Two interpretations are discussed on the basis of the experimental results: (I) Deterministic approach. The effect of the current is interpreted in terms of a current dependent effective magnetic field, or spin-torque. There are two possibilities. Either the action of the field is to reduce the potential barrier, and the magnetization reversal is due to activation at the temperature of the lattice, like in usual magnetic after-effect experiments (there is no dynamical states). Or the effective field or torque excites precession or spin-waves, which appears as an effective temperature in the magnetic measurements. This last interpretation however is ruled out by the fact that the energy involved is far beyond the Curie temperature. (II) Stochastic approach. The measured effective temperature is due to the relaxation of the spin of the conduction electrons, that play the role of environmental degree of freedom on the magnetization. The huge energy involved is due to the fluctuations of magnetic moments between the current and the magnetization (and not directly due to magnetic excitations). The magnetization reversal or magnetic excitations are a consequence of this process. The magnetic system would then be analogous to an open system where spin injection is balanced between both non-symmetric interfaces of the ferromagnetic layer. This interpretation is illustrated in the framework of a four electron channel model. [1] J.-E. Wegrowe, Phys. Rev. B 68, 214414 (2003), [2] Myers et al. Phys. Rev. Let. 89, 196801 (2002), [3] Urazhdin et al. Phys. Rev. Let. 91, 146803 (2003), [4] Fabian et al. , Phys. Rev. Let. 91, 257209 (2003).

2:15 PM *I6.3
Nanowire arrays for magnetoelectronics. Na hyoung Kim, Liwen Tan, Ryan Cobian, Jia Zou and Bethanie J. H. Stadler; University of Minnesota, Minneapolis, Minnesota.

As the size of electronic devices decreases, the current fabrication technology is limited and the need for new ways to go beyond this limit is becoming more urgent. There is also an increased interest in adding magnetic functionality to electronics for applications such as MRAM. This work will review novel methods being used for fabrication of nanometer-scale magnetoelectronics, and will then focus on using controlled self assembly techniques for making arrays of magnetic nanowires of various shapes and size. Specifically, nanoporous alumina was used as a template for growing nanowires from 10-100nm in diameter via electrochemical deposition. These wires were closely spaced when using pure self assembly of the alumina pores. However, imprint stamping the Al prior to anodization has allowed increased interpore spacing, large area ordering, and controlled placement of the pores and the subsequent nanowires. Nanowires grown in nanoporous alumina are straight and strictly parallel to each other with high aspect ratios. The crystallographic alignment of magnetic materials can be controlled using variations in growth parameters, including an applied magnetic field. The magnetic and electronic properties of the nanowires vary with size and alignment. In order to achieve 3 terminal magnetoelecronic nanodevices, Y-junction nanowires were also grown in Y-shaped nonporous templates which were prepared by two-step anodization. These junction wires also provide the ability to connect two or more nanodevies, which is critical to the long-term success of developing nanoelectornics. This work focused on Co Y-junction nanowires with 20nm braches on 40nm trunks. The magnetic properties were seen to follow the softer of the two sizes (20nm in this case). Multilayers of

Co/Cu have also been grown which enable the coercivity of each of the Co sizes to be expoited together. Magnetotransport measurement was made on both the Y-junction nanowires and the multilayers in order to demonstrate the effect of the junction and the interfaces on magnetoresistance.

2:45 PM I6.4
Synthesis of Cobalt/Polymer Composite Nanotubes.
Kornelius Nielsch[1], Fernando J. Castano[2], Caroline A. Ross[2] and Ramkumar Krishnan[2]; [1]BMBF Nanotechnology Research Group, Max Planck Institute of Microstructure Physics, Halle, Germany; [2]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Magnetic nanowires and nanoparticles exhibit multifunctional properties and are useful in a broad range of applications such as drug or gene delivery, or for magnetic imaging. In contrast, there has been very little work reported on magnetic nanotubes, which represent a new class of anisotropic multifunctional nanoparticles. In the present work we report on a novel approach for the fabrication of ferromagnetic nanotubes and present results concerning the magnetic properties of Co nanotubes. The surfaces of the pores in self-ordered porous alumina membranes are wetted with a polystyrene or poly-l-lactide layer containing a metallo-organic precursor with a thickness of 40 to 70 nm. Decomposition of the precursor leads to the formation of thin-walled magnetic tubes with diameters of 160 - 450 nm and wall thicknesses of a 1 to 5 nm. During an annealing process at 180 C, a cobalt thin-film forms at the oxide pore-wall/polymer interface. After removing the inner polymer tube and an KOH-etch single Cobalt nanotubes can be found on top of the membrane structure. Room temperature magnetic measurements show that the tubes have a lower saturation field parallel to their axes, while the in-plane direction is a harder axis. The magnetic properties on varying the wall thickness of the nanotubes will be discussed. This synthesis method is not limited to Co. We have also precipitated metallic Fe and Ni based on the polymer wetting of porous templates. The financial support from the NSF and the German Federal Ministry for Education and Research (BMBF, Project No. 03N8701) is greatly acknowledged.

3:30 PM I6.5
Self-Assembled Single Crystal Ferromagnetic Iron Nanowires formed by Decomposition. Ladan Mohaddes-Ardabili[1], H. Zheng[1], S.B. Ogale[2], B. Hannoyer[3], S.R. Shinde[2], T. Zhao[1], D. G. Schlom[4] and R. Ramesh[1,5]; [1]Department of Materials Science and Enginerring, University of Maryland, College Park, Maryland; [2]Department of Physics, University of Maryland, College Park, Maryland; [3]Institut des Materiaux, Universite de Rouen, Cedex, France; [4]Department of Materials Science and Engineering, Pennsylvania State University, University Park, Pennsylvania; [5]Department of Materials Science and Engineering and Department of Physics, University of California, Berkeley, California.

We are probing the effect of thermodynamics environments on the phase stability of complex perovskite oxides using the La-Sr-M-O3 (T=Fe, Co, Ni, Mn) perovskites as model systems. Deposition in 100mTorr of oxygen leads to the formation of single phase epitaxial perovskites. Deposition under reducing environments, leads to the formation of self-assembled arrays of nanopillars. Specifically, in the case of the Fe system the deposition under reducing conditions leads to spontaneous formation of an array of single crystalline α-Fe nanowires embedded in an antiferromagnetic LaSrFeO4 matrix. We observe 3-dimensional heteroepitaxy between the nanopillar, the matrix and the substrate. At growth temperature of 840 C, square shaped α-Fe pillars with a lateral width of 40-50 nm are formed. As the deposition temperature is reduced the shape evolves progressively into octahedral and then circular section. The diameter of the nanowires reduces to 4-6 nm for the growth at 560 C. The maximum coercivity is achieved for nanowires with average diameter of 15-20 nm grown at 760 C (M = 0.95 Msat). The magnetic properties of the nanowires with different diameters are measured at 300, 100 and 5 K and the trend is discussed. The large remanence and sizable coercivity of the nanowires make them desirable for high-density data storage and other magnetic device applications. In addition, we have also used the films containing α-Fe nanowires as a template to establish a novel method to grow carbon nanotubes (CNTs). The Fe nanowires serve as a nucleation site to form CNTs. This work is supported partly by NSF-MRSEC under contract No. DMR-00-80008 and by an ONR MURI program under contract No. N000140110761.

3:45 PM I6.6
Spintronics Based on Manganite Nanowires. Bo Lei, Chao Li, Song Han, Daihua Zhang, Zuqin Liu and Chongwu Zhou; Dept. of E.E.-Electrophysics, Univ. of Southern California, Los Angeles, California.

Systematic studies have been carried out based on the La0.67Ca0.33MnO3 (LCMO) and La0.7Sr0.3MnO3 (LSMO) nanowires as colossal magnetoresistance (CMR) materials. Herein, a generic non-equilibrium synthesis technique was used to epitaxially form LCMO and LSMO conformal coatings on MgO vertical nanowire templates. The nature of these core-shell nanowires was investigated by various techniques including X-ray diffraction (XRD) and high-resolution TEM (HRTEM). Electrical measurements were further performed to characterize the spin-dependent transport properties under different magnetic fields. A persistence of magnetoresistance (MR) and metal-insulator phase transition was achieved down to nanoscale. Moreover, LSMO nanowire exhibited MR at room temperature and metal-insulator transition above room temperature. This work should stimulate a lot interest for the research of CMR, especially at nanoscale dimensions.

4:00 PM I6.7
Synthesis and Spintronic Studies of MgO/Fe3O4 Core-Shell Nanowires. Daihua Zhang, Zuqin Liu, Song Han, Chao Li, Bo Lei and Chongwu Zhou; EEEP, University of Southern California, Los Angeles, California.

High quality MgO/Fe3O4 core-shell nanowires have been successfully synthesized via pulsed laser deposition technique. The material composition and stoichoimetric ratio have been carefully examined and confirmed with a variety of characterization techniques including X-ray diffraction, X-ray photoelectron spectroscopy, transmission electron microscopy and energy-dispersive X-ray spectroscopy. These novel structures have rendered unique opportunities to investigate the transport behavior and magnetoresistance (MR) property of Fe3O4 in its one-dimensional form. Room temperature MR of 1.2% was observed in the as synthesized nanowires under a magnetic field of B = 1.8 T, which has been accounted for the tunneling of spin-polarized electrons across the anti-phase boundaries. Our work may pave the way for using Fe3O4 nanowires as building blocks for future spintronic devices and systems.

4:15 PM I6.8
Kinetic Pathway for the Formation of One-Dimensional Magnetic Atom Wires on Stepped Cu(111) Surface. Yina Mo[1], Kalman Varga[2,4], Efthimios Kaxiras[1,3] and Zhanyu Zhang[4,2]; [1]Physics, Harvard University, Cambridge, Massachusetts; [2]Physics Department, University of Tennessee, Knoxville, Tennessee; [3]Division of Engineering, Harvard University, Cambridge, Massachusetts; [4]Condensed Matter Science Division, Oak Ridge National Lab, Oak Ridge, Tennessee.

Using first-principles total-energy calculations, we elucidate a novel and intriguing kinetic pathway for the formation of Fe nanowires on the upper edge of a a monatomic-layer-high step on Cu(111). The kinetic pathway involves two key steps. First, a row of Fe atoms self-bury themselves just one surface lattice constant away from the step edge, with minimal potential energy barrier. With such a base line, additional Fe adatoms diffusing on top will then feel a strong attraction to the buried wire, thereby forming an atomic wire at the upper edge. We will explore the potential applicability of the kinetic mechanism in other related systems, and study the corresponding magnetic properties of such noval nanostructures. We will also compare our theorectical predictions with existing experiments.

SESSION I7/D4: Joint Session: Magnetic Random Access Memory (MRAM)
Chairs: Russel Cowburn and Jon Slaughter
Wednesday Morning, December 1, 2004
Back Bay B (Sheraton)

8:30 AM *I7.1/D4.1
Magnetoresistive Random Access Memory. Johan Akerman, Philip Brown, Brian Butcher, Renu Dave, Mark DeHerrera, Mark Durlam, Brad Engel, Mark Griswold, Greg Grynkewich, Jason Janesky, John Martin, Srinivas Pietambaram, Nick Rizzo, Jon Slaughter, Ken Smith, Ji-Jun Sun and Tehrani Saied; Freescale Semiconductor, Chandler, Arizona.

Magnetoresistive random access memory (MRAM) employs a magnetoresistive device integrated with standard silicon-based microelectronics, resulting in a combination of qualities not found in other memory technologies: MRAM is non-volatile, has unlimited read and write endurance, and has demonstrated high-speed read and write operations. Recent technology developments of MRAM based on Magnetic Tunnel Junction (MTJ) devices is reviewed. The properties of our unique toggle-switching MRAM bit is discussed and compared to those of the conventional switching approach. For the first time a comprehensive review of the reliability of the MTJ tunneling dielectric and the current carrying write lines will be presented. Scaling of these results to operating conditions demonstrates the reliability of our 4Mb

MRAM chip.

9:00 AM *I7.2/D4.2
Spin-Transfer Switching In Nanometer-Sized Magnetic Tunnel Junctions For MRAM Application. Yiming Huai, R & D Department, Grandis Inc., 1266 Cadillac Court, Milpitas, California.

Spin-polarized current induced magnetization switching has stimulated considerable interest in recent years due to its rich fundamental physics and great potential for new magnetoelectronic applications.[1] Low switching current density and high read signal are required for the application of the spin transfer switching to non-volatile magnetic memory (MRAM). We present here a study of spin transfer switching in nanometer-sized magnetic tunnel junctions (MTJs) with low resistance-area product (RA) ranged from 1-10 $\Omega\mu m^2$ and TMR=1-30%. Bottom PtMn and IrMn exchange-biased MTJ films were deposited in a magnetron sputtering cluster system. A thin tunneling barrier was formed by natural oxidation of the pre-deposited thin Al layer. MTJ films were subsequently patterned into nanometer ellipse shaped pillars using both deep UV lithography (combined with resist trimming)[2] and e-beam lithography. Spin-transfer switching has been consistently observed in patterned MTJs with dimensions down to 0.1x0.2 μm^2. Low switching current density Jc 10^6 A/cm^2 has been achieved using low moment free layer CoFeB. High TMR values about 30% were obtained in spin-transfer induced switching and attributed to homogenous and continues thin Al_2O_3 barrier grown on smooth bottom lead with a roughness (RMS) of 2-3 $\AA$. These result could have potential applications for a spin transfer based MRAM. [1] J. A. Katine, F. J. Albert, R. A. Buhrman, E. B. Myers, and D. C. Ralph, Phys. Rev. Lett. 84, 3149 (2000); J. Grollier, V.Gros, A. Hamzic, J. M. George, H. Jaffes, A. Fert, G. Faini, J. Ben Youssef, and H. Le Gall, Appl. Phys. Lett. 78, 3663 (2001); J. Z. Sun, D. J. Monsma, D. W. Abraham, M. J. Rooks, and R. H. Koch, ibid. 81, 2202 (2002); M. R. Puffall, W. H. Rippard, and T. J. Silva, resistance ibid. 83, 323 (2003); S. Urazhdin, H. Kurt, W. P. Pratt, and J. Bass, ibid. 83, 114 (2003). [2] Yiming Huai, Frank Albert, Paul Nguyen, Mahendra Pakala and Thierry Valet, Appl. Phys. Lett. 84, 3118 (2004).

9:30 AM I7.3/D4.3
Magnetotransport in Flux-Closure Multilayered Nanomagnets. Fernando J. Castano, D. Morecroft, W. Jung and C. A. Ross; Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

During the last decade considerable attention has been devoted to the fabrication and characterization of thin film magnets with sub-micron lateral dimensions (nanomagnets). Multilayered nanomagnets can be engineered to exhibit large resistance changes depending on the relative orientation of the magnetization within each of the magnetic layers comprising the structure. This in turn allows for bits of information to be stored by controlling the magnetic configurations exhibited by these small elements. Present magnetic random access memory (MRAM) designs use large arrays of elongated nanomagnets which can be read and written using conductor lines [1]. Ring-shaped nanomagnets have been proposed as alternative MRAM cells [2], in part due to the existence of a range of stable magnetic configurations which could allow for high-density MRAM devices storing more than one bit per nanomagnet. The magnetotransport properties of ring-shaped single-magnetic-layer structures with widths of 200 nm and diameters exceeding 1 micron have previously been investigated [3]. In this contribution we report on the magnetic and magnetotransport properties of sub-micron diameter elliptical-ring magnets with widths of 90 nm and above. The rings are fabricated using single layer NiFe or Co, or NiFe (6 nm)/ Cu (3-6 nm)/ Co (4 nm) pseudo-spin-valve thin film structures. A multilevel lithography process involving electron-beam lithography and lift-off processing was used to fabricate magnetic rings with gold contacts. Magnetometry shows that single layer rings transform between onion (bidomain) and vortex (flux-closed) states, at switching fields which increase with decreasing ring diameter and ring width. For example, 360 nm diameter, 160 nm wide Co rings have an onion-vortex transition at 150 Oe and a vortex-reverse onion transition at 850 Oe, while the corresponding values for a 110 nm wide ring are 240 Oe and 1900 Oe. Resistance changes result only from anisotropic magnetoresistance of the material. In the case of multilayer rings, more complex magnetic behavior occurs because each layer has different switching fields, and magnetotransport effects originate from giant magnetoresistance in the structure. The magnetotransport properties reflect the different states within each magnetic layer, as well as the exchange and magnetostatic coupling between layers. In particular, the effects of varying the width of the rings and the thickness of the Cu spacer layer on the magnetic and magnetotransport behavior will be discussed. [1]S. Durlam et al, IEDM technical Digest 2004, session 34, paper#6. [2] J.G. Zhu et al, J. Appl. Phys. 87 6668 (2000). [3] M. Klaui et at, Phys. Rev. Lett. 90, Art. No.097202 (2003).

9:45 AM I7.4/D4.4
Size Dependent Properties of Current-Confined CPP Spin Valve Device. Hao Meng, Jianguo Wang, Yunfei Ding and Jian-Ping Wang; Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota.

Current-perpendicular-to-plane (CPP) spin valve device has the potential to replace the current-in-plane (CIP) device for high density magnetic recording head and other spintronics applications. In order to achieve its intrinsic high magneto-resistance (MR) ratio, the resistance coming from the active layers of CPP spin valve has to be increased [1]. Several approaches such as dual spin valve structure, nano-oxide layer, and new materials have been investigated by many groups. Another effective approach to increase the resistance is to reduce the current crossing area. In this work, size effects on the CPP spin valve were investigated. A series of samples with small pillar area (75×135 nm^2, 100×217 nm^2 and 184×415 nm^2 with ellipse shape) were fabricated in our lab. The processes include thin film sputtering, electron-beam lithography, ion milling etching and magnetic annealing. Nano-oxide-layers (NOL) were also introduced in the present work and functioning as current confine to further reduce the effective area for current passing through. With dot size decreasing, higher MR and MR ratio were achieved, which indicates that device is approaching to its intrinsic MR ratio with size decreasing. However, the results show a non-linear relationship between dot area and MR ratio. This is because that the conducting lead contact resistance in the MR measurement is still too high to be neglected, thus the spin valve active layer resistance couldn't dominate the measurement result, which causes MR ratio lower than the intrinsic value. Detail results will be presented in full paper. 1. Atsushi Tanaka, Yoshihiko Seyama, Arata Jogo, Hirotaka Oshima, Reiko Kondo, Hitoshi Kishi, Chikayoshi Kamata, Yutaka Shimizu, Shin Eguchi, and Kazuaki Satoh, "Readout Performance of Confined-Current-Path Current-Perpendicular-to-Plane Heads", IEEE Trans. Magn., 40, 203, (2004) Corresponding Author Email: jpwang@ece.umn.edu

SESSION I8: Magnetic Semiconductors and Oxides
Chair: Pat Ryan
Wednesday Morning, December 1, 2004
Independence W (Sheraton)

10:30 AM *I8.1
Magnetism and Transport in Room-Temperature Diluted Magnetic Wide Band-Gap Semiconductors. A. B. Pakhomov, B. K. Roberts, K. A. Griffin and Kannan M. Krishnan; Department of Materials Science, University of Washington, Seattle, Washington.

Recent expectations for a breakthrough in further miniaturization and new functionalities in semiconductor electronics have been enhanced by the prospects of spin electronics. New device architectures utilizing the spin degree of freedom of carriers have been proposed with the most attractive approach for spin injection into a semiconductor being the use of a ferromagnetic dilute magnetic semiconductor (DMS). In widely studied DMS materials such as GaAs:Mn, the magnetic order has been proven to be mediated by carriers that are highly spin polarized due to sp-d exchange interactions. However, the Curie temperatures of these materials are below room temperature. Prospective DMS candidate materials include wide band gap, room temperature DMS, such as TiO_2:Co, ZnO:Co, GaN:Cr, AlN:Cr etc, but in these materials spin polarization is not proven, and questions of the origin of ferromagnetism as well as the granularity of the transition metal dopants need to be answered. Our work is focused on synthesis of true oxide ferromagnetic DMS (avoiding nanometer scale magnetic inclusions) with the emphasis on structural characterization, measurement of magnetic and transport properties and understanding the correlations between carriers and magnetism. Materials, including ZnO:Cr, ZnO:Co and anatase TiO_2:Co, with Curie temperatures > 365K, were synthesized by a variety of sputtering techniques and characterized by a range of electron, photons and scanning probe methods. Multilayers of Co and Al-doped ZnO, with nominal layer thicknesses on the atomic scale were deposited by ion beam sputtering. We will discuss an interesting dimensionality crossover from a DMS superlattice to discontinuous magnetic metal/semiconductor multilayers observed with increasing metal content in the multilayers. Through RF magnetron co-sputtering of ZnO and Cr metal on α-plane Al_2O_3 and UHV anneal, ferromagnetic ordering was achieved in ZnO:Cr films. Saturation moment approaching 4 μ_B per Cr ion is consistent with the theoretical value for the Cr^{2+} state, but decreases with increasing concentration. This proves that magnetism does not arise from CrO_2 inclusions where Cr would be in the Cr^{4+} state (M = 2 μ_B/ion). Co-doped anatase TiO_2 was grown by magnetron sputter deposition from composite oxide targets and followed by UHV annealing. The moment of 1.1 μ_B/Co ion is interpreted as the low spin configuration of Co^{2+} in Co-doped anatase. In both cases of TiO_2:Co and ZnO:Cr no evidence of

clustering of secondary phases, including metallic Cr or Co, was found in extensive structural or spectroscopy measurements. An important conclusion of our work is that carrier-mediated mechanisms of magnetic ordering are not applicable to these wide band gap ferromagnetic materials. In fact, they remain ferromagnetic in the dielectric state without carrier co-doping. It would probably be more appropriate to refer to these materials as diluted magnetic dielectrics (DMD) rather than DMS. We also discuss possible spintronics applications of DMD. This work was supported by NSF/ECS #0224138 and by the Campbell Endowment at the University of Washington.

11:00 AM I8.2
The effects of Mn on InAs nanowire synthesis for magnetoelectronic applications. Steven J. May, Jian-Guo Zheng, Dinna Ramlan, Bruce W. Wessels and Lincoln J. Lauhon; Materials Science and Engineering and Materials Research Center, Northwestern University, Evanston, Illinois.

Ferromagnetic semiconductors are promising materials for the realization of spintronic devices, and semiconductor nanostructures (dots, rods, wires) provide a context for exploring the effects of reduced dimensionality the on electronic and magnetic properties of semiconductors. We have pursued manganese doping of size-tunable InAs semiconductor nanowires in order to discover potentially useful manifestations of nanoscale ferromagnetism in semiconductor materials. The experiments also address the fundamental challenge of doping nanostructures with impurities of limited solubility. Gold nanoparticles on GaAs(111) wafers were used to initiate the vapor-liquid solid growth of epitaxial InAs nanowires using trimethylindium (TMIn) and arsine (AsH3) in a metalorganic vapor phase epitaxy (MOVPE) reactor. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) studies were used to determine crystallinity and growth direction and to confirm VLS growth. The presence of the manganese precursor tricarbonyl(methycyclopentadienyl)manganese (TCMn) during VLS growth had a profound influence nanowire morphology and composition. At low growth temperatures, TCMn led to the self-organized growth of highly ordered dendritic InAs nanowire structures, whereas at high temperatures, dendritic growth was suppressed, and MnAs quantum dot on InAs nanowire structures were formed. Energy dispersive x-ray spectroscopy (EDS) and energy electron loss spectroscopy (EELS) measurements on individual dendritic nanowires in a TEM revealed concentrations of Mn at the branch tips, indicating that Mn clusters assist in the nucleation and definition of the branched nanowires. HRTEM was used to identify the Mn containing tip clusters and electron diffraction confirmed that the branches maintained well defined orientations with respect to the growth substrate. By increasing growth temperatures, dendritic growth was suppressed and the growth of an epitaxial InMnAs shell promoted. Some tendency towards phase separation was indicated by the formation of epitaxial MnAs quantum dots on a nanowire core. The ferromagnetism of the hexagonal MnAs dots was confirmed by magnetic force microscopy and suggests potential routes to new magnetoelectronic functionality in these self-assembled nanocomposite materials.

11:15 AM I8.3
Enhancement of Ferromagnetic Properties in (Ga,Mn)N Nanowires by Nitrogen Plasma Treatment. Jeong Min Baik[1], Yoon Shon[2], Tae Won Kang[2] and Jong-Lam Lee[1]; [1]Materials Science & Engineering, POSTECH, Pohang, Kyungbook, South Korea; [2]Quantum Functional Semiconductor Research Center, Dongguk University, Seoul, South Korea.

Ferromagnetic (Ga,Mn)N nanowires have considerable potential as high intensity data storage devices and nanosensors due to their nanosize and anisotropic magnetic response. It was also reported that compared with bulk materials, the nanometer-sized materials could have high coercivity and the ratio of remanence to maximum saturation magnetization (M_r/M_s) closed to 1. However, it is difficult to obtain room temperature ferromagnetism due to the formation of N-vacancies near the surface region. In this paper, we have proposed a new method for the enhancement of the ferromagnetic properties in (Ga,Mn)N nanowires using nitrogen plasma treatment. (Ga,Mn)N nanowires were grown on c-plane sapphire substrates by the reaction of pure gallium metal and $MnCl_2$ powder in a horizontal CVD chamber under a flow of ammonia gas, 50 - 150 sccm. Au films were used as the catalyst particles and nanowires were grown at temperature of 900 °C. The nanowires were then exposed to nitrogen plasma at 250 °C for 10 min. SEM images showed that (Ga,Mn)N nanowires have lengths up to hundreds of micrometers and diameters ranged from 50 to 150 nm. The Mn concentration in nanowires was controlled by varying an ammonia flow rate through the CVD chamber, 5% at 150 sccm. No secondary phases were observed in (Ga,Mn)N nanowires by HR-TEM images. The hysteresis loops of all samples showed clear ferromagnetic behaviors. After nitrogen plasma treatment, the ferromagnetic signal increased and maintained to room temperature. From SRPES, the Ga/N atomic ratio decreased and the Fermi level shifted about 0.2 eV toward the VBM with N-plasma treatment, meaning that N-vacancies decreased and hole concentration increased. This provides evidence that the origin of the enhancement in ferromagnetic properties originated from the enhancement of ferromagnetic interaction among Mn ions via holes.

11:30 AM I8.4
Room Temperature Ferromagnetism in Mn-ion Implanted Si: A New Diluted Magnetic Semiconductor. C. A. Awo-Affouda, M. Bolduc, A. Stollenwerk, M. B. Huang, F. Ramos and V. P. LaBella; College of NanoScale Science and Engineering, University at Albany-SUNY, Albany, New York.

Utilizing the spin of the electron in semiconductor devices holds great potential to provide novel, high-speed device structures. The integration of ferromagnetism into these device structures is needed to couple to electron spin. Diluted magnetic semiconductors (DMS) have been demonstrated as a successful method for integrating ferromagnetism through doping of a semiconductor crystal with an additional transition metal impurity such as Mn. In this talk we demonstrate that silicon can be made ferromagnetic above room temperature through manganese ion implantation. 300-keV Mn-ions were implanted to concentration of (0.1-0.8) at.% yielding a saturation magnetization of (0.1-0.6) emu/g. The strength of ferromagnetism increases with Mn concentration and post implantation annealing. The Curie temperature is found to be greater than 400 K. The carrier type has a strong influence on the magnetic properties, similar to other DMS systems. Data from several structural analysis techniques will be presented that indicate the perfection of the crystal structure after annealing, giving evidence that substitutional Mn maybe occurring.

11:45 AM I8.5
Electronic Structure of the Strained (La,Ba)MnO3 Thin Films Studied by Hard X-Ray Core-Level Photoemission. Hidekazu Tanaka[1], Yasutaka Takata[2], Koji Horiba[2], Munetaka Taguchi[2], Tomoji Kawai[1] and Keisuke Kobayashi[3]; [1]ISIR-Sanken, Osaka Univ., Ibaraki, Osaka, Japan; [2]RIKEN/SPring-8, Sayo-gun, Hyogo, Japan; [3]JASRI/SPring-8, Sayo-gun, Hyogo, Japan.

We present a report on electronic structure of the strained (La,Ba)MnO3 thin films with various film thickness studied by Hard X-ray Photoemission Spectroscopy (HX-PES). Curie temperature of ferromagnetic (La,Ba)MnO3 thin film could be enhanced by arranging film thickness via tensile strain effect, so that room temperature ferromagnetism has been realized even in thin ultra thin film form [1]. By using this characteristic of this material, ferromagnetic field effect transistor working at room temperature has been reported [2]. To evaluate electronic structure, bulk sensitive photoemission spectroscopy is strongly required due to ex-situ treatment of films for device construction. (La0.85Ba0.15)MnO3 epitaxial thin films (thickness : 300nm. 20nm, 3nm) were prepared on Nb-doped SrTiO3 (001) single crystal substrate. After film formation, films were annealed in 1atm O2 for 10 hours. TC for films are 82K, 299K and 100K, respectively. After magnetization measurement by SQUID magneto-meter, HX-PES measurements were performed at an undulator beamline BL29XU of SPring-8. The excitation energy was set to 5.95 keV with the bandwidth of 70 meV. In HX-PES spectrum for Mn 2p, new broad satellite peak was observed for 300nm thickness film. For 20nm thickness film whose ferromagnetism was strongly enhanced by substrate strain, a sharp satellite peak was observed. On the other hand, no satellite peak was observed in the 3nm film. The intensity of observed satellite peaks almost correspond to the magnitude of magnetization and metallic conduction of films. A theoretical calculation revealed the intensity of satellite peak corresponds to density of state (DOS) at Fermi level. HX-PES spectrum could observe electronic structure of internal part of film (not limited to surface), which directly correspond to physical property of films. Ref. [1]. Phys. Rev. B 64 (2001) 224418, [2] Appl. Phys. Lett. 83 (2003) 4860

SESSION I9: Magnetic Nanostructures in Biotechnology
Chair: Kannan Krishnan
Wednesday Afternoon, December 1, 2004
Independence W (Sheraton)

1:30 PM *I9.1
Magnetoresistive Sensors and Magnetic Nanoparticles for Biotechnology. Guenter Reiss[1], Hubert Brueckl[1], Andreas Huetten[1], Joerg Schotter[1], Brzeska Monika[1], Anke Becker[2], Paul B. Kamp[2], Alfred Puehler[2] and Peter Jutzi[3]; [1]Physics, University of Bielefeld, Bielefeld, Germany; [2]Biology, University of Bielefeld, Bielefeld, Germany; [3]Chemistry, University of Bielefeld, Bielefeld, Germany.

The detection as well as the manipulation of single molecules on a

common technological platform is of great interest for both basic research on biological or chemical systems as well as for applications in, e.g., antibody detection. A promising approach is the detection of small magnetic carriers with the newly developed magnetoresistive sensors which would be capable of creating a completely electronic measurement system. Moreover, this system would be addtionally compatibel with a main stream development in microelectronics, namely the so called MRAM. Both the principles of the measurement technique as well as new developments in the preparation of magnetic carriers are demonstrated. It is shown that paramagnetic beads can be detected by highly sensitive magnetoresistive sensors yielding a purely electronic signal. Different configurations are discussed and the results for Giant Magnetoresistance sensors are compared to an analysis of the same biological systems marked with fluorescence dyes. This shows, that down to a conentration of about 10 pg/μl of, e.g., DNA molecules, the magnetoresistive technique is competitive to nowadays standard analysis methods. The capability of the Tunneling Magnetoresistance sensors to detect even single markers is additionally demonstrated by a model experiment using the tip of a magnetic force microscope to mimic the presence of a magnetic particle on top of the sensor surface. The magnetic carriers detected by the sensors are, mostly paramagnetic magnetite beads embedded in a polymer matrix with sizes from some μm down to about 100nm. They are linked to, e.g., DNA or proteins (often by a avidin-biotin bond) and thereby enable highly specific detection of complementary molecules. These magnetic particles often suffer from their broad size distribution and the relatively small magnetic moment. With the new colloidal synthesis of superparamagnetic or ferromagnetic Co, CoFe and FePt nanocrystals by, e.g., pyrolythic decomposition of CVD precursor molecules, magnetic markers with superior magnetic moments, smaller size and size distribution can be produced. Here, the question about their potential to replace magnetite is addressed. Starting from a magnetic analysis of the corresponding magnetophoretic mobility of Co and FeCo based alloys their synthesis and resulting microstructural and magnetic properties as function of the underlying particle size distribution and the stability of the oleic acid ligand are discussed. Moreover, the magnetic particles offer an additional feature: They can be manipulated on chip via currents running through specially designed line patterns. We show, that this manipulation can be performed in a precise and reproducible manner, enabling locally enhanced concentration or even the measurement of binding forces with very low loading rates. Thus, magnetic markers in combination with magnetoresistive sensors are a promising choice for future integrated lab-on-a-chip Systems.

2:00 PM *I9.2
Magnetic Microarray for Ultrasensitive Molecular Diagnostics. Shan X. Wang, [1]MSE, Stanford University, Stanford, California; [2]T.J. Watson Research Center, IBM, Yorktown Heights, New York; [3]Stanford Genome Technology Center, Stanford University, Palo Alto, California.

We present proof-of-concept experiments and modeling towards a high-sensitivity magnetic microarray (dubbed MagArrayTM) for ultrasensitive molecular diagnostics. In this technology we "tag" a DNA fragment (or other biological samples) with a high moment superparamagnetic nanoparticle, which is in turn detected by a high sensitivity spin valve (SV) detector array. The detector can count the number of magnetic tags with a resolution of 1-20 tags, depending on the type of magnetic tags and spin valve sensors deployed. The magnetic microarray can potentially count individual biomolecules, likely leading to a "killer application" of magnetic nanotechnology in biology and healthcare. This work is supported by DARPA through US Navy grant # N000140210807.

2:30 PM I9.3
Characterization of Superparamagnetic Iron Oxide Particles for Biomedical Applications. H. Choi[1], Wojciech Dmowski[2], F. Huang[1] and I-W. Chen[1]; [1]Materials Science and Engineering, University of Pennsylvania, Philaelphia, Pennsylvania; [2]Materials Science and Engineering, University of Tennessee, Knoxville, Tennessee.

Superparamagnetic iron oxide nanoparticles are a powerful T2 contrast agent in magnetic resonance (MR) imaging for biomedical applications. Typically, they are co-precipitated with a hydrophilic long chain polymer coating in order to assure long circulation in patient's body. Although the iron oxide in this application has been variously named different Fe-containing phases, there is no definitive identification because of the small size (a few nm) of the crystals. We have systematically investigated the chemistry, structure, and magnetic properties of iron oxide nanoparticles as a function of precipitation conditions. Using synchrotron near edge fine structure and pair distribution function, we have identified the valence and the crystal structure of the nanoparticles. These results will be presented along with a discussion of the potential for further improvement of these nanoparticles for MR imaging applications. Examples of functionalization of nanoparticles and their use for in vivo targeted imaging will be presented.

2:45 PM I9.4
Iron Oxide Nanoparticles for DNA-detection. Hao Zeng[1,2], D. B. Robinson[2], Shan X. Wang[2], G. Li[2], R. White[2], R. L. Sandstrom[1] and Shouheng Sun[1]; [1]IBM T.J. Watson Research Center, Yorktown Heights, New York; [2]Materials Science and Engineering, Stanford University, Stanford, California.

We have developed iron oxide based magnetic nanoparticle bio-labels for detecting DNA hybridization with spin valve sensors. Monodisperse Fe2O3 and MFe2O4 (M = Fe, Mn) nanoparticles with sizes tunable from 10-20 nm have been prepared via high temperature solution phase synthesis. They are chemically stable and magnetically soft with magnetization between 70 to 80 emu/g that is suitable for quantitative spin valve sensor analysis. As synthesized, the particles are stabilized with hydrophobic surfactants, and dispersed in non-polar solvents. They can be transferred into aqueous solutions by ligand exchange. After surface functionalization, single strand DNA (s-DNA) is attached to the particle surfaces. The particles are further immobilized on a substrate surface by hybridization with a complimentary s-DNA anchored on the surface. SEM images show uniform coverage of nanoparticles on substrates for complimentary DNA while none coverage for non-complementary ones. Magnetization curves show much higher moment per unit area for complimentary DNA as compared to non-complimentary ones. Significant changes in the senor resistance due to the presence of only tens of nanoparticles have been observed. These demonstrate that monodisperse, surface functionalized iron oxide based nanoparticles can indeed serve as labels for highly sensitive DNA sequence detection.

SESSION I10: Novel Magnetic Nanostructures and Fabrication Techniques
Chair: Shan X. Wang
Wednesday Afternoon, December 1, 2004
Independence W (Sheraton)

3:15 PM *I10.1
Pulse Thermal Processing: A Revolutionary Approach for Processing Nanomaterials. Puja Kadolkar, Ronald D. Ott and Craig A. Blue; Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Pulse Thermal Processing using High Density Infrared (HDI) Plasma Arc Lamp has been investigated as an enabling manufacturing tool for processing nanomaterials and thin-films. HDI acts as a single source lamp offering unique capabilities of processing broad areas with power densities approaching that of a laser. The extremely high radiant energies delivered by the plasma arc lamp provides heating rates in the order of 2,000 C/s to 20,0000 C/s through a single pulse on a millisecond time frame, thus allowing controlled diffusion on a nano-meter scale. The ability to design the functionality of nanomaterials offers tremendous potential to exploit this technology for a wide range of applications based on nanotechnology. This present article discusses application of HDI to perform a) phase transformation in FePt nanoparticle systems for magnetic media applications b) precise control of sintering of TiO2 nanoparticles for photovoltaic applications and c) crystallization of amorphous Si for photovoltaic and thin-film transistor (TFT) applications.

3:45 PM I10.2
Phase-Controlled synthesis of Cobalt Nanoparticles Using a Microfluidic Reactor. Yujun Song, Edward Doomes, Zhanhu Guo, Challa Kumar and Josef Hormes; Center for Advanced Microstructures and Devices, Louisiana State University, Baton Rouge, Louisiana.

A key requirement for the realization of nanotechnology's technological potential is the ability to produce nanoparticles with well defined, tailored properties in a cheap and reproducible way. Though claimed by many groups, such a controlled synthesis is not yet possible e.g. for metallic nanoparticles. There are strong indications in the literature that every detail of the synthesis reaction is influencing the final product and its properties. Thus, a crucial step towards a controlled synthesis of nanoparticles is the detailed understanding of the various chemical processes that take place during the synthesis of nanoparticles. The control of nanocrystal size, shape and structure is even more important in the case of cobalt nanparticles as Co possesses multiple crystal structures very close in energy and there is strong correlation between crystal structure and the magnetic properties. For permanent magnetic application such as recording media, anisotropic high magnetic coercivity hcp phase is the preferred structure. The more symmetric fcc phase with low coercivity is useful for soft magnetic applications. Size and shape controlled synthesis of cobalt nanoparticles have been reported recently by

several groups. At CAMD, we are using mainly synchrotron radiation based X-ray absorption spectroscopy (EXAFS and XANES) for determining these electronic and geometric properties and standard squid measurements for the magnetic properties. The analysis of EXAFS and XANES spectra, respectively, provide detailed information about geometric and electronic structure around the excited atom (type and number of neighbours in the next coordination shells, radial distance to these shells, valency of the excited atom, electronegativity of neighbouring atoms etc.) and because these measurements do not require long-range order, they are especially suitable for nanoparticles. In this contribution we discuss several examples of changes in the electronic and geometric properties of Co - nanoparticles caused by the variation of various parameters during the wet chemical synthesis (surfactants etc.). Then we present results showing that cobalt nanoparticles of controlled crystal phase can be prepared using a newly developed microfluidic reactor by manipulating flow rates and quenching times. -Whereas a high flow rate (0.9ml/min) of reactants followed by quick quenching of the reaction generates a fcc phase, a low flow rate (0.084ml/min) followed by quick quenching provides hcp phase and a low flow rate(0.084ml/min) with slow quenching results in epsilon -phase.

4:00 PM I10.3
Pulsed Filtered Vacuum Arc Deposition of Magnetic Multilayers and Nanocomposite Thin Films. Y.W. Lai[1], M.F. Chiah[1], N. Ke[1], W.Y. Cheung[1], Quan Li[3,2] and S.P. Wong[1,2]; [1]Dept of Electronic Engineering, Chinese University of Hong Kong, Shatin, Hong Kong; [2]Materials Science & Technology Research Center, Chinese University of Hong Kong, Shatin, Hong Kong; [3]Dept of Physics, Chinese University of Hong Kong, Shatin, Hong Kong.

We have developed a pulsed filtered vacuum arc deposition system consisting of three arc sources operating in pulse mode. A plasma of the cathode material is formed by arc discharge between the cathode and the anode initiated by a triggering pulse of one μs pulse width while the arc current pulse width is 2.5 ms. The plasma is guided to the substrate through a bent magnetic field to filter out the neutral and macro-particles. The composition of the deposited film can be conveniently controlled by varying the discharge conditions and pulse sequences of the respective arc sources, and by monitoring the integrated charges arriving at the substrate from the respective sources. This system has been applied to fabricate magnetic multilayers and nanocomposite thin films of various compositions. Examples include CoAg granular thin films, Co-C, CoPt-C, FePt-C, FePt-Cu, FePt-Ag and PrCo-C nanocomposite films of various compositions, as well as FePt-C multilayers. The structural and magnetic properties of these films and their dependence on the composition and thermal processing conditions will be reported. In particular, results on an attempt to lower the ordering temperature to form fct-FePt-X (X=C, Cu or Ag) nanocomposite films by a multilayer deposition plus rapid thermal annealing approach will be reported and the mechanisms leading to the ordering temperature lowering will be discussed. This work is supported in part by the Research Grants Council of Hong Kong SAR (Ref. Number: CUHK4216/00E).

4:15 PM I10.4
Preparation of Magnetic Hollow Spheres of Submicrometer on Polystyrene-Bead Templates. Kunio Awaga[1], Hirofumi Yoshikawa[1], Kenta Hayashida[1], Yasuharu Kozuka[1], Asami Horiguchi[1], Shunji Bandow[2] and Sumio Iijima[2]; [1]Dept. of Chem., Nagoya Univ., Nagoya, Aichi, Japan; [2]Meijo Univ., Nagoya, Aichi, Japan.

Macro-size ferromagnetic materials generally form domain structures to reduce their magnetostatic energy, but the formation of domain walls is not energetically favored in small magnets of micrometer or submicrometer. In particular, ferromagnetic dots of this size, are known to exhibit a curling spin configuration? that is, a magnetization vortex, in the case that the thickness is much smaller than the diameter. In this context, the preparation of magnetic hollow submicron-spheres is a promising approach for developing new magnetic phenomena. In the present work, we prepared magnetic hollow spheres of fcc-Co, Co3O4, Ln2O3 (Ln= Dy, Ho, Er, Eu), etc. with diameter 500 nm and thickness 40 nm, using polystyrene-bead templates. To prepare the magnetic hollow spheres, at first, the 600nm PS beads were coated with basic carbonate salts of the metal ions by a controlled hydrolysis of urea. PVP was used to prevent the PS beads from aggregation. Hollow spheres of the metal oxides were prepared by calcination at 500 deg. C. in air, whereas metallic cobalt hollow particles were obtained by calcination at 500 deg. C. under a 1:1 mixed gas of H2 and N2. SEM and TEM images confirm that the spherical shapes were maintained even after calcinations and the inside is empty. The mean diameters of these particles were estimated to be ca. 500 nm with a thickness of ca. 40 nm from the SEM images. This shrinkage from the original PS bead is probably caused by the evaporation of the PS beads and volatile elements in the inorganic layers during calcination. The macroscopic magnetic measurements on the Co particles indicated that they are a very soft ferromagnet with a coercivity of ca. 40 Oe. The measurements on Co3O4 revealed the antiferromagnetism with TN=30 K below which an unusual FC magnetization appeared. The Ln2O3 particles were found to be antiferromagnets. I will discuss the shape effects on the magnetic properties.

4:30 PM I10.5
Field-Induced Magnetic Anisotropy in Ball-Milled Powder Particles. N. Poudyal[1], B. Altuncevahir[1], V. Chakka[1], K.-H. Chen[1], T. Black[1], J. P. Liu[1], Y. Ding[2] and Z.L. Wang[2]; [1]University of Texas at Arlington, Arlington, Texas; [2]Georgia Institue of Technology, Atlanta, Georgia.

Nd2Fe14B and Sm2Co17 particles of sub-micro sizes have been prepared by ball milling. Structural and magnetic characterization reveals that these sub-micron particles consisting of nano-size grains exhibit strong magnetic anisotropy when they are milled in a magnetic field. The remanent magnetization to saturation magnetization ratio (Mr/Ms) for the field-milled samples is remarkably higher than those milled without field. The increase of the Mr/Ms value upon field milling is in the range from 15 to 25%. X-ray diffraction analysis confirms the alignment of nanograins in the field-milled particles. Based on in-situ observations of the in-field ball milling in a transparent container, the mechanism of the field-induced anisotropy in the nanostructured hard magnetic particles is discussed.

4:45 PM I10.6
Defect Induced Magnetism in Nano Diamonds. Saikat Talapatra[1,3], T. Kim[1], J. Cheng[1], M. Shima[1], M. B. Huang[2], R. Vajtai[3] and P. M. Ajayan[1,3]; [1]MS & E, Rensselaer Polytecnic Institute, Troy, New York; [2]Physics, SUNY, Albany, New York; [3]Rensselaer Nanotechnology Center, RPI, Troy, New York.

The placement and measurement of individual electronic state or nuclear spins arranged in regular arrays on surfaces of bulk solid-state materials are recently suggested as basic building blocks for new technologies for ultra high-density data storage and / or computing via Quantum Cellular Automata (QCA) or Quantum Computing (QC) architectures. The basic experimental requirements in this approach are the ability to fabricate regular arrays of nuclear spins, individual atoms, and isolated electronic states on solid surfaces or in bulk materials beneath surface layers. The main problem in fabricating such structures and devices is the experimental difficulty in placing individual spins, atoms, or ions in regular arrays in bulk solid-state materials. One possible solution is to instead use encapsulated nuclear spins, ions or metal atoms clusters with in few nanometer sized fullerenes, bucky onions or diamond nanocrystallites, and fabricate the required arrays for posssible molecular computing and or data storage application. A possible mechanism for creating such structures could be achieved through ion implantation. In this study we report on the results of magnetic measurements performed on nitrogen (15N) and Carbon (12C) ion implanted nano diamonds (NDs) with implant energy of 100 KeV for different doses. Room temperature magnetic measurements on the doped NDs show an evidence of ferromagnetic hysteresis behavior. We propose that this behavior is due to the implant induced structural modification of the nano diamonds. The ion beam generates a mixture of sp3/sp2 bonded carbon network in the ND system which behaves ferromagnetically. The extent of magnetization from both types of implants are compared and discussed on the basis of the magnetic measurements. These results could lead to a better understanding of the ion implantation pathways into nano particles for encapsulation as well as magnetization and /or electronic/ nuclear spin applications in the high density memory or solid-state quantum bits areas, respectively.