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-Institut für Physik
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
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 depending upon the bias condition, exciting 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 beyond the previous bottom-up strategies may 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
temperature. Structures as thin as 5nm Ti / 20nm CoCrPt exhibit perpendicular magnetic crystalline anisotropy due to preferential growth of the CoCrPt layers on 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 periodic layer deposition diameter of about 25 nm. We carry out 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 arrays, that is, the patterns of dots on the wafer, over large areas by the use of topographic substrate features, making the structures promising candidates for patterned media and other applications.

9:45 AM 11.4 Design and Synthesis of Core-Shell Magnetic Nanoparticles and the Application of Nanoparticles in the Fabrication of Arrays of Magnetic Nanostructures. Hong-Yong Tong1, and Qijie Guo1, 2. 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, such as exchange coupling in 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 29 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. 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 temperature [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 as platinum-iron oxide, with different FePt alloys 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 dispersive 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, 12436. [3] Q. Guo, X. Teng, S. Rahman, H. Yang, J. Am. Chem. Soc., 2003, 125, 630.

SESSION 12: Magnetic Multilayer Films and Nanocomposite Materials

Chair: Caroline Ross

Monday Morning, November 29, 2004
Independence W (Sheraton)

10:30 AM 12.1 (FeCo/Cu) Multilayer Structures as Strain Gauges. Stefano Dokupil, Milan-Thomas Boothman, 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 in combined magnetic layers [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 magnetostriective 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. In this presentation, we will show that the stress-induced characteristics of this (FeCo/Cu) GMR trilayer and multilayer systems in which the positive magnetostrictive FeCo and the negative magnetostrictive Ni replace the sensing and reference layer of the 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 magnetic sensing layer. Loehndorf, M., Dokupil, S.; T.; Tews, M.; Quandt; E., Ruehrig, R., Wecker, J.: Highly sensitive strain sensors based on magneto tunnel junctions (MTJs). Appl. Phys. Lett., 81 (2002), 213 [2] Loehndorf, M.; Dokupil, S.; Wecker, J.; Ruehrig, R.; Quandt, E.: Magnetostrictive free layer materials. J. Magn. Magn. Mater., 272/276 (2004), 2023.


Conventional magnetic thin film sensors using giant magnetoresistance (GMR) and tunneling magnetoresistance (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 axis 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 the only pinned layer has perpendicular easy axis. The perpendicular anisotropy of the free layer is slightly smaller than its demagnetizing field (4Pi Ms). 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 perpendicular easy axis, while the pinned layer is 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 a 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. Herein in order to achieve both high sensitivity and proper operating field range, the materials for the layers with perpendicular magnetic 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.


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 magnetic properties, the magnetic field dependence of the ring, and the effect of the 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-diffraction lenses to generate arbitrary patterns on the surface of a photore sist-coated substrate. Single ferromagnetic layers and exchange-biased thin film structures, which were patterned using ZPAL, were employed as ferromagnetic and antiferromagnetic layers, respectively. They were deposited using dc-triode magnetron sputtering on elliptical rings of different widths. The films were deposited in a magnetic field resulting in exchange pinning parallel to the long axis of the elliptical. 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 layer.
exhibited asymmetric two-step hysteresis. After the elliptical-rings were saturated opposite to the pinning direction, the first switching from an onion state to a vortex state occurred at 5 Oe before an external 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, which was used to cancel remanence and confirm this behavior and shows remnant vortex states in the first case and remnant 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 A thicknesses, a remanent field of 400 Oe, and a coercivity of 700 Oe 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 12.4
Investigation of Exchange Coupling in Thickness Gradient Fe/Sm-Co and Co/Sm-Co Magnetic Bilayers: Minghui Yu1, 2, J. Hattrick-Simpers1, H. Ougiuchi3, I. Takeuchi3, J. P. Lin3, S. E. Loffland3, J. W. Freeland3, L. A. Binder5 and D. Josell1; 1Materials Science and Engineering, University of Maryland, College Park, Maryland; 2Department of Physics, University of Texas at Austin, Arlington, Texas; 3Department of Physics, Rowan University, Glassboro, New Jersey; 4Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois; 5Materials 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 magnetic component and the high magnetic 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 interface 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 exchanged hysteresis loops using 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 12.5
Characterization of the Distribution of Fe Particles Included in Carbon Nanotubes by SQUID Measurements: Cheol Eui Lee1, Jae Won Jang1, Kyu Won Lee1 and Cheol Jin Lee2; 1Physics, Korea University, Seoul, South Korea; 2Nanotechnology, Hanyang University, Seoul, South Korea.

We have controlled the Fe catalyst particle distribution in multilayer carbon nanotubes (MWNTs) by means of a phase growth of 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 Fe particles 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 remnant magnetization of Fe particles with changing Fe concentration.

11:45 AM 12.6
Magnetic Properties of FeCo Nanoparticles Dispersed in Aluminum Acrygel Matrix: Andrea Palpi, 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 sizes and temperatures which can be strongly affected by interparticle interactions; moreover, FeCo supported particles can be exploited for catalytic applications. In this work, nanocrystalline γ-Al2O3 and Fe-Co-Al2O3 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 these materials was performed by means of small-angle 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-Al2O3 occurs via a sequence of stages: in the parent aerogel an alkyldervative of boehmite is observed, whose calcination gives rise to a disordered product finally to γ-Al2O3 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-Al2O3 where metal ions partially fill the vacancies. Nanocomposites constituted of FeCo alloy nanoparticles dispersed into γ-Al2O3 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 cristalline 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 13: Spintronics

Chairs: Yiming Hua and Jian-Ping Wang
Monday Afternoon, November 29, 2004
Independence W (Sheraton)
impact further developments in this rapidly advancing field.

2:00 PM 13.2

**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 5 to 10 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 has been demonstrated. The work presented previously [1] is now complemented with logical AND/OR nanowire junctions and additional elements for signal fan-out and signal cross-overs. The demonstrator is 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 13.3

**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-based systems, such as non-volatile, rapidly re-configurable, 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 experimental results are achieved 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 be realized based on a normal pinned and a synthetic pinned structure MTJ element. The XOR gate is proposed for the first time. A Weston-bridge was designed and fabricated to read this one MTJ element logic device. MTJ elements 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 the magnetic 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 where similar samples have been excited by short in-plane magnetic pulses (stroboscopic "pump-and-probe" experiments). The advantages and disadvantages of our novel approach 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 in-plane ac excitation field. A sharp threshold was observed: A change of the excitation field by 1 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) measurement at the STXM. In addition, the thre way MTJ 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. Tamura and J.A. Barn, J. Appl. Phys. 91, 8034, 2002 (2002) / S.-B. Choe et al., Science, 304, 420, 2004 /3/ H. Stoll et al., Appl. Phys. Lett., 84, 3328, 2004.

2:30 PM 13.5

**Trends in Nano-Scaled Magnetic Reader Transducer Song S Xue, Patrick J Ryan Advanced Transducer Development, Seagate Recording Head, Minneapolis, 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 decreases, the performance degradation becomes more pronounced, and the need for new technologies that allow for continued improvement in are density becomes more critical. As a result, there have been many efforts directed at improving the magnetic reader typically has a reader width less than 100 nm. As the reader width decreases, the performance degradation becomes more pronounced, and the need for new technologies that allow for continued improvement in are density becomes more critical. As a result, there have been many efforts directed at improving the performance of the magnetic reader. One such technology is the spin-valve transistor. This technology has been used to improve the performance of the magnetic reader by increasing the total signal-to-noise ratio of the system, increasing the commercial viability of the spin-valve transistor. In the currently topical field of Spintronics, it is the spin of the electron, rather than the charge, that is to be characterized. 3:30 PM 13.6

**Avalanche Spin-valve Transistor. Kasey Joe Russell 1, Ian Appelbaum 1, Wei Yi 1, Douwe Momma 2, Federico Capasso 1, Charles Marcus 2, Venkatesh Narayananmurti 2, Micah Hannon 2 and Arthur Gossard 2; 1Harvard University, Cambridge, Massachusetts, 2Materials, 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 output. Here, a spin-valve transistor with a GaAs/AlGaAs avalanche-multiplying collector is demonstrated, and greater than 10000% magnetoresistance variation is obtained at 5x multiplications. The avalanche-multiplying collector 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 13.7

**A Novel Method for Fabrication of Magnetic Spin Valves. Shashi Paul, Aloke Kuwai and Manish Chhiowal; Ceramic & Materials Engineering, Rutgers University, Piscatway, New Jersey.**

In the current topical field of Spintronics, it is the spin of the electron, rather than the charge, that is to be characterized. Spintronics behavior. There is active interest in the search for new materials in which charge carriers can be injected by preferential spin orientation that can be controlled in the material. Recently, the use of "conjugate organic semiconductor spin-valves" [1] have been reported in this context. In both these reports the used material is Manganese, which is a ferromagnetic material with a 100% spin polarization. The polymer and Manganese, acting in concert, have been observed to enhance the magnetoresistance by 30% to 40%. A model explaining the use of polymer spin-valves has been proposed by Xie et. al [5]. Thus, in this case, it is suggested that the 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 spin orientation up to a certain length within 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.
In this work, we prepare a blend of poly-vinyl-phenol (PVP) and CrO₂ particles to use as a spin valve; the size of the CrO₂ particles around 1 μm. A thick film of a PVP and the CrO₂ 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 CrO₂ blend to improve the magnetoresistance properties of our spin valve devices. I. V. Dedić, M. Murgia, F. C. Matsuoka, C. Taliani, S. Barbanera, Solid State Communications, 181, 122 (2002). Z. H. Xia, Z. Valy Vardany, and Jing Shi, Nature, 427 (2004). S. J. Xie, K. H. Ahn, D. L. Smith, A. R. Bishop, and A. Saxena, Phys. Rev. B, 125202, 67 (2003).

Effective Magnetoviscosity of Ferrofluids Planar-Couette Flow. Xiaowei He and Marius 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 magnetocytosynthesis treatment of cancer. New ferrofluid applications involve ferrohydrodynamic properties of ferrofluids. Ferrofluid spin velocity, shear stress, and magnetoviscosity are calculated for a planar-Couette ferrofluid, with applied uniform DC magnetic fields parallel and transverse to the duct axis using Shilinov's 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.

Permanently Linked Rigid Superparamagnetic Chains. Harpreet Singh, 1 T. Alan Hatton and Paul E. Laibinis, 2; 1Department of Chemistry, The University of Alabama, Tuscaloosa, Alabama; 2Department of Nuclear Engineering and Radiological Sciences, The University of Michigan, Ann Arbor, Michigan.

Magnetoreheological (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 polysiloxane beads modified by the layer-by-layer technique. The dynamic response of these chains to an external applied magnetic field was also modeled.

Structural and magnetic properties of Al₂O₃/Ni₃AlFe₂O₄ thin films: From superparamagnetic nanoparticles to ferromagnetic multilayers. Inna L. Sokolets, 1 Björnvin Björnsson, 1 Per Norlen, 1 and Jun Lu, 2; 1Physics, Uppsala University, Uppsala, Sweden; 2Material Science, Uppsala University, Uppsala, Sweden.

[Al₂O₃(18Å)/Ni₃AlFe₂O₄(8-30Å)]ₙ 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 spin-induced magnetization in such multilayers is proportional to the 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.


Iron oxide (magnetic) nanocrystals were synthesized in non-coordinating solvents by thermal decomposition of iron (III) carboxylate salts. This approach produces highly monodisperse materials (z = 5-15%) in sizes ranging from 6 to 30nm. The attractive feature of this approach are the (a) large amounts of 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 long period. This method may become a general strategy for the synthesis of high quality metal oxide nanocrystals.
Self-Assembly of Magnetic FePt and FePt(M) Nanoparticles. Xiangcheng Sun1, David E. Nilde2, Kai Sun3 and Lumin Wang4;

1Chemistry Depart., Rutgers, The State University of New Jersey, Piscataway, New Jersey; 2Center for Materials for Information Technology, State University of New Jersey, Piscataway, New Jersey, Tuscaloosa, Alabama; 3Nuclear 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 oleylamine. The observed TEM grids samples were obtained by dropping dilute solutions of monodispersive FePt or FePt(M) nanoparticles onto carbon-coated copper TEM grids, and the solvent was allowed to evaporate at room temperature for 60 min. As-prepared particles have a chemically disordered face-centered cubic lattice with average diameter of 4–8 nm and are superparamagnetic. These magnetic particles are 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 dipole 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 magnetic controlled with uniform size and composition distributions. References [1] S. H. Sun et al., Science 287 (2000)1889. [2] H. Zeng et al., J. Amer. Chem. Soc. 121 (2000) 2055. [3] X. C. Sun et al., J. Appl. Phys. 93 (2000) 7337.

Optimization of Fe/Co Nano-Particles Composite for RF Application. Philippe Renaud1, Celine Desvaux2, Peter Fejes3, Catherine Amiens4 and Bruno Chaudret5, 1TSO, Freescale Semiconductor, Toulouse, France; 2Freescale Semiconductor, Toulouse, France; 3LCC, 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 on Fe/Co nanoparticles synthesized by organometallic precursors, where optimized process conditions led to elemental redistribution within particles and 3D organization into densely packed supercrystals. Microscopic observations were carried out through transmission electron microscopy (TEM) and X-ray diffraction patterns. The results were compared with those obtained for Fe and Co nanoparticles that have been responsible for the 2-D or 3-D self-assembly process. It is crucial to prepare the magnetic controlled with uniform size and composition distributions. References [1] S. H. Sun et al., Science 287 (2000)1889. [2] H. Zeng et al., J. Amer. Chem. Soc. 121 (2000) 2055. [3] X. C. Sun et al., J. Appl. Phys. 93 (2000) 7337.

A new nanocomposite was made of core/shell Fe3O4 nanoparticles coated with a copolymer brush. The Fe3O4 cores were synthesized by the solvothermal method. The core/shell structure was prepared by the grafting of alkoxy groups followed by addition of mercapto groups. The surfactant molecules were then removed by heating in a solution of toluene to give a final product. The Fe3O4 cores were embedded in a copolymer chain, which makes the Fe3O4 core-shells very stable against oxidation. The magnetic properties of the copolymer-shelled Fe3O4 nanoparticles were measured using a SQUID magnetometer and AC permeabilities up to 18GHz were demonstrated. Fe3O4 particles were prepared from Fe(II) and Fe(III) salts in a mixture of hydroxide and ethanol. The Fe3O4 nanoparticles were then coated with a polymer chain via copolymerization. The polymer chains were then grafted onto the Fe3O4 nanoparticles using aminated groups. The final product was then characterized using a SQUID magnetometer and AC permeabilities up to 18GHz were demonstrated. Fe3O4 particles were prepared from Fe(II) and Fe(III) salts in a mixture of hydroxide and ethanol. The Fe3O4 nanoparticles were then coated with a polymer chain via copolymerization. The polymer chains were then grafted onto the Fe3O4 nanoparticles using aminated groups. The final product was then characterized using a SQUID magnetometer and AC permeabilities up to 18GHz were demonstrated. Fe3O4 particles were prepared from Fe(II) and Fe(III) salts in a mixture of hydroxide and ethanol. The Fe3O4 nanoparticles were then coated with a polymer chain via copolymerization. The polymer chains were then grafted onto the Fe3O4 nanoparticles using aminated groups. The final product was then characterized using a SQUID magnetometer and AC permeabilities up to 18GHz were demonstrated. Fe3O4 particles were prepared from Fe(II) and Fe(III) salts in a mixture of hydroxide and ethanol.
or an extraction magnetometer (x ≈ 26, 30); maximum applied field: 50 kOe in both cases. The magnetoresistance was measured by the four-contact technique. Nickel (Ni) and copper (Cu) films were prepared at room temperature by a DI Nanoscope workstation. The films with x ≈ 14 can be pictured as interacting superparamagnets [1], with Fe particle size of the order of 2 nm, while the films with x ≈ 26 magnetize through coherent magnetic domains. The nanowires, 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 500 K. When plotted vs. reduced magnetization, the MR curve of the systems richer in Fe (x ≈ 26) exhibits a box-like behavior distinctive of the proximity magnetoresistance proper of concentrated magnetic systems with competing interactions [2]. On the other hand, in the system richer in Ag, it displays a 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 1 at all temperatures for x ≈ 14 (indicating a frustrated ferromagnetic behavior with ultrashort magnetic coherence length), while it is of the order of unity for x ≈ 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 preparation 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 [3]. P. Allia et al., Phys. Rev. B64, 144420 (2001) [2]. P. Allia et al., Phys. Rev. B67, 174412 (2003).


Semicontacting and magnetic nanoparticles are attracting interesting 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 shape, size, 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 size calculated from the 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.


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 resistance 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 change at different orientations. The magneto-resistance behaviors are discussed based on domain wall properties.


Catalyst-assisted growth of single crystal calcium hexaboride (CaB₆) nanowires was achieved by pyrolysis of diborane (B₂H₆) over calcium oxide (CaO) powder at 850-900 degree C and 135 Torr in a quartz tube furnace. Calcium/Palladium (Ca/Pd) surfaces were 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/ELS data proves the magnetic order of large, smooth particles. The CaB₆ nanowires have diameter of 15-40 nm, and length of 1-10um. Such CaB₆ nanowires have potential applications in nanocomposites and nanoelectronics. Moreover, they can be used for observation of the currently controversial magnetic and electrical properties of CaB₆, but on nanoscale samples. We appreciate the support of the National Science Foundation (grant EEC-0210126), and the Office of Naval Research grant (No. N000140210870).

14.15 Highly Magnetic Nickel Nanostrands Fabrication of a new High Aspect Ratio Nanoparticle. George Hann1, Matt Pettit2 and Max D. Alexander3. 1Polymer Branch, Air Force Research Laboratory, Dayton, Ohio; 2Metal 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 3 micrometers to a few microns in diameter by several 1000 micrometers. 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 specimen 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.

14.16 The Use of Hexagonal Mesoporous Silica Matrices for the Preparation of Controlled-Anisotropy Iron Nanowires. Andrey Anatolievich Pleshanov1, Kirill Sergeevich Napoleon2, Irena Valerievna Kolesniki2, Alexey Viktorovich Lukashin1, Yuri Dmitrievich Tret’yakov1, Peter Goernert1, Natalia Anatolievna Grigorieva3, Sergei Grigoriev3,4 and Alexey Vorobiev3,4. 1Department of Materials Science, Moscow State University, Moscow, Russian Federation; 2INVENT e.V., Jena, Germany; 3St-Petersburg State University, St-Petersburg, Russian Federation; 4St-Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg, Russian Federation; 5Institute 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 data density and access rate. However, usually very small (10-1000 nm³) magnetic nanoparticles shows para- or superparamagnetic properties, with very low blocking temperatures and no correlation 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 source for synthesis of anisotropic systems due to the limitation of reaction zone by the pore walls. Here we suggest a novel variant of synthesis of ordered magnetic nanoparticles 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 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 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 µm. The use of these wires for magneto-transport measurements, 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 nanoactive elements in the matrices, which could find an application in various
Mm.

a-Fe

The aspect ratios of these magnets.

from 650 to 800 0 C in an inert atmosphere. The materials have been fields at room temperature (e.g. 1500

sensitivity than AMR sensors to detect the magnetic field and field

obtained from a template having 100 nm diameter pores show relatively rougher diameters in range of 46 nm to 50 nm, and

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).

We describe the production of aligned multi-walled carbon nanotubes filled with Fe-Co alloys. The method involves the aerosol thermalization of toluene-ferrocene-cobaltocene solutions at temperatures ranging from 650 to 800 0 C in an inert atmosphere. The materials have been carefully characterized using state-of-the-art high-resolution transmission electron microscopy (HTETM), energy electron loss spectroscopy (EELS), scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX), electron diffraction, HREM-STM elemental mapping, X-ray powder diffraction and SQUID magnetometry. The results indicate that different stoichiometries of Fe-Co alloys could be produced at different temperatures. We noted that the formation of Fe-Co 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 Fe-Co alloy phase in the carbon nanotube matrix. The Fe-Co 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.

Magnetic nanostructures with GMR for the Detection of Movement of MEMS Microgears. Neamtu G. Jenica1,2; I University of Wisconsin, Madison, Wisconsin; 2Northwestern University, Evanston, Illinois.

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 some nanometers. When the magnetic field lies in the film plane the measured voltage is produced when the magnetic field is applied normal to the film plane. This effect has been found

the magnetic field is applied normal to the film plane are less

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, the tunnel junction magnetoresistance is dependent on the relative orientation of the magnetization vectors in the adjacent magnetic layers. Broadly, when the magnetic field is applied normal to the film plane the measured voltage is 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 for a film the magnetic nanostructures are attractive candidates for use as movement sensors.

Synthesis and Characterization of BiFeO3 Nanotubes. Tae-Jin Park1, Yuanbing Mao2 and Stanislaus S. Wong2; 1Chemistry, Stony Brook University, Stony Brook, New York; 2Materials and Chemical Sciences, Brookhaven National Laboratory, Upton, New York.

Polycrystalline bismuth ferrite (BiFeO3) multiferroic nanotubes have been fabricated using a modified sol-gel technique. As-synthesized BiFeO3 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 ratio of these BiFeO3 nanotubes reach larger than 150:1. BiFeO3 nanotubes obtained from a template having 100 nm diameter pores show relatively rougher diameters in range of 30 nm to 35 nm and lengths of up to several microns. BiFeO3 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).


The Cu-Co system has been widely investigated because it exhibits several promising multifunctional properties for structural, catalytic, 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.

Structure and Magnetic Properties of Shock Consolidated BiFeO3 Exchange-Coupled Multiferroic Hard Magnets. Zhiqiang Jin1,2, J. Ping Liu2 and Nareesh N. Thadhani3; 1School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia; 2Department 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 BiFeO3 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 nanocrystalline BiFeO3 powders and solid-state interparticle bonding were obtained, with retention and even refinement of the nanoscale 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-compression 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.

Size effect on the exchange-bias behavior in ferromagnetic La0.67Sr0.33MnO3 / SrRu03 bilayers. Xiaogang Ke1, Leland Belenky2, Chang-Beom Eom3, Mark Rachowski1, Dmitry Rudometov1, and Venkat Chandrasekhar1; 1University of Wisconsin, Madison, Wisconsin; 2Northwestern University, Evanston, Illinois.

Epitaxial La0.67Sr0.33MnO3 (LSMO) / SrRu03 (SRO) ferromagnetic bilayer has been grown on SrTiO3 (STO) substrates by pulsed laser deposition with atomic layer control. By magnetic field 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. Rachowski, L. J. Belenky, C. B. Eom, to appear on June 28th in Appl. Phys. Lett. [2] X. Ke, M. S. Rachowski, L. J. Belenky, C. B. Eom, to be submitted.

Magnetic and Transport Properties of Nanocomposite Fe/Fe3-xO4 and Fe3-xO4 Films Prepared by Plasma Deposition. Junbo Yang1,2,3, S. R. Mulk3, Xiaodong Zhou1, W. J.

14.17

14.18

14.19

14.20

14.21

14.22

14.23
Reflective, pinhole-free, Fe/Fe$_2$O$_3$ and Fe$_{1-x}$/Fe$_2$O$_3$ 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$_{1-x}$/Fe$_2$O$_3$ films (x > 7%) composite film shows that electrical characteristically decreases as the Fe-content decreases. The metal to insulator transition (MIT) temperature shifts to a higher temperature as compared to Fe$_2$O$_3$, due to the increased contribution of Fe. The Verwey transition 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$_{1-x}$/Fe$_2$O$_3$ film has a negative magnetoresistance (MR) of about 4% and 8% at room temperature and 80 K, respectively.

**14.24 Magnetic and Transport Properties of Ferromagnetic-PEEK Polymer Nanocomposite Prepared via Ion-implantation.**

Kartik C. Ghosh1, T. Keh1, T. Kamin1, S. Mishra2, R. Patel3, M. Curry1 and R. E. Giedd1; 1Physics, Astronomy and Materials Science, Southwest Missouri State University, Springfield, Missouri; 2Physics, 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 other properties that have promising 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 treated via beam-deposited nitrogen ions on a polymer poly ether ketone (PEEK) sheet pre-deposited with different thickness of magnetic thin film. The microstructure of nanocomposites was studied by scanning electron microscopy, X-ray diffraction, and magnetic force microscopy. The structural evaluation of the composite via TEM suggests the presence of very fine nanoparticles in the range 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 film. Characterizations such as electrical conductivity, magneto-transport and Hall magnetometry 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 magnetometry shows that 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.


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 (DMSs) and wide-gap semiconductors have attracted many research groups. Great interest has recently been 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 DMSs, the precise mechanism is still controversial. It is believed that in an intrinsic oxide, Ga$_2$O$_3$ is intrinsically an insulator with a band gap of 4.8 eV. 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 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$_2$O$_3$, (Ga$_{1-x}$Fe$_x$)$_2$O$_3$ 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$_2$O$_3$ powder and iron nitrate, Fe(NO$_3$)$_3$·9H$_2$O, as the starting materials, while the sintering above 900°C led to a canted spin magnetic 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 Ga$_{1-x}$Fe$_x$O$_3$ was obtained up to $x \approx 0.08$ with no indication of secondary phases or other impurity according to X-ray diffraction measurements. For the samples with $x \approx 0.08$, α-Fe$_2$O$_3$ (hematite) phase appeared, which is known to show canted spin magnetism. The hematite phase seems to have nothing to do with the magnetic behavior. This 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$_2$O$_3$ powder as iron source, α-Fe$_2$O$_3$ phase in addition to β-Ga$_2$O$_3$ phase was precipitated when the low-temperature sintering was attempted. The result suggests 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$_2$O$_3$. The reason for spin ordering in this system is now under investigation. It is, however, expected that this finding will help to elucidate the underlying mechanism for room-temperature ferromagnetism in the DMSs as in the recent report by Coey and coworkers, in which ferromagnetic coupling of ferric ions via an electron trapped in a bridging Fe center is proposed to explain the high Curie temperature. New mechanism of inducing ferromagnetism may be developed through this study.

**14.26 Effects of Defects on the Electrical and Magnetic Properties of Ga$_{1-x}$Mn$_x$As Layer.**

Dongwan Koh1,2, Jin-Bum Park1, Young Ju Park3, Jeoung Il Lee3, Chunjin Park4, Hooyong Cho5, Young Mi Kim6, Il-Weo Park7 and Koriun Soo Chung1; 1Nano Device Research Center, Korea institute of Science and Technology, Seoul, South Korea; 2Department of Physics, Dongguk University, Seoul, South Korea; 3Seoul Branch, Korea Basic Science Institute, Korea University, Seoul, South Korea; 4Department 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$_x$As with Mn mole fraction of x in the range of 0.03 ≤ x ≤ 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 clarified by the deep level transient spectroscopy measurement. The prime species of defects are found to be A$_{Ga}$ and M$_{As}$ etc.

**14.27 TRANSFERRED TO 18.4**

**14.28 Nanomagnetic Structures in (Ga,Cr)$_3$As$_3$. Abdellah Dakhama, Philip Crider, Nothin E. Baresford 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. The (Ga,Cr)$_3$As$_3$ 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 distributed magnetic moment (DMM) model in which cooperating ions in clusters are having a distribution of moments. The magnitude of the magnetic moments indicates an average dimension of 5 nm. STM images also reveal structures of particles 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 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).

**14.29 TEM studies of Magnetically Phase Separated La$_{1-x}$Sr$_x$CoO$_3$. Ryan S. Thompson, Chris Leighton, Jing Wu and C. Barry Carter; Dept. of Chemistry & 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 MgO-templated superconducting thin films. We have studied the magnetic inhomogeneity in Cobaltites by conventional magnetometry, magneto-transport, 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.


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 ultrasonic 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 a decreased 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 x less dissipation and we conclude that they will be suitable for use in MRFM on nuclear spins.

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

The modification of magnetic properties induced by high dose Sm ion implantation into magnet-sputtered FeCo$_{50}$Co$_{50}$ thin films on Si substrates has been investigated. For this, a combinatorial materials synthesis approach was applied in order to screen a wide range of magnet materials, shape, and temperature on dissipation and we conclude that they will be suitable for use in MRFM on nuclear spins.

14.32 Magnetic Phase Boundaries in Ferromagnetic Nanostructures. Scott Whitenberg 1,2 and Patrick Nicholson 1,2; 1Chemistry Dept., University of New Orleans, New Orleans, Louisiana; 2Advanced Materials Research Institute, University of New Orleans, New Orleans, Louisiana.

The magnetic phase for single domain ferromagnetic nanostructures is known to depend on geometrical factors. In this work, the most stable magnetic phase is determined for several geometries (rhomboids, 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.


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 of the new 2D MRAM cells. Therefore, it is important to study the response of such magnetic systems to fields applied along different directions with respect to each other, and to understand the role of 2D magnetic switching. In this work, we present a new method that 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 range of systems that include magnetic nanostructured materials with different dimensionalities as nanoparticles, 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 magnetisation reversal. We gratefully acknowledge support from DARPA grant No. MDA973-05-1-0012.

14.34 In-Situ Magnetic Field Induced Structure and Properties of Experimental Spinel Ferrite Thin Films Prepared by Pulsed Laser Deposition (PLD) (Dynamic Aurora PLD Method). Naekei Wakiya 1, Toyokazu Nagamune 1, Takanori Kiguchi 2, Kazuo Shinozaki 3 and Nobuyasu Mizutani 2,1; 1Department of Metallurgy and Ceramics Science, Tokyo Institute of Technology, Tokyo, Japan; 2Center 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]. 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 800°C is realized. We named this system as "Dynamic Aurora PLD". (001) epitaxially grown ferrite films with spinel structure ((Ni,Zn)Fe$_{2}$O$_{4}$, CoFe$_{2}$O$_{4}$, and MgO-$\text{Al}_{2}$O$_{3}$/Co$_{3}$O$_{4}$/YSZ-buffered Si(O01) substrate) were prepared on SrTiO$_{3}(001)$ and MgO-$\text{Al}_{2}$O$_{3}$/Co$_{3}$O$_{4}$/YSZ-buffered Si(001) substrate and the Dynamic Aurora PLD apparatus. Magnetic field during deposition causes spin flip of planar magnetic easy axis, and 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 on deposition on the thin film 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.

14.35 Nanostructure Control Made Dramatic Improvement in Characteristics of Magnetic Field of REBa$_{2}$Cu$_{3}$O$_{7}$ at 77 K. M. Miyahira Murayama 1, Saki Naomichi 2, Muramatsu Masatoshi 3 and Koshizuka Naomi 1,2; 1Superconductivity Research Laboratory, ISTEC-SRL, Morioka, Iwate, Japan; 2Superconducting Materials Laboratory, Shibaura Institute of Technology, Tokyo, Tokyo, Japan.

Melt processed high Tc superconductors have 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 magnet systems 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 necessary. This review reports on two nanostructure pinning media and their ways of their creation. Microstructure analysis by transmission electron microscopy (TEM) and scanning tunneling microscopy (STM) results are able to recognize the nanometer scale pinning defects, to show their magnetic field dependence and help to identify the key structural features responsible for the improved superconducting performance. The two new pinning agents extend the use of REBa$_{2}$Cu$_{3}$O$_{7}$ composites both towards high magnetic fields.
Fabrication of FePt/M (M = C, Ag) Nanoparticle Thin Films With Perpendicular Magnetic Anisotropy.

**SESSION 15: Magnetic Nanoparticles**

**Chairs:** Kornelius Niehaus and Eric Wegrowe

**Tuesday Morning, November 30, 2004**

**Independence W (Sheraton)**

**8:30 AM 15.1**

Fabrication of FePt/M (M = C, Ag) Nanoparticle Thin Films With Perpendicular Magnetic Anisotropy. G. C. Hadjipanayis1, J. Wan2, Y. Zhang2, Yunhe Huang2, and Dieter Weller1, Department of Physics, University of Delaware, Newark, Delaware; 2Seagate 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 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 350°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 film thickness is 4 nm. In FePt/Ag, 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 nanoparticles 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 15.2**

C-Axis Oriented L10 FePt Magnetic Nanoparticles Formed by Coupling Local-Epithaxity with Non-Epithaxity. Suguru Noda, Yoshiko Tsuji, Akira Sugiyama, Fumio Onoda, and Hiroshi Konyamya, Department of Chemical System Engineering, The University of Tokyo, Tokyo, Japan.

FePt is a promising candidate for high density perpendicular magnetic recording [1]. To be practically useful, FePt should have chemically ordered L10 structure, c-axis orientation, a few-nanometer particle size, inter-particle spacing, and in-plane 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 nanocrystals within matrices [4], and self-assembly of chemically synthesized core-shell nanoparticles [5]. However, all 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 with 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 to template and c-axis oriented 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. X-ray diffraction (XRD) analysis of the samples showed that the FePt nanoparticles have a out-of-plane coercivity of 6.2 kOe. This approach opens a new route to form nanoparticles on arbitrary substrates with good structural controllability. Work supported by JSPS and MEXT.

**10:00 AM 15.3**

Spontaneous embedment and self-organization of metallic nanoparticles in phospholipid multilayers.

Bernd F. Kellinghaus1, Anneteg Terheiden, Christian Mayer, Olga Dmitrieva2, and Mehmet Acet3, Institute for Metallic Materials, Dept. Metastable and Nanostructured Materials, IFW Dresden, Germany; 2Physical Chemistry, University Duisburg-Essen, Duisburg, Germany; 3Experimental Physics, AG Farle, University Duisburg-Essen, Duisburg, Germany.

Recently, we have shown that the deposition of gas-phase prepared metallic nanoparticles onto multilayers of phospholipids leads to the formation of two-dimensional positional order of the particles. This arrangement of particles in ordered patches of 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 deposition 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) heating up to T = 35°C under 30 min. 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 showed an increasing density of nanoparticle assemblies as the temperature 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. As 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. 1L. Terheiden, C. Mayer, M. Moh, B. Stahlecker, S. Stappert, M. Acet, and B. Kellinghaus, Appl. Phys. Lett. 84 (2004) 3891. 2L. Terheiden, B. Kellinghaus, S. Stappert, M. Acet, and C. Mayer. J. Chem. Phys. 121 (2004), 510.
9:45 AM 15.5
Synthesis of FePt/Fe3O4 and CoPt/CoFe2O4 Core-Shell Nanoparticles with Tunable Core Size and Shell Thickness. Min Chen1*, Shouheng Sun1, J. Ping Liu1, R. L. Sandstrom1 and C. B. Murray1; 1Department of NanoScience and Devices, IBM Watson Research Center, Yorktown Heights, New York; 2Department 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 limits their application in the superparamagnetism, leading to magnetic thermal instability of these spherical geometry. We systematically studied the magnetic properties of 

3D super-lattices of nanospheres and nanocubes, a true crystallization in the chemistry of the particles. In a second step, the lecture will describe the physical properties of the particles and the role of the different 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 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 emphasis will be devoted to the self-assembly of the particles and to the formation of 2D super-lattices of microcubes and 3D super-lattices of nanospheres and nanocubes, a true crystallization process. Some applications in physics and microelectronics will be described.

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 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 fromfcc 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 will relax the size of the particles, which have 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 15.6
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 spherical 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 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 fromfcc 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 will relax the size of the particles, which have 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.

11:00 AM 15.7

Colloidal magnetic nanoparticles (NPs) have many applications in magnetic recording, separations and biochemistry. After partially oxidizing Co NPs with H2O2, an exchange magnetic field of 0.3 Oe is observed when the Co NPs are spin-coated on a non-magnetic substrate. CoO NPs are subjected to annealing in a reducing atmosphere at different temperatures for different annealing conditions will also be discussed.

Acknowledgement: Research is supported in part by DARPA/ARO under grant DAAD 19-03-1-0038.

11:30 AM 15.8
Manipulation of Nickel Nanoparticles Deposited on HOPG. Massoud Atashbar1, Valery Bliznyuk2, Deep Banerji1 and Srikanth Singamaneni1; 1Electrical and Computer Engineering, Western Michigan University, Kalamazoo, Michigan; 2Electrical and Computer 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 1M Na2SO4, 0.1 M Na2SO4, and 0.1 M Na2SO4. Nickel nanoparticles were electrochemically deposited by cyclic voltammetry. 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 grooves 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 nanowires 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. The deposition of nanoparticles was 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.
A Novel Fabrication Technique for Interacting Ferromagnetic-metal Nanoparticle Systems: Fine-tuning of Particle Interactions

Diamonduro and Nanostructure Science for Magnetic Applications, Tonnai 3, Kensuke Akaigawa 3, Hiroshi Shinkai 2, Shingo Ikeda 3, Hideki Nanao 2, Chiharu Matsuoka 3, Takakn Kashiwagi 2,3, and Masayuki Hagiwara 2,3, Japan Science and Technology Agency, Saitama, Japan; 3Kazan University, Kazan, Russia; 4Hitachi Metals Ltd., Saitama, Japan; 5RIKEN, Saitama, Japan; 6Yokohama City Univ., Yokohama, Japan.

Macroscopic properties of interacting ferromagnetic-metal nanoparticle systems have been studied for decades. These systems have a strong potential for designing and fabricating novel electronic devices, such as spintronic devices and magnetic memories. 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 polyeimide (PI), films by applying a chemical surface modification technique. The technique involved a simple alkali treatment resulting in an ion exchange reaction, and subsequent 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 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 16: Magnetic Nanowires and Nanotubes

Chair: Bernd Rellinghaus and David J. Sellmyer
Tuesday Afternoon, November 30, 2004
Independence W (Shertton)

1:30 PM 16.1

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.


2:00 PM 16.2


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) nanopillar arrays performed. The time-resolved magnetic force microscopy 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 nano-pillars and 2.5 eV (30 000K) in Ni nanowires, for a current of typically 10 5 A/cm2 [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) Stochastic approach: the effective magnetic field, or spin-torque, appears as an effective temperature in the magnetic measurements. This 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 an 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]. [1] J.-E. Wegrowe, Phys. Rev. B 68, 214414 (2003). [2] Myers et al. Phys. Rev. Let. 89, 196802 (2002). [3] Urazhdin et al. Phys. Rev. Let. 91, 146803 (2003), [4] Fabian et al., Phys. Rev. Let. 91, 257209 (2003).

2:15 PM 16.3

Nanowire arrays for magnetoelectronics. Na hyoung Kim, Liwen Tan, Ryan Cobb, Jin Zuoi and Bethanie J.J. Studier; 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 aluminas were used as a template for growing nanowires from 10-100nm in diameter via electrochemical deposition. Nanowires 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 pore and the subjacent nanowires. Nanowires grown in nanoporous aluminas 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: applied magnetic field, the substrate magnetic and electronic properties of the nanowires vary with size and alignment. In order to achieve 3 terminal magnetoelectric nanodevices, Y-junction nanowires were also grown in Y-shaped nanoporous templates which were released by the SF6 anodization. These junction wires also provide the ability to connect two or more nanowires, which is critical to the long-term success of developing nanoelectronics. This work focused on Co Y-junction nanowires with 50nm tracks on 40nm trunks. The plan is to follow the softer of the two sizes (20nm in this case). Multiarrays of
Co/Cu have also been grown which enable the coercivity of each of the Co sizes to be exploited together. Magnetotransport measurement was made on magnetic nanowires to establish the magneto-transport properties and to demonstrate the effect of the junction and the interfaces on magnetoresistance.

3:45 PM 16.4
Synthesis of Cobalt/Polymer Composite Nanotubes.
Kornelius Niezgoda1, Fernando J. Castano2, Caroline A. Ross3 and Ramakumar Krishnan4. 1BMBF Nanotechnology Research Group, Max Planck Institute of Microstructure Physics, Halle, Germany; 2Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Magnetic nanowires and nanopillars 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 nanomaterials. 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 polyvinyl 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 4 to 6 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 Co nanotubes can be found on top of the membrane structure. Room temperature magnetic measurements show that the tubes above a lower saturation field parallel to their axes, while the in-plane direction is a harder axis. The magnetic properties on varying the thickness of the nanotubes will be discussed. This synthesis method is not limited to Co. We have also precipitated single Cobalt nanotubes can be found on top of the membrane substrate. The surfaces of the pores in self-ordered porous alumina membranes are wetted with a polyvinyl 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 4 to 6 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 Co nanotubes can be found on top of the membrane structure. Room temperature magnetic measurements show that the tubes above a lower saturation field parallel to their axes, while the in-plane direction is a harder axis. The magnetic properties on varying the thickness of the nanotubes will be discussed. This synthesis method is not limited to Co. We have also precipitated single Cobalt nanotubes can be found on top of the membrane substrate. The surfaces of the pores in self-ordered porous alumina membranes are wetted with a polyvinyl 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 4 to 6 nm. Decomposition of the precursor leads to the formation of thin-walled magnetic tubes with diameters of 160 - 450 nm and wall thicknesses of 4 to 6 nm. Decomposition of the precursor leads to the formation of thin-walled magnetic tubes with diameters of 160 - 450 nm and wall thicknesses of 4 to 6 nm.
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. 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 in nanometer-sized magnetic tunnel junctions (MTJs) with low resistance-area product (RA) ranged from 1-10 fJ/μm² and the Curie temperature Bottom Plateau. MTJ films were deposited in a magnetron sputtering cluster system. 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 and e-beam lithography. Spin-transfer switching has been consistently observed in patterned MTJs with dimensions down to 0.1 μm². Low switching current density Jc 10⁶ A/cm² has been achieved using low moment free layer CoFeB. High TMR values about 30% were obtained in spin-transfer induced switching and attributed to homogeneous and continuous thin Al₂O₃ barrier grown smooth bottom lead with a roughness (RMS) of 2-3 Å. This barrier could have potential application for a spin transfer based MRAM. 

clustering of secondary phases, including metallic Cr or Co, was found in extensive structural or spectroscopy measurements. An important conclusion of these studies was that Mn-doped InAs nanowires, unlike conventional magnetic materials, are not able to be treated as dilute magnetic semiconductors (DMS) rather than DMS. We also discuss possible spintronics applications of DMS. This work was supported by NSF/ECS #0224138 and by the Campbell Endowment at the University of Washington.

11:00 AM 18.2

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

Ferromagnetic semiconductor materials are promising materials for the realization of spintronic devices, and semiconductor nanostructures (dots, rods, wires) provide a context for exploring the dynamics of ferromagnetic ordering on the nanoscale. We have pursued manganese doping of size-tunable InAs semiconductor nanowires in order to discover potentially useful materials or magnetic semiconductors. The experiments also address the fundamental challenge of ferromagnetic nanostructures, including the use of impurities of limited solubility. Gold nanoparticles on GaAs(111) wafers were used to initiate the vapor-liquid-solid (VLS) growth of epitaxial InAs nanowires using trimethylindium (TMI) and arsine (AsH3) in a metalorganic vapor phase epitaxy (MOVPE) reactor. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) studies were used to study the growth direction and growth morphology. HRTEM was used to identify the branched nanowires. 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 18.3

Enhancement of Ferromagnetic Properties in (Ga,Mn)N Nanowires by Nitrogen Plasma Treatment. Joung Min Baik1, Yoon Shon2, Tae Won Kang1 and Jong-Lam Lee1; 1Materials Science & Engineering, POSTECH, Pohang, Kyungbook, South Korea; 2Quantum 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 higher coercivity and the ratio of remanence to maximum saturation magnetization (M/Ms) closed to 1. 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 MnCl2 powder in a horizontal CVD chamber under a flow of ammonia gas, 50 - 150 sccm. As 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 260 °C for 10 min. SEM images showed that (Ga,Mn)N nanowires had lengths up to hundreds of micrometers and diameters ranging from 50 to 150 nm. The Mn concentration in nanowires was determined by XPS measurements. The intensity of observed satellite peaks almost correspond to the concentration of Mn in nanowires. The experiments also address the fundamental challenge of ferromagnetic nanostructures, including the use of impurities of limited solubility.

11:30 AM 18.4

Room Temperature Ferromagnetism in Mn-ion Implanted Si: A New Diluted Magnetic Semiconductor. C. A. Arzoumanidis, M. Bolduc, A. Stollenwerk, M. B. Huang, F. Ramos and V. P. LaBella; College of NanoScience 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 work 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 analyses techniques were presented that indicate the perfection of the crystal structure after annealing, giving evidence that substitutional Mn may occur.

11:45 AM 18.5

Electronic Structure of the Strained (La,Ba)MnO3 Thin Films Studied by Hard X-Ray Core-Level Photoemission. Hideyuki Tanaka1, Yasutaka Takata1, Koji Horiita2, Munetsu Taguchi3, Tomoju Kawa1 and Keisuke Kobayashi3; 1ISIR-Sanken, Osaka Univ., Ikariy, Osaka, Japan; 2RIKEN/SPring-8, Sayo-gun, Hyogo, Japan; 3JASRI/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 photo emission spectroscopy is strongly required due to ex-situ treatment of films for device construction. (La0.85Ba0.15)MnO3 epitaxial thin films (thickness : 300nm) were prepared on Nb-doped SrTiO3 (001) single crystal substrate. Films were annealed in 1atm O2 for 10 hours. TC for films are 82K, 299K and 100K, respectively. After magnetization measurement by SQUID magnetometer, HX-PES measurements were performed at an undulator beamline BL29U 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, broad peak with shape 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 peaks corresponds to density of states (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 properties of films. Ref. [1]. Phys. Rev. B 64 (2001) 254418, [2] Appl. Phys. Lett. 83 (2003) 4860.
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 additionally compatible with standard preamplifiers 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 the used 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 even at a concentration of about 0.1 mg/mL 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 magnetic 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–bienain 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 nanoparticles, e.g., pyrolytic deposition 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 magnetoresistive mobility of Co and FeCo based samples, we combine 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.

**SESSION 110: Novel Magnetic Nanosystems and Fabrication Techniques**

**Chair: Shan X. Wang**

**Wednesday Afternoon, December 1, 2004**

**Indepedence (W-Sheraton)**

**3:15 PM 110.1**

**Pulse Thermal Processing: A Revolutionary Approach for Processing Nanomaterials**

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 20,000 C/s through a single pulse on a microsecond 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 Tb2O3 nanoparticle for photovoltaic applications and c) crystallization of amorphous Si for photovoltaic and thin-film transistor (TFT) applications.
submicrometer. Spherical shapes were maintained even after calcinations and the squid measurements for the magnetic properties. The analysis of several groups. At CAMD, we are using mainly synchrotron radiation on Polystyrene-Bead Templates. Kunio Awaga, Hirofumi excited atom, electronegativity of neighbouring atoms etc.) and coordination shells, radial distance to these shells, valency of the 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 phases 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 generated a low flow rate (0.084ml/min) followed by quick quenching provides bcp phase and a low flow rate (0.084ml/min) with slow quenching results in epsilon -phase.

4:00 PM 110.3 Pulsed Filtered Vacuum Arc Deposition of Magnetic Multilayers and Nanocomposite Thin Films. Y.W. Lai, M.F. Chinh, N. Ke, W.Y. Cheung, P. Quan, and S-P. Wong. 1st Dept of Electronic Engineering, Chinese University of Hong Kong, Shatin, Hong Kong. 2Materials Science & Technology Research Center, Chinese University of Hong Kong, Shatin, Hong Kong; 3Dept of Physics, Chinese University of Hong Kong, Shatin, Hong Kong.

We have developed a pulsed filtered vacuum arc deposition system consisting of three sources operating in pulse mode. A plasma of the cathode material is formed by an arc discharging between the cathode and the substrate 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 PtCo-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 fcc-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: CUKH1210/05E).


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, CoS4, Li2Co3 (Ln=Dy, Ho, Er, Eu), etc. with diameter 500 nm and thickness 40 nm, using polyurethane-bend templates. To prepare the magnetic hollow spheres, at first, the 600nm PS beads were coated with basic carbonates salt 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. TEM and SEM 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 CoS4 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 110.5 Field-Induced Magnetic Anisotropy in Ball-Milled Powder Particles. N. Poudyal, B. Allunaceul, Y. Chik additionally K.-H. Chen, T. Black, J. P. Liu, Y. Ding and Z.L. Wang. 1University of Texas at Arlington, Arlington, Texas; 2Georgia Institute of Technology, Atlanta, Georgia.

N2Fe214B 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 permanent 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.


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 a fcc phase, a low flow rate, and the ability to fabricate 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 clusters with few nanometer sized fullerene, bucky onions or diamond nanocrystals, and fabricate the required arrays for possible 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.