SYMPOSIUM HH
Magnetic Sensors and Sensing Systems

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* Invited paper
HH1.1  
Phase Separation and Melting of Charged Ordered State in Ru doped Manganese by Neutron Diffraction Study.  
Kanndaka Ramachand and Anna Lloret Megias; LANSCE, Los Alamos National Laboratory, Los Alamos, New Mexico.

Small amount of Ru substitution (< 10 %) for Mn in charge-ordered (CO) manganese would destroy charge-ordering and induce a ferromagnetic metallic state. Ru substitution in perovskite manganese compounds is made 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 compounds Pr0.5Ca0.5Mn1-xRu0.3 and Pr0.5Sr0.5Mn1-xRu0.3 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 diffraction intensities.

HH1.2  
Chemical Synergy Laboratory, Lomonosov Institute Of General and Inorganic Chemistry RAS, Moscow, Russian Federation;  
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Institute of Chemistry of Russian Academy of Sciences, Moscow, Russian Federation.

The discovery of colossal magnetic resistance (CMR) effect in mixed-valence perovskite of the type R1-xAxAuxMnO3 (R = La, Pr, Nd, Sm; A = Ca, Sr, Ba, Pb) has promoted stable interest to these compounds. Manganese with CMR-effect are attractive due to their potential applications in high temperature superconducting oxide fuel cells (SOFC), chemical sensors, catalysts, and magnetic sensors [1-3]. Functional properties of manganese strongly depend on their composition, microstructure and therefore synthetic pre-history.

Traditional ceramic methodology has some significant disadvantages, including long duration and high (above 1000°C) 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 base necessity. In present work we propose new technique for the synthesis of Nd0.5Ba0.5MnO3 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 obtained compounds. This work was supported by the RFBR grants no. 04-03-25218, 04-03-32827 and 03-03-32813, programme Universities of Russia (projects UR.06.02.551 and UR.06.01.038) and complex programme of scientific research of Russian Academy of Sciences, 1. A. P. Ramirez, J. Phys. Condens. Matter, 1997, 9, p. A17. 2. S. P. Isaac, N. D. Mathur, J. E. Evetts, Appl. Phys. Lett., 1998, 72, p. 2038. 3. X. L. Wang, S. X. Dou, H. K. Liu, Appl. Phys. Lett., 1998, 73, p. 396.

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

The colossal magnetoresistance (CMR) effect near ferromagnetic transition (Tc) in manganese oxides (La,Sr)n+2(Mn,Fe)n+1O3n+3 with n = 2 [La(Sr)327] and n = 3 [La(Sr)113] has been expected to be applicable as 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 La0.25Sr0.75O3, La0.5Sr0.5O3 and La0.5Sr0.5 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 γ<7.0 were annealed at 600–800°C for 100–1000 h under flowing oxygen to introduce excess oxygen. The oxygen controlled La0.5Sr0.5O3 (γ = 0.3) single crystals indicated a sharp ferromagnetic transition with Tc ~ 100 K except the as-grown sample which includes local lattice distortions. The Tc of the samples annealed under flowing oxygen slightly increased and the magnetization below Tc 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 axes was changed from c-axis to 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 BaCe02 ceramics sintered using microwave irradiation. Alexander S. Vanetsay, Andrei V. Orlov, and Yuiri D. Tretjakov;  
Chemical Synergy Laboratory, Lomonosov Institute Of General and Inorganic Chemistry RAS, Moscow, Russian Federation;  
Department of Materials Science, Lomonosov Moscow State University, Moscow, Russian Federation.

In recent works [1, 2] it was proven that no interaction between BaMoO3 (M = Zr, Ce) and HTSC-melt (YBa2Cu3O7− δ, Ba2Cu2O4, CuO) at 1050°C occurs. This fact shows the possibility of the practical application of BaMoO3 ceramics for the HTSC technology. In present work possibilities of microwave irradiation 2.45 GHz (oven output power - 2.4 kW) and conventional resistance furnaces. The analysis of sintered samples was performed using XRD, DTA/TG analysis and particle size distribution analysis (laser diffraction method). It was shown that the sintering rate of BaMoO3 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. I. A. L. Vinokurov, O. A. Shlyakhitin, Young-Jei Oh, A. V. Orlov, Yu. D. Tretjakov, Supercond. Sci. Tech., 16(2003), p.416. 2. A. V. Orlov, L. O. Vinokurov, Yu. D. Tretjakov, 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. Ljudmila A. Pozhar, Alan T. Yacobi; Franko Zmuidzinas and William C. Mitchell; Chemistry, Western Kentucky University, Bowling Green, Kentucky; 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., experimentally theory-based, computationally) by means of the Hartree-Fock (HF) and multi configuration self-consistent field (MCSF) methods as realized by the GAMESS software. The 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 calculated 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 the interaction 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 could be identified. In atoms of other elements 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, the curved, four-probe results on 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. And In-based clusters with V or Mn atoms that inclusion of V or Mn atoms thoroughly destabilizes these clusters, thus indicating that synthetic evolution of InAs clusters with V or Mn atoms, even in quantum confinement, may prove difficult.

HH1.6 Flexible and Insulating Superparamagnetic Composites. Robert Sailer, Anthony N. Carusso, Jamie Baxter, Philip Boukouvala, Debashish Das, Mark Tompkins, and Bob Schneider; 1Center for Nanoscale Science and Engineering, North Dakota State University, Fargo, North Dakota; 2NVE 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 independent future use of the coating based on Fe is its use as a high stress, high performance target of these materials which are expected to be disposable given their cost-effective formulation and fabrication. The approach to formulation and fabrication will be highlighted, and details on device enhancements will be presented. This research was supported by Defense Microelectronics Activity/DARPA.


The resistance and magnetoresistance (MR) of three-dimensional current-perpendicular-to-plane (CIP) 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 CIP 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 lead to four-probe MR that differs from the intrinsic MR of the CIP 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 CIP pillars with wide, thin leads.

HH1.8 Magnetic and structural characterization of FeNi films developed for MR field sensor applications. John Petrov, Chris Petridis, Spyros Dipsas, Anette Eleonora Gunnes, Arne Olsen, and Evangelos Hristoforou; 3Department of Physics, University of Oslo, Oslo, Norway; 4Centre for Materials Science and Nanotechnology, University of Oslo, Oslo, Norway; 5Laboratory 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 imprinting in-plane rotational magnetic 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 monolayer CMOS compatible field sensors. Kerr microscopy studies on 30 nm Fe80Ni20 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. Magnetoelastic 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 α (1486.6 eV) and Mg K α (1253.6 eV) radiation, in order to acquire chemical state information from different depth levels in the studied nanoparticles. The TEM data showed that the outermost surface is dominated by Fe oxide of thickness ~ 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 ~ 2.5 nm. Nickel was found 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 Magnetoeimpedance Multilayer for Magnetic Sensor Application. Duhyun Lee, K. H. Jeong, Y. S. Kim and S. J. Suh; 1Dept. of Advanced Materials Eng., Sungkyunkwan University, Suwon, Kyonggi-do, South Korea; 2AMPIT, 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 tunnel constrictor in microwave electronics, the magnetoeimpedance (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 1/f pattern and patterned with 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$_{58}$Fe$_{18}$Mo$_{24$ wt. %. Photolithography and lift-off were carried out for micro-pattern. Changing the shape and the thickness of NiFeMo and Ag layer, magnetoeimpedance was observed. The 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 reasonable to previous results. 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 does 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 Hc is used typically because this region shows reversible behavior. In our multilayer, the region below the Hc also showed almost reversible behavior due to its low hysteresis loss. This region almost linear impedance change and had the sensitivity about 10 %/Oe.


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 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 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 only example of the use of 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, 1Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan; 2Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan; 3Yuge National College of Medicine, Tokyo, Japan; 4Applied Physics, Tokyo University of Marine Science and Technology, Tokyo, Japan.

We prepared the Y$_{0.33}$Sr$_{0.67}$CoO$_3$ compound 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 ($\lambda=1064$ nm) and pulsed laser ($\lambda=1050$ 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 under O$_2$, Co$_2$, and O$_3$-annealing. The Co$_2$-annealing 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-prepared sample is larger than the O$_2$-annealed one and the T$_J$ is smaller than 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$_3$ could provide a novel mechanism to make it useful for its magnetic-photo sensor device application.

**SESSION HH2**

**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 Material Technologies, 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, where the magnetization was rotated by an angle of 90 degrees during the individual sputtering steps. The magnetic layers (FeCoBSi) where separated by thin SiO$_2$ layers. The lamination prevents elevated eddy currents in the rather thick cores (in the range of 5 $\mu$m) and the formation of closure domains which would increase high frequency losses. The diameters of the fabricated toroidal inductors are between 1 mm and 4 mm. Such devices were fabricated on 6" Si/SiO$_2$ 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 SiO$_2$ membranes. An applied pressure results in compressive (or tensile) stress on the magnetic core and leads to a rotation of the crossed anisotropy magnetic core 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 functionality of the device as a pressure sensor. High frequency characterisation was done by means of a network analyzer. Measurements will be presented proving 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, 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. Tsybulya, 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 minimize the MgO barrier in MgO/TMn barriers as much 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 thicknesses the minority-spin resonant bands at the 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 epilayer 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**


We have investigated a variety of soft magnetic layers as sensor 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 are found in tri-layer structures with a non-magnetic film separating two soft magnetic films. The alloy Ni$_{77}$Fe$_{14}$Cu$_{5}$Mo$_{4}$ 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 the pinned layer. [1] A partial solution is found in the use of a synthetic antiferromagnetic as the pinned film. The antiferromagnetic alignment apparently has 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. Desin 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 production 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 development of material development benefits from realistic atomistic simulation such as 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 demonstrate typical development issues in these unique devices. This work has been assisted by Professors Xiaowen Zhou, Haydn Wadley, Jim Howie from the University of Virginia, Dr. David Larson from Imago, and Dr. Jim Daughton, Cathy Nordman, Mark Tondra, Carl NVE. The financial support has been provided by DARPA, MDA, NIST, and NSF.

10:15 AM *HH2.5


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 work, 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 directly observe the magnetic field of an integrated circuit non-invasively by measuring spatially field magnetic field generated by the circuit.

11:15 AM HH2.7


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 good agreement 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 device with a magnetic field dependence of the ratio than the shorted Hall bar structure (a two terminal device) is only about 25. In addition, the 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 4.2 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 will also show the effect of biasing these sensors in 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


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 write in tracks 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 current approaches to fabricate high-density 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 (MRJ), 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


1London Centre for Nanotechnology, London, United Kingdom; 2Department of Physics and Texas Center for Superconductivity, University of Houston, Houston, Texas.

We describe the development and testing of a high- Tc SQUID measurement system designed for medical device applications, which embodies the following features: - Efficient transfer of magnetic signals from the SQUID using non-superconducting coils and cables, which makes feasible a hand-held probe suitable for clinical use; - Correlated signal detection that 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 sensor corresponding to the signal generated by applying a field of 100 pT to 100 µg of magnetite Fe3O4 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


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Spintronic biochips incorporate a target arraying mechanism (current lines) and a magnetic nanoparticle detector (magnetoresistive sensor). Biomolecular recognition detection occurs through hybridization. In the 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 multipoire 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 µm2) and 250 nm MicroMold labels at various label concentrations. New MgO barriers are being incorporated in the sensors (150% TMR at 150 Ohm µm2) leading to a much improved magnetic field sensitivity (400 pT/s/sqrHz). 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-CNDNA hybridization recognition (cystic fibrosis mutation detection) or micro-organism detection (Salmonella).

2:30 PM *HH3.3

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 1 microns can be pulled magnetically from side-to-side or top-to-bottom in a microfluidic channel. Also, detection of relatively large (say >1 micrometer) 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 and identifying labeled biological objects, 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. The first sensor 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.

3:45 PM HH13.6
Magnetometer based on the opto-electronic microwave oscillator. Andrej B. Matsko, Dmitry Sterekalov 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 microwave 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 nG dynamic range. The idea is to put the technology of Opto-Electronic Oscillator (OEO) to advantage, and to stabilize 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 OEO 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 cell containing an atomic vapor cell. There is no need for a microwave cavity. The microwave frequency may be swept via the sidesteps of modulated light. This allows for minimizing the size and reducing the magnetometer power consumption without performance loss.

4:00 PM HH13.7
Magnetic Sensors based on Novel Magnetoresistance Effect in Organic Semiconductor Sandwich Devices. Goundarajan Veeraraghavan,1 Omer Mermer,2 Thomas Lee Francis3, Yungang Sheng1, Tho Duc Nguyen1 and Markus Wohlgemuth4,5 1Department of Electrical and Electronic Engineering, University of Iowa, Iowa city, Iowa; 2Department 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 \( \sigma \)-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 magnetoresistive materials (OMAR) that we have discovered is as large as 10\% for small magnetic fields of \( B = 10 \text{ mT} \) at room temperature. This MR effect is therefore among the largest of any bulk material. The devices consist of a thin layer of polymer or small molecule deposited between two carbon electrodes. The OMAR 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 of 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. OLED devices made from polythienylene (9,9-diocyfluoren-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 flexible device structures for use in many applications for other MR devices. Interested readers should further look at our publications and a demonstration video at our website http://ostc.physics.uiowa.edu/~verg/. This work was supported by Carver Foundation and NSF ECS 04-29011.

4:15 PM HH13.8
Spin Injection from Ferromagnetic Cobalt Nanodots into Pt-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-orbit coupling in such conjugated materials, has been an insurmountable obstacle for spin injection and transport applications. Experimental evidence of spin injection was observed recently in low molecular-weight conjugated molecules using magnetoresistance measurements. For similar success, however, has not been demonstrated in high molecular-weight polymers. Here, we report spin-polarized hole injection in fluorescent polymes (2-methoxy-5-(2-ethylhexyloxy)-1,4-phenlenediyne) in fluorescent 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-polarization efficiency...
4:30 PM *HH3.9
Progress Toward a Thousand-Fold Reduction in 1/f Noise in
Magnetic Sensors using an AC MEMS Flux Concentrator.
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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.