SYMPOSIUM I
Fabrication and New Applications of Nanomagnetic Structures

November 28 - December 1, 2004

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* 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, exciton 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 produce nanomagnetic devices suitable for the study of spin-transfer effects, and will discuss some of the materials challenges associated with the fabrication of improved spin-transfer devices. The objective of the tutorial is to provide attendees with a basic understanding of spin transfer and its potential for technological applications. A perspective on some of the materials science and physics challenges that need to be addressed for further advances in the field, both for expanded scientific understanding and for the development of significant applications, will be presented.

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

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

Instructor:
Robert A. Buhrman
Cornell University
temperature. Structures as thin as 5 nm Ti / 20 nm CoCrPt exhibit
perpendicular magnetic crystalline anisotropy due to preferential
growth of the CoCrPt layer along 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 period of 49 nm. The FePt nanoparticles are important precursors, as they can be used for creating multiphasic nanoparticles and nanocomposites with predetermined elements and designed nanostructures. I will discuss in this paper the design and synthesis of platinum-iron 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 couple the formation of core-shell nanoparticles one component at a time. Core-shell nanoparticles made in this way can have different core diameters and shell thicknesses. These core-shell nanoparticles can be converted into various single-phased or core-shell nanoparticles that contain various FePt alloys at the elevated temperatures [2]. The platinum-iron 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.

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; these involve magnetic exchange coupling/bias in particular. In this context, core-shell nanoparticles are important precursors, as they can be used for creating multiphasic nanoparticles and nanocomposites with predetermined elements and designed nanostructures. I will discuss in this presentation the design and synthesis of platinum-iron 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 couple the formation of core-shell nanoparticles one component at a time. Core-shell nanoparticles made in this way can have different core diameters and shell thicknesses. These core-shell nanoparticles can be converted into various single-phased or core-shell nanoparticles that contain various FePt alloys at the elevated temperatures [2]. The platinum-iron 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.

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exhibited asymmetric two-step hysteresis. After the elliptical-rings were saturated opposite to the pinning direction, the first switching from an onion to a vortex state occurred at 5 Oe before the Nanopillar 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 800 G is applied which was the case here confirming this behavior and shows remnant vortex states in the first case and remanent onion states in the second case. The ‘reverse onion’ state, which is not favored by the exchange bias, was not found in any MFM images of the films explored, neither was the twisted vortex 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 coercive field of 150 Oe and remanent fields of 58 Oe. This is an indication of the saturating field direction. Exchange-pinned and single-layer ring results will be compared, and micromagnetic simulation results will be discussed.


Materials Science and Engineering, University of Maryland, College Park, Maryland; 2Department of Physics, University of Texas at Arlington, 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 layer with 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 contact and stronger binding resulting in a more coherent interface between Fe and Sm-Co layers. Separate exchange couplings of the soft layer with Co and Sm in the hard layer are revealed through measuring the elemental dependence of the MOKE and XMCD technique. Results from bilayer libraries made by a combinatorial electron-beam evaporation system with FePt as the hard layer will also be presented.


Physics, Korea University, Seoul, South Korea; 2National Nanotechnology, Hanyang University, Seoul, South Korea.

We have controlled the Fe catalyst particle distribution in multimwalled carbon nanotubes (MWNWs) by means of the phase growth at 950 °C with constant Ar carrier gas flow rate and varying CO reaction gas flow rates. Magnetic properties of the MWNWs with various growing conditions were characterized by means of SQUID measurements in which superparamagnetic particles were observed. Control of the size and number of the Fe particles included in MWNWs 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 Dispersion in Alumina Aerogel Matrix, Andrea Palagi, 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 magnetic properties which can be strongly affected by interparticle interactions; moreover, FeCo supported particles can be exploited for catalytic applications. In this work, nanocrystalline γ-Al2O3 and FeCo-Al2O3 nanocomposite aerogels with high surface areas and pore volumes were prepared by high temperature supercritical drying of alcogsols obtained by a fast sol-gel procedure. A complete investigation of morphological and structural properties of the these materials was performed by means of both conventional and high resolution transmission electron microscopy, X-ray diffraction and X-ray absorption spectroscopy, the magnetic properties were investigated by means of static zero field cooled (ZFC) and field cooled (FC) magnetization, measured both by fixing the external magnetic field and varying the temperature and by fixing temperature and varying the external magnetic field (ZFC and FC hysteresis cycles). The formation of γ-Al2O3 occurs via a sequence of stages: in the parent aerogel an alkyldervative of boehmite is observed, whose calcination gives rise to a disordered phase finally to γ-Al2O3 which is stable up to 1000 °C. In the presence of iron and calcation, 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 affords 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 width and distribution of size of the alloy nanoparticles dispersed in the crystalline alumina matrix. Moreover, a first-order 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

Chair: Yiming Huai and Jian-Ping Wang
Monday Afternoon, November 29, 2004
Independence W (Sheraton)


A spin-polarized current can exert a substantial torque on the moment of a thin film nanomagnet onto which it impinges through the direct transfer of spin angular momentum from the conduction electrons to the ferromagnetic moment. The spin transfer can give rise to dynamic effects that depend upon the magnetic field and current bias applied to the nanomagnet. At low fields, spin transfer can cause reversible magnetic switching of the nanomagnet, while at high fields spin transfer from a DC current can excite the nanomagnet into a steady-state magnetic oscillation, with the frequency of this microwave oscillation being tunable by the field and current bias. This spin transfer effect is providing a new means of studying ferromagnetic behavior and magnetic dynamics at the nanoscale. It is also opening up the possibility of both direct-current-switched, non-volatile, dense magnetic memory and of nanoscale microwave oscillators for information processing applications. In this presentation I will describe some recent experiments that have investigated spin-transfer effects both in spin-valve nanopillar structures and in nanoscale magnetic tunnel junctions with very thin tunnel barrier layers. I will discuss the phase diagram based on the modified Landau-Lifshitz-Gilbert equation that appears to successfully describe much of the behavior of a nanomagnet under magnetic field and spin current bias, and recent experiments and simulations that have examined the effect of thermal fluctuations on the spin-transfer behavior. These include temperature-dependent measurements of thermally-activated telegraph noise fluctuations in regimes of the phase diagram that are thermally-bi-stable, as well as measurements of nanoscale magnetic dynamics in both the GHz frequency (steady state response), and nanosecond time (pulse response) regimes. I will also discuss some current progress towards reducing the critical current density for the reversible spin-transfer switching of a thermally-bi-stable nanomagnet and towards narrowing the linewidth and enhancing the phase stability of a nanomagnet microwave oscillator. I will conclude with a brief discussion of some of the challenges and opportunities that may
Our SR-FMR measurements are consistent with size and normal pinned structure: junctions, where logic functions are performed. This allows successive logic elements to be simply and directly connected together with no intermediate conversion stage. The logical NOT function we have reported previously is now complemented with logical AND/OR nanowire junctions and additional elements for signal fan-out and signal cross-over. We demonstrate a working nanowire logic circuit in which all four of these basic logic element types are shown to operate together. [1] Allwood et al. Science 296, 2002 (2002)

Programmable spintronics logic devices based on a single magnetic tunnel junction element, Jiruuo Wang, Hao Meng and Jian-Ping Wang; ECE department, University of Minnesota, Minneapolis, Minnesota.

Programmable Spintronics Logic Devices have absorbed more attentions due to its many potential advantages compared with semiconductor logic devices, such as non-volatile, rapidly re-configurable variations, high integration density etc. So far, based on a single MR element with pinned structure, maximum four logic functions (AND, OR, NAND, NOR) can be realized [1]. A novel programmable spin logic device is designed and fabricated based on a single magnetic tunnel junction element (MTJ). By introducing a novel current input line passing through MTJ element itself and using thermally assisted switching for the pinned layer magnetization with other two separated input current lines, full logic functions (AND, OR, NAND, NOR, XOR and NXOR) can realized based on a normal pinned and a synthetic pinned structure MTJ element. The MTJ gate is proposed for the first time. A Weston-bridge was designed and fabricated to record this one MTJ element logic device. MTJ elements with 1μm² size and normal pinned structure: (Ta200Å/CoFe30A/NiFe40A/MnIr30Å/CoFe30A/(AI7 Å) oxidation /CoFe30A/NiFe40A/Ta200Å), have low resistance of 5.3 Ω and high resistance of 7.2 Ω, which gives the MR ratio 149%. The operation of logic device is performed in two steps. First step is named SET/that sets MTJ element to an initial logic gate state, and second step is named LOGIC that the MTJ element output depends on these inputs. The programmable spintronics logic device chip picture is shown, each die has four same logic devices. The operation of the XOR and OR logic function is discussed, and about 3 mV output difference for logical 0 and 1. The output can be improved by increasing MTJ resistance and MR ratio. [1] A. Ney, C.Pamukh, R.Koch and K.H.Ploog. "Programmable computing with a single magnetoresistive element," Nature, 425, 485-487, 2 Oct. (2003).

Magnetic Vortex Core Switching Studied by Spatially Resolved Ferromagnetic Resonance, Hermann Stoll1, Bartel Van Wassenberge1, Aleksander Puzic1, Tolek Tyiszcak2, Hubert Brueckl2 and Karsten Rott3; 1MPI for Metals Research, Stuttgart, Germany; 2Chemical Sciences Division, LBNL, Berkeley, California; 3Fakultaet fuer Physik, Universitaet Bielefeld, Bielefeld, Germany.

Studies are presented on in-plane magnetic vortex dynamics in micron-sized Permalloy patterns and on deliberate switching of the orientation of the out-of-plane vortex core. Sub-nm time-resolved measurements are performed for the first time at a Scanning Transmission X-ray Microscope (STXM). The ferromagnetic domain patterns were excited by a "spatially resolved ferromagnetic resonance" (SR-FMR) technique which was occasionally used in optical Kerr microscopy /1/. The vortex movement of the magnetic Landau structure of a 1 micron x 1 micron Permalloy pattern (50 nm thick) was excited by a continuous external in-plane ac magnetic field at a frequency close to that of the eigen-mode of the vortex Landau (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 50 nm (given by the in-focused exit slit of 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 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 /2/ where similar samples have been excited by short in-plane magnetic pulses (stroboscopic "pump-and-probe" experiments). The advantages and disadvantages of our novel ferromagnetic resonant "spatially resolved FMR" measurements are discussed in comparison to time-domain "pump and probe" experiments /2,3/. Surprisingly the chirality of the magnetic vortex movement observed in our sample could be deliberately switched by adjusting the amplitude of ac excitation field. A sharp threshold was observed: A change of the excitation field by 10 percent at the threshold level produced a well defined repeatable change in the chirality of the magnetic vortex movement, indicating a switching of the orientation of the vortex core from the "up" to the "down" position and vice versa. Trajectories of the two different modes of vortex movements were derived from our measured data. The nanometer-scale vortex core orientation can be detected by "spatially resolved FMR" measurements at the STXM. The chirality of the magnetic vortex core orientation as a step forward for using the orientation of the vortex core, e.g., for data storage purposes. /1/ S. Tanaka and J.A. Bain, J. Appl. Phys. 91, 8034, 2002 (2002); S. Choe et al., Science, 304, 420, 2004 (2004) /3/ H. Stoll et al., Appl. Phys. Lett., 84, 3328, 2004

Avalanche Spin-valve Transistor, Kasey Joe Russell1, Ian Appelbaum2, Wei Yi1, Doug Maxson3, Federico Capasso1, Charles Marcus2, Venkatesh Narayananmurthi1, Micah Hannon1 and Arthur Gossard2; 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. Here, a spin-valve transistor with a GaAs/AIGaAs avalanche-multiplying collector is demonstrated, and greater than 1000% magnetocurrent variation is obtained at 35x multiplication. This indicates that the intrinsic amplification of the magnetic-field sensitive collector current should allow for fabrication of spin-valve transistors with high gain in a variety of materials. For devices limited by receiver sensitivity, this avalanche multiplication can increase the total input-to-noise ratio of the system, increasing the commercial viability of the spin-valve transistor.

A Novel Method for Fabrication of Magnetic Spin Valves, Shashi Paul, Alok Kaulwal and Manish Chhowalla; Ceramic & Materials Engineering, Rutgers University, Piscataway, New Jersey.

In the currently topical field of Spintronics, it is the spin of the electron, rather than the charge, that is invoked to characterize device behavior. There is active interest in the search for new materials in which charge carriers can be injected by preferential spin orientation that can be manipulated in the material. Recently, the use of conjugate organic semi-conductors [1,2] has been reported in this context. In both these reports the used material is Manganite, which is a ferromagnetic material with a 100% spin polarization. The polymer and Manganite, acting in concert, have been observed to enhance the magnetoresistance by 30% to 40%. A model explaining the use of polymer as a spacer layer has been proposed by Xie et al. [3]. Thus far, 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 injected spin orientation up to a certain length in the polymer. Encouraged by such reports, we attempt to observe an increase in the magnetoresistance in a Chromium Dioxide system, using a novel procedure. Chromium Dioxide is ferromagnetic in nature and has already been extensively used in the recording.
applications. In this work, we prepare a blend of poly-vinyl-phenol (PVP) and Cr02 particles to use as a spin valve; the size of the Cr02 particles needed for the spin valve was 40 nm. A thick film of a PVP and the Cr02 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.


14.1 Effective Magnetoviscosity of Ferrofluids Planar-Conette Flow. Xinwei He and Marisa Zahn, EECS, MIT, Cambridge, Massachusetts.

Ferrofluids are suspensions of permanently magnetized colloidal particles immersed in a suitably chosen carrier fluid. Ferrofluids are of increasing interest in the design of magneto-responsive colloidal extractants, micro fluidic pumps and actuators driven by alternating or rotating magnetic fields, and in biological applications such as drug delivery vectors, magnetic cell sorting schemes, and magnetocytolysis treatment of cancer cells. The ferrofluids used in these new ferrofluid applications involve hydrophobically modified organo-silicon particles. Ferrofluid spin velocity, shear stress, and magnetoviscosity are calculated for a planar Conette ferrofluid flow, with applied uniform DC magnetic fields parallel and transverse to the duct axis using Shliomis’ first magnetization relaxation equation, generally valid for low magnetic fields. For simplicity, we take the ferrofluid to be linearly magnetizable with constant magnetic susceptibility. With the assumption of incompressible flow, the symmetric 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 fifth order algebraic torque equation. This analysis describes the conditions for multi-value effective magnetoviscosity and spin velocity.

14.2 Permanently Linked Rigid Superparamagnetic Chains. Harpreet Singh1, T. Alan Hatton1 and Paul E. Laibinis2; 1Chemical Engg., Massachusetts Institute of Technology, Cambridge, Cambridge, Massachusetts; 2Department of Chemistry, The University of Alabama, Tuscaloosa, Alabama; 3Department 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 are prepared by adsorbing magnetic nanoparticles on the surface of the polystyrene beads modified by the layer-by-layer technique. The dynamic response of these chains to an applied magnetic field was also modeled.

14.3 Structural and magnetic properties of Al2O3–Ni16Fe28 thin films: From superparamagnetic nanoparticles to ferromagnetic multilayers. Inna I. Serebryakova1, Bjorgvin Hjorvarsson1, Per Norberg1,2, 3, and Jun Lu2; 1Physics, Uppsala University, Uppsala, Sweden; 2Material Science, Uppsala University, Uppsala, Sweden.

[Al2O3(18Å)/Ni16Fe28(8-30Å)]10 films were deposited by dc and rf magnetron sputtering on thermally oxidized Si(001) substrates. It has been shown that by changing the thickness of NiFe layer it is possible to vary the magnetic and structural properties of the films from superparamagnetic nanoclusters in amorphous matrix to ferromagnetic multilayers with well-defined layered structures. The superparamagnetic magnetization decreases with increasing NiFe layer thickness indicating the presence of magnetically inactive layer at the interfaces. The thickness of this layer corresponds to 0.6 monolayer for the flat continuous film and 2.1 monolayer for the film which consists of magnetic nanoclusters.

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

Iron oxide (magnetic) nanocrystals were synthesized in non-coordinating solvents by thermal decomposition of iron (III) carboxylate salts. This approach produces highly monodisperse materials (σ = 5-15%) in sizes ranging from 6 to 30 nm. 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/ferrofluid applications. The as-prepared iron oxide nanocrystals were very stable in both solution and solid state forms, and no particle aggregation was observed over a two month period. This method may become a general strategy for the synthesis of high quality metal oxide nanocrystals.

14.5 Water-Dispersible FePt Nanoparticles Having α-Mercapto-α-carboxylic Acid Ligands. David Eugene Nikles1,2, Jaya J. Mabry3, Laura B. Taylor1,2, Francis C. Geagor7, G. Bagaria1, Xiangcheng Sun1, Earl T. Ada1, Mohammad Shamsuzzoha1, Kai Sun5, Lu-min Wang6 and Duane T. Johnson1; 1Center for Materials for Information Technology, The University of Alabama, Tuscaloosa, Alabama; 2Department of Chemistry, The University of Alabama, Tuscaloosa, Alabama; 3Department of Nuclear Engineering and Radiological Sciences, The University of Michigan, Ann Arbor, Michigan.

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

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

Metal ferrite nanoparticles show great interest because of their potential applications in technology, ranging from materials for recording media devices, magnetic targets for drug delivery and contrast-enhancement agents for magnetic resonance imaging. The creation of heterostructures in which metal ferrites alternate in a layer-type architecture offers the possibility of tuning their magnetic and electronic properties which make them desirable materials for such applications. In this work we present a simple solution for the characterization of core/shell CoFe2O4/ZnFe2O4 nanoparticles. The spin oxides CoFe2O4 and ZnFe2O4 are both ferrimagnets with the difference that CoFe2O4 is a hard ferrimagnet with high coercive fields and ZnFe2O4 is a soft ferrimagnet with no coercivity. It is interesting to study how such differences affect the magnetic properties of the resulting core/shell nanoparticles. The nanoparticles were synthesized through the high-temperature combustion of the corresponding metal acetylacetonates in the presence of oleic acid and oleylamine as capping agents [1]. Characterization by XRD and TEM showed that the particles are highly crystalline and monodispersed. These magnetic properties were measured with a SQUID instrument at different temperatures and magnetic fields. Magnetic measurements showed that the nanoparticles displayed a dramatic exchange bias behavior resulting from the interaction of the magnetic spins at the interface between the soft and hard layers. Hysteresis data suggested that as the field is reversed after saturation, the spins of...
ZnFe$_2$O$_4$ farthest apart from the CoFe$_2$O$_4$/ZnFe$_2$O$_4$ interface reoriented first, while the spins of ZnFe$_2$O$_4$ closest to the interface remained pinned by the adjacent CoFe$_2$O$_4$ layer so that the coercive field of the hard layer was finally reached. Thus, the soft magnet is the first to be demagnetized. This behavior has been previously observed in epitaxial thin ferrite films [2] and is reported here for the first time in solubilized nanoparticles. [1] S. Robinson, S. Raoux, P. M. Rice, S. X. Wang and G. Li, J. Am. Chem. Soc., 126 (2004) 273. [2] Y. Suzuki, Adv. Mater. Res., 31 (2003) 265.

### 14.7 Self-Assembly of Magnetic FePt and FePt(M) Nanoparticles.

Xiongchun Sun$^1$, David A. Nadir$^2$, Kaixun Sun$^3$ and Lumin Wang$^3$.

1Chemistry Depart., Rutgers, The State University of New Jersey, Piscataway, New Jersey; 2Center for Materials for Information Technology (MINT), The University of Alabama, 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 have been synthesized by chemically polyol or superhydride reduction in the presence of stabilizers oleic acid and oleyl amine. The observed TEM grids samples were obtained by dropping dilute solutions of monodisperse FePt or FePt(M) nanoparticles onto carbon-coated copper TEM grids, and the solvent was allowed to evaporate at room temperature [3]. As-prepared particles have a chemically disordered face-centered cubic lattice with average diameter of 4.8 nm and are superparamagnetic. These magnetic particles 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 with uniform size and composition distributions. References [1] S. H. Sun et al., Science 287 (2000)1989. [2] H. Zeng et al., J. Magn. Magn. Mater., 492 (2009) 205. [3] X. C. Sun et al., J. Appl. Phys. 93 (2003) 7337.

### 14.8 Optimization of Fe-Co Nano-Particles Composite for RF Application.

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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 thanks to TEM and HRTEM which allows to reveal the complex 3D microstructure. 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 in 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 with uniform size and composition distributions. References [1] S. H. Sun et al., Science 287 (2000)1989. [2] H. Zeng et al., J. Magn. Magn. Mater., 492 (2009) 205. [3] X. C. Sun et al., J. Appl. Phys. 93 (2003) 7337.

### 14.9 Preparation and Magnetic Properties of Hollow Nano-Spheres of Cobalt and Cobalt Oxides.

Kenta Hayashida$^1$, Yasuharu Kozuka$^1$, Asami Horiguchi$^1$, Kunto Awaga$^1$, Shunji Bandow$^2$ and Sumio Iijima$^2$.

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The study of nano-scale morphology is especially interesting in the case of magnetic materials, because their properties are governed by their shape and texture. The preparation of magnetic hollow nano-spheres is a promising approach for developing new magnetic phenomena. In the present work, we prepared magnetic hollow nanospheres of cobalt and cobalt oxide with diameter of 500 nm and thickness 40 nm using polystyrene-bead templates, and carried out magnetic measurements on the obtained materials. To prepare the hollow spheres of cobalt and cobalt oxide, at first, the 600 nm PS beads were coated with basic cobalt carbonate (1) by a controlled hydrolysis of urea. Hollow spheres of cobalt oxide (2) were prepared from 1 by calcination at 500 degree centigrade for 3 h in air, and, further, metallic cobalt hollow particles (3) were obtained from 2 by calcination at 500 degree centigrade for 4 h under a li mixed gas of H2 and N2. TEM and SEM images of 2 and 3 confirm that the spherical shapes were maintained even after calcinations and the inside is empty. The mean diameters of 1-3 were estimated to be 680, 500 and 500 nm, respectively. As-prepared particles were well dispersed in hydrocarbon solvents and monodispersed 1-3D 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 with uniform size and composition distributions. References [1] S. Sun, H. Zeng, D. B. Robinson, S. X. Wang and G. Li, J. Am. Chem. Soc., 126 (2004) 273. [2] Y. Suzuki, Adv. Mater. Res., 31 (2003) 265. [3] S. H. Sun et al., Science 287 (2000) 1989.

### 14.10 Preparation of Magnetic Hollow Nano-Spheres of Cobalt and Cobalt Oxides.

Kenta Hayashida$^1$, Yasuharu Kozuka$^1$, Asami Horiguchi$^1$, Kunto Awaga$^1$, Shunji Bandow$^2$ and Sumio Iijima$^2$.

1Department of Chemistry, Graduate school of Science, Nagoya University, Nagoya, Japan; 2Department of Materials Science and Engineering, Meijo University, Nagoya, Japan.

The study of nano-scale morphology is especially interesting in the case of magnetic materials, because their properties are governed by their shape and texture. The preparation of magnetic hollow nano-spheres is a promising approach for developing new magnetic phenomena. In the present work, we prepared magnetic hollow nanospheres of cobalt and cobalt oxide with diameter of 500 nm and thickness 40 nm using polystyrene-bead templates, and carried out magnetic measurements on the obtained materials. To prepare the hollow spheres of cobalt and cobalt oxide, at first, the 600 nm PS beads were coated with basic cobalt carbonate (1) by a controlled hydrolysis of urea. Hollow spheres of cobalt oxide (2) were prepared from 1 by calcination at 500 degree centigrade for 3 h in air, and, further, metallic cobalt hollow particles (3) were obtained from 2 by calcination at 500 degree centigrade for 4 h under a li mixed gas of H2 and N2. TEM and SEM images of 2 and 3 confirm that the spherical shapes were maintained even after calcinations and the inside is empty. The mean diameters of 1-3 were estimated to be 680, 500 and 500 nm, respectively. As-prepared particles were well dispersed in hydrocarbon solvents and monodispersed 1-3D 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 with uniform size and composition distributions. References [1] S. Sun, H. Zeng, D. B. Robinson, S. X. Wang and G. Li, J. Am. Chem. Soc., 126 (2004) 273. [2] Y. Suzuki, Adv. Mater. Res., 31 (2003) 265.
or an extraction magnetometer (x \approx 26, 30); maximum applied field: 50 kOe in both cases. The magnetoresistance was measured by the four-probe technique. Nickel (Ni) and hematite (Fe2O3) powders were mixed at room temperature by a DI Nanoscope workstation. The films with x \leq 14 can be pictured as interacting superparamagnets [1], with Fe particle size of the order of 2 nm, while the films with x > 26 magnetize through coherent rotation of the magnetic moment, possibly composed of many correlated Fe particles. All films exhibit negative magnetoresistance (MR), whose intensity decreases monotonically with temperature. The MR displays no apparent saturation up to 50kOe. When plotted vs. reduced magnetization, the MR curves of the systems richer in Fe (x > 26) exhibit a box-like behavior distinctive of the proximity magnetoresistance proper of concentrated magnetic systems with competing interactions [2]. On the other hand, the systems richer in Ag display a non-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 one at all temperatures for x > 26 (indicating a frustrated ferromagnetic behavior with ultrashort magnetic coherence length), while is of the order of unity for x \leq 14 (indicating a nearly complete loss of correlation among single particle moments). The change from an interacting superparamagnetic behavior to a disordered ferromagnetic phase is described by the growth of the magnetic correlation length, and takes place gradually with increasing x. AFM observations point to a similar granular structure in all films, possibly induced by the preparing conditions with average particle size of 50 nm. Each of these large, smooth particles contains smaller Fe particles, evidenced by magnetic measurements, and embedded in the Ag matrix [1]. P. Allen et al., Phys. Rev. B64, 144420 (2001) [2] P. Allen et al., Phys. Rev. B67, 174412 (2003).


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


Single Cobalt zigzag wires with different widths 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 microns, each. The oxidation of the cobalt wires was 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 magnetoresistance 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 mTorr in a quartz tube furnace equipped with a water-cooled Pyrex liner and a power effective catalyst. TEM electron diffraction and Raman spectroscopy indicate that the nanowires are single crystal CaB6 and have a preferred [001] growth direction. Analysis of TEM/EDX/EELS data proves that the magnetic order of the nanowires is dominantly an amorphous oxide shell material. The CaB6 nanowires have diameter of 15-40 nm, and length of 1-10 um. Such CaB6 nanowires have potential applications in nanocomposites and nanoelectronics.

We plan to investigate the current vs. magnetic and electrical properties of CaB6, but on nanowire samples. We appreciate the support of the National Science Foundation (grant EEC-01210126), and the Office of Naval Research grant (No. N000140110875).

14.15 Highly Magnetic Nickel Nanostands Fabrication of a new Hex-Axis: Ratio Nanoparticle. George Hansen1,4, Matt Pettit1 and Max D. Alexander1, 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 nanostands, has been created and evaluated. These nanostands are strud of pure nickel, and can be controllably mass produced in sizes ranging from about 50nm in diameter by 3 microns to a few microns in diameter by several 1000 microns. These materials are readily processable in a variety of host resin systems, and can be easily aligned into patterns by controlling the magnetic field applied to the specimens during the processing. Here we will illustrate the various morphological and electrical properties of the nickel nanostands 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. Andrei Anatolievich Eliseev1, Kirill Sergeevich Napolskii1, Inna Volodymyra Kolesnik2, Alexey Viktorovich Lukashin3, Yuri Dmitrievich Tretjakov4, Peter Goernert4, Natalia Anatolievna Grigorieva5, Sergei Grigoriev6,7 and Alexey Vorobiev4,5, 1Department of Materials Science, Moscow State University, Moscow, Russian Federation; 2Institut f"{u}r V. Jung, 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 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 reservoir for synthesis of nanoparticles 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 and 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 is due to crystallization and growth of metal ions 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 render high coercive force up to 460 Oe (at 300K) and saturation magnetization of 3 gr/m2. These features open possibilities for new applications in high-density information storage. Besides the control over diameter of the pores enables us to define the anisotropy parameters of nanowires. Thus, our approach leads to functional materials with nanostructured active elements in the matrices, which could find an application in various...
fields of engineering and technology. This work is supported by RFBR (03-03-32182) and INTAS (01-204).

14.17 Synthesis and Characterization of BiFeO₃ Nanotubes. Tae-Jin Park¹, Yuanbing Mao² and Stanislaus S. Wong;¹
¹Chemistry, New York City College of Technology, CUNY, 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 ratios of these BiFeO₃ nanotubes reach larger than 150:1. BiFeO₃ nanotubes obtained from a template having 100 nm diameter pores show relatively rounded diameters in range of 40-60 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 coupled with the energy dispersion X-ray spectroscopy (EDX) as well as the selected area electron diffraction measurement (SAED).

14.18 Production and Characterization of Ferromagnetic Alloyed-Nanowires inside Carbon Nanotubes. Ana Laura Elias A¹, Julio A. Rodriguez Mazo¹, Ashaberto Zambudio, Marion Rojas², Florencio Lopez Díez³, Emilio Munoz Sandoval, Humberto Terrones, Mauricio Terrones³, M. R. McCarty², David J. Smith², Dmitri Golberg³, Chengchun Tang² and Yoshio Band³;¹Advanced Materials Department, IPICYT, San Luis Potosi, S.L.P., Mexico; ²Department of Physics and Astronomy, Arizona State University, Tempe, Arizona; ³International Center for Young Scientists, National Institute for Materials Science, Tsukuba, Ibaraki, Japan.

We describe the production of aligned multi-walled carbon nanotubes filled with Fe-Co alloys. The method involves the aerosol thermalization of toluene-ferroocene-cobaltocene solutions at temperatures ranging from 650 to 800 °C in an inert atmosphere. The materials have been carefully characterized using state-of-the-art high-resolution transmission electron microscopy (HRTEM), energy loss spectroscopy (EELS), scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX), electron diffraction, HREELS-STM elemental mapping, X-ray powder diffraction and SQUID magnetometry. The results indicate that different stoichiometries of FeₓCo₁₋ₓ 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 (110) parallel to the carbon nanotube axis. 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 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 monitored with GMR nanostructures, deposited onto IC system. We have deposited GMR nanostructures (FM/NM/FM) onto patterned MEMS structures. Here, FM denotes NiFe (Permalloy≈20%) Cu layers or combination using Py-Co layers. As NM we have deposited Cu or Al₂O₃ layers. In order to study the magnetic sensitivity we made GMR and Hall effect measurements for the Py/Cu/Pt/Fe/Mn, Py/Al₂O₃/Pt/Fe/Mn, Pt/Co/Cu/Pt/Co/Pt/Fe/Mn and Pt/Co/Cu/Pt/Al₂O₃/Pt/Fe/Mn multilayer structures. When the magnetic field lies in the film plane the measured voltage is produced by the Planar Hall Effect (PHE) which, basically, is an Anisotropic Magneto-resistance Effect (AMR). In this work PHE measurements were employed to evaluate the magnetization reversal process of 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 Julliere model for FM/FM/FM tunneling structures predicts that the tunnel junction magnetoresistance is dependent on the relative orientation of the magnetization vectors in the adjacent magnetic layers separated by an insulating film. The sign and magnitude of the magnetoresistance change when the magnetic field is applied normal to the film plane are less than the values predicted from the shape anisotropy and give us information regarding the films roughness. Due to a very sharp change of resistance with magnetic field obtained for a particular orientation of the magnetic nanostructures are attractive candidates for use as movement microsensors.


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 complemented 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 hysteretic curves of magnetic Cu-Co alloys with various microstructures will also be discussed.

14.21 Structure and Magnetic Properties of Shock Consolidated Bulk Exchange-Coupled High Magnetic Nanomagnets. Zhiqiang Jin¹,², J. Ping Liu¹ and Naresh N. Thadhani;¹ School 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 CuCo 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 Cu-Co bulk nanocomposites were obtained, with retention even refinement of the nano-scale grain sizes of the soft and hard phases. Reduction in nanocrystalline grain size was observed to be caused by generation of shear bands during shock-compression which in addition to truncating pre-existing 25 nm size grains also contained 10 nm size grains. Optimal magnetic properties, similar to those of the starting materials, but higher than those of commercial bonded magnets, were obtained in the recovered bulk exchange-coupled nanocomposites. Post-shock heat treatments resulted in the improvement of coercive field, which is related directly to the dependence of effective anisotropy on the grain size. In this paper, the unique attributes of the shock-processed nanocomposites including sintering 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.

14.22 Size effect on the exchange-bias behavior in ferromagnetic La0.67Sr0.33MnO3 / SrRuO3 bilayers. Xiaodong Zhou, W. J. Lee, L. J. Belenky, C. B. Eom, to be submitted.

Epitaxial La0.67Sr0.33MnO3 (LSMO)/ SrRuO3 (SRO) ferromagnetic bilayers have been grown on SrTiO3 (STO) substrates by pulsed laser deposition. 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. 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. Rachkowski, L. J. Belenky, C. B. Eom, to appear on June 28th in Appl. Phys. Lett. [2] X. Ke, M. S. Rachkowski, L. J. Belenky, C. B. Eom, to be submitted.

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

Reflective, pinhole-free, Fe/Fe2O3 and Fe3-αFe/Fe2O3 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 Fe2O3/Fe2O3+αFe (α > 7%) composite film is characterized by a linear relationship between the conduction current density (J) and the field (E) as J = JE = AE2. The field dependence of the film temperature (M-T) shows the Verwey transition temperature ranging from 95 to 136 K, and decreasing as the Fe/O ratio decreases. The Fe2O3 film has a negative magnetoresistance (MR) of about 4% and 8% at room temperature and 80 K, respectively.


Since magnetic semiconductors with Curie temperature (Tc) above room temperature are greatly demanding for the development of spintronic devices, diluted magnetic semiconductors (DMSs) and wide-bandgap semiconductors have attracted many research groups. Great interest has recently been stemmed due to high temperature ferromagnetism in oxides such as ZnO with Co or Mn doping, TiO2 with Co and SnO2 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. Also it is believed that Fe-doped β-Ga2O3 is intrinsically an insulator with a band gap of 4.8 eV. It becomes an n-type semiconductor when Sn+ or oxygen defects are introduced. Great advantage is expected if one could achieve ferromagnetic DMS, based on this conducting wide-band gap oxide, because 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-Ga2O3 (Ga2-αFe)2O3, by a solid-state reaction and a behavior of ferromagnetic ordering was observed at room temperature in the samples sintered at low temperatures below 900°C using Ga2O3 powder and iron nitrate, Fe(NO3)3•9H2O, as the starting materials, while the sintering above 900°C led to an anti-ferromagnetic behavior. The higher temperature showed spin-glass-like behavior, meaning that long-range ferromagnetic ordering does not exist. When the sample was sintered at 500°C, the single phase of β-Ga2O3 was obtained up to α = 0.08 with no trace of secondary phases or other impurity according to X-ray diffraction measurements. For the samples with x > 0.08, α-Fe2O3 (hematite) phase appeared, which is known to show canted spin magnetism. The hematite phase seems to have nothing to do with the magnetic behavior of the system because the magnetization per total iron atom was decreased when the hematite phase was present. On the other hand, starting with Fe2O3 powder as iron source, α-Fe2O3 phase in addition to β-Ga2O3 phase was precipitated when the low-temperature sintering was performed. The result suggests the existence of magnetic nanoparticles. Hall magnetometry shows that as the Mn concentration (x > 7%) increases the behavior of the sample changes from ferromagnetic to superparamagnetic. The reason for spin canted in this system is now under investigation.

Effects of Defects on the Electrical and Magnetic Properties of Ga1-xMnxAs Layer. Dongwan Ko, Jin-Bum Park, Young Ju Park, Jeoung Il Lee, Chunjin Park, Hooyoung Cho, Young Mi Kim, Il-Weo Park and Koran Soo Chung; 1Nano Device Research Center, Korea institute of Science and Technology, Seoul, South Korea; 2Dep. of Physics, Dongguk University, Seoul, South Korea; 3Seoul Branch, Korea Basic Science Institute, Korea University, Seoul, South Korea; 4Dep. of Electronic Engineering, Kyung Hee University, Young-In, South Korea.

We investigated the effects of V/III flux ratios on the Curie temperature, Tc, in GaMnAs (DMS/s) thin films. The samples were grown with different thickness of iron source, Fe(N03)3 and W. B. Yelon et al.; 1Dep. of Physics, Northeastern University, Boston, Massachusetts.

Alloys of GaAs with chromium have been shown to form nanomagnetic structures,1) in addition to having high Curie temperatures. (Ga, Cr)As grown by MBE exhibits unusual magnetic, transport and structural properties. At low temperatures the magnetization increases rapidly with increasing field due to the alignment of ferromagnetic units (nanomagnets or polarons) having large dipole moments of order 10-100 Bohr magnetons. A standard model of superparamagnetism is inadequate for describing both the field and temperature dependence of the magnetization M(H,T). In order to explain M(H) 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 14. The STM images also show structures of patches 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[-(T/Tc)1/4] over a range of conductivity, irrespective 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).

TEM studies of Magnetically Phase Separated La1-xSr2CoO4. 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 magnetic anisotropy in magnetic thin films. To overcome these difficulties, we created microcantilevers with high aspect ratio to study magnetic fluctuations. Magnets with high aspect ratio of length to width (l/w > 10) showed smaller dissipation at 77K than at 4.2K, applied static magnetic field along the short axis of oblong magnets (l/w > 2.5) showed decreasing dissipation as magnetic field is increased. Compared to cobalt magnets of similar size, these microcantilevers demonstrated lower dissipation and we conclude that they will be suitable for use in magnetic resonance force microscopy (MRFM).

Recent work in magnetic resonance force microscopy (MRFM) suggests that magnetic fluctuations in a microcantilever’s tip could be a potential source of deteles for better spin relaxation. We have measured thermomagnetic fluctuations in submicron nickel magnets using ultrasonic cantilever frequency shift magnetometry and have compared the effect of magnetic material, shape, and temperature to fluctuations. Magnets with high aspect ratio of length to width (l/w > 10) showed smaller dissipation at 77K than at 4.2K. Surprisingly, applied static magnetic field along the short axis of oblong magnets (l/w > 2.5) showed decreasing dissipation as magnetic field is increased. Compared to cobalt magnets of similar size, these microcantilevers demonstrated lower dissipation and we conclude that they will be suitable for use in MRFM on nuclear spins.

14.30 Magnetic Dissipation of Single Submicron Magnets Characterized by Cantilever Magnetometry. Tie Ng Ng, Neil Jenkins and John MacLean; Chemistry and Chemical Biology, Cornell University, Ithaca, New York

Pulsed laser deposition (PLD) is widely used for thin film preparation. In the literature, PLD in the magnetic field was reported by several authors.[1,2]. In these reports, permanent magnets such as Sm-Co alloy were used to generate magnetic field during deposition. In the permanent magnet system, it is impossible to change the magnitude of magnetic field. It is also difficult to raise the substrate temperature during deposition since permanent magnets are heat-sensitive. Therefore, this system can be regarded as a kind of "Dynamic Aurora PLD". To overcome these difficulties, we created a novel PLD system that is able to maintain 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,Mn,Fe,Co,Fe,Co,O, etc.) were prepared on SrTiO3(001) and MgO-AI2O3/CeO2/YSZ-buffered SiO(001) substrate using the Dynamic Aurora PLD apparatus. Magnetic field during deposition can result in the crystalline orientation of films produced; therefore, deposition rate was increased with magnetic field. In addition, lowering of crystallization temperature, improvement of crystallinity, and increase of magnetization were observed in-situ magnetic field deposition on the film structure, microstructure, and magnetic properties will be clarified. [1] T. Kobayashi, et al., Jpn. J. Appl. Phys., 39 (2000) 1817. [2] N. Wakiya, et al., Jpn. J. Appl. Phys., 41 (2002) 7242.

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

Melt processed high Tc superconductors have been developed for various applications including superconducting performance. The two new pinning agents extend the range of applications for magnetic thin films. The future applications range from small lossless bearings or superconducting motors. The magnetic phase 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 required. This report reviews our on-going work on new magnetic pinning media and the ways of their creation. Microstructure analysis by transmission electron microscopy (TEM) and scanning tunneling microscopy (STM) results are able to recognize the nanometer size pinning defects, to show their magnetic properties and to help in identifying the key structural features responsible for the improved superconducting performance. The two new pinning agents extend the use of LREBa2Cu4O8 composites both towards high magnetic fields.
Fabrication of FePt/M (M = C, Ag) Nanoparticle Thin Films With Perpendicular Magnetic Anisotropy

Chairs: Kornelius Niebach and Christian Wegrowe
Tuesday Morning, November 30, 2004
Independence W (Sheraton)

8:30 AM 15.1

Perpendicular of Physics, University of Delaware, Newark, Delaware; Seagate Technology, Newark, Delaware.

2Departments of Magnetic Nanoparticles with Perpendicular Anisotropy 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 fcc 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 desired 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 metal showed an improved 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 in the FePt increases for the fcc ordered phase as indicated by the shift in the [002] XRD peak. The magnetic and microstructural properties can be easily tuned by varying the thickness of sputtered FePt film with a maximum coercivity of 33 kOe obtained when the thickness of 4 nm FePt was embedded in Ag. For TEM images showed that isolated particles with smaller average particle size (down to a few nanometers) were formed when the thickness of sputtered FePt film is less than 4 nm. However, with a further increase of thickness of sputtered FePt film, a continuous layer of FePt particles was observed and the coercivity decreased rapidly due to domain wall motion mechanism. Work supported by NSF DMR-0302544 and Seagate Technology.

9:30 AM 15.2

C-Axis Oriented L10-FePt Magnetic Nanoparticles Formed by Coupling Local-Epithaxy with Non-Epithaxy, Suguru Noda, Yoshiko Tsuji, Akira Sugiyama, Fumio Otsuka and Hiroshi Koniyama; 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 used, FePt should have chemically ordered L10 structure, c-axis orientation, a few-nanometer particle size, inter-particle spacing, and inch-scale homogeneity. Various fabrication methods have been proposed to achieve these goals, including epitaxial growth on monocrystalline MgO substrates [2], vapor-deposition on polycrystalline MgO seed layers [3], and magnetron sputtering of FePt nanoparticles onto multi layers of phospholipid molecules [4]. These methods lack a concept to satisfy those structural requirements simultaneously. In this work, we propose a new concept, "local epithaxy on non-epithaxy films", satisfying all of those requirements. Non-epitaxial, polycrystalline films having preferred orientation not in in-plane but in out-of-plane directions are used as template. Disorder in in-plane orientation of template expectedly yields single FePt nanoparticles on single template grains whereas order in out-of-plane orientation of templates expectedly yields out-of-plane oriented FePt nanoparticles. Rock-salt crystals tend to have (100) out-of-plane orientation to minimize surface energy, which plane have the same symmetry as that of (001) plane of face-centered-tetragonal (fct) FePt. TiN was firstly deposited on each of the epitaxy-ordered grains and 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 epitaxially oriented. As indicated by the shift in the [002] XRD peak. The magnetic and microstructural properties can be easily tuned by varying the thickness of FePt film, a continuous layer of FePt nanoparticles was observed when the thickness of 4 nm FePt was embedded in Ag. For TEM images showed that isolated particles with smaller average particle size (down to a few nanometers) were formed when the thickness of sputtered FePt film is less than 4 nm. However, with a further increase of thickness of sputtered FePt film, a continuous layer of FePt particles was observed and the coercivity decreased rapidly due to domain wall motion mechanism. Work supported by NSF DMR-0302544 and Seagate Technology.

9:00 AM 15.3

SESSION 15: Magnetic Nanoparticles

Seagate Technology, Newark, Delaware; Department of Physics, University of Delaware, Newark, Delaware; Department of Physics of Materials, University of Duisburg-Essen, Duisburg; German Research Center for Geosciences, Dresden, Germany; Physical Chemistry, University Duisburg-Essen, Duisburg, Germany; Experimental Physics, AG Farle, University Duisburg-Essen, Duisburg, Germany.

Recently, we have shown that the deposition of gas-phase prepared metallic nanoparticles onto multilayers of phospholipids in the liquid crystalline, the intermediate, and the gel phase supported by silicon substrates. After the particle deposition, the samples were subjected to different moderate thermal treatments: (a) 2 hours at T = 35°C under vacuum irradiation with UV light and subsequent storage at T = 35°C under different moisture conditions. The results were studied by atomic force microscopy (AFM) and scanning electron microscopy (SEM). AFM images showed an increasing degree of lateral ordering of the particles in the lipid multilayer going from the gel phase to the liquid crystalline phase. At the same time, SEM data show the increase of inter-particle distances consistent with the formation of a lipid double layer between the particles. The thermal post-treatment leads to a thinning of the separating layer, probably formed by phospholipid molecules with interdigitating aliphatic chains, accompanied by the formation of a self-organized hexagonal lattice. An alternative route to self-organization could be induced by repulsive forces between adjacent particles: latest results show that the application of a homogeneous magnetic field perpendicular to the layer may lead to particle arrangement under preservation of the full double layer. This effect is attributed to the dipolar repulsion of neighbouring particles with parallel alignment of their magnetic moments as enforced by virtue of the external field. The effect of varying both the polar head groups and the aliphatic chains of the phospholipids is discussed. The work is supported by the Deutsche Forschungsgemeinschaft within SFB 445 [1] and by the German Science Foundation (DFG). [1] A. Terheiden, Ch. Mayer, K. Moh, B. Stahlmecke, S. Stappert, M. Acet and B. Rellinghaus, Appl. Phys. Lett. 84 (2004) 3891. [2] A. Terheiden, B. Rellinghaus, S. Stappert, M. Acet, and Ch. Mayer, J. Chem. Phys. 121 (2004), 510.

9:30 AM 15.4

SESSION 15: Magnetic Nanoparticles

Arthur B. Hirsch, Jürgen Pawlek, and Andrea Brandmayr, Institute of Physics, University of Innsbruck, Austria; Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, Alabama; 2Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, Alabama; 3Department of Physics and Astronomy, The University of Alabama, Tuscaloosa, Alabama.

Heating films of FePt nanoparticles to temperatures required for transformation from the as-prepared fcc phase to the ferromagnetic L10 phase also results in undesirable particle agglomeration and grain-growth. FCC FePt/TX ternary alloy nanoparticles, where X is Cu, Ag, or Au, were prepared by the diol reduction of platinum(II) acetylacetonate and a source of the third element (i.e. silver acetate), while thermally decomposing iron carbonyl. Heating self-assembled films of the particles transformed them to the L10 phase. For the case of FePt/Cu nanoparticles the Cu remained in the particles after heating substituting for Fe atoms in the structure of fcc and L10 phases. There was no lowering of the temperature required for the phase transformation, relative to that required to transform FePt. When films containing only Ag or Au left the particles the temperature required to transform the particles to the L10 phase was substantially lower. This suggests that the vacancies arising when the Ag or Au left the particles allowed the Fe atoms to move more easily to their L10 lattice position at lower temperature. However, careful examination of the x-ray diffraction curves showed considerable increase in crystallite size for the case of FePtAg and FePtAu, even at these lower temperatures, but less sintering for FePtCu nanoparticles. This suggests that additive Ag...
9:45 AM 15.5
Synthesis of FePt/Fe3O4 and CoPt/CoFe2O4 Core-Shell Nanoparticles with Tunable Core Size and Shell Thickness. Min Chen1,2, Shizhong Sun1, J. Ping Liu1, R. L. Sandstrom1 and C. B. Murray1; 1) D. Nano-Devices, IBM Watson Research Center, Yorktown Heights, New York; 2) Department of Physics, University of Texas at Arlington, Arlington, Texas.

FePt and CoPt nanoparticles are a class of hard magnetic nanoparticles that are chemically stable. They have great potential for applications in ultrahigh density magnetic recording media, highly sensitive magnetic sensors and advanced nanocomposite permanent magnets. Synthesis of spherical 2-4 nm FePt nanoparticles has been well established, and elongated CoPt nanoparticles with a diameter of 2 nm and a length of 8 nm has recently been reported. However, the small size of the 2-4 nm in dimension of the both FePt and CoPt nanoparticles cannot be their magnetic characteristic due to superparamagnetism, leading to magnetic thermal instability of these particles. We report our improved one-step synthesis of FePt/Fe3O4 and CoPt/CoFe2O4 core-shell nanoparticles with core tunable from 3 to 8 nm (in diameter), shell from 1 to 5 nm (in thickness). The synthesis also leads to controlled particle shape in either sphere or cube. The core/shell particles can be easily dispersed in hydrocarbon solvent, facilitating their self-assembly into nanoparticle superlattices. The phase ordering temperature of the particles from fcc to fct is found to decrease significantly for the larger sized particles, and the particles annealed under inert gas have a coercivity up to 1.7 Tesla. Annealing under inert atmosphere indicates that the presence of oxides on the surface retards the crystallization at high temperature (up to 650 degrees). Structure and magnetic properties at different annealing conditions will also be discussed.

Acknowledgement: Research is supported in part by DARPA/ARO under grant DAAD 19-03-1-0008.

10:30 AM 15.6

The use of organometallic precursors allows the synthesis in mild conditions of metal nanoparticles displaying a controlled size, shape and surface environment. This method has been extended to the synthesis of bimetallic magnetic nanoparticles of controlled anisotropy. We have furthermore evidenced recently the ability of these particles to change their size or shape according to the properties of the surface ligands present. The lecture will focus on the synthesis of the particles and the demonstration of the presence and role of the different ligands in the chemistry of the particles. In a second step, the lecture will describe the physical properties of the particles and the role of Coordination Chemistry to orientate the growth of the particles to control their monodispersity and their shape (spheres, rods, cubes, wires). A special point will be devoted to self-assembly of the particles and to the formation of 2D super-lattices of nanorods and 3D super-lattices of nanospheres and nanocubes, a true crystallization process. Some applications in physics and microelectronics will finally be described.

11:00 AM 15.7

Colloidal magnetic nanoparticles (NPs) have many applications in magnetic recording, separations and biochemistry. After partially oxidizing Co NPs, their magnetic thermal stability is enhanced through exchange biasing. Oxidized Co NPs have been used as a prototype for studying exchange bias, but many previous studies were of limited usefulness because they used polydisperse or agglomerated particles. Here we report the magnetic properties of NPs with a spherical geometry. We systematically studied the magnetic properties of pure Co, Co/CoO and pure CoO NPs through temperature- and field-dependent SQUID measurements. Co/CoO NPs have increased their thermal stability and exhibit exchange fields of more than 1000 Oe. At temperatures below 50 K, the magnetization versus field curve is shifted along the magnetization axis due to pinned spins, and the exchange field is suppressed. This magnetization shift and the exchange field can be controlled independently of each other. The origin of these effects will be discussed.

11:15 AM 15.8
Magnetic Properties of Iron Nanoparticles of New Crystal Structure. Catherine Amiens1, Olivier Margiart, Bruno Chaudret1, Pierre Lecante2 and Marc Respaud2; 1) LCC, CNRS, Toulouse, France; 2) CEMES, CNRS, Toulouse, France; 3) LMNO, INSA, Toulouse, France.

The synthesis of non-oxidized iron nanoparticles of a few nanometers is very challenging given the high oxidizability of this element and the very few precursors available. Fe(N(SiMe3)2)2 was recently demonstrated to cleanly nanoparticle-synthesis of all-iron nanoparticles of cubic shape when decomposed under dihydrogen in a solution of hexadecylamine and oleic acid. These particles were in the size range 7-11 nm and self-assembled into strongly magnetically coupled cubic super-crystals. Here we report that isolated iron nanoparticles with sizes below 3 nm with a very narrow size distribution can also be synthesized from this amido complex. Independent nanoparticles have been obtained in an organic polymer matrix, namely poly(2,6-dimethyl-1,4-phenyleneoxide) via solution phase synthesis. The nanoparticles have been characterized by TEM, XAS and Mössbauer spectroscopy and magnetic measurements on a SQUID magnetometer. XAS measurements evidence a crystallographic structure different from the reported so far for Fe NPs. Octahedral sites are not present, which leads to a less dense structure resembling the e-phase or polytetrahedral arrangements described recently for cobalt. Mössbauer spectra and magnetic measurements show non oxidized iron nanoparticles for Fe nanoparticles with less than 500 atoms, the magnetization is enhanced as compare to pure bulk material, reaching the value of 2.58 (0.1) Bohr magneton per Fe atom for a radius of 200-250 atoms, close to those previously reported for gas phase clusters. A magnetic increase of the effective anisotropy has been evidenced, approximately 8 times the bulk value. The magnetic properties illustrate the major role played in Fe nanoparticles by the surface. which regulates both the magnetization and the nanoparticles and the equilibrium of these effects will be discussed.

11:30 AM 15.9
Manipulation of Nickel Nanoparticles Deposited on HOPG. Massoud Ataiehse, Valery Bliznyuk, Deep Banerji and Srilanthi Singhamannel; 1) Electrical and Computer Engineering, Western Michigan University, Kalamazoo, Michigan; 2) Computer Science and Engineering Department, Western Michigan University, Kalamazoo, Michigan.

In this paper, we describe the deposition of nickel nanoparticles and nanowires on the surface of Highly Oriented Pyrolytic Graphite (HOPG). Freshly cleaved surface of HOPG is a very active surface with a number of broken chemical bonds promoting nucleation of the metal being deposited on top of it. These active sites for nucleation are V shaped grooves. HOPG was exposed to an aqueous plating solution of 1mM NiSO4·6H2O (Sigma Aldrich) 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 grains and followed the grooves of HOPG and hence the grains deposited on adjacent grooves were parallel with respect to each other. By adjusting 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 include applied potential and final voltages of -1.0 V and -0.4 V respectively, scan rate of 4000 mV/s and a scan time of 60 seconds. The deposition of Ni is a highly sensitive process and the parameters were varied to optimize the resulting deposition parameters. The deposition process was monitored using optical microscopy and SEM.
MFM was employed to establish correlation between the redistribution of magnetized nanoparticles and their magnetic field. The critical forces required to overcome various inter-molecular interactions (e.g., frictional and Vander Waals) in order to redistribute the nanoparticles was estimated to be 12 nN with help of AFM tip nanomanipulation. Detail of the experimental results will be reported.

11:45 AM 16.10
A Novel Fabrication Technique for Interacting Ferromagnetic-metal Nanoparticle Systems: Fine-tuning of Particle Diameter and Interparticle Spacing. Satoshi Tomura, Kenkuke Akamatsu, Hiroshi Shinkai, Shingo Ikeda, Hidemi Nawafune, Chiharu Mitsumata, Takanari Kashiwagi 1,2, and Masayuki Hagiwara 1,2, 3, Japan Science and Technology Agency, Saitama, Japan; 2Kanon Univ., Kobe, Japan; 3Hitachi Metals Ltd., Saitama, Japan; 4RIKEN, Saitama, Japan; 5Yokohama City Univ., Yokohama, Japan.

Macroscopic properties of interacting ferromagnetic-metal nanoparticle systems strongly affect the magnetic field. The present technique allows us to open a new way to realize tailor-made magnetic structures.

SESSION 16: Magnetic Nanowires and Nanotubes
Chair: Bernd Rellinghaus and David J. Sellmyer
Tuesday Afternoon, November 30, 2004
Independence W (Sheraton)

1:30 PM 16.11
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, CMIRA 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) nanometric pillars is performed. The time-resolved measurements show that the response of the magnetization exhibits typical activation processes and two level fluctuations [1,2,3,4]. The variation of the activation energy (or equivalently, the effective temperature) of a ferromagnetic layer under current injection is measured with various experimental protocols. The measured energy is about 0.2 eV (2400 K) for Co/Cu/Co nano-pillars and 2.5 eV (30 000K) in Ni nanowires, for a current of typically 10^-7 A/cm^2 [1] Such huge energies are far beyond the Curie temperature, and beyond the range of energy of spin-wave excitations. The response of the magnetization is also studied as a function of the asymmetry of the interfaces. Two interpretations are discussed on the basis of the experimental results: (I) Deterministic approach. The last interpretation however is ruled out by the fact that the energy involved is far beyond the Curie temperature. (II) Stochastic approach. The measured effective temperature is due to the relaxation of the spin of the conduction electrons, that play the role of environmental degree of freedom on the magnetization. The huge energy involved is due to the fluctuations of magnetic moments between the current and the magnetization (and not directly due to magnetic excitations). The magnetization reversal or magnetic excitations are a consequence of this process. The magnetic system would then be analogous to an open system where spin injection is balanced between both non-symmetric interfaces of the ferromagnetic layer. This interpretation is illustrated in the framework of a four electron channel model [1] J.-E. Wegrowe, Phys. Rev. B 68, 214414 (2003), [2] Myers et al. Phys. Rev. Let. 89, 196801 (2002), [3] Urashin et al. Phys. Rev. Let. 91, 146803 (2003), [4] Fabian et al., Phys. Rev. Let. 91, 257209 (2003).
Co/Cu have also been grown which enable the coercivity of each of the Co sizes to be enhanced. Magnetotransport measurement was made on the Y-junction nanowires and the multilayers in order to demonstrate the effect of the junction and the interfaces on magnetoresistance.

3:45 PM 16.4
Self-Assembler Patterning of Organic Nanostructures for Electronics Applications device. A row of Fe atoms upper edge. We will explore the potential applicability of the kinetic pathway agreement with existing experiments.

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

8:30 AM 17.1/D4.1
Magnetoactive Random Access Memory. Johan Almenara, Philip Brown, Brian Butcher, Renu Dave, Mark DeHerrera, Mark Slaughter, Ken Smith, Ji-Jun Sun and Tehrani Saied; Freescale Semiconductor, Chandler, Arizona.

Magnetoresistive random access memory (MRAM) employs a magnetoresistive device integrated with standard silicon-based microelectronics, resulting in a combination of qualities not found in other memory technologies: MRAM is non-volatile, has unlimited read operations. Recent technology developments of MRAM based on Magnetic Tunnel Junction (MTJ) devices is reviewed. The properties of our unique-toggle-switching MRAM bit is discussed and compared to those of the conventional switching approach. For the first time we present a comprehensive review of the reliability of the MTJ tunneling dielectric and the current carrying write lines will be presented. Scaling of these results to operating conditions demonstrates the reliability of a 4Mb
Spin-polarized current induced magnetization switching has stimulated considerable interest in recent years due to its rich fundamental physics and great potential for new spin-electronic 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 switching in nanometer-sized magnetic tunnel junctions (MTJs) with low resistance-area product (RA) ranging from 1-10 fJ/mV² and Threshold Voltage (Vth) Bottom Plateau MTJ films were deposited in a magnetron sputtering cluster system. A thin tunneling barrier was formed by natural oxidation of the pre-deposited thin Al layer. MTJ films were subsequently patterned into nanometer ellipse shaped pillars using both deep UV lithography (combined with resist trimming) and e-beam lithography. Spin-transfer switching has been consistently observed in patterned MTJs with dimensions down to 0.1x0.2 µm². Low switching current density Jc 10⁴ 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 homogenous and continuous thin Al₂O₃ barrier grown on smooth bottom lead with a roughness (RMS) of 2-3Å. This could have potential applications for a spin transfer based MRAM.

Recent expectations for a breakthrough in further miniaturization and new functionalities in semiconductor electronics have been enhanced by the prospects of spin electronics. New device architectures utilizing the spin degree of freedom of carriers have been proposed with the most attractive approach for spin injection into a semiconductor being the use of a ferromagnetic dilute magnetic semiconductor (DMS). In widely studied DMS material such as GaMnAs, the magnetization order has been proven to be mediated by carriers that are highly spin polarized due to spin-orbit exchange interactions. However, the Curie temperatures of these materials are below room temperature. Previous DMS candidate materials include wide band gap room temperature DMS, such as TiO₂:Co, ZnO:Co, GaN:Cr, AIN:Cr etc, but in these materials spin polarization is not proven, and questions of the origin of the nonmagnetism as well as the granularity of the formation of nonmagnetic dopants need to be answered. Our work is focused on synthesis of stable ferromagnetic DMS (avoiding nanometer scale magnetic inclusions) with the emphasis on structural characterization, measurement of magnetic and transport properties and understanding the correlations between carriers and magnetism. Materials, including ZnO:Cr, ZnO:Co and anatase TiO₂:Co, with Curie temperatures > 365K, were synthesized by a variety of sputtering techniques and characterized by a range of electron, photons and scanning probe methods. Multilayers of Co and Al-doped ZnO with nominal layer thicknesses in the atomic scale were deposited by ion beam sputter deposition. We will discuss an interesting dimensionality crossover from a DMS superlattice to discontinuous magnetic inclusions with widths of 90 nm and above. The rings are fabricated using single layer NiFe or Co, or NiFe (6 nm)/Cu (3-6 nm)/Co (4 nm) pseudo-spin-valve thin film structures. A multilevel lithography process involving electron-beam lithography and lift-off processing was used to fabricate magnetic rings with gold contacts. Magnetometry shows that single layer rings transform between onion (bimodal) and vortex (flux-closed) states, at switching fields which increase with decreasing ring width. For example, 360 nm diameter, 160 nm wide Co rings have an onion-vortex transition at 150 Oe and a vortex-reverse onion transition at 850 Oe, while the corresponding values for a 110 nm wide ring are 240 Oe and 1900 Oe. Reversal chains result only from magnetic instability of the material. In the case of multilayer rings, more complex magnetic behavior occurs because each layer has different switching fields, and magnetotransport effects originate from giant magnetoresistance in the structure. The magnetoresistance and magnetotransport properties are different states within each magnetic layer, as well as the exchange and magnetostatic coupling between layers. In particular, the effects of varying the width of the rings and the thickness of the Cu spacer layer on the magnetotransport and switching behavior are discussed.

Current-perpendicular-to-plane (CIP) spin valve device has the potential to replace the current-in-plane (CIP) device with high density magnetic recording head and other spintronics applications. In its intrinsic high magneto-resistance (MR) ratio, the resistance coming from the active layers of CIP spin valve has to be increased [1]. Several efforts have been made through such as donut valve structure, nano-oxide layer, and new materials have been investigated by many groups. Another effective approach to increase the resistance is to reduce the current crossing area. In this work, size effects on the CIP spin valve were investigated through donut valve structure with small pillar area (75x135 nm², 100x217 nm² and 184x415 nm² with ellipse shape) were fabricated in our lab. The processes include thin film sputtering, electron-beam lithography, ion milling etching and magnetic annealing. Nano-oxide-layers (NOL) were also introduced in the present work and functioning as current confine to further reduce the effective area for current passing through. With dot size decreasing, higher MR and MR ratio were achieved, which indicates that device is approaching to its intrinsic MR ratio with size decreasing. The results show a non-linear relationship between dot area and MR ratio. This is because that the conductive lead contact resistance in the MR measurement is still too high to be neglected, thus the spin valve active layer resistance dominates the measurement result, which causes MR ratio lower than the intrinsic value. Detailed results will be presented in full paper.

Recent expectations for a breakthrough in further miniaturization and new functionalities in semiconductor electronics have been enhanced by the prospects of spin electronics. New device architectures utilizing the spin degree of freedom of carriers have been proposed with the most attractive approach for spin injection into a semiconductor being the use of a ferromagnetic dilute magnetic semiconductor (DMS). In widely studied DMS material such as GaMnAs, the magnetization order has been proven to be mediated by carriers that are highly spin polarized due to spin-orbit exchange interactions. However, the Curie temperatures of these materials are below room temperature. Previous DMS candidate materials include wide band gap room temperature DMS, such as TiO₂:Co, ZnO:Co, GaN:Cr, AIN:Cr etc, but in these materials spin polarization is not proven, and questions of the origin of the nonmagnetism as well as the granularity of the formation of nonmagnetic dopants need to be answered. Our work is focused on synthesis of stable ferromagnetic DMS (avoiding nanometer scale magnetic inclusions) with the emphasis on structural characterization, measurement of magnetic and transport properties and understanding the correlations between carriers and magnetism. Materials, including ZnO:Cr, ZnO:Co and anatase TiO₂:Co, with Curie temperatures > 365K, were synthesized by a variety of sputtering techniques and characterized by a range of electron, photons and scanning probe methods. Multilayers of Co and Al-doped ZnO with nominal layer thicknesses in the atomic scale were deposited by ion beam sputter deposition. We will discuss an interesting dimensionality crossover from a DMS superlattice to discontinuous magnetic inclusions with widths of 90 nm and above. The rings are fabricated using single layer NiFe or Co, or NiFe (6 nm)/Cu (3-6 nm)/Co (4 nm) pseudo-spin-valve thin film structures. A multilevel lithography process involving electron-beam lithography and lift-off processing was used to fabricate magnetic rings with gold contacts. Magnetometry shows that single layer rings transform between onion (bimodal) and vortex (flux-closed) states, at switching fields which increase with decreasing ring width. For example, 360 nm diameter, 160 nm wide Co rings have an onion-vortex transition at 150 Oe and a vortex-reverse onion transition at 850 Oe, while the corresponding values for a 110 nm wide ring are 240 Oe and 1900 Oe. Reversal chains result only from magnetic instability of the material. In the case of multilayer rings, more complex magnetic behavior occurs because each layer has different switching fields, and magnetotransport effects originate from giant magnetoresistance in the structure. The magnetoresistance and magnetotransport properties are different states within each magnetic layer, as well as the exchange and magnetostatic coupling between layers. In particular, the effects of varying the width of the rings and the thickness of the Cu spacer layer on the magnetotransport and switching behavior are discussed.
clustering of secondary phases, including metallic Cr or Co, was found in extensive structural or spectroscopy measurements. An important conclusion was that ferromagnetic ordering on magnetic materials is not applicable to these wide band gap ferromagnetic materials. In fact, they remain ferromagnetic in the dielectric state without carrier co-doping. It would probably be more appropriate to replace these materials as diluted magnetic semiconductors (DMS) rather than DMS. We also discuss possible spintronic applications of DMS. This work was supported by NSF/ECSE #0224138 and by the Campbell Endowment at the University of Washington.

The effects of Mn on InAs nanowire synthesis for magnetoelectronic applications

In 2005, they remained ferromagnetic in the dielectric state without carrier co-doping. It would probably be more appropriate to replace these materials as dilute magnetic semiconductors (DMS) rather than DMS. We also discuss possible spintronic applications of DMS. This work was supported by NSF/ECSE #0224138 and by the Campbell Endowment at the University of Washington.

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

Enhancement of Ferromagnetic Properties in (Ga,Mn)N Nanowires by Nitrogen Plasma Treatment

Ferromagnetic (Ga,Mn)N nanowires have considerable potential as high density data storage devices and nanosensors due to their nanosize and anisotropic magnetic response. We employed nitrogen plasma treatment of (Ga,Mn)N nanowires using nitrogen plasma treatment. The plasma treatment was performed under a flow of ammonia gas, 50 - 150 sccm. Au films were implanted to concentration of (0.1-0.8) at.% yielding a saturation magnetization of 0.1-0.8 emu/g. The strength of ferromagnetism increases with Mn concentration and post implantation annealing. The Curie temperature is found to be greater than 400 K. The carrier type has a strong influence on the magnetic properties, similar to other DMS systems. Data from several structural analysis techniques were presented that indicate the perfection of the crystal structure after annealing, giving evidence that substitutional Mn may be occurring.

Electronic Structure of the Strained (La,Ba)MnO3 Thin Films Studied by Hard X-Ray Core-Level Photoemission.

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). Systematic temperature dependence of ferromagnetic (La,Ba)MnO3 thin films was enhanced by arranging film thickness via tensile strain effect, so that room temperature ferromagnetism has been realized even in thin ultrathin film form. By using this characteristic of this material, ferromagnetic field effect transistor working at room temperature has been reported. To evaluate electronic structure, bulk sensitive photoemission spectroscopy is strongly required due to ex-situ treatment of films for device construction. (La,Ba)MnO3 epitaxial thin films (thickness: 300 nm, 20 nm, 3 nm) were prepared on Nb-doped SrTiO3 (001) single crystal substrate. The films were annealed in 1 atm 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 BL29XU of SPring-8. The excitation energy was set to 5.95 keV with the bandwidth of 70 meV. In HX-PES spectrum for Mn 2p, new broad satellite peak was observed for 300nm thickness film. For 20nm thickness film whose ferromagnetism was strongly enhanced by substrate strain, a sharp satellite peak was observed. On the other hand, no satellite peak was observed in the 3nm film. The intensity of observed satellite peaks almost correspond to the magnitude of magnetization and metallic conduction of films. A theoretical calculation revealed the intensity of satellite 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) 224418, [2] Appl. Phys. Lett. 83 (2003) 4860.

Magneto Resistive Sensors and Magnetic Nanoparticles for Biotechnology

The detection as well as the manipulation of single molecules on a
common technological platform is of great interest for both basic research on biological or chemical systems as well as for applications in, e.g., antibody detection. A promising approach is the detection of small magnetic carriers with the newly developed magnetoresistive sensors which would be capable of creating a completely electronic measurement system. Moreover, this system would be additionally compatible with current electronics in microelectromechanical systems, 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 hybridizing 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 fluorescent dyes. This shows, that already at a concentration of about 10^6 particles/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 obtained 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-biotin bond) and thereby enable highly specific detection of complementary molecules. These magnetic particles often suffer from their broad size distribution and the relatively small magnetic moment. With the new colloidal synthesis of superparamagnetic or ferromagnetic Co, CoFe and FePt nanoparticles, by, e.g., pyrolytic decomposition of CVD precursor molecules, magnetic markers with superior magnetic moments, smaller size and size distribution can be produced. Here, the question about their potential to replace magnetite is addressed. Starting from a magnetic analysis of the corresponding magnetic moment of Co and Fe based alloys alloys their synthesis and resulting microstructural and magnetic properties as function of the underlying particle size distribution and the stability of the oleic acid ligand are discussed. Moreover, the magnetic particles offer an additional feature detectable 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 extraction 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.

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


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

We have developed iron oxide based magnetic nanoparticle bio-labeled for detecting DNA hybridization with spin valve sensors. Monodisperse Fe2O3 and MnFe2O4 (M = Fe, Mn) nanoparticles with sizes tunable from 10-20 nm have been prepared via high temperature solution phase synthesis. They are chemically stable and magnetically soft with a magnetization between 70 to 80 emu/g that is suitable for quantitative spin valve sensor analysis. As synthesized, the particles are stabilized with hydrophobic surfactants, and dispersed in non-polar solvents. They can be transferred into aqueous solutions by ligand exchange. After surface functionalization, a single strand DNA (s-DNA) is attached to the particle surfaces. The particles are further immobilized on a substrate surface by hybridization with a complimentary s-DNA anchored on the surface. SEM images show uniform coverage of nanoparticles on substrates for complementary DNA while none coverage for non-complementary ones. Magnetization curves show much higher moment per unit area for complimentary DNA as compared to non-complementary ones. Significant changes in the sensor resistance due to the presence of only tens of nanoparticles have been observed. These demonstrate that monodisperse, surface functionalized iron oxide based nanoparticles can indeed serve as labels for highly sensitive DNA sequence detection.

SESSION 110: Novel Magnetic Nanotechnologies and Fabrication Techniques

Chair: Shan X. Wang
Wednesday Afternoon, December 1, 2004
Independence Wing (Sheraton)

3:15 PM 110.1 Pulse Thermal Processing: A Revolutionary Approach for Processing Nanomaterials, Pujj Radhakrishnan, Ronald D. Ott and Craig A. Bine; Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Pulse Thermal Processing using High Density Infrared (HDI) Plasma Arc Lamp has been investigated as an enabling manufacturing tool for processing nanomaterials and thin-films. HDI acts as a single source lamp offering unique capabilities of processing broad areas with power densities approaching that of a laser. The extremely high radiant energies delivered by the plasma arc lamp provides heating rates in the order of 2,000 °C/s to 20,000 °C/s through a single pulse on a microsecond time frame, thus allowing controlled diffusion on a nanometer-scale level. The ability to design the functionality of nanomaterials offers tremendous potential to exploit this technology for a wide range of applications, including photovoltaic applications and c) crystallization of amorphous Si for photovoltaic applications and c) crystallization of amorphous Si for photovoltaic and thin-film transistor (TFT) applications.

3:45 PM 110.2 Phase-Controlled synthesis of Cobalt Nanoparticles Using a Microfluidic Reactor, Yujun Song, Edward Doomes, Zhanhu Guo, Chaila Kumar and Josef Hornes; Center for Advanced Microstructures and Devices, Louisiana State University, Baton Rouge, Louisiana.

A key requirement for the realization of nanotechnology's technological potential is the ability to produce nanoparticles with well-defined, tailored properties in a cheap and reproducible way. Though claimed by many groups, such a controlled synthesis is not yet possible even for metallic nanoparticles. There are strong indications in the literature that every detail of the synthesis reaction is influencing the final product and its properties. Thus, a crucial step towards a controlled synthesis of nanoparticles is the detailed understanding of the various chemical processes that take place during the synthesis of nanoparticles. The control of nanocrystal size, shape and structure is even more important in the case of cobalt nanoparticles as Co possesses multiple crystal structures very close in energy and there is strong correlation between crystal structure and the magnetic properties. For permanent magnetic application such as recording media, anisotropic high magnetic coercivity bcc phase is the preferred structure. The more symmetrical fcc phase with low coercivity is useful for soft magnetic applications. Size and shape controlled synthesis of cobalt nanoparticles have been reported recently by
Several groups. At CAMD, we are using mainly synchrotron radiation based X-ray absorption spectroscopy (EXAFS and XANES) for determining electronic and geometric properties and standard qaud square measurements for the magnetic properties. The analysis of EXAFS and XANES spectra, respectively, provide detailed information about geometric and electronic structure around the excited atom (type and number of neighbours in the next coordination shells, radial distance to these shells, valency of the excited atom, electronegativity of neighboring atoms etc.) and because these measurements do not require long-range order, they are especially useful for nanoparticles. In this contribution, we discuss several examples of changes in the electronic and geometric properties of Co nanoparticles caused by the variation of various parameters during the wet chemical synthesis (surfactants etc.). Then we present results showing that cobalt nanoparticles of controlled crystal phases can be prepared using a newly developed microfluidic reactor by manipulating flow rates and quenching times. Whereas a high flow rate (0.5ml/min) of reactants followed by quick quenching of the reaction generates a hcp phase, a low flow rate (0.084ml/min) followed by quick quenching provides bcc 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. Lai1, M.F. Chinn1, N. Ke1, W.Y. Cheung1, Quan Li2, and S.P. Wong1,2. 1Dept. 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 arc discharge between the cathode and the anode initiated by a triggering pulse of one μs 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 fct-FePt-X (X=Co, 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: CUK1216/00E).

4:15 PM 110.4
Preparation of Magnetic Hollow Spheres of Submicrometer on Polystyrene-Bead Templates. Kunio Awa1, Hirofumi Yoshikawa1, Kenta Hayashida1, Yasuhiro Kozuka1, Asami Horiguchi1, Shunjii Bandow2 and Sumio Iijima2. 1Dept. of Chem., Nagoya Univ., Nagoya, Aichi, Japan; 2Meijo Univ., Nagoya, Aichi, Japan.

Macro-sized 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 particularly suitable for nanoparticles. In this contribution, we discuss several examples of changes in the electronic and geometric properties of Co nanoparticles caused by the variation of various parameters during the wet chemical synthesis (surfactants etc.). Then we present results showing that cobalt nanoparticles of controlled crystal phases can be prepared using a newly developed microfluidic reactor by manipulating flow rates and quenching times. Whereas a high flow rate (0.5ml/min) of reactants followed by quick quenching of the reaction generates a hcp phase, a low flow rate (0.084ml/min) followed by quick quenching provides bcc phase and a low flow rate (0.084ml/min) with slow quenching results in epsilon phase.

4:30 PM 110.5
Field-Induced Magnetic Anisotropy in Ball-Milled Powder Particles. N. Poudyal1, B. Altuncuvali2, Y. Chakka1, K.-H. Chen1, T. Black1, J. P. Lin1, Y. Ding2 and Z.L. Wang2. 1University of Texas at Arlington, Arlington, Texas; 2Georgia Institute of Technology, Atlanta, Georgia.

N2FeV14B and Sm2Co17 particles of sub-micro size have been prepared by ball milling. Structural and magnetic characterization reveals that these sub-micron particles consisting of nano-scale grains exhibit strong magnetic anisotropy only when they are milled in a magnetic field. The remanent magnetization to saturation magnetization ratio (Mr/Ms) for the field-milled samples is remarkably higher than those milled without field. The increase of the Mr/Ms value upon field milling is in the range from 15 to 25%. X-ray diffraction analysis confirms the alignment of nanograins in the field-milled particles. Based on in-situ observations of the in-field ball milling in a transparent container, the mechanism of the field-induced anisotropy in the nanostructured hard magnetic particles is discussed.

4:45 PM 110.6
Defect Induced Magnetism in Nano Diamonds. Suki Talapatra1,2, T. Kim1, J. Cheng1, M. Shin1, M. B. Huang2, R. Vajtai3 and P. M. Ajayan1,3. 1MS & E, Rensselaer Polytechnic Institute, Troy, New York; 2Physics, SUNY, Albany, New York; 3Rensselaer Nanotechnology Center, RPI, Troy, New York.

The placement and measurement of individual electronic state or nuclear spins arranged in regular arrays on surfaces of bulk solid-state materials are recently suggested as basic building blocks for new technologies for ultra high-density data storage and/or computing via Quantum Cellular Automata (QCA) or Quantum Computing (QC) architectures. The basic experimental requirements in this approach are the ability to fabricate regular arrays of nuclear spins, individual atoms, and isolated electronic states on solid surfaces or in bulk fcc phase, a low flow rate for preparing such structures with good surface properties, and the ability to fabricate these structures with devices in the experimental difficulty for placing individual spins, atoms, or ions in regular arrays in bulk solid-state materials. One possible solution is to instead use encapsulated magnetic nuclei, ions or metal clusters with few nanometer sized fullerences, bucky onions or diamond nanocrystals, and fabricate the required arrays for possible molecular computing and/or data storage applications. 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 in 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.