SYMPOSIUM HH

Magnetic Sensors and Sensing Systems

November 30 - December 1, 2005

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* Invited paper

SESSION HH1: Poster Session
Chair: Jian-Ping Wang
Wednesday Evening, November 30, 2005
8:00 PM
Exhibition Hall D (Hynes)

HH1.1
Phase Separation and Melting of Charge Ordered State in Ru doped Manganites by Neutron Diffraction Study.
Kannadka Ramesha and Anna Llobet Megias; LANSCE, Los Alamos National Laboratory, Los Alamos, New Mexico.

Small amount of Ru substitution (< 10 %) for Mn in charge-ordered (CO) manganites would destroy charge-ordering and induce a ferromagnetic metallic state. Ru substitution in perovskite manganites could promote ferromagnetism in two ways, by valence effect and by inducing a superexchange interactions with surrounding Mn+3 species. To probe the dramatic role played by Ru in destroying the robust CO state, we have carried out structural and magnetic neutron diffraction studies on two series of manganites, Pr0.5Ca0.5Mn1-xRuxO3 and Pr0.5Sr0.5Mn1-xRuxO3 in the temperature range 300-10 K and our results would be presented in the poster. The role of Ru in inducing the ferromagnetic state would also be analyzed using the atomic pair distribution function from observed diffracted intensities.

HH1.2
Sol-gel synthesis of neodymium-barium manganites utilizing microwave irradiation.
Alexander S. Vanetsev[1], Anastasiya E. Chekanova[3], Elena A. Eremina[2] and Yurii D. Tretyakov[2]; [1]Chemical Synergy Laboratory, Kurnakov Institute Of General and Inorganic Chemistry RAS, Moscow, Russian Federation; [2]Department of Chemistry, Lomonosov Moscow State University, Moscow, Russian Federation; [3]Lomonosov Moscow State Academy of Fine Chemical Technology, Moscow, Russian Federation.

The discovery of colossal magnetic resistance (CMR) effect in mixed-valence perovskites of the type $R_{1-x}A_xMnO_3$ (R - La, Pr, Nd, Sm; A - Ca, Sr, Ba, Pb) has promoted stable interest to these compounds. Manganites with CMR-effect are attractive due to their potential application as electrode materials in solid oxide fuel cells (SOFC), chemical sensors, catalysts, and magnetic sensors [1-3]. Functional properties of manganites strongly depend on their composition, microstructure and therefore synthetic pre-history. Traditional ceramic method has some significant disadvantages including long duration and high (above 1000^oC) temperature of synthesis and difficulties in controlling of cation stoichiometry. Therefore the development of new fast methods of synthesis of such compounds is the task of the barest necessity. In present work we propose new technique for the synthesis of $Nd_{0.7}Ba_{0.3}MnO_3$ phase via sol-gel process utilizing microwave irradiation. Micromorphology and magnetic properties of obtained samples are compared with those synthesized by decomposition of nitrates mixture. It is shown that combination of microwave treatment and sol-gel technique allows to reduce temperature and duration of synthesis and also to improve magnetic properties of resulting material. This work was supported by the RFBR grants No. 04-03-32183, 04-03-32827 and 03-03-32813, programme Universities of Russia (projects UR.06.02.551 and UR.06.01.039) and complex programme of scientific research of Russian Academy of Science. 1. A. P. Ramirez, J. Phys. Condens. Matter, 1997, 9, p. 8171. 2. S. P. Isaac, N. D. Mathur, J. E. Evetts, Appl. Phys. Let., 1998, 72, p. 2038. 3. X. L. Wang, S. X. Dou, H. K. Liu, Appl. Phys. Let., 1998, 73, p. 396.

HH1.3
Effects of excess oxygen on physical properties of La(Sr)327 and La(Sr)113.
Yuui Yokota, Jun-ichi Shimoyama, Shigeru Horii and Kohji Kishio; Department of Applied Chemistry, University of Tokyo, Bunkyo-ku, tokyo, Japan.

The colossal magnetoresistance (CMR) effect near ferromagnetic transition (T_C) in manganese oxides $(La,Sr)_{n+1}Mn_nO_{3n+1}$ with n = 2 [La(Sr)327] and ∞ [La(Sr)113] has been expected to be applicable as for magnetic sensors etc. Achievements of decreased electrical resistivity and enhancement of magnetoresistance at room temperature, however, are required for their practical applications. In our previous study, thermogravimetric measurements revealed that polycrystalline samples of La(Sr)327 had relatively large oxygen nonstoichiometry, while magnetic and/or electronic properties of these systems have been controlled only by changing the doping level of Sr. In the present study, we have systematically studied various physical properties of single crystals of La(Sr)327 and La(Sr)113 as functions of Sr composition and oxygen content. Crystal boules with starting compositions of $La_{2-2x}Sr_{1+2x}Mn_2O_y$ and $La_{1-x}Sr_xMnO_y$ were grown by the floating zone method. Small rectangular crystals cut from the crystal boules were annealed at 1000°C for 100 h in air and quenched to room temperature. Then the quenched samples having the oxygen content y~7.00 were annealed at 600~800°C for 100~1000 h under flowing oxygen to introduce excess oxygen. The oxygen controlled $La_{1.4}Sr_{1.6}Mn_2O_y$ (x = 0.3) single crystals indicated a sharp ferromagnetic transition with T_C ~100 K except the as-grown sample which includes local lattice distortions. The T_C of the samples annealed under flowing oxygen slightly increased and the magnetization below T_C largely increased with annealing time under H // ab, while the magnetization under H // c was almost unchanged by oxygen doping. After the oxygen annealing, magnetization under H // ab became larger than that under H // c. These results means that the magnetic easy axis was changed from c-axis to the ab-plane by the excess oxygen, *i.e.*,an increase of manganese valence, which is consistent with the change in the Jahn-Teller distortion direction confirmed by the powder X-ray analysis. Systematic variations of magnetoresistance and magnetization behaviors of La(Sr)327 and La(Sr)113 as functions of excess oxygen content and Sr doping level will be reported.

HH1.4
High density $BaCeO_3$ ceramics sintered using microwave irradiation.
Alexander S. Vanetsev[1], Andrei V. Orlov[2] and Yurii D. Tretyakov[2]; [1]Chemical Synergy Laboratory, Kurnakov Institute Of General and Inorganic Chemistry RAS, Moscow, Russian Federation; [2]Department of Materials Science, Lomonosov Moscow State University, Moscow, Russian Federation.

In recent works [1, 2] it was proven that no interaction between $BaMO_3$ (M = Zr, Ce) and HTSC-melt ($YBa_2Cu_3O_{7-x}$, $BaCuO_2$, CuO) at 1050^oC occurs. This fact shows the possibility of the practical application of $BaMO_3$ ceramics for the HTSC technology. In present work possibilities of microwave irradiation for sintering of $BaCeO_3$ ceramics was studied. To enhance sinterability we make an addition of 0-5% (weight) of low-melting phase (CuO). Sintering of samples was carried out at T = 900-1500^oC using microwave Multilab 2.5 oven (output power - 2.4 kW, frequency - 2.45 GHz) and conventional resistance furnaces. The analysis of sintered samples was performed using XRD, DT/TG analysis and particle size distribution analysis (laser diffraction methods). It was shown that densification rate of $BaCeO_3$ ceramics during liquid phase sintering at low temperatures is seriously affected by the trace amounts of secondary phases. Application of microwave processing allows to reduce significantly the sintering duration and, in some cases, to reduce the temperature of sintering. This work was supported by the RFBR grant No. 03-03-32813 and complex programme of scientific research of Russian Academy of Science. 1. A. L. Vinokurov, O. A. Shlyakhtin, Young-Jei Oh, A. V. Orlov, Yu. D. Tretyakov, Supercond. Sci. Tech., 16(2003), p.416. 2. A. V. Orlov, A. L. Vinokurov, A. S. Vanetsev, Yu. D. Tretyakov, A. V. Koltsov, K. L. Gavrilov, R. Levi-Setti, Mend. Comm., 2004, 14 (04), p.183.

HH1.5
Magneto-optical Properties of Small Atomic Clusters of Ga and In with As, V and Mn.
Liudmila A. Pozhar[1], Alan T. Yeates[2], Frank Szmulowicz[2] and William C. Mitchel[2]; [1]Chemistry, Western Kentucky University, Bowling Green, Kentucky; [2]Materials and Manufacturing Directorate, Air Force Research Lab, Wright-Patterson AFB, Ohio.

Density of magnetic elements in sensors and magnetic memory materials increases by several orders of magnitude when such elements are synthesized in channels of several atomic diameters in width provided by alumina and silica membranes. While the confinement helps stabilize the atomic clusters/wires and reduce spin-disordering temperature effects, it also affects dramatically magneto-optical properties of the confined atomic systems. Moreover, correlations between cluster structure/stoichiometry, channel structure/composition and magneto-optical properties of the confined atomic clusters can be used to synthesize magnetic elements and heterostructures with desirable magneto-optical properties. In this work, several stable, small pyramidal clusters of Ga and In atoms with As, V and Mn have been synthesized virtually (i.e., fundamental theory-based, computationally) by means of the Hartree-Fock (HF) and multi configuration self-consistent field (MCSCF) methods as realized by the GAMESS software. The pre-designed clusters have been developed by minimization of the clusters' total energy under spatial constraints applied to the positions of the clusters' atoms, to model the clusters' synthesis in quantum confinement. The corresponding vacuum counterparts of the pre-designed clusters have been synthesized when the spatial constraints are relaxed. The electronic energy level structure (ELS), direct optical transition energy (OTE), and charge and spin distributions of all of the synthesized clusters have been studied in detail and compared to those of the corresponding Ga and In clusters with As atoms that do not contain V or Mn (such clusters have been reported in previous publications of the authors). This comparison leads to several important conclusions concerning effects caused by inclusion of V and Mn atoms into non-magnetic clusters. Thus, substitution of As atoms by V or Mn ones in the majority of the studied cases destabilizes otherwise stable non-magnetic clusters, so that only very few such clusters containing V or Mn atoms remain stable. The OTEs of these stable clusters are several times smaller than those of the corresponding non-magnetic clusters. Most importantly, the stable clusters containing V or Mn atoms reveal noticeable magnetism. In particular, their spin distributions embrace the clusters and reach beyond the regions of space occupied by the clusters' atoms. This signifies collectivization of the atomic spin distributions. Interestingly, In-based clusters with As without V or Mn atoms do not possess this property. Another significant feature of In-based clusters with As is that inclusion of V or Mn atoms thoroughly destabilizes these clusters, thus indicating that experimental synthesis of InAs clusters with V or Mn atoms, even in quantum confinement, may prove difficult.

HH1.6

Flexible and Insulating Superparamagnetic Composites.
Robert Sailer[1], Anthony N. Caruso[1], Jamie Baxter[1], Philip Boudjouk[1], Douglas L. Schulz[1], Peter Eames[2], Mark Tondra[2] and Bob Schneider[2]; [1]Center for Nanoscale Science and Engineering, North Dakota State University, Fargo, North Dakota; [2]NVE Corporation, Eden Prairie, Minnesota.

Coatings that provide both magnetic flux isolation and concentration are targeted for optimization of magnetic field sensors by reducing 1/f noise and providing a means of controlling internal and/or external magnetic fields in galvanic isolators. While high permeability materials are currently employed in these applications, the ability to produce stable films thicker than 10 microns using conventional microelectronic processes is yet to be fully developed. The goal of the current project is to develop flexible and insulating superparamagnetic composite materials for use as magnetic flux concentrators and shields. The insulating and/or flexible nature of the composite coatings might also enable new strain sensor applications. An induced moment of 10 emu/g in at least 30 Oe is the performance target of these materials which are expected to be disposable given their cost-effective formulation and fabrication. The approach to formulation and film growth will be highlighted, and details on device enhancements will be presented. This research was supported by Defense Microelectronics Activity/DARPA.

HH1.7

Four-probe Magnetoresistance of Current-perpendicular-to-plane Structures. Hua Zhou, Mark Covington and Michael Seigler; Seagate Technology, Pittsburgh, Pennsylvania.

The resistance and magnetoresistance (MR) of three-dimensional current-perpendicular-to-plane (CPP) structures have been calculated via numerical finite element solutions of the Laplace equation. This model accounts for the non-uniform current paths in a four-probe geometry that can yield MR that differs from the intrinsic MR of the isolated CPP pillar with spatially uniform current flow. We calculated the four-probe MR for various geometries and resistivities of both the normal metal leads and the magnetoresistive pillar. From a single, unified approach, we are able to consistently account for the disparate behavior that has been previously published. In particular, we identify conditions that produce four-probe MR that differs from the intrinsic MR of the CPP pillar and highlight those situations where the four-probe resistance is negative. Finally, we present a simple analytical formula for the MR ratio that is applicable to narrow CPP pillars with wide, thin leads.

HH1.8

Magnetic and structural characterization of FeNi films developed for MR field sensor applications. John Petrou[3], Chris Petridis[3], Spyros Diplas[1,2], Anette Eleonora Gunnaes[1], Arne Olsen[1] and Evangellos Hristoforou[3]; [1]Department of Physics, University of Oslo, Oslo, Norway; [2]Centre for Materials Science and Nanotechnology, University of Oslo, Oslo, Norway; [3]Laboratory of Physical Metallurgy, School of Mining and Metallurgy Engineering, National Technical University of Athens, Athens, Greece.

Forced super-paramagnetic behavior of Fe-Ni thin films has been achieved by imposing an on-plane rotational magnetization field. The magnetization field was obtained by transmitting sinusoidal and cosine fields of amplitude larger than the field anisotropy of the thin film. Such an arrangement targets to the development of new types of monolithic CMOS compatible field sensors. Kerr microscopy studies on 30 nm Fe60Ni40 films illustrated a single magnetic phase on the thin film surface, with coercive and anisotropy fields of 120 A/m and 400 A/m respectively. Magnetoresistive studies also demonstrated a soft magnetic behaviour with minima and maxima corresponding to the above mentioned values. These results correspond to a soft phase of a thin permalloy film. X-ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM) were used to study the surface and bulk structure of the films. XPS studies were performed by using both Al K alpha (1486.6 eV) and Mg K alpha (1253.6 eV) radiation, in order to acquire chemical state information from different depths in the sample. The results showed that the outermost surface is dominated by Fe oxide of thickness $\sim$ 4 nm. High resolution Ni 2p spectra showed a depletion of Ni on the outermost surface and an enhancement of its presence after a depth of $\sim$ 2.5 nm. Nickel was found almost exclusively in metallic form, as expected from the thermodynamic stability of the Fe and Ni oxides. It was concluded that the surface of the film consists of a mixture of an ultra-thin Fe oxide and Ni in metallic form, which do not seriously affect the magneto-resistive and magneto-optic response of the film.

HH1.9

Micro-patterned NiFeMo Magnetoimpedance Multilayer for Magnetic Sensor Application. Duhyun Lee[1], K. H. Jeong[1], Y. S. Kim[2] and S. J. Suh[1,2]; [1]Dept. of Advanced Materials Eng., Sungkyunkwan University, Suwon, Kyonggi-do, South Korea; [2]AMPIT, Sungkyunkwan University, Suwon, Kyonggi-do, South Korea.

The impedance of soft ferromagnetic material is very sensitive to the external magnetic field. To apply this phenomenon for magnetic field sensor, for example, a triaxial compass in mobile electronics, the magnetoimpedance (MI) material should be integrated into a chip. However, the most promising MI materials of Co-based amorphous ribbon or wire are not compatible with semiconductor process. Thus, this study adopted the NiFeMo multilayer, which could be deposited with sputter and patterned with conventional photolithography. The sandwich-type multilayer of Ta/NiFeMo/Ta/Ag/Ta/NiFeMo/Ta was deposited on the silicon substrate with sputtering, where the Ta is for isolation layer, NiFeMo for magnetic sensing layer and Ag for conducting layer. The composition of NiFeMo was Ni_{79}-Fe_{16}-Mo_5 wt. %. Photolithography and lift-off were carried out for micro-patterning. Changing the shape and the thickness of NiFeMo and Ag layer, magnetoimpedance change was observed. Under fixed NiFeMo condition (thickness: 0.3 μm, width: 100 μm, length 300 μm), increase of Ag thickness (0.1-0.9 μm) enhanced the MI ratio from 6% to 34% linearly, where the width and length of Ag were 20 μm and 400 μm respectively. The change of NiFeMo thickness also showed similar tendency and 0.3 μm was the optimum. Regarding the effect of pattern shape, the length was fixed to 300 μm and the width was varied from 100 to 500 μm for NiFeMo. Narrow NiFeMo showed higher MI ratio. This result is opposite to previous studies. Generally wide width of magnetic layer enhances the transverse anisotropy, and thus increases the change of magnetization while external field changes. Our result can be attributed to the dead area in NiFeMo that dose not change its magnetization direction and hinders the rotation of neighboring magnetization. It means the width of NiFeMo is unnecessarily wide. In case of Ag width change from 10 to 50 μm, narrow Ag showed higher MI ratio. It is due to the fact that narrow conduction layer enhances the closed loop formation of magnetic flux in magnetic layer. For sensor application, the field region above the H_k is used typically because this region shows reversible behavior. In our multilayer, the region below the H_k also showed almost reversible behavior due to its low hysteresis loss. This region showed almost linear impedance change and had the sensitivity about 10 %/Oe.

HH1.10

Iron Oxide Core-Shell Composites as Sensing Materials.
Lingyan Wang[1], Xiajing Shi[2], Jin Luo[2], Susan Lu[2], Benjamin Kum[1] and Chuan-Jian Zhong[1]; [1]Chemistry, State Univ. of New York at Binghamton, Binghamton, New York; [2]Systems Science and Industrial Engineering, State Univ. of New York at Binghamton, Binghamton, New York.

Magnetic nanoparticles are attracting increasing interest for information storage, drug delivery, medical imaging, catalysis, and sensors. The ability to control the size and surface composition of iron oxide nanoparticles is particularly important for these applications. This paper reports findings of an investigation of the synthesis of monolayer-capped iron oxide core (iron oxide)-shell (gold) nanocomposite and their thin film assembly towards sensing materials. The coating of iron oxide nanoparticle cores with gold shells leads to the formation of Fe oxide@Au core-shell nanoparticles with controllable surface properties. In addition to evidence from TEM detection of the change in particle size, UV-Vis observation of the change in surface plasmon resonance band, and XRD detection of disappearance of the magnetite diffraction peaks after coating the gold shell, the formation of the core-shell morphology was further confirmed by DCP-AES composition analysis of Au and Fe in the molecularly-mediated thin film assembly of Fe oxide@Au particles. The interparticle ligand exchange-precipitation chemistry at the gold shell is to our knowledge the first example demonstrating the inter-shell reactivity for constructing molecularly-mediated thin film assemblies of Fe oxide@Au particles. The nanoparticle assemblies have been tested as array sensing materials on chemiresistors for detecting toxic gases and volatile organic compounds. Preliminary results will be discussed, along with their implications to designing interfacial reactivities and applying pattern recognition for sensing array applications.

HH1.11
Abstract Withdrawn

HH1.12
Magnetic Field Effect and Photo-induced magnetism on $Y_{0.33}Sr_{0.67}CoO_3$ compound. Zhang YuFeng, [1]Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan; [2]Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan; [3]Yuge National College of Mari.Technology, Ehime, Japan; [4]Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan; [5]Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan.

We prepared the $Y_{0.33}Sr_{0.67}CoO_3$ compounds by a conventional solid state reaction method which sintered in air or under oxygen flow, then annealed at 400 degree under oxygen or nitrogen flow for O_2-processed sample. Power X-ray diffraction results show the existence of single phase crystal structure with a common crystal structure. A DC magnetization jump was found at around 180 K (T_J) with a large thermal hysteresis under 100 Oe external field indicating a kind of magnetic phase transition in O_2-processed sample. The magnetic memory effect may also exist, T_J shifts to lower temperature and magnetization decreases below T_J after the CW laser (λ=1064 nm) and pulsed laser (λ=1050 nm) during the magnetic measurement. There is a photo-induced magnetization upon irradiation with laser. The similar phenomena have been found in the sample prepared in air and annealed in O_2 and N_2. The magnetization jump may come from the inter-spin state transition on Co^{3+} ion, e.g., from high spin state to intermediate spin state. At the same time, the magnetization of air-processed sample, N_2-annealed and O_2-annealed are larger than the O2-processed sample and the T_J is higher than that of under the same magnetic field. The choice of preparation processing is important to make thin-film for application. The magnetic memory effect and the ability of the photo-induced magnetization with respect to the field on $Y_{0.33}Sr_{0.67}CoO_3$ compound provide a novel mechanism that may be useful for its magnetic-photo sensor device application.

SESSION HH2
Chairs: Hubert Brueckl and Mark Tondra
Thursday Morning, December 1, 2005
Room 308 (Hynes)

8:30 AM HH2.1
A Pressure Sensing Device based on a Crossed Anisotropy Inductive Element. Michael Frommberger[1], Clemens Schmutz[1], Jeffrey McCord[2] and Eckhard Quandt[1]; [1]Smart Materials, Research Center caesar, Bonn, Germany; [2]Institute for Metallic Materials, IFW Dresden, Dresden, Germany.

In an inductor operating at high frequencies the hard axis of the integrated material has to be aligned parallel to the driving ac magnetic field. This was realized in a toroidal inductor design by sequential deposition of magnetic layers possessing uniaxial anisotropy, whereas the wafer was rotated by an angle of 90 degrees during the individual sputtering steps. The magnetic layers (FeCoBSi) where separated by thin SiO2 layers. The lamination prevents elevated eddy currents in the rather thick cores (in the range of 5 μm) and the formation of closure domains which would increase high freqeuncy losses. The diameters of the fabricated toroid inductors are between 1 mm and 4 mm. Such devices were fabricated on 6" Si/SiO2 wafers, where the metallization was realized by electroplating copper, planarization of the first metallization was obtained by using BCB resist. A pressure sensitive device could be realized by fabricating the inductors on SiO2 membranes. An applied pressure results in compressive (or tensile) stress on the magnetic core and leads to a rotation of the crossed magnetization into a state where the anisotropy is radial. In this state the effective permeability of the core changes by a factor of 2. The device fabrication steps will presented. An emphasis will be put on the magnetic domain formation in the multilayered magnetic cores and their dependence on applied pressure (stress) in view of the funcionality of the device as a pressure sensor. High frequency charcterisation was done by means of a network analyzer. Measurements will be presented proofing the concept of crossed anisotropy magnetic cores and the us of such inductive elements as sensing part of a highly sensitive pressure sensor. M. Frommberger, J. McCord, E. Quandt, High frequency properties of FeCoSiB thin films with crossed anisotropy, IEEE Trans. Magn. 40, 2004, 2703-2705 M. Frommberger, C. Schmutz, M. Tewes, E. Quandt, W. Hartung, R. Losehand, J. McCord, Integration of crossed anisotropy magnetic core into toroidal thin film inductors, IEEE Microwave Theory and Techniques, Vol. 53, No. 6, June 2005.

8:45 AM HH2.2
Boosting Magnetoresistance in Fe/MgO/Fe Tunnel Junctions. Kirill D. Belashchenko, Julian Velev and Evgeny Y. Tsymbal; Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, Nebraska.

The recent discovery of large magnetoresistance values in MgO-based magnetic tunnel junctions [1,2] aroused significant interest due to potential application of these junctions as magnetic field sensors. For this application it is critical to make the MgO barrier as thin as possible in order to match the junction resistance to other electronic components. Measurements for epitaxial Fe/MgO/Fe junctions show, however, that tunneling magnetoresistance (TMR) decreases precipitously for barrier thickness below 2nm [2]. In this paper we elucidate the origin of this behavior and propose the way to enhance TMR for thin MgO barriers. We investigate the electronic structure and spin-dependent tunneling in epitaxial Fe/MgO/Fe(001) tunnel junctions using a first-principles approach. We find that for small MgO barrier thickness the minority-spin resonant bands at the two interfaces make a significant contribution to the tunneling conductance for the antiparallel magnetization, whereas these bands are, in practice, mismatched by disorder and/or small applied bias for the parallel magnetization. This explains the experimentally observed decrease in TMR for thin MgO barriers. We predict that a monolayer of Ag epitaxially deposited at the interface between Fe and MgO suppresses tunneling through the interface band and may thus be used to boost the TMR for thin barriers. [1] S. S. P. Parkin, C. Kaiser, A. Panchula, P. M. Rice, and B. Hughes, Nature Materials 3, 862 (2004). [2] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, and K. Ando, Nature Materials 3, 868 (2004).

9:00 AM HH2.3
Soft Magnetic Layers for Low-Field Detection with Magnetic-Tunnel-Junction Sensors. William F. Egelhoff, Robert D. McMichael, Mark D. Stiles, Frank Johnson, Alexander J. Shapiro, Cindi L. Dennis, Brian B. Maranville and Cedric J. Powell; NIST, Gaithersburg, Maryland.

We have investigated a variety of soft magnetic layers as sense layers for magnetic-field sensors. We find that in thin-film form, some of these soft materials can have susceptibilities approaching those of the corresponding bulk material. In general, the highest values occur in tri-layer structures with a non-magnetic film separating two soft magnetic films. The alloy Ni77Fe14Cu5Mo4 of the mu-metal family is the softest thin-film material we have found, and we can achieve susceptibilities values above 100,000 using it in tri-layer structures. The major impediment we have found to using these very soft layers in low-field sensors is that the susceptibility decreases by almost two orders of magnitude when the soft structure is incorporated in a standard spin valve or tunnel junction. The problem appears to be stiffening of the soft layer by the stray field from ripple in the pinned layer.[1] A partial solution is found in the use of a synthetic antiferromagnetic as the pinned film. The antiferromagnetic alignment appears to have a canceling effect on the stray field.. In this talk, we will illustrate the problem, present our attempts to solve it, and discuss the outlook for achieving significant improvements in thin-film, low-field sensors. [1] M. Tondra, J. M. Daughton, C. Nordman, D. Wang, and J. Taylor, J. Appl. Phys. 87, 4679 (2000).

9:15 AM *HH2.4
Recent Development of Magnetoresistive Devices and Their Applications. Dexin Wang, NVE Corporation, Eden Prairie, Minnesota.

Advanced magnetoresistive materials have made great strides in the past decade driven by intensive R&D efforts in labs from both research institutes and industries worldwide which has led to successful and significant commercialization. Beyond read-heads that is in production for magnetic recording and MRAM that is arguably in preproduction stage, there are a vast variety of other devices using these materials being investigated, developed, and even tested in field. These include devices that directly sense magnetic field above and below the Earth's field range, and derivative devices that utilize magnetic field as a means to facilitate other measurement functions. It is well known that advanced magnetoresistive materials can offer large signal, high sensitivity, small size, low weight, low cost, and complex functions. It is also true that the development of applicable devices involves subtle and careful considerations in all the aspects during concept, design, fabrication, and implementation stages, in order to meet the requirements. In this presentation, I will selectively address the issues involved in such a development process that have not been addressed before. The basic magnetoresistive material development benefits from realistic atomistic simulation as in the case of magnetic tunnel junctions. A new in-stack biasing scheme is exploited to achieving linear performance for a magnetic field sensor using magnetic tunnel junctions. An external bias approach is adapted to achieve an angle sensor using a spin valve material that has significant hysteresis. These approaches and devices will be used as examples to illustrate typical development issues in these unique devices. This work has been assisted by Professors Xiaowang Zhou, Haydn Wadley, Jim Howe from the University of Virginia, Dr. David Larson from Imago, and Drs. Jim Daughton, Cathy Nordman, Mark Tondra, Carl Smith from NVE. The financial support has been provided by DARPA, MDA, NIST, and NSF.

10:15 AM *HH2.5
Zigzag Shaped Magnetic Sensors. David P. Pappas, Magnetic Sensors, Quantum Devices Group, National Institute of Standards and Technology, Boulder, Colorado.

Recently, it has been shown that the magnetization in nano- and micro-scale magnetic structures follows the contour of the edges. In particular, it has been shown that the magnetization in zig-zag shaped structures follows closely the shape of the element, with alternating +90 and -90 degree domain walls pinned at the corners. In this wrork, we have studied these structures using magneto-transport measurements, scanning electron microscopy with polarization analysis, and micromagnetic simulations. We show that this simple and unique geometry can be used as a single-axis magnetic field sensor. In this configuration, the sensors are primarily sensitive to fields parallel to the applied current. These results can be interpreted in terms of a coherent rotation model of the magnetization. These results show that it is possible to obtain optimal magnetic biasing of MR sensors purely by engineering the shape at the nano-scale level.

10:45 AM *HH2.6
Low Noise and Highly Sensitive Magnetic Tunneling Junction Sensors. Gang Xiao, Physics Department, Brown University, Providence, Rhode Island.

We have developed micron-scale magnetic tunnel junction (MTJ) sensors that are characterized by low field noise and high field sensitivity. Our research shows that magnetic stability in the magnetic tunneling electrodes is a crucial factor in reducing the low frequency noise in small MTJs. Our careful thermal annealing process has allowed us to obtain some of lowest noise magnetic sensors. With these sensors, we have built biomagnetic sensors sensitive enough to detect a single magnetic particle. We have also built scanning MTJ microscopes that can construct the electrical current distribution of an integrated circuit non-invasively by measuring spatially feeble magnetic field generated by the circuit.

11:15 AM HH2.7
Extraordinary Magnetoresistance Sensor Designs for Magnetic Recording. Michael A. Seigler, Hua Zhou and Thomas F. Ambrose; Seagate Technology, Pittsburgh, Pennsylvania.

We studied the prospect of using extraordinary magnetoresistance devices as read head sensors through finite element modeling. We first reproduced results from two papers in the literature and demonstrated that we can get correct results with our software. Then we studied some novel structures such as a three terminal device and a shorted Hall bar structure. The three terminal device gives a much higher magnetoresistance ratio than the shorted Hall bar structure (a two terminal device), mainly because the voltage increase in the other voltage probe is suppressed. The effect of the semiconductor geometry and bit orientation with respect to the magnetic recording media is studied for a recorded bit size of 10 nm x 50 nm. For a 20 nm x 50 nm semiconductor geometry and vertical bit orientation, we get a magnetoresistance ratio of over 8% for the three terminal device. For a device thickness of 100 nm, the change in resistance (DR) and the minimum resistance (R0) are about 8.7 Ohms and 103 Ohms respectively, giving a signal voltage of 8.7 mV for a sense current of 1 mA. For the shorted Hall bar geometry, also for a bit size of 10 nm x 50 nm, we got a magnetoresistance ratio of nearly 4% for a 10 nm x 50 nm Hall bar. The corresponding DR and R0 are 4.2 Ohms and 108 Ohms respectively, giving a signal voltage of 4.2 mV for a sense current of 1 mA. Considering that these devices do not have magnetic noise nor is their frequency response limited by the gyromagnetic frequency, as in a more conventional magnetic spin-valve sensor, we would say that both the three terminal device and the shorted Hall bar configuration are very promising to be used as read head sensors, with the shorted Hall bar configuration being more worthy to try because of its relatively simple structure. We'll also show the effect of biasing these sensors into a more linear operating regime by applying a constant magnetic field, which increases the device complexity, but would be the preferred mode of operation.

11:30 AM *HH2.8
Trends in Nano-Scaled CPP Magnetic Transducers.
Pat J. Ryan and Song Xue; Advanced Transducer Development, Seagate Technology Inc., Bloomington, Minnesota.

For the past 50 years or so, areal density in magnetic recording has increased by almost 8 orders of magnitude. Today, the advanced magnetic readers typically have dimensional widths of less than 100 nm. As these dimensions continue to shrink, trade-offs among performance, magnetic stability, and reliability pose serious technological challenges for further increasing areal density. We will review process technologies to fabricate nano-scale magnetic read sensors. We will also discuss the current reader device options available to HDD recording. A roadmap of technology that includes Magneto-resistive Tunnel Junctions(TMR), CCP-CPP-SV, and metal CPP SV will be discussed. Scaling challenges in meeting future requirements will be addressed.

SESSION HH3
Chairs: Hubert Brueckl, William F. Egelhoff and Jr.
Thursday Afternoon, December 1, 2005
Room 308 (Hynes)

1:30 PM *HH3.1
Making Magnets Work for Healthcare: A Hand-Held Room Temperature Squid Probe with a 60 pT Detection Limit.
Simon Hattersley[1], Audrius Brazdeikis[2] and Q. A. Pankhurst[1];
[1]London Centre for Nanotechnology, London, United Kingdom;
[2]Department of Physics and Texas Center for Superconductivity, University of Houston, Houston, Texas.

We describe the development and testing of a high-T_c SQUID measurement system designed for medical device applications, which embodies the following features: - Efficient transfer of a magnetic signal to the SQUID using non-superconducting coils and cables, which makes feasible a hand-held probe suitable for clinical use; - Correlated signal detection which allows the extraction of signals at sub-millivolt levels and the rejection of thermal noise, mains and other interference sources; - Detection of a field of 60 pT at the sense coil, corresponding to the signal generated by applying a field of 100 μT to 100 μg of magnetite Fe_3O_4 at a displacement of 30 mm from the probe tip. The properties and limitations of the system will be discussed, as will future prospects for healthcare applications involving its use. In particular we will describe a medical tool capable of magnetically detecting sentinel lymph nodes during breast cancer surgery.

2:00 PM *HH3.2
Biomolecular Recognition Assays Using Spintronic Biochips and Magnetic Field Assisted Hybridization. Paulo P. Freitas[1], H. A. Ferreira[1], F. Cardoso[1], J. Germano[2], L. Sousa[2], M. Piedade[2], J. M. Lemos[2], B. A. Costa[2], V. Martins[3], L. Fonseca[3], J. S. Cabral[3], L. A. Clarke[4] and M. D. Amaral[4]; [1]INESC MN, Lisbon, Portugal; [2]INESC ID, Lisbon, Portugal; [3]BERG, IST, Lisbon, Portugal; [4]Chemistry and Biochemistry Department, Faculty of Sciences, University of Lisbon, Lisbon, Portugal.

Spintronic biochips incorporate a target arraying mechanism (current lines) and a magnetic nanoparticle detector (magnetoresistive sensor). Biomolecular recognition detection occurs through three phases: first, biomolecular targets are labeled with magnetic nanoparticles; second, the labeled target biomolecules are guided towards surface-immobilized biomolecular probes; and third, target-probe recognition is detected by measuring the field created by the immobilized magnetic markers using magnetoresistive sensors, after proper washing procedures to clean non-specifically bound targets. Recent MR biochip demonstrators were designed as multiprobe chips with capacity for up to 25 probes (INESC MN, spin valve sensors) or 64 probes (NRL-NVE, GMR sensors). In order to facilitate extension of these biochip demonstrators to a larger number of probes (or to allow more statistical assay information), a new biochip architecture was developed where each probe site consists of a Magnetic Tunnel Junction (MTJ) in series with a Thin Film Diode (TFD). MTJ and TFD resistances and areas were optimized for maximum signal output. The present demonstrator has the capacity for 256 probes. Each probe site contains also a U-shaped current line designed for magnetically assisted hybridization. First results were obtained with MTJ sensors with AlOx barriers (25% TMR at 200 to 400 Ohm μm^2) and 250 nm Micromod labels at various label concentrations. New MgO barriers are being incorporated in the sensors (150% TMR at 150 Ohm μm^2) leading to a much improved magnetic field sensitivity (400 pT/$sqrt$Hz). The biochip is being integrated in a credit card size printed circuit board with all signal control electronics (including temperature control), and data output is transferred into a PDA by a wireless protocol. Biomolecular assays are being done for DNA-cDNA hybridization recognition (cystic fibrosis mutation detection) or micro-organism detection (*Salmonella*).

2:30 PM HH3.3
Design of a System for Counting Magnetically Labeled Biochemical Analytes in A Microfluidic Channel. Mark Tondra,

NVE Corporation, Eden Prairie, Minnesota.

Basic tools for manipulation and detection of magnetic objects in microfluidic channels have been designed, fabricated, and tested. These demonstrations show that magnetic objects in the range of 10 nm to 10 microns can be pulled magnetically from side-to-side or top-to-bottom in a microfluidic channel. Also, detection of relatively large (say >1 micron) magnetic objects in flow has been demonstrated by several groups. These demonstrated tools, when combined in an appropriately designed microfluidic system, will be capable of rapidly counting magnetically labeled biochemical analytes such as cells, bacteria, and even molecules. This presentation will give a description of the overall system concept and present specific micro-chip designs and data. The design depends on the combination of several technical concepts. These include 1) magnetoresistive sensors for detection of labeled objects, 2) application of high magnetic field gradients on the 10 micron and smaller length scale, 3) advantageous use of microfluidic forces, and 4) use of biochemical binding assay techniques to attach magnetic labels to objects of interest.

3:15 PM HH3.4
Magnetic Microcalorimeter Sensors for High-Resolution X-ray Microanalysis. Barry L. Zink, Quantum Sensors Project, NIST, Boulder, Colorado.

Microcalorimeter x-ray detectors are the current state-of-the-art in high-resolution energy-dispersive x-ray spectroscopy for materials analysis and other applications. These detectors can resolve energy differences of better than 1 part in 2000 over a wide energy range which includes the low energies needed to study x-ray fluorescence of nanoparticles and very thin films. As the performance of present devices approaches theoretically predicted limits, new sensor technologies are required to continue improving energy resolution to solve next-generation microanalysis problems. Microcalorimeter x-ray detectors with magnetic sensors show promise for improved energy resolution. This presentation describes our recent efforts at NIST which focus on lithographically patterned microcalorimeter detectors with SQUID-based magnetic sensors, with the goal of multiplexed arrays of very high-resolution x-ray detectors.

3:30 PM HH3.5
Gallium Nitride Heterostructure Based Micro-Hall Sensors for High Temperature Applications. Takuya Yamamura[2] and Adarsh Sandhu[1,2]; [1]Quantum Nanoelectronics Center, Tokyo Institute of Technology, Tokyo, Japan; [2]Electrical Engineering and Electronics, Tokyo Institute of Technology, Tokyo, Japan.

Experimental results on the use of AlGaN/GaN two-dimensional electron gas heterostructures for fabricating micro-Hall sensors for use at temperatures as high as 600^{o}C are described. The sensors will be used as part of a ehigh temperaturef version of our scanning Hall probe microscope for studying the behavior of ferromagnetic domains at elevated temperatures [1]. The maximum stable operating temperature of Si, GaAs and InSb Hall sensors is about 200^{o}C, above this temperature intrinsic conduction renders such devices inoperable. For extremely high temperature applications it is necessary to consider alternative materials for fabricating high performance Hall sensors. The AlGaN/GaN heterostructures were grown by molecular beam epitaxy on a sapphire substrates and had a room temperature sheet carrier concentration and electron mobility of 1.1x10^{13} cm^{-2} and 900 cm^2/Vs, respectively. Micrometer sized Hall crosses were defined by photolithography and argon ion milling. The minimum field sensitivity (B_{min}) of a 50μm x 50μm device was about 0.35G/Hz$^{1/2}$ at 600^{o}C compared with 0.9mG/Hz$^{1/2}$ at room temperature. It is not possible to realize such a figure of merit using conventional semiconductors. The B_{min} increased at $\sim$300^{o}C due to temperature related changes in the Hall coefficient and contact resistance of the device. Factors influencing the choice of materials for high temperature ohmic contacts and the ultimate limit in temperature are discussed. [1] A. Sandhu, A. Okamoto, I. Shibasaki and A. Oral, Microelectronic Engineering, vol.73, p.524, (2004)

3:45 PM HH3.6
Magnetometer based on the opto-electronic microwave oscillator. Andrey B. Matsko, Dmitry Strekalov and Lute Maleki; MS 298-100, Jet Propulsion Laboratory, Pasadena, California.

We present a scheme for an all-optical self-oscillating magnetometer based on the opto-electronic oscillator stabilized with an atomic vapor cell. We demonstrate a proof of the principle with DC magnetic field measurements characterized by 100 nG sensitivity and 1-1000 mG dynamic range. The idea is to put the technology of Opto-Electronic Oscillator (OEO) to advantage, and to combine it with an atomic vapor cell filter. We propose using the effect of Electromagnetically Induced Transparency (EIT) to stabilize the OEO. The EIT resonances are applicable for construction of all-optical miniature atomic clocks and magnetometers. It is possible to produce a stable clock microwave signal or stable microwave signal tunable by the magnetic field using the same OEO, simply by locking the oscillator frequency to the magneto-insensitive or magneto-sensitive atomic transitions respectively. In this manner, both goals of sensitivity and accuracy could be approached. Our device is self-oscillating and, hence, it differs from the passive EIT magnetometer demonstrated previously. On the other hand, the OEO-based magnetometer is different from other active magnetometers, where stability is achieved through the microwave field stored in a microwave resonator or an rf coil containing an atomic vapor cell. There is no need for a microwave cavity in the OEO because the microwave energy is carried as the sidebands of modulated light. This allows for minimizing the size and reducing the magnetometer power consumption without performance loss.

4:00 PM HH3.7
Magnetic Sensors based on Novel Magnetoresistance Effect in Organic Semiconductor Sandwich Devices.
Govindarajan Veeraraghavan[1], Omer Mermer[2], Thomas Lee Francis[1], Yugang Sheng[2], Tho Duc Nguyen[2] and Markus Wohlgenannt[2]; [1]Department of Electrical and Computer Engineering, University of Iowa, Iowa city, Iowa; [2]Department of Physics and Astronomy, University of Iowa, Iowa city, Iowa.

Organic semiconductors are being actively researched for use in organic light emitting diodes (OLEDs), transistors, and photovoltaic devices. A recent discovery of large magnetoresistance (MR) at room temperature in these π-conjugated materials has indicated a huge potential for their use in magnetic sensors. The effect was observed in both macromolecular polymers and small molecular devices. The organic magnetoresistance effect (OMAR) that we had discovered is as large as 10% for small magnetic fields of B = 10 mT at room temperature. This MR effect is therefore amongst the largest of any bulk material. The devices consist of a thin layer of polymer or small molecule deposited between two electrodes. The OMAR sensors thus have a sandwich structure similar to OLEDs. Surprisingly, these devices do not require magnetic electrodes. To the best of our knowledge, the discovered MR effect is not adequately described by any MR mechanisms known to date. We characterize the effect in polymer and small molecule sandwich devices. The dependence of the OMAR effect on voltage, film thickness, temperature, electrode materials, and (unintentional) impurity concentration is discussed. OMAR devices made from polyfluorene (poly (9,9-dioctylfluorenyl-2,7-diyl)) polymer and tris-(8-hydroxyquinoline) aluminum (Alq3) small molecule show the most promise among the materials we tested. We show that the functional dependence of OMAR on the magnetic field is approximately universal in all the materials we studied. The OMAR devices can be manufactured cheaply on flexible substrates, and can be transparent. Our devices therefore hold promise for applications where large numbers of MR devices are required, such as magnetic random-access-memory (MRAM) and applications related to OLED display screens such as touch screens where the position of a magnetic stylus is detected (patent pending). Our devices do not require ferromagnetic electrode materials resulting in flexibility in material choice not available for other MR devices. Interested readers should further look at our publications and a demonstration video at our website http://ostc.physics.uiowa.edu/~wrg/. This work was supported by Carver Foundation and NSF ECS 04-23911.

4:15 PM HH3.8
Spin Injection from Ferromagnetic Cobalt Nanodots into Pi-Conjugated Organic Materials. Bin Hu, Yue Wu, Anping Li, Jane Howe and Jian Shen; Materials Science and Engineering, University of Tennessee, Knoxville, Tennessee.

Conjugated polymers as soluble semiconductors have demonstrated facile material processing and morphologically tunable transport properties in optoelectronic devices. The long spin-relaxation time, due to the weak spin-orbital coupling in such conjugated materials, has been increasingly attractive for spin injection and transport applications. Experimental evidence of spin injection was observed recently in low molecular-weight conjugated molecules using magneto-resistance measurements. Similar success, however, has not been demonstrated in high molecular-weight polymers. Here, we report spin-polarized hole injection in fluorescent poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEHPPV) and phosphorescent iridium complex molecules Ir(ppy)3 from ferromagnetic cobalt nanodots. We found that the spin injection leads to magnetic field-dependent electroluminescence as compared to non spin-polarized injection in the MEHPPV and the Ir(ppy)3. The detailed studies of electroluminescence and photoluminescence indicate that the spin-polarized hole injection increases the singlet-to-triplet exciton ratio. We suggest that this increased exciton ratio is a consequence of the population redistribution of charge transfer states in the recombination of spin-polarized holes and non spin-polarized electrons. Moreover, the spin-injection efficiency decreases rapidly when the cobalt nanodots percolate to form a continuous film.

4:30 PM *HH3.9

Progress Toward a Thousand-Fold Reduction in 1/f Noise in Magnetic Sensors using an AC MEMS Flux Concentrator.

Alan S. Edelstein[1], Greg Fischer[1], Michael Pedersen[2], E. R. Nowak[3] and Shu-Fan Cheng[4]; [1]AMSRD-ARL-SE-SS, U.S. Army Research Laboratory, Adelphi, Maryland; [2]MEMS Exchange, Reston, Virginia; [3]University of Delaware, Newark, Delaware; [4]Naval Research Laboratory, Washington DC, District of Columbia.

It is widely recognized that *1/f* noise is a serious problem in using magnetic sensors. For example, the noise at 1 Hz for the sensors with the highest values of magneto-resistance, magnetic tunnel junctions, is a thousand times larger than the noise at high frequencies. We are working on developing a device, the MEMS flux concentrator, that will mitigate the effect of *1/f* noise. It accomplishes this by placing the flux concentrators that are often used in magnetic sensors on MEMS structures. The MEMS flaps containing the flux concentrators are driven to oscillate at kHz frequencies by electrostatic comb drives. Shifting the operating frequency reduces the *1/f* noise. Depending upon the sensor and the desired operating frequency, the reduction in *1/f* noise can be as large as one to three orders of magnitude. We have succeeded in fabricating working versions of all the components of the device and have observed the desired 15 kHz normal resonant mode of the MEMS structure. The Q is about 30 and it only requires microwatts of power to drive the motion. We have used spin valves for our magnetic sensors because they represent a mature technology that is limited by *1/f* noise. The measured field enhancement provided by the flux concentrators agrees within 10% with the value estimated from finite element calculations. Noise measurements provide strong evidence that the device will mitigate the effect of *1/f* noise. Solutions to the sole remaining fabrication problem will be discussed.