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AND

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In association with
NUS National University of Singapore
A*STAR Institute of Materials Research and Engineering
Nanyang Technological University
Symposium E

Nanostructured Magnetic Materials and Their Applications

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S. N. PIRAMANAYAGAM, Data Storage Institute, Singapore

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Scope of Symposium

This symposium focuses on nanostructured magnetic materials with the emphasis on various applications, such as data storage, electronics and biomagnetics. The topics of the symposium include magnetic recording, spintronics, magneto-optics, magneto-mechanics, hard & soft magnets and modelling/simulation. Selected papers will be published in Journal of Nanoscience and Nanotechnology.

Symposium Topics

- Magnetic thin films and nanostructures in magnetic recording (recording media and read/write devices)
- Magneto-electronic, magneto-optic and magneto-mechanical properties of nanostructured magnetic materials
- Nanomagnets with high energy products
- Nanomagnets in soft-magnetic and microwave applications
- Nanostructured Magnetic materials for bio-medical applications
- Domain structure and magnetization reversal mechanisms of magnetic nanostructures
- Modeling/simulation of magnetic nanostructures
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Abstracts

A00039-00040

Synthesis and Magnetic Properties Studies of NiS

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The compounds (TMEDA) M (SC(O)C6H5)2 (M = Ni, 1; Mn, 2) have been synthesized and characterized by X-ray crystallography. Both of the monomeric molecular precursors have been used to make the corresponding monodispersed NiS (two different phases) and cubic phase MnS nanocrystals (NCs) under specific experimental conditions. Changing the surfactants yielded low-temperature rhombohedral β-NiS NCs with millerite structure in dodecanethiol and high-temperature hexagonal α-NiS NCs with NiAs-type structure in oleic acid, while monodispersed hexagonal shaped α-MnS NCs with rock-salt structure were obtained in the presence of a combination of oleyamine and dodecanethiol surfactants. The NCs have been characterized by X-ray powder diffraction patterns, transmission electron microscopy, selected area electron diffraction patterns, and energy-dispersive X-ray analysis. In the magnetic properties studies, noticeable magnetic signals have been detected for both rhombohedral and hexagonal phase of NiS, but the rhombohedral phase exhibits stronger magnetization than the hexagonal phase. Rhombohedral NiS NCs has a magnetization of 1 emu/g at a field of 5 kOe and a coercivity of 10 Oe. Hexagonal NiS NCs has a magnetization of 1.7 emu/g at a field of 5 kOe and a coercivity of 50 Oe.

A00095-00585

Low Temperature Molecular Beam Epitaxy of Ferromagnetic Silicide for Spin-Transistors with SiGe Channel

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Research and development for new semiconductor devices which enable ultrahigh speed operation, ultra low power dissipation, and/or multi-functional operation are strongly required to overcome a scaling limit of complementary CMOS (metal-oxide-semiconductor) performance. In line with this, Si-based heterostructure technologies have been widely developed in a quarter century. Among them, development of the SiGe heteroepitaxy technique on Si substrates enabled strained growth, modulation doping, and formation of quantum well structures, which achieved significant enhancement of carrier mobility and resonant tunneling transport. What is the next jump? New functions created by spin injection from ferromagnetic electrodes into semiconductor channels or quantum dots are big candidates to be used for this purpose. To combine such spintronics with Si-based heterostructure technologies, we have been developing atomically controlled heteroepitaxy of ferromagnetic silicide Fe3Si on the group-IV semiconductor (Si, SiGe, Ge et. al) platform. This paper reports our recent progress in novel epitaxial growth of Fe3Si (Curie temperature: 840K, Spin polarization: 43%) on SiGe for the application of group IV-based spin-transistors.

In the experiment, Fe and Si were co-evaporated (60-200°C) on Si and Ge substrates with (100), (110), and (111) orientations by using MBE (molecular beam epitaxy) system. From Rutherford back scattering (RBS) axial-channeling measurements, large values of the minimum yield exceeding 65 % were obtained for (100) and (110) substrates. These values were drastically decreased to less than 7 % by substituting (111) substrates. Detailed experiments indicated that both Fe/Si ratio and growth temperature were key factors to improve interface quality of Fe3Si/Ge (111). Very low minimum yield of 2.2 % was achieved by tuning Fe/Si ratio exactly to 3/1 and optimizing growth temperature (130°C). Cross-sectional transmission electron microscope (TEM) observation demonstrated the atomically flat interface of Fe3Si/Ge (111). In addition, its electron diffraction pattern indicated strong super-lattice reflection spots, which confirmed the formation of ordered DO3-type Fe3Si layers. Magnetic properties were evaluated by using the vibrating sample magnetometer (VSM), which showed the growth-temperature dependent coercivities. A smallest value (0.8 Oe) was obtained from the sample with highest crystal quality (minimum yield : 2.2%). Weak uniaxial anisotropy supposed to originate from a uniaxial lattice strain was observed, where the anisotropy field was very small (7 Oe). Consequently, formation of source/drain electrodes with uniform magnetic properties is expected to be realized by using the shape anisotropy. Electrical properties were also evaluated by using current-voltage and capacitance-voltage measurements, which indicated good Schottky characteristics with the barrier height of 0.56 eV. The ratio of the on-current to the off-current was the order of 103.

These results will be a powerful tool to realize new-type group IV-based spin-transistors, i.e., SiGe channel with high mobility and Fe3Si source/drain for spin-injection.
Superparamagnetic iron oxide nanoparticles have been attracted a great attention in the biomedical field such as magnetic separation, drug delivery, cancer hyperthermia and magnetic resonance imaging (MRI) enhancement. Iron oxides particularly magnetite (Fe3O4) and maghemite (γ-Fe2O3) are very promising candidates in this field due to their nontoxicity and high chemical stability. The major difficulty in the synthesis of ultrafine particles is to control the particle size and its distribution at the nanosized scale. This difficulty arises from the fact that the nanoparticles form aggregates and continuously grow to minimize the overall surface free energy. Also, in in vivo applications, hydrophilic particles show prolonged blood circulation minimizing the absorption of plasma proteins and nonspecific uptake by reticular-endothelial system (RES), like macrophage cells. Therefore, the search for facile and flexible synthetic routes which are able to produce water soluble monodispersed iron oxide nanoparticles without particle aggregation is of extreme importance to realize the full potential of these materials in biomedicine. In this work, we have synthesized both the hydrophobic (organic solvent soluble) and hydrophilic (water soluble) iron oxide nanoparticles with in the acceptable size distribution using a single step synthetic route which includes the thermal decomposition of iron acetylacetonate, Fe(acac)3 in an appropriate stabilizing surfactant media.

Both the as prepared hydrophobic and hydrophilic nanoparticles can be dispersed well in an appropriate solvent to obtain stable ferrofluid suspension. Size and morphology of the nanoparticles are determined by TEM while, structure of the particles is identified by XRD, FTIR, XPS and TGA measurements. Magnetic properties of the particles are determined using VSM and SQUID measurements. Particle size and the saturation magnetization (MS) of the nanoparticles are tuned varying reaction parameter. Highly crystalline and superparamagnetic nanoparticles with higher MS are obtained under optimized reaction condition. Cytotoxicity, specific absorption rate (SAR) and relaxivity measurements indicate that the as synthesized water soluble superparamagnetic nanoparticles have great potential for cancer hyperthermia and MRI applications.

Nanosized Li-Ni-Zn ferrites with general chemical formula \( \text{Li}_{1-x} \text{Ni}_{0.75-x/2} \text{Zn}_{x/2} \text{Fe}_2\text{O}_4 \) Where \( x = 0, 0.1, 0.3, 0.5, 0.7 \) & 0.9 have been synthesized from a simple polymer matrix based precursor solution. The solution was composed of metal nitrates with polymer PVA and disaccharide (sucrose). Thermolysis/flame pyrolysis of the precursor mass at an external temperature around 500°C resulted in the oxide phase X-ray diffraction studies confirmed the formation of single phase ferrites. The particle size was determined from the scanning electron microscopy. SEM micrographs reveal that the average grain diameter increases with Zn content up to 0.15 and then decreases beyond this limit. The average grain diameter measures 16-33nm, i.e. nanocrystalline. It is attributed to the relation between magnetic properties and microstructure. The variation of saturation magnetization (\( M_s \)) with content of Zn shows that the saturation magnetization (\( M_s \)) increase with Zinc contents up to \( x=0.5 \) and shows a decreasing trend later on.

Magnetic nanoparticles have a variety of applications ranging from those in biomedical field (e.g. targeted drug delivery, MRI) to manufacture of memory and energy storage devices as well as ferrofluids, to synthesis of products useful in translational biological research such as biosensors and biomarkers. However, control of properties like uniform shape and anisotropy, narrow size distributions, sensitivity to magnetic fields, existence of a single magnetic domain, and biocompatible surface functionalization (for biological and biomedical purposes) poses the greatest
Magnetotactic bacteria are a special class of bacteria that are capable of synthesizing magnetic nanoparticles, with a very robust control over the afore-mentioned properties. Different types of these bacteria biologically manufacture nano-magnets of magnetite and greigite by consuming iron salts from their growth environment. In this work, we report our findings on biological manufacturing of nano-magnets by the magnetotactic bacteria *Magnetospirillum gryphiswaldense*. After optimizing the growth conditions for the magnetotactic bacteria in shake flasks, we successfully scaled up magnetosome production from these bacteria to a 3 L bioreactor under dynamically controlled oxygen supply. We have achieved biological production of nanomagnets with 1.5 times the productivity (in mg/L/day) reported till date. The nanomagnets have a mean diameter of 38nm with narrow size distributions. Structural characterization of the nanomagnets done using High-Resolution Transmission Electron Microscopy (HRTEM) suggests they are monocrystalline. The nanomagnets are spherical in shape but have cubo-octahedral facets that clearly show the crystal planes of magnetite. Using microdiffraction and Energy Dispersive X-ray (EDX) analysis techniques, we have seen the particles are composed of crystalline magnetite. Characterization of magnetic properties of the nanomagnets both inside and outside the bacteria has also been performed using various techniques, results of which will also be presented. While discussing our results on large-scale biological production of bio-friendly nano-magnets, we provide important stoichiometric information along with energy requirements for biological synthesis of nano-magnets. We believe that our results are extremely valuable in the present and as well as the future for exploiting the huge potential of biologically derived magnetic nanoparticles.

**A00159-00759**

**Effect of Microstructure on Electrical and Magnetic Properties of Ni-Mg-Zn Nano Ferrites**

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Nano ferrites with the general chemical formula Ni₀.₅₋ₓ Mgₓ Znₓ Fe₂O₄ (x = 0.1 to 0.5) have been synthesized by chemical route. X-ray diffraction patterns exhibit single phase face centered cubic structure. IR absorption bands ν₁ and ν₂, are assigned to the vibrations of tetrahedral and octahedral complexes respectively. The splitting of ν₂ bands indicates the presence of Fe³⁺ ions at octahedral sites. SEM micrographs exhibit the development of porosity at the base of neck of grains. The presence of metal vacancies results in larger pores at the boundaries of the crystallites. An average grain diameter is calculated by line intercept method. VSM studies show the small values of Ms/Mr which is attributed to the presence of MD particles in all the samples. The variation of resistivity with temperature shows the break at Curie temperature due to transition from ferromagnetic to paramagnetic region, obeying Verwey de Bore mechanism.

**A00159-03295**

**Temperature Dependent Resistivity and Microstructure of Mg-Zn Nano Ferrites**

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The nano ferrites with the chemical formula Mgₓ₋₀.₅ Znₓ Fe₂O₄ (where x = 0.1, 0.2, 0.3, 0.4 and 0.5) were synthesized by auto combustion method (chemical method). The formation of single phase cubic spinel structure of ferrite is confirmed by XRD studies. The scanning electron microscopy (SEM) is used to understand the microstructure of the ferrite and average grain diameter. The grain size is greatly influenced on the resistivity, microstructure, electric and magnetic properties. The DC resistivity was measured by two probe method. The resistivity of the ferrite decreases with increase in temperature indicating semiconducting nature. At x = 0.1, the resistivity is low means the conductivity is due to holes (p-type conductivity) and at x = 0.5, the resistivity is high means the conductivity is due to electrons (n-type conductivity).

**A00189-00368**

**The Structural Properties of Magnetite/Porous Silica Nanocomposite and its Applications in Cosmetics**

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This scientific literature demonstrates a growing interest in magnet-support composite, driven primarily by their application in cosmetic products as an enhancer of blood-circulation and a volumizing agent of hair.
The properties of polymer-encapsulated magnetite nanoparticle / porous silica nanocomposite, which have the potential to be used as enhancer of blood-circulation and volumizing agent of hair in the cosmetic products of anti-darkening cream and mascara, have been studied.

Magnetite/porous silica nanocomposite (MSN) is composed of spherical magnetite nanoparticle with mean diameter of about 10 nm or less and porous silica pigment with mean diameter of 50 nm. Magnetite/porous silica nanocomposite (MSN) was prepared by the method of a reduction-precipitation with ferric chloride as starting material. It was partially reduced to ferrous salts by Na2SO3 before alkalining with ammonia. The uniform distribution of magnetite nanoparticles on the all volumes of nanocomposite is shown. The mean diameter of magnetite / porous silica nanocomposite (MSN) was 50 nm. In SEM (Scanning Electron Microscope) observation, it is shown that the mean size of nanoparticles, before and after introducing porous silica matrix, was not changed.

Then for the control of particles and convenience into cosmetic products, Magnetite/porous silica nanocomposite (MSN) was encapsulated with PMMA (Mw = 15,000) by being absorbed on to pore of porous silica surface.

The structural properties of the magnetite / porous silica, and PMMA-encapsulated magnetite / porous silica were characterized by X-ray diffraction, BET measurement, as well as by vibrating sample magnetometry.

Brillouin light scattering. Brillouin spectra were recorded in a backscattering geometry with an in-plane magnetic field applied perpendicular to the triangular base. Five peaks, with frequencies up to 30 GHz, are observed. A semi-quantitative approach based on the macrospin model, together with micromagnetic simulations, has been employed to analyze the experimental data. The three highest-frequency peaks are attributed to quantized surface spin wave modes which accord well with predicted frequencies from the analytic model. The two lowest-frequency modes are found to be localized at the edge, with the second lowest-frequency mode exhibiting characteristics of a backward volume mode. It has been analyzed using the WKB-like approach. Simulations reveal that, at sufficiently high applied fields, our lowest-frequency edge mode has a Kittel-like nature, in contrast to nanodots where previous studies reveal that this mode is center-localized.

**Measurement of Spin Dynamics of a Triangular Nanomagnet**

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Dynamic properties of small laterally patterned magnetic elements have attracted great interest due to their applications in magnetic storage or sensor devices. While surface spin wave modes in special geometries like rectangle and circular disk can be accounted for by quantization of the wave vectors, those in an equilateral triangle has yet to be investigated. In our research, we report both the experimental and theoretical studies of the spin dynamics in equilateral nanotriangles. A low-density 2D array of permalloy equilateral triangles with edge length 190 nm, thickness 20 nm and inter-element (edge-to-edge) spacing 400 nm was fabricated by high resolution electron beam lithography and its spin dynamics investigated using Brillouin light scattering. Brillouin spectra were recorded in a backscattering geometry with an in-plane magnetic field applied perpendicular to the triangular base. Five peaks, with frequencies up to 30 GHz, are observed. A semi-quantitative approach based on the macrospin model, together with micromagnetic simulations, has been employed to analyze the experimental data. The three highest-frequency peaks are attributed to quantized surface spin wave modes which accord well with predicted frequencies from the analytic model. The two lowest-frequency modes are found to be localized at the edge, with the second lowest-frequency mode exhibiting characteristics of a backward volume mode. It has been analyzed using the WKB-like approach. Simulations reveal that, at sufficiently high applied fields, our lowest-frequency edge mode has a Kittel-like nature, in contrast to nanodots where previous studies reveal that this mode is center-localized.
the frequencies of the three peaks observed in the p-s polarized spectrum decrease almost linearly. Our results reveal that even for the sample with smaller spacing of only 80 nm, the interaction between neighboring dots is negligible, suggesting that to observe the interaction effect that has been found between long wires, the spacing between nanomagnets should be much smaller.

Synthesis of multiferroic MnWO$_4$ Nanobelts and Nanorods by a Solution Phase Route
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We report on the controlled synthesis of multiferroic MnWO$_4$ nanobelts and nanorods via a facile solvothermal/hydrothermal strategy. The nanobelts and nanorods of MnWO$_4$ are thoroughly characterized by X-ray diffraction, transmission electron microscopy, scanning electron microscope and magnetic measurements. Possible mechanisms of MnWO$_4$ nanobelts and nanorods growth and size and shape evolution are proposed. The effect of the size and shape of MnWO$_4$ nanostructures on improving magnetic properties of nanomaterials is also discussed.

A New Spintronic Material (Fe,Co)$_x$-C$_{1-x}$/Si Nanostructure
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The discovery of Giant Magnetoresistance (GMR), which won the Nobel Physics Prize in 2007, initiated the study of spintronic materials and spintronic devices. The first generation metallic spintronic devices, such as GMR devices, MTJ devices and MRAM have already been commercialized. The more exciting next generation spintronic devices are semiconductor based spintronic devices, such as spin-FET, spin-LED, spin-RTD, etc. because the spintronics materials can not only serve as the switch but also a memory cell. Scientists have already injected spin into some semiconducting materials, such as GaAs or ZnO. However, spin injection into Si is only successful at low temperature. Also some attempts have been made to study the C-based spintronic materials. However, until now the carbon nanotubes have magnetoresistance (MR) only at low temperature below 120K.

We prepared the ferromagnetic metal and carbon composite. It is found that if the granule sizes of carbon or ferromagnetic metal are micrometer scale, the Co-C granular composite, Ni-C granular composite and Fe-C granular composite have positive MR of 58.9%, 44.1% and 50% respectively at magnetic filed of 5T and room temperature. It is even found that if the granule size of carbon is micrometer scale, pure carbon granular composite has a positive MR of 35% at 5T and room temperature. Also these materials have linear MR at certain temperatures. If the granule sizes of carbon or ferromagnetic metal are nanometer scale, the MRs of these composites have almost zero MR, i.e., these MRs are size dependent.

We further synthesized the Fe or Co doped carbon film on n-type Si substrate and found that the MR of these films is different from that of the (Fe-, Co-, Ni-) carbon granular composite. Despite the particle size of Fe or Co is nanometer scale and C film is amorphous in these films, both Co-C film and Fe-C film have positive MR of a few tens percentages at 5T and room temperature. Moreover, pure carbon film deposited at 27°C has a positive MR of 11%. It is found that the p-n junction at C/Si interface plays an important role in MR. It is also found that the MR mechanism is different from any known MR mechanisms, i.e., this kind of carbon base materials is a new kind of MR materials. We also found that these materials have some novel physical properties, such as current or bias dependent MR, giant electroresistance, switch effect, photoconductivity, pressure sensitivity and gas sensitivity. Study this carbon base spintronic material may throw a light on developing a new kind of spintronic materials.

Aliovalent-Ion and Magnetic Field Induced Phase Transition in Multiferroic BiFe$_{1-x}$Ti$_x$O$_3$ System
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Multiferroic compounds with general formula BiFe$_{1-x}$Ti$_x$O$_3$ (x=0.1, 0.2, 0.3 and 0.35) have been synthesized by conventional solid state reaction method. The effect of Ti substitution on ferroelectric and magnetic properties is studied. From x-ray diffraction (XRD) analysis, we observed a rhombohedral to orthorhombic phase transition for x>0.3. From SQUID measurements, a magnetic field induced phase transition has been observed in the BiFe$_{1-x}$Ti$_x$O$_3$ system for x=0.3. An anomaly in dielectric constant and dielectric loss in the vicinity of antiferromagnetic Néel temperature (T$_N$) and a small enhancement in magnetization have been observed. Magnetization measurements above room temperature showed no systematic variation in antiferromagnetic. Néel temperatures on Ti substitution.
Further it is seen that this system shows the coupling between electric and magnetic dipoles exhibiting magnetoelectric (ME) effect at room temperature and possess high dielectric constant.

**A00262-01681**

**Ferromagnetic and Structural Properties of Fe3Si Thin Films on Si substrates**

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Fe3Si is an attractive ferromagnetic material as it has a high Curie temperature of 840 K and a high degree of calculated spin polarisation at the Fermi level (DO3 structure) for spintronic applications. While such functionalities typically require the Fe3Si layer to be grown epitaxially on semiconductor substrate in order to achieve an efficient spin injection, other spintronic functionalities may not require the ferromagnetic film to be highly textured. However to-date, non-epitaxial Fe3Si and its properties have not been reported widely so far though other ferromagnetic materials in polycrystalline form were studied for spintronic applications. We presented herein the ferromagnetism of Fe3Si thin films deposited on Si substrates and the strong correlation with the structural properties.

Fe and Si were co-sputtered onto Si substrates at appropriate deposition rates to form Fe3Si. The deposited Fe3Si film has an in-plane magnetic isotropy with coercive field $H_c$ of 5 Oe, squareness ratios $M_r/M_s$ of 0.9 and saturation magnetization $M_s$ of ~940 emu/cm$^3$. The out-of-plane magnetism on the other hand, is anisotropic with magnetic anisotropy field $H_{K}$ ~10 kOe. Both in-plane and out-of-plane magnetism were maintained even upon annealing up to 350 °C. The deposited and annealed Fe3Si were crystalline with (220) planes with no increase in the fine grain sizes (20 nm), correlating well with the stable magnetic properties of the films measured. Depth profiling of the film using secondary ion mass spectroscopy (SIMS) showed that a Si-rich interfacial layer existed at the Fe3Si/Si interface. The presence of the layer ~2 nm thick confirmed with x-section transmission electron microscopes (XTEM), probably helps to stabilise the overlying Fe3Si phase against inter-diffusion during thermal annealing which accounts for the near unchanging $M_s$ value measured at the higher temperature. We attributed the thermal stability of Fe3Si to the deliberate choice of deposition rates for Fe and Si in this study which affects the respective nucleation rates and in turn influences the resultant morphology of the as-deposited and annealed Fe3Si films and their magnetic behaviours.

**A00256-00893**

**Domain Wall Trapping in Nanoscopic Asymmetric Rings**

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Manipulation of spin distributions in nanoscale magnetic elements is essential for magnetic data storage and spintronic device applications. When the lateral size of the magnetic element approaches the nanoscale limit, the confinement of spins caused by the geometrical parameters becomes comparable to the internal characteristic length. This effect provides avenues to manipulate the magnetic configurations purposely using lateral patterns. A number of geometries have been employed to control the magnetization behaviours, for instance, notches have been purposely created in a ring to form an obstacle for the propagation of a domain wall; A flattening into a circular dot has been introduced to control the vertical direction via energy minimization. In this work, we propose and investigate a novel shape of nanoscopic ring magnets to pin a domain wall in exact position. Using asymmetric ring structure, it is possible to control the domain wall position without having to create defect or notches in the nanoscopic ring.

We have used OOMMF program to simulate the magnetization process of 12 nm-thick NiFe asymmetric rings with an asymmetric ratios of 0.2. The asymmetric ratios is set to be the distance between the centers of the two circles $l$ divided by the difference between the outer diameter, $D_o$ and the inner diameter, $D_i$, i.e. $r = l / (D_o - D_i)$. Our results reveal the magnetic switching of the asymmetric rings can be controlled via parameters of the ring asymmetricity, and the film thickness. A local vortex-free reversal process and a controlled circulation of flux-closure can be obtained in which the magnetization is oriented circumferentially and there are no domain walls. One interesting feature observed is that a 90° like domain wall is pinned at the thinnest point of the asymmetric ring when an in-plane magnetic field is applied. This pinning behavior occurs in the nucleation free switching process when the rings switch from the bi-domain state also called ‘onion’ state to the flux-closure state. The domain wall pinning behavior can be explained from the aspect of energy competition.

The pattern was created using electron-beam lithography technique and a 12-nm-thick NiFe film was deposited using UHV sputtering deposition technique. The final structure was obtained after a metal lift-off process. Magnetic characterization results that measured by the magneto-optical Kerr effect will be presented.
Non-innocent Ligand Metal Complexes: Metal - Organic Magnets

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Metal-organic magnets have been of great interest for the past two decades due to their potential application in molecular devices and in spintronics. Many hybrid organic ligand/metal ion molecular materials are magnetic at lower temperature but lose their magnetism as the temperature rises. Miller et al have prepared solvent-free thin films of the V[TCNE]x magnet via the low-temperature chemical vapour deposition (CVD) of V(CO)x and TCNE. Hicks et al reported a new class of quinone molecular magnets with Ni(II), which works at room temperature.

The coordination chemistry of ligands containing a quinone function has been receiving increasing interest due to their potential in sensing and molecular devices. These molecules may be classified as “non-innocent” due to their ability to be reduced to their semiquinone and hydroquinone/catecholate forms via a series of one electron reductions. The interaction of the radical semiquinone of these molecules with a paramagnetic transition metal ions is of particular interest in the filed of magnetism and the literature is replete with the examples of transition metal with α-semiquinonel ligands and their derivatives. We have synthesised metal complexes of 2,3,5,6-tetraamino-1,4-benzoquinone using paramagnetic transition metal ions using to prepare metal-organic magnets. The synthesis of the ligand, metal complexes and challenges in their characterisation details to date are discussed here.

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Directional Alignment of FeCo Crystallites in Si/NiFe/Ru/FeCoB Multilayer with High Anisotropy Field above 500 Oe

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Large saturation magnetization 4πM_s and high in-plane magnetic anisotropy field H_k around several hundreds Oe are essentially required to get magnetic thin films available in an X-band devices because of the resonance frequency f_r is proportional to (H_k M_s)^1/2. In this study, Si/NiFe/Ru/FeCoB multilayered films were prepared by DC facing target sputtering (FTS) system. FeCoB layers have large saturation magnetization of 22 kG. In addition to the high 4πM_s, large in-plane magnetic anisotropy is appeared in FeCoB upper layers prepared using DC FTS technique and adoption of Ru underlayer. An easy axis of magnetic anisotropy field in FeCoB upper layer appeared along the parallel direction to the facing direction of the targets in a FTS system. These films can achieve very high H_k above 400 Oe. In our previous study, it was found that the directional alignment and anisotropic lattice distortion of FeCo crystallites in the film are the origins of high anisotropy field. In this study, growth processes of the anisotropic structure of FeCo crystallites were observed.

Effect of thickness of upper FeCoB layer on H_k was investigated. The thickness of FeCoB upper layers were varied from 10 nm to 200 nm. Although the H_k of the 10 nm-thick FeCoB film was 300 Oe, H_k of the films increased as the thickness increased up to 50 nm. However, H_k increased gradually for thickness above 50 nm. H_k reaches 540 Oe at the film thickness of 200 nm. This increase of H_k with FeCoB thickness might be caused by anisotropic growth of FeCoB crystallites in FeCoB layer.

A directional alignment and growth of FeCo crystallites was observed through rocking curve analysis of X-ray diffraction along easy and hard axes, respectively. Few differences were observed in the FWHM for each axis until the FeCoB thick below 50 nm. However, the differences of FWHM of the rocking curves along each axis were observed when the thickness became thicker than 50 nm. FWHM of 7.4 degree and 6.4 degree were observed for the easy and hard axes directions, respectively, in the film with 200 nm thick FeCoB layer. These results indicate the anisotropic crystalline alignment is developed by not only the effect of an interface with the underlayer, but also oblique incidence effect of the depositing particles in the FTS system.

The pole figure measurement of Si/NiFe/Ru indicated little directional dispersion. Ru layer possess preferential orientation of Ru(001), no distorted debye ring of Ru(002) was observed. This result also means the little relation of crystallinity between Ru and FeCo crystallites as noted above.

Such anisotropic directional alignment and distortion developed by an anisotropic growth mechanism were observed in Si/NiFe/Ru/FeCoB multilayered film with a remarkably high H_k of 540 Oe. FeCo crystallites were extended along the easy axis. Such directionally distortion of FeCo crystallites induce a magnetoelastic energy through the inverse magnetostriiction effect, it might be a reason that the high in-plane magnetic anisotropy appeared.
Induced Magneto-optical Inversion in Bidispersed Magnetorheological Fluid

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Ferrofluid based magnetorheological (MR) fluid is synthesized using chemical co-precipitation technique. An inversion in Magneto-optical effect is observed in this bidispersed fluid. With the applied magnetic field strength this fluid exhibits extremum and inversion in sign, which depends on the small and large particle ratio in the bidispersed fluid. Induced birefringence and dichroism in certain colloids exhibit inversion in sign of the magneto-optical effect. In this experiment a bidispersed MR fluid composed of micron size magnetite spheres (~3µm) are dispersed in a magnetite ferrofluid having particle size ~ 10nm. Conventional MR fluids are composed of suspensions of magnetically soft particles in a non-magnetic liquid carrier. Certain unusual light scattering effects are observed in this type of bidispersed MR fluids. Here magnetically induced extinction of light for two orthogonal states of polarization the extinction of light in two different configurations, (i) the E vector of the incident light perpendicular to the direction of magnetic field vector H (i.e. E⊥H), and (ii) the E vector of the incident light parallel to the direction of magnetic field vector H (i.e. E||H). It is shown that the magneto optical effect exhibits extremum and inversion only for one state of polarization. The field dependent extremum and inversion depends on the ratio of number of small and large particles in the bidispersed fluid. Magneto optical effects in such system are quite intriguing because of the overall effect arises due to two orthogonal torques on large and small magnetic particles. Further it is also known that light scattering properties of large and small particles are quite different, hence appropriate light scattering theory should be used to analyze certain effects. If the particles are very large compared to the wavelength of the incident light geometrical optics may be used to derive induced extinction in a magnetic field. Complications arises when the system contains small as well as large particles of same family (i.e. the case in this study), this is because the effects exhibited by the small particles are governed by one characteristic function while the effect exhibited by coarse particles are governed by quite different characteristic functions. At low field strengths the magnetooptical effect is due to large particles. At intermediate field strength the inversion will occur and it will depend upon the relative number distribution of large and small particles.

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Magneto-Optical Spectroscopy of Nanostructured Magnetic Materials

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Magneto-optical spectroscopy such as magneto-photoluminescence (magneto-PL), magnetic circular dichorism (MCD) and magneto-optical Kerr Effect (MOKE)/Faraday spectroscopy are powerful probes for investigating spin-related phenomena in condensed matter. Combined with Femtosecond time-resolved techniques such as time-resolved MOKE (TR-MOKE) and time-resolved Faraday Rotation (TR-FR), they have provided extensive information and new insights into the diverse spin-related phenomena. Recently, we have installed a 7T Oxford Instruments Spectromag™ System at the Femtosecond Dynamics Laboratory at Nanyang Technological University. In this work, we report on the magneto-optical studies performed at this laboratory on two representative magnetic systems: colossal magnetoresistance (CMR) manganite single crystals (La1-xPbxMn1-yCuO3) and dilute magnetic semiconducting Cu-doped ZnO nanowires.

CMR manganites have been subjected to extensive research due to their unique magnetic and electrical properties. The physical origin of this phenomenon has been attributed to the double-exchange model. However, this double-exchange mechanism of carriers between Mn2+ and Mn3+ ions alone cannot account for all the observed changes such as metal-insulator transition in these materials. Other factors include the highly correlated nature of the spin, lattice, charge and orbital degrees of freedom. In this work, we investigate the dynamics of nanoscopic magnetic clusters in La1-xPbxMn1-yCuO3 single crystals using transient reflection spectroscopy and TR-MOKE. Samples with Cu-doping (y ≥ 0.02) exhibited a re-entrant metal-insulator (M-I) transition at low temperatures. The effects of Cu-doping on the quasi-particle and spin relaxation dynamics in this strongly correlated system are not clear. Through comparing these results, the charge and spin dynamics were independently investigated.

Spintronics with semiconductors have attracted widespread attention as it combines the advantages of semiconductors (i.e. gate control, optical coupling etc) with the potential of magnetic materials (i.e. current control by spin manipulation and non-volatile memory). However, many basic questions pertaining to the origin of intrinsic ferromagnetism and the spin transport properties in these dilute magnetic semiconductor (DMS) materials remain open. In this work, we report on the MCD and TR-MOKE studies of the Cu-doped ZnO nanowire system. Recently, Xing et.
al. reported on the existence and enhancement of room-temperature ferromagnetism in this system by structural inhomogeneity. MCD provides us with a sensitive tool to probe the intrinsic magnetism and electronic structural properties of this system; while TR-MOKE provides us with a means to investigate the spin coherence as well as the spin interactions between the carriers and dopants in this Cu-doped Nanowire system.

Transition Metal Doped ZnO Nanostructures with Room Temperature Ferromagnetism

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Diluted magnetic semiconductors (DMSs) have attracted considerable research interest in recent years due to their great potential applications in spintronic devices. In this paper, one-dimensional Zn$_x$Me$_{1-x}$O (Me=Mn, Co, Ni) DMSs nanorods with various doping concentrations have been prepared by a simple hydrothermal route at low temperature. The as obtained samples were characterized by X-ray diffraction (XRD), transmission electron microscopy (TEM), high-resolution transmission electron microscopy (HRTEM) and energy dispersive spectrum (EDS). XRD and high-resolution TEM characterizations indicated that the as-prepared samples were single-crystalline wurtzite structure and no transition metallic or other secondary phases were found in the nanorods. The field dependence of magnetization (M-H curve) of the as obtained samples measured at room temperature demonstrated that all the Mn, Co and Ni doped ZnO show obvious ferromagnetic characteristic. Moreover, the doping concentration dependence of room temperature ferromagnetism for transition metal doped ZnO nanorods were investigated in detail, we found that the saturation magnetization increases with the doping concentration increase for the Mn and Co doped samples, while for the Ni doped samples, the saturation magnetization firstly increases and then decreases with Ni dopant concentration increasing. We think the room temperature ferromagnetism in transition metal(Mn, Co, Ni) doped ZnO nanorods could be considered as a result of the exchange interaction between free delocalized carriers (hole or electron from the valence band) and the localized d spins on the transition metal ions. The room temperature ferromagnetism of the synthesized ZnO based DMSs makes them potentially useful as build components for spintronic devices.

The industrial application of nano materials has grabbed a paramount importance owing to their improved characteristics. Hexagonal ferrites especially M-type ferrites have been proved to be the promising candidates for nano materials owing to their case of applicability in high density recording media, microwave absorption devices, magneto-optic recording media, etc.

Keeping a bird’s view over, the samples of varied combinations of M-type substituted hexaferrites are synthesized by a novel ingenious technique i.e. ‘microwave induced sol gel combustion route’. The samples are produced by blending nitrates and chlorides as oxidants accompanied with fuels like urea, glycine, citric acid, etc as reducing agents. The substitution of Co$^{2+}$ & Sn$^{4+}$ ions lie essentially in the octahedral and tetrahedral sites. As the Fe$^{3+}$ ions are being replaced by Co$^{2+}$ & Sn$^{4+}$ ions, the probability of having oxygen vacancies in the structure was found to be greatly reduced.

The magnetic particles produced by conventional solid state reactions are often larger than those produced by sol gel combustion route. Larger particles of magnetic oxides generally exhibit multidomain magnetic structure whereas nanosized particles generally exhibit single domain magnetic structure. The simultaneous or coupled divalent and tetravalent substitution of Co$^{2+}$ & Sn$^{4+}$ for Fe$^{3+}$ ions greatly helps to improvise the magnetic parameters such as curie temperature, coercivity, remanent magnetization, saturation magnetization & squareness of hysteresis.

The structural comparison is being analysed through the XRD, SEM, Hysteresis loop etc. The samples so synthesized are found to be reseasonably homogeneous and the average particle size of the sample synthesised is found to be in the nano range. Thereby confirms the production of nano ferrites and hence will be more useful for the various applications.

Further attempts could possibly lead to investigate their vitality in aerospace and military applications. Even the utility of the samples is kept under rigorous study to check their suitability for platter in magnetic storage media to give extra dimensions for their viability.
Size-dependence of Calorimetric Properties of Iron-oxide Nanoparticles for Magnetic Particle Hyperthermia

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The treatment of metastatic cancer and the development of alternatives to systemic and non-specific therapies such as chemo- and radiotherapy have been one of the greatest healthcare challenges the world is facing today. The identification of colloidal suspensions at the nanoscale as means for medical applications has hence been a focus of biomedical research in recent years. Continuous re-engineering and optimisation of synthesis processes of magnetic nanoparticles presented exceptional properties that suggest a novel and promising approach to address this problem. One of the extraordinary properties of iron-oxide particles in the superparamagnetic regime is that they release energy in form of heat when exposed to a high-frequency (RF) alternating magnetic field. The calorimetric potential of these compounds is predominantly dependent on two parameters, namely the magnetic field strength and the frequency. The latter is proportional to the dimensions and size distributions of the spherical particles. Experimental confirmation of a priori correlation of calorimetric properties as well as optimisation of parameters have been limited by the polydispersity of nanoparticle solutions. Until now, the synthesis of nanoparticle suspensions only produced polydisperse distributions that lack optimisation or characterisation for hyperthermic treatment. Our group has explored this issue using nanoscale fractionation processes and established a relation between the dimensions of spherical nanoparticles with their calorimetric properties. This is the first time that asymmetric flow-field-flow fractionation (A4F) has been used beyond its analytical capabilities of separating iron-oxide nanoparticles and the fractions utilised for further material characterisation and testing. A number of characterisation methods are then applied to the fractionated monodisperse nanoparticles including magnetic characterisation using a magnetic property measurement system (MPMS) comprising of hysteresis above and below the blocking temperature and FC-ZFC curves, XRD analysis, calorimetric, AC susceptibility and ferric/ferrous content analysis. The polydisperse solutions are provided by Chemicell and Micromod and monodisperse fractions of them are used to test existing theoretical predictions of particle size-dependent calorimetry. Our recent results have shown a critical need to investigate fractionated magnetic nanoparticle systems within the size range of 5 to 30 nm. Moreover, the reproducibility of characterising colloidal suspensions are discussed and the accuracy at fractionating are considered. This research determines essential parameters that dictate the heating rate of nanosized magnetic suspensions in order to develop optimised agents for hyperthermic cancer therapy.

Excessive-Ferrocene-Induced Fe-Filled Carbon Nanotubes Synthesized by Floating Catalytic Chemical Vapor Deposition and Their Magnetic Property

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Iron-filled carbon nanotubes (CNTs) have been attracting intense attention in recent years. In this nanocomposite, carbon coating can, on the one side, protect ferromagnetic materials from oxidation in the outside environment and, on the other side, reduce magnetic coupling between magnetic phases. Further more, the metal nanowires or nanoparticles encapsulated in CNTs can show quantum effects as their dimensions decrease to the nanoscale. So these materials have unique electronic, magnetic properties. It has been suggested that these materials might find important applications in diverse areas such as magnetic data storage, electromagnetic wave-absorbing materials and magnetic resonance imaging.

In this paper, we report the synthesis of iron-filled CNTs with excessive by floating catalytic chemical vapor deposition (FCCVD). To synthesize iron-filled well-aligned carbon nanotubes, ethanol was employed as carbon source, high pure N2 and 3%H2/Ar as carrier gas, ferrocene as catalyst precursor for CNT growth and the source of iron. We obtained iron-filled carbon nanotube arrays on quartz substrates. The iron-filled carbon nanotubes were characterized by employing scanning electron microscopy, transmission electron microscopy, energy dispersive X-ray spectroscopy, X-ray diffraction and Raman spectroscopy. The magnetic property of as-synthesized iron-filled CNTs was evaluated by vibrating sample magnetometer at room temperature.

We have synthesized iron-filled CNTs by FCCVD with employing extremely excessive ferrocene as both catalyst precursors for growing CNTs and iron source for filling CNTs. So during the growth process, there is sufficient iron source to form better filling of iron into CNTs. The iron filled in CNTs is a mixture of α-Fe, γ-Fe and Fe3C, but the α-Fe phase iron dominates. The magnetic property of
these iron-filled CNTs has been investigated using VSM and they exhibit an average coercivity of about 257.05G.

**Giant Magneto-impedance Effect of Melt Spun Co\textsubscript{x}Fe\textsubscript{64}Ni\textsubscript{4}Si\textsubscript{8}Cr\textsubscript{19-x}Si\textsubscript{8}Cr\textsubscript{3}Al\textsubscript{x} (x = 0, 1, 2, and 3) Soft Magnetic Ribbons**

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Studies of giant magneto-impedance (GMI) of Co\textsubscript{x}Fe\textsubscript{64}Ni\textsubscript{4}B\textsubscript{19-x}Si\textsubscript{8}Cr\textsubscript{3}Al\textsubscript{x} (x = 0, 1, 2, and 3) soft magnetic ribbons obtained by the single roller melt spinning process were performed. GMI measured at different frequencies (100, 500, and 1000 kHz) and results show that the replacement of B by Al causes a little increase in the GMI ratio (\(\Delta Z/Z = ((Z(H) - Z(H_{\text{max}}))/Z(H_{\text{max}}))\)) and the maximum GMI ratio were obtained in the stress released sample with x=2. Structural studies of the samples have been carried out by transmission electron microscopy (TEM) and X-ray diffraction (XRD). Base on TEM and XRD patterns there are not any nanocrystalline phases in the samples.

**Ion Beam Modification of Exchange Coupling to Fabricate Patterned Media**

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Hard disk drives satisfy the major need for storage with high capacities at cheaper cost. This is possible because of the continuous utilization of innovations such as read-sensors with giant and tunnel magnetoresistance, perpendicular recording etc. to overcome the physical limitations. Areal densities of about 600 Gbits/in\(^2\) have been demonstrated with perpendicular recording technology. However, alternative technologies such as heat-assisted magnetic recording (HAMR) or bit-patterned media are needed to push the areal density beyond 1 Tbts/in\(^2\).

Nano-imprint lithography using molds fabricated by electron beam lithography is considered as the most popular approach for the fabrication of bit-patterned media. In such a method, the patterning process leaves the magnetic islands with a topography that is not desirable for stable flying of the magnetic head. Therefore, alternative techniques are being investigated. Ion beam modification has been carried out on Co/Pd multilayers, which leaves the Co/Pd multilayers in two states: the high-coercivity region (not affected by ion beam irradiation) and low-coercivity region (affected by ion beam irradiation). However, for patterned media, media with low remanent magnetization (Mr) and high Mr regions are needed rather than low and high Hc regions.

In this paper, we have investigated the use of ion beam modification of media surface that is at a low Mr state to start with. The low Mr state is achieved by the use of synthetic antiferromagnetic coupling obtained in Co-alloy/Ru/Co-alloy trilayer structure. Films of the type, Substrate/Ta/Ru/CoCrPt:SiO\textsubscript{2} (15 nm) /Ru(0.8 nm)/CoCrPt:SiO\textsubscript{2} (t nm) were prepared by dc magnetron sputtering. The Ta and Ru layers below the recording layers (CoCrPt:SiO\textsubscript{2}) were meant for obtaining good perpendicular anisotropy in the CoCrPt:SiO\textsubscript{2} layers. The Ru layer in between the two recording layers provided the highest antiferromagnetic coupling constant at 0.8 nm. The thickness of the CoCrPt:SiO\textsubscript{2} layers at the top was varied from 1 to 5 nm. A focused-ion-beam system with Ga\(^+\) ions was used for modification of the exchange coupling at the CoCrPt:SiO\textsubscript{2}/Ru/CoCrPt:SiO\textsubscript{2} interface of for the total or partial removal of the top CoCrPt:SiO\textsubscript{2} layer. Films were irradiated with different doses of Ga ions for systematic investigation. Magnetic force microscopy (MFM) in conjunction with atomic force microscopy (AFM) was used for the observation of patterns.

The antiferromagnetic coupling constant J was found to be about 0.2 erg/cm\(^2\) for most of the films. Clear kinks in the first quadrant were observed in the hysteresis loops for all samples. The Mr of the films was found to decrease with the increase in thickness of the top layer, because of the antiferromagnetic coupling between the two magnetic layers. AFM and MFM observations indicated that patterned regions of low and high Mr can be observed with ion beam irradiation. A systematic study of this technique will be presented.
Preparation and Characterisation of Copper(II) Complex of \(2,2',\)-[Nonane-1,9-Diylibs(Nitrilomethylidyne)]Diphenol as Spintronic Material

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Complex of \(2,2',\)-[nonane-1,9-diylibs(nitrilomethylidyne)] diphenol (salnon) with copper(II) ion was designed as spintronic material to be cast as thin film by Langmuir-Blodgett technique. The corresponding diamagnetic zinc complex was also prepared as a reference. The complexes were prepared by both one-pot and step-wise reactions. In one-pot reaction, 2-hydroxybenzaldehyde, 1,9-diaminononane and the corresponding metal ethanoate were refluxed in methanol. In step-wise reaction, the ligand salnon was first prepared from 2-hydroxybenzaldehyde and 1,9-diaminononane and completely characterised by FTIR, \(^1\)H-NMR, and single crystal X-ray crystallography. The ligand was then reacted with the corresponding metal ethanoate in refluxing methanol. The complexes were characterised by FTIR, elemental analysis, room temperature magnetic susceptibility, UV-visible-NIR spectroscopy, thermogravimetry and differential scanning calorimetry.

The Synthesis and Magnetic Properties of Iron Phosphide Nanorods

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Iron phosphide nanorods were prepared by the thermal decomposition of organometallic precursor (Fe(CO)\(_5\)) in the mixture of trioctylphosphine (TOP) and didodecyldimethy ammonium bromide (DDAB) at 300°C. To promote the growth nanorods, spherical iron oxide nanoparticle with the diameter of \(~7\) nm were used as a nucleating agent. During the reaction, Fe(CO)\(_5\) decomposes to iron atoms, which deposits on spherical particle seeds, forming rod shape particles. The growth mechanism is due to DDAB that assembles to rod-like micelles in the solution, connecting the spherical iron oxide nanoparticles, and finally spherical particles transform to rod shape. The aspect ratio of nanorods were manipulated from 4 to 20 by multiple injections of Fe(CO)\(_5\) and TOP. As prepared nanorods characterized by X-ray diffraction revealed the \(\text{Fe}_2\text{P}\) structure. The magnetization measurements showed that the blocking temperature of these nanorods increases with aspect ratio of nanorod, followed by a decrease of the blocking temperature with aspect ratio of nanorod. As long as we control carefully the injection condition, we could obtain even higher aspect ratio of iron phosphide nanorod with different magnetic properties, and it will provide various applications in nanotechnology.

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Electric Polarization in a Rashba Strip Coupled With a Spiral Spin Density Wave

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The magnetoelectric effect in a Rashba strip is studied, which is coupled to a spiral spin density wave (SDW). The polarization, if it can be induced, must be perpendicular to the plane constructed by the helix axis and the wave vector of the SDW. But these three vectors do not always form a right-hand system as suggested by other theoretical models. With the Rashba spin-orbit or the exchange couplings varied, the polarization oscillates and can take both positive and negative values. The polarization can be induced at any occupation ratio except half-filling, and the maximum polarization usually appears at a low occupation ratio. With the strip width larger than the spin precession length, the oscillation amplitude no longer increases with the width.

Nanostructured Magnetic Particles with Polystyrene and Their Magnetorheological Applications

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Magnetorheological (MR) fluids are known to be colloidal suspensions of magnetic particles in a non-magnetic fluid. Under an applied magnetic field, the MR fluid is a free-flowing liquid having a consistency similar to that of motor oil. Exposure to a magnetic field transforms the fluid into a plastic-like solid in milliseconds. MR fluids, along with their electrical analogues, electrorheological fluids, have been regarded as intelligent fluids being used in electromechanical devices such as dampers, clutches and brakes. For MR fluids, critical factors, which include the stability against sedimentation and higher saturated magnetization, as well as the large magnetic field-induced yield stress and low viscosity in the absence of magnetic field, should be endowed for better applicability. Thus, 

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various magnetic species or alloys have been investigated. In order to fit the above mentioned factor for MR applications, the magnetic particles undergo different nano-scaled processing to possess unique nanostructure.

Carbonyl iron (CI, average particle size: 4.5 μm; bulk density: 7.86g/cm³) particles are superior candidate of MR fluids due to the high saturation magnetization as well as the appropriate particle size, however, they have severe sedimentation problem due to the large mismatch of the particle density to the carrier oil. Therefore, diverse strategies have been introduced to modify pristine CI particles to meet the requirements of industrial application for MR fluids. Among them, a method of coating shells on the surface of CI particles has become popular due to the produced favorable core-shell structure along with the apparently decreased density for synthesized composite particles. In this study, polymeric shells of polystyrene (PS) have been formed onto the surface of the inorganic magnetic particles via conventional in-situ dispersion polymerization. Besides, we have constructed a dense nest composed of conducting carbon nanotube (CNT) on the surface of CI particles with the aid of chemical grafting reagents which are capable of joining the organic-inorganic phases. A double wrapping process was adopted to wrap CI particles with polymeric shell of PS and CNT layers to get much decreased bulk density, consequently improving the sedimentation problem.

In addition to CI particles, another magnetic species, magnetite particles which exhibit good magnetic property but much lower density have also been introduced. In this system, magnetite particles were embedded within PS matrix via facile in situ method. In addition, mesoporous PS spheres were fabricated to load magnetite particles to achieve core-shell structured particles with much lower density. Recently, CNT was adopted as host, in which magnetite particles were deposited on the surface through a facile method.

Both SEM and TEM images showed the unique morphology for the above mentioned magnetic composite particles. XRD, TGA, and VSM data described the crystalline structure, organic-inorganic composite as well as the magnetic property, separately. Then, MR characterizations were investigated via conventional rotational mode and oscillation mode. Finally, sedimentation test was made upon the synthesized magnetic composite particles as a function of time.
Energy Efficient Magnetic Nanomaterials

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Novel energy efficient permanent magnet systems and innovative solid state cooling devices can be produced from giant energy product magnetic nanomaterials and high temperature magnetocaloric materials. Novel chemical synthesis methods, e.g., sol-gel followed by reduction-diffusion, were utilized to synthesize exchange-coupled Nd-Fe-B + FeCo nanoparticles, the structure and properties of these nanoparticles will be described. The composition and microstructure dependent elevated temperature magnetic properties of melt spun rapidly solidified nanocrystalline RE-TM-B (RE=Nd, Pr, Dy, Fe, V-based) alloys with enhanced hard magnetic properties were studied. Reducing grain size and Co or Dy substitution had a significant beneficial effect on thermal stability. Attractive low values of temperature coefficients of remanence and coercivity were observed in these exchange coupled materials, energy product values greater than 100 KJ/m³ were obtained in nanophase alloys. The magnetocaloric properties of melt spun amorphous Fe based magnetocaloric materials with high refrigerant capacity were studied and the effect of subsequent nanocrystallization was determined, these results will be reported.

Anamalous Magnetic Behavior in Fe2Val1-xBx Heusler Alloys

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The most intriguing characteristics of Heusler alloys with general formula X2YZ, where X and Y are the elements with partly occupied d-electron orbital and Z is a sp-electron metal, exhibit a range of diverse physical properties i.e, (i) the occurrence of semiconductor-like transport behavior despite having all highly conducting metallic constituents; (ii) properties are sensitive to the minute structural and chemical disorder; (iii) reported to have non-magnetic ground state in spite of having 50% iron as one of the constituents. However, the existence of magnetically disordered state has also been suggested and attributed to antisite-defects. Experimental results suggest that apart from the transition elements present in the alloy the Z element in Fe2V-based Heusler alloy plays an important role in altering the transport as well as magnetic properties of the alloys. From theoretical calculations also it is suggested that the hybridization of Al-sp states Fe, V-d states plays a major role in non-magnetic state of Fe2VAl alloy. Therefore, it is important to understand the role of conduction electrons (of the Z atom) and the sp-d hybridization of Z and Fe, V atoms in the magnetic properties of the Fe2V-based alloys. We expect the substitution of smaller isoelectronic atom can throw some light in understanding the atomic size effects related properties. In this study we report the magnetic behavior of the isoelectronic Fe2VAl1-xBx (x=0-1) Heusler compositions to: (i) establish the role of hybridization of Al-sp states Fe, V-d states on the magnetic behavior (ii) know whether the isoelectronic substitution that resulted in semiconductor-metal transition has direct bearing on magnetic behavior.

Alloy ingots of Fe2VAl1-xBx (x=0-1) were prepared with high purity elemental constituents using an arc-melting furnace followed by a prolonged annealing in an evacuated quartz tubes at 1000°C for 48 hours to improve the homogeneity of the alloys. Magnetic properties [M (H) and field cooled/zero field cooled M (T)] were studied in the temperature range 5-300 K and up to the fields of 15 kOe using a commercial SQUID Magnetometer (Quantum Design, model MPMS). The AC Susceptibility (χ) was measured using a homemade setup in the temperature range 15-300K. A rapid increase in the magnetization values with a minute amount of B substitution in Fe2VAl at Al sites has been observed. Although higher boron containing alloys show a ferromagnetic like M(H) characteristics, thermomagnetization data (ACS and ZFC/FC) at low fields and at different frequencies suggests the presence of large ferromagnetic clusters. Therefore it may be suggested that the ferromagnetic like behavior in this system could be due to the intercluster coupling. Besides, this thermo magnetization curves found to obey Bloch’s law for the samples x>0, at higher fields (H=3000 Oe) providing additional support to our conclusions. A detailed magnetic characteristics will be presented and the results will be discussed in light of existing cluster glass models.

Financial assistance from BRNS (DAE), India is gratefully acknowledged.
Fluorescent Magnetic Nanocarrier for Enhanced Two Photon Triggered Drug Delivery
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Current light triggered drug delivery systems are applicable only in the ultraviolet and visible regions of the spectrum, where skin is poorly transmissive, limiting treatment to topical ailments. The utilization of two-photon absorption (TPA) phenomena has impacted many biological and nanomedicine applications including bioimaging, drug delivery, and phototherapies. In this study, a novel nanoformulation for targeted drug delivery which utilizes nanophotonics through the fusion of nanotechnology with biomedical application has been developed. The approach involves energy-transferring magnetic nanoscopic co-assembly fabricated of rhodamine B (RDB) fluorescent dye grafted gum arabic modified Fe$_3$O$_4$ magnetic nanoparticle and photosensitive linker by which dexamethasone drug is conjugated to the magnetic nano-assembly. The advantage offered by this nanoformulation is the indirect photo triggered on demand drug release by efficient up-converting energy of the near IR (NIR) light to higher energy and intraparticle energy transfer from the dye grafted magnetic nanoparticle to the linker for drug release by cleavage. The synthesized nanoparticles were found to be of ultra small size (13.3 nm) and are monodispersed in aqueous suspension. Dexamethasone (Dexa) drug conjugated to RDB-GAMNP by photosensitive linker showed appreciable release of Dexa by photo triggered response on exposure to a radiation having wavelength in the NIR region whereas no detectable release was observed in dark. Photo triggered response for the nano formulation not bearing the rhodamine B dye was drastically less as less Dexa was released on exposure to NIR radiation which suggest that the photo-cleavage of linker and release of Dexa mainly originated from the indirect excitation through the uphill energy conversions based on donor-acceptor model FRET. The promising pathway of nanophotonics for the on demand release of drug makes this nanocarrier very promising for applications in nanomedicine.

Magnetic and Hydrogenation Properties of Nanocrystalline MgCo$_{2-x}$Ni$_x$ System
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A serious bolt neck for the full usage of hydrogen is the lack of appropriate storage materials. A suitable material for hydrogen storage is one of the key requirements for a possible hydrogen economy. Magnesium is one of the lightest storage materials known, it is abundant and inexpensive. The main problem with using magnesium as a storage material for hydrogen is its high binding energy with hydrogen, since it desorbs hydrogen at high temperature (300 - 350°C). Alloying of magnesium with transition metals can result in a substantially improved dissociation activity due to the presence of d-electrons in transition metals. More recently, systems like Mg-Fe and Mg-Co have been shown to be stable during cyclic hydrogenation. The hydride formation enthalpies of Mg-Fe-H & Mg-Co-H systems are found to be comparable to that of MgH$_2$, while the value for Mg-Ni-H is approximately 15% lower. So In this work, we tried to work on tie line by replacing Co in MgCo$_2$ by Ni up to a molar ratio 1:1. Simultaneously we prepared nanocrystalline structures using a High energy ball milling technique. The samples were characterized by XRD, SEM and VSM in terms of their structural, morphological and magnetic properties. The hydrogenation properties are presented in terms of PCT curves and the thermodynamic parameters are calculated using Van’t Hoff plots.

Magnetic Properties of Cobalt Nanoparticles Covered by a Polymer Chitozan Molecule
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Cobalt nanoparticles are of a great interest because of unique optical, electronic and magnetic properties that diverse substantially from bulk. For example, nanoparticles have a large magnetization of saturation and high temperature of transition into superparamagnetic state in comparison with bulk material. They have a broad range of applications as information storage, magnetic sensors, drug delivery system in oncology and etc. For practical usage it is necessary to obtain dispersal nanodimensional particles of certain size and therefore to avoid aggregation, nanoparticles of inorganic metals are covered by various surface active substances (carboxyl, sulfuric acid, bioactive polymers). Such materials may substantially change properties of nanoparticles. The aim of this work is to study magnetic properties Co nanoparticles (Co-np)
interacting with the chitozan molecule. Chitozan (chit) biopolymer possess a range of interesting properties such as high affinity to metals, adsorption and antibacterial properties, high biological activity and compatibility with human tissue. Properties of Co-chit clusters have been studied using ab initio molecular dynamics method. Binding energy and magnetic moment of Co-np at adsorption to chit is calculated depending on size of Co-np. Stable structures of small bare Co clusters (up to 8 atoms) have been defined by global optimization of total energy. The most stable isomers are triangle, rhombus, bicapped trigonal pyramid, pentagonal pyramid, tetragonal bipyramid with a capped atom and tetragonal antiprism for 3-,4-,5-,6-,7- and 8-atomic clusters. Magnetic moment per atom of bare Co-np increases with increasing cluster size (2.82 Mb for Co8) and Co6 has a minimum value of moment (2.54 Mb). Binding energy of complex of Co clusters+chit molecule have a tendency to increase, and shows stabilisation of Co clusters in chit molecule with the exception of Co4 that is more stable in a bare state than in a complex with chit. Value of magnetic moment of Co clusters except for Co6 and Co8 in a polymer matrix tends to decrease and is less than of bare Co clusters. We intend to continue our investigations of magnetic and electronic properties of such systems with increasing their size up to a few nanometers that may help in practical usage of these nanoparticles in nanotechnology.

A00593-01081
Spin Polarization and Spin Transport in Ferromagnetic / Organic Structure
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In organic semiconductor spintronic devices, the up-spin and down-spin polarons have different density once spin injection happens from ferromagnetic electrodes into organic semiconductors. For the different spin density of two spin channels could induce different conductivity, the different conductivity between the up-spin and down-spin polarons directly dominates the spin polarization. Here the effect of spin-dependent conductivity on the spin polarization is extensively studied applying the spin drift-diffusion equation on the ferromagnetic (FM)/organic (OSE) structure. It is found that the spin dependence of the electrical conductivity is induced by the spin injection and closely related to the induced spin density (or spin accumulation). The calculations show that the electrical conductivity induced by up-spin polarons (down-spin polarons) is position-dependent in the OSE just as the spin accumulation. And the match level of conductivities can affect the spin-dependent conductivity at the interface of the FM/OSE to a great extent. In addition, it is found that in the low-voltage regime (eV<<kT), the electric-field can effect the current spin polarization α(x) in the FM/OSE system.

A00611-02850
Preparation of Enzyme-Immobilized Multi-responsive Alginate-g-PVA Microparticles
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Recently, magnetic particles have been attractive in biomedical and bioengineering applications such as target drug delivery, detoxification of biological fluids, separation and purification of biomolecules, clinical diagnosis and enzyme immobilization. Sodium alginate is biocompatible and can be physically cross-linked with multivalent cations in mild condition and has been widely utilized in a variety of biomedical applications.

Fe-Alg-g-PVA/Fe3O4 magnetic microparticles have been prepared by physically cross-linking alginate-g-PVA with ferrous ion in a surfactant-free emulsion system and then transformed into ferromagnetic microparticles via a self oxidation procedure. In this article, alginate-g-PVA is used to form α-amylase-immobilized magnetic microparticles. The release behavior of the α-amylase-immobilized magnetic microparticles exhibits pH-sensitive. The microparticles are utilized to catalyze the hydrolysis of starch and behave magnetic responsive.

The experimental results suggest that such a kind of microparticles is potential for encapsulating bioactive substances and suitable for various applications such as drug targeting delivery and immobilizing enzyme.

A00615-01119
Multi-level Storage and Reduction of Spin Transfer Currents in Perpendicular Magnetic Anisotropy Magnetoresistive Devices
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Magnetoresistive devices based on layers with perpendicular magnetic anisotropy (PMA) have been receiving increasing interest as they do not suffer from magnetisation curling at the edges of patterned elements. Furthermore, the theoretical expressions for spin transfer switching (STS) currents show higher spin torque efficiencies for PMA devices. These advantages make PMA devices promising candidates for spin torque magnetic random access memory (ST-MRAM) that can be scaled towards high storage densities.
PMA single-spin valves (SSV) and dual-spin valves (DSV) based on CoFe/Pd bilayers were deposited using UHV dc magnetron sputtering onto thermally oxidised Si wafers, achieving high current-in-plane giant magnetoresistance (CIP-GMR) of 9.7% and 15.2%, respectively. The film structures of Ta/Pd/Soft layer/Cu/Hard layer/Pd/Ta and Ta/Pd/Hard layer1/Cu/Soft layer/Cu/Hard layer2/Pd/Ta were realised for SSVs and DSVs, respectively. We studied the effect of the Ta seed layer, crystalline orientation, annealing and various CoFe alloy compositions on PMA and GMR. We also describe the switching behaviour of a perpendicular DSV with four distinct resistance states, showing that it behaves as a simple additive combination of the GMR contributions at the interfaces of its two constituent SSV. By varying the Co or CoFe spin filter layer thicknesses at the interfaces of one Cu spacer layer from 2 to 6 Å, a linear dependence of GMR across the selected spacer layer was demonstrated, without affecting the GMR contribution across the second Cu spacer layer. Using this strategy, the intermediate resistance levels in a four-state perpendicular DSV can be adjusted independently, creating flexible platform for multi-state storage.

In order to reduce STS current densities in PMA devices for practical ST-MRAM, we used the Landau-Lifshitz-Gilbert formalism to study the performance of a perpendicular GMR device with several magnetic layer configurations. We propose a multilayer structure in which the insertion of an additional spin polariser with in-plane anisotropy adjacent to the perpendicular free layer can enhance the STS efficiency and switching speed of the device. Although an additional in-plane or perpendicular spin polariser can both increase STS speeds, it was found that a canted spin polariser with an angle from 40° to 80° out of the film plane enhances STS efficiency more than a fixed in-plane or perpendicular polariser. To support our simulation results, we deposited a CoFe in-plane spin polariser adjacent to the free layer of a perpendicular SSV, thus creating a modified-dual spin valve (m-DSV). For 100 nm diameter devices, concurrent STS of both magnetic layers was observed for positive currents, making the parallel-to-anti-parallel (P→AP) transition impossible. In m-DSV devices, we observed 60% reduction in the energy barrier for AP→P transitions, and 40% reduction in critical current density \( J_{c_{\text{AP} \rightarrow \text{P}}} \) with 10 ns STS current pulses compared to SSV devices. Furthermore, the m-DSV structure enabled the soft layer to switch independently from the hard layer via STS.

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Colossal magnetoresistance (CMR) manganites have been subjected to extensive research due to their unique magnetic and electrical properties. The physical origin of this phenomenon has been attributed to the double-exchange model. However, this double-exchange mechanism of carriers between Mn3+ and Mn4+ ions alone cannot account for all the observed changes such as metal-insulator transition in these materials. Other factors include the highly correlated nature of the spin, lattice, charge and orbital degrees of freedom. Ultrafast optical techniques are powerful probes for investigating the quasiparticle and spin relaxation dynamics in these strongly correlated systems. Recently, Zhao et. al. reported a re-entrant metal insulator (M-I) transition in single crystals of Cu-doped manganites La1-xPbxMnO3 (x = 0.14). The re-entrant M-I transition at low temperatures was observed in samples with Cu-doping (y >= 0.02) and was attributed to the charge carrier localization due to lattice distortion caused by Cu doping at Mn sites. However, there have been no reports on the effects of Cu-doping on the spin-lattice interaction in these materials. In this work, we investigate the spin-lattice relaxation in single crystals of La1-xPbxMn1-y-zCuyO3 (x = 0.14, y = 0, 0.01, 0.02, 0.04, 0.06 and z = 0.02, 0.08, 0.11, 0.17, 0.20) that were grown by the flux melt technique. The substitution of Mn sites with a transitional element Cu allows one to study the critical role of Mn ions in CMR materials. The couplings between the spin, lattice, charge and orbital degrees of freedom in the relaxation dynamics of the nanoscopic magnetic clusters in this CMR system were investigated using Femtosecond time-resolved spectroscopy. Transient reflection spectroscopy and time-resolved magneto-optical Kerr spectroscopy have been employed to probe the quasiparticle relaxation and the photo-induced dynamics of magnetization. We observed the presence of periodic oscillations in the transient reflectivity signal near the metal insulator transition. These oscillations are attributed to the phonon-polariton interactions. The origins of the re-entrant M-I transition in this novel system were also discussed in light of these new findings.
Soft Ferromagnetic \textit{FeSi} Thin Films by Pulsed Laser Deposition

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Due to high Curie temperature and high spin polarization, ferromagnetic \textit{FeSi} thin films have attracted a lot of attention in spintronics and magneto-electronic devices. This paper reports on the preparation of \textit{FeSi} thin films by pulsed laser deposition (PLD) and radiofrequency plasma discharge assisted PLD (RF-PLD). A Nd:YAG laser beam was focused on a \textit{FeSi} target, in vacuum or in the presence of an argon RF plasma beam. The substrate temperature (from RT to 500\textdegree C), gas pressure (5-50 Pa) and the RF plasma beam influence on \textit{FeSi} thin films were particularly studied. Atomic force microscopy, sampling electron microscopy, spectral-ellipsometric measurements, X-ray diffraction, and vibrating sample magnetometry were performed to test the thin films’ properties.

Co nanoparticles have been synthesized using Polyaniline-assisted synthesis route. The formed structures have been characterized for structural, morphological, transport and magnetic properties. X-Ray Diffraction technique has been used to confirm the FCC structure of elemental cobalt. Fourier transform Infrared Spectroscopy has been used to understand the conjugational chemistry. Vibrating sample Magnetometry technique has been utilized to study the magnetic properties of the structure at room temperature. The transport studies have been correlated with magnetization data to envisage the potential of these systems as magnetic semiconductors.

In second approach, Cobalt nanoparticles have been embedded in polymeric-cages, which envisage interesting applications for radio frequency shielding. Cobalt nanoparticles were trapped in polyvinyl alcohol (PVA) matrix to yield self-supporting magnetic films in PVA slime. 20 nm, Co encapsulated with a weak citrate coat when caged in PVA matrix exhibited persistence of magnetism and good radio-frequency response. The details of the work done will be discussed in this presentation.

Nanoparticles of Maghemite and Substituted Maghemite (\textit{γ-MFe}_2\textit{O}_3 where \textit{M} = \textit{Al}, \textit{Cr}, \textit{Mn}, \textit{Zn} and 0 \leq \textit{x} \leq 1.3): A Comparative Study

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Magnetic nanoparticles of pure and substituted iron oxides were prepared by auto combustion and wet chemical methods. The samples prepared by the first process had mixed phase of hematite and maghemite where as by the later process it was essentially maghemite phase for all substituted maghemites (\textit{γ-MFe}_2\textit{O}_3 where \textit{M} = \textit{Al}, \textit{Cr}, \textit{Mn}, \textit{Zn} and 0 \leq \textit{x} \leq 1.3). XRD patterns and TEM analysis suggest that these samples were essentially of monophasic nature for substituted maghemite and the size of the particles was observed in the range between 5 to 25 nm. Al- and Mn-substituted maghemites initially show increase in the saturation magnetization with substitution but it decreased after reaching a maximum value at \textit{x} = 0.07 and 0.2 for the two substituted maghemites respectively. On the other hand Cr- and Zn-substituted maghemite displayed continuous decrease in magnetization with
substitution. Curie temperature and blocking temperature for all the substituted maghemites decreased continuously with increased substitutions. Due to higher magnetization value of Mn-substituted maghemite (for \( x = 0.2, 78 \, \text{Am}^2/\text{kg} \)), the magnetic suspension made out of it had higher heating ability and specific absorption rate compared to the suspensions made up of Al-substituted maghemite (for \( x = 0.07, 70 \, \text{Am}^2/\text{kg} \)) or pure maghemite (62 \( \text{Am}^2/\text{kg} \)). Magnetic hyperthermia treatment using Mn-substituted maghemite could kill the cancerous cells effectively.

A00821-02095

Growth and Magnetic Properties of Fe-Ni based Amorphous Nanocolumns Obtained by Oblique Angle Vapour Deposition

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Fe-Ni based amorphous alloys are increasingly becoming a hot topic of research because of their potential in finding end uses in fields such as power electronics, sensors and actuators. The amorphous local structure in these alloys plays a major role in the reduction of magnetic anisotropy energy and the corresponding improvement in properties such as coercivity and permeability. In addition, the random atomic structure leads to the increase in resistivity making them suitable for high frequency applications. With the advent of these materials showing excellent magnetic properties, the nanostructured form of this material will be important from an application point of view. The development of nanostructured magnetic materials makes it possible to miniaturize magnetic devices and integrate them in circuit board.

Thin film deposition at oblique angles has some advantages in obtaining nanostructured magnetic materials. This technique utilizes physical vapor deposition to deposit films on a substrate oriented at an oblique angle to the vapor source. The vapor atoms travel to a fixed substrate at large oblique angle respective to the surface normal of the substrate. The evaporant nucleates on the substrate; the region behind the nucleus does not receive any further vapor because of the shadowing by the nucleus. Therefore, vapor will only be deposited onto the nucleus. This preferential growth dynamics gives rise to the formation of isolated columnar structures. The morphology of such films will be a resultant of the competition between smoothing due to surface diffusion of adatoms and roughening due to self shadowing process. Some of the advantages of this technique are 1) no template is required 2) high temperature is not required and 3) no harmful chemicals are involved.

In the present work we report on the growth of magnetic nanocolumns via oblique angle deposition. The evolution of the magnetic properties with the growth of the columns was studied using atomic force microscopy (AFM) and magnetic force microscopy (MFM). It has been observed that surface roughness of substrate greatly affects the final morphology of the columnar structures. Thick and large columns were obtained on a glass substrate when compared to that on a smooth silicon substrate. The morphology of the resultant films determined their magnetic properties. Due to their higher number density, exchange coupling was present for nanocolumn arrays prepared on silicon substrates. On the other hand, well separated nanocolumns on glass substrate resulted in exchange isolated magnetic domains. These results indicate that oblique angle deposition on a patterned substrate can result in well separated nanocolumns which can be promising for future high density recording applications.

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Observation and Manipulation of Domain Walls in Soft Magnetic Nanowires

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Much attention has been focused recently on the properties of domain walls (DWs) in quasi-planar magnetic nanowires made from soft magnetic materials such as permalloy. The topic is a particularly fertile one in that walls with completely different structures can exist over an extended range of wire width and thickness. The most prominent DW types are vortex and transverse DWs, denoted as VDW and TDW respectively. Further classification is necessary according, for example, to the chirality and polarity of a VDW. Whilst the energy does not vary with chirality or polarity, the way the degenerate walls interact with deliberately or inadvertently introduced irregularities in the wire can vary markedly. This then is a rich field for scientific exploration but a problem for those developing the device potential of such wires.

Direct observation of DW structures and the ability to study directly how DWs with different structures interact with notches and anti-notches fabricated in the wires provides a powerful way forward. We have used Lorentz transmission electron microscopy (LTEM) to determine quantitatively the distribution of induction in the various extended DWs
that form in the wires. By the application of local or global magnetic fields or by spin-polarised currents, DWs can be nucleated and subsequently propagated along nanowires in situ in the TEM. This has allowed us to study, inter alia, (i) the structure of DWs in straight and curved wires, (ii) how the potential energy landscape varies as VDWs with different chiralities approach an asymmetric notch or anti-notch and (iii) the extent to which DWs act as elastic objects capable of significant extension.

For head-to-head DWs the lateral extent is determined more by the geometry of the wire than by the detailed magnetic properties, provided the material anisotropy is sufficiently low. In terms of interaction with asymmetric notches and anti-notches we have identified the orientation of magnetisation towards the leading edge of the DW packet as a key parameter. If this is similarly oriented to the local magnetisation in the (anti-)notch the (anti-)notch tends to act as a potential well; otherwise the (anti-)notch acts as a potential barrier. Most surprising at first sight is the extent to which DWs can deform to many times their length in a uniform wire. In the case of a VDW this is primarily associated with the pinning of the vortex within the non-uniform section of the nanowire.

In addition to the experiments described above we will discuss how direct observation of complex magnetic structures can be correlated with electrical measurements, thereby giving insight into the origin of the rich variety of transport phenomena observed in magnetic nanowires.

Intrinsic Ferromagnetism in Transition Metal Doped In$_2$O$_3$

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We present our recent results on transition metal doped In$_2$O$_3$, including bulk material, thin film and devices. A systematic study of structural, magnetic and transport properties was performed on Fe, Cr, Cu and Mo doped or co-doped bulk In$_2$O$_3$ and ITO under various sintering pressures. Extensive magnetic, electric transport and point contact Andreev reflection (PCAR) measurements have been carried out. The results indicate that these materials are chemical homogeneous but magnetic inhomogeneous materials. The ferromagnetism in some of these materials is intrinsic which is due to oxygen vacancy mediated interaction. The electric transport can be clarified by two-channel transport model. The PCAR measurement results indicate high surface spin polarization and ferromagnetism on nonmagnetic In$_2$O$_3$ and ITO. High quality ferromagnetic transition metal doped In$_2$O$_3$ thin film has been obtained. Point contact techniques have been employed to measure the spin polarization and the critical current of spin torque. TMR devices have been fabricated and novel results have been obtained.

Controlled Synthesis of Anisotropic Magnetic Nanocrystals

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Synthesis of monodisperse magnetic nanocrystals with controlled shape and size has attracted much attention in developing nanocrystals for information storage, permanent magnet nanocomposite, catalysis and biomedical applications. Here we report the controlled synthesis of anisotropic magnetic nanocrystals, which range from nanoparticles, nanocubes, nano-octahedraons, to nanorods and nanowires.

Microwave-induced Dehydration of Autocombustion Barium Ferrite Nanoparticles

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Nanostructure barium ferrite powders were synthesized using the sol–gel combustion method. Analytic purity of iron nitrate, barium nitrate, citric acid and ammonia was used as starting materials. Fe$^{3+}$ to Ba$^{2+}$ molar ratio of 11.5 was kept constant, mixed with citric acid solution and further pH values adjustment using ammonia. The solution was dehydrated by microwave heating for 3 hours to form a loose powder. Thermal decomposition behavior of the as burnt samples was examined using differential thermal analysis and thermogravimetric with heating rate of 10 °C/min. The as-burnt powders were calcined in air for 2 hours at four different temperatures from 550 °C to 950 °C, with heating rate of 10 °C/min. The phase identification and particle morphology of the calcined
Magnetic and Optical Studies on Chemically Synthesized Co-Doped CeO₂ Nanoparticles

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Magnetically doped CeO₂ is a promising Dilute Magnetic Semiconductor (DMS) which is anticipated that the introduction of room-temperature ferromagnetism into cubic system will facilitate the integration of spintronics device with advanced silicon microelectronic devices. CeO₂ and Co-doped CeO₂ were prepared at room temperature using a precursor method which involves co-precipitation of Co²⁺ and Ce⁴⁺ ions using ammonia hydroxide from the aqueous cerium nitrate and cobalt nitrate solutions. Finally the precipitated products were characterized by using X-Ray diffraction (XRD), Transmission electron microscopy (TEM), Field emission scanning electron microscopy (FESEM), Raman spectroscopy, Photoluminesence (PL) and Vibrating sample magnetometer (VSM). X-ray diffraction pattern shows a diffraction peak at 29.4° corresponding to (111) reflection plane normal to c axis of a cubic fluorite structure of CeO₂. The XRD analysis of the as-prepared and annealed powders shows the same crystalline fluore structure. From the TEM images, it was clear that the grain size of the spherical and nano-sized particles were found to be around 20 nm. The surface morphology of synthesized Co-doped cerium oxide shows the agglomeration on nanoparticles. In Raman spectra, a peak at 465 cm⁻¹ corresponds to synthesized CeO₂ is in good agreement with the peak of commercial powder. Photoluminescence emission around 540 nm could be the result of defects including oxygen vacancies in the crystal with electronic energy levels below the 4 f band. These defects possibly act as radiative recombination centers for electrons initially excited from the valence band to the 4 f band of the oxide. The magnetic properties of synthesized powder were investigated using Vibrating Sample Magnetometer (VSM), by measuring hysteresis loops. Moreover, it has been observed that the increase of the Coercivity (Hc) value with the increase of doping concentration. The ability to create Co doped ceria with better magnetization at room temperature using co-precipitation method can be used as a promising material for spintronics devices.

Spin Current, Charge Current, Heat Current and Spin-Electronics

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In magnetic nanostructures, there are two conservation laws between the conduction electrons and the magnetic moment. The first is the angular momentum conservation which brings about the spin angular momentum transfer between them. This is a key concept for controlling the magnetization direction in a variety of spintronics (spin-electronics) devices such as magnetic tunnel junctions and nano-magnetic wire devices with domain walls. The other conservation law is that of energy between the conduction electrons and the magnetic moment. When the internal field on the conduction electrons due to the magnetic moment changes during the propagation in a magnet, the magnetic energy stored in the conduction electrons is released as the spin-motive force.

The spin-motive force is derived by extending the Faraday’s law of electro-magnetism: The non-conservative force acting on the electronic charge results in the work, which is the origin of the electromotive force. In the same way, the non-conservative force acting on the electronic spin degree causes the work, which brings about the spin-motive force. When the numbers of up and down spin electrons are different in a magnet, the difference of the force acting on up and down spin electrons gives rise to the electromotive force.

Here, various phenomena caused by the conservation laws are discussed. We also examine spin and charge currents induced by temperature gradient and/ or heat current in a ferromagnet.
Three-Dimensional Iron-filled Carbon Nanotube Arrays Synthesized by Floating Catalytic Chemical Vapor Deposition

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Iron-filled carbon nanotubes have been attracted many attentions for their potential applications in magnetic force microscopy, biochemical nano-sensors, nanocomposites and electromagnetic wave-absorbing materials.

Ethanol as carbon source not only possesses low toxicity, easier storage and transportation, but also does not tend to form amorphous carbon on dissociation. So in our experiments, we use ethanol as carbon source to synthesize carbon nanotubes.

In this paper, we report floating cataly chemical vapor deposition (FCCVD) for synthesizing three-dimensional iron-filled carbon nanotubes arrays. We utilized ferrocene as catalyst precursor to synthesize carbon nanotubes by FCCVD. The FCCVD setup consists of two-stage furnace fitted with independent temperature controllers, carbon source supply system, carrier gas supply system and pump system. The ethanol was introduced into furnace tube by bubbling liquid ethanol under carrier gas flow of 100sccm 3%H2/Ar and 100sccm N2. Catalyst precursor ferrocene was place at low temperature (300°C) region. Then ferrocene gas was introduced into high temperature (higher than 850°C) region by carrier gas. Ferrocene was decomposed to form iron nano-particles as catalysts. These catalysts catalyzed the growth of carbon nanotubes which were deposited on substrates and the wall of furnace tube. After about 3h synthesis time, we obtained mass production of carbon nanotubes.

The deposits were characterized by employed scanning electron microscopy, transmission electron microscopy, and Raman spectroscopy.

The iron-filled CNTs deposit not only on the top surface but also on the side surfaces of the quartz substrate. And we can notice that the CNT arrays are all perpendicular to the surface, whether on the top surface or on the side surface. It means that the fashion of growth of iron-filled CNT arrays is three-dimensional, which is a great difference with the previous reports on the growth of iron-filled CNT arrays.

Ion-implantation Studies on Perpendicular Media

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Magnetic films with a perpendicular anisotropy have application in several areas such as recording media for hard disk drives, spin-valves and MRAM devices. In one of the future technologies for hard disk media, perpendicular recording media needs to be patterned either lithographically or otherwise. Such patterned nanostructures will have magnetic islands in a sea of non-magnetic matrix, providing improved thermal stability of magnetization in addition to providing a lower noise, ease of writing information etc. However, several challenges remain in making this technology practically useful for practical applications.

Even though obtaining small dots (<12 nm in size) with a narrow spacing (<12 nm) by lithography is a challenge by itself, planarization – a process by which the lithographically modified topography is flattened, is considered as another issue. If the disk is not planarized, the read-write head will have instability and drop in the flying heights. Therefore, alternative methods are sought to make patterned media without lithography. Ion-beam modification is considered as one possible approach to make patterned media. Irradiation with an ion-beam has been found to modify the magnetic properties of Co-Pt-Co sandwiches and (Pt-Co)n-Pt multilayers. In this study, we have studied the effect of ion implantation in CoCrPt-SiO2 perpendicular media which are used in current generation perpendicular recording technology.

The samples were conventional perpendicular recording media with soft magnetic underlayer, Ru intermediate layers and CoCrPt-oxide based recording layers. All the layers were sputtered on both sides of the disk as per the norm of the hard disk media products. The samples were irradiated on one side by C12 ions with an energy of 78 keV, with doses of 2x1011 ions/cm2 and 1x1016 ions/cm2. The irradiated and as-deposited sides were tested for magnetic properties by Polar Kerr Magnetometer, crystallographic texture by X-ray Diffraction (XRD), thickness-dependent composition measurement using Auger Spectroscopy etc.

The as-deposited samples had a rectangular hysteresis loop with a coercivity of 5358 Oe. Ion implantation with a dose of 2x1011 ions/cm2 did not lead to any significant changes. However, a dose of 1x1016 ions/cm2 led to a reduction in coercivity.
Novel Reduction Diffusion Synthesis of Nd$_2$Fe$_{14}$B

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Permanent magnets play a vital role in present day technologies such as speakers, home appliances, door lock actuators, sensors, actuators, motors, automobiles, medical equipments, hard disc drives etc. NdFeB magnets have the highest energy product in the category of permanent magnets; hence they are the material of choice for several demanding high technology applications. However, the energy product and other magnetic properties obtained experimentally are considerably lower than theoretical predictions. Hence there is considerable interest in novel synthesis methods which can result in nanostructures with improved magnetic properties. The current methods of synthesis of NdFeB based magnets mainly comprise physical techniques such as chemical milling and arc melting processes. Chemical synthesis of NdFeB based magnets still remains a challenge because of the high reactivity of Nd and the difficulty in obtaining the appropriate chemical composition and crystal structure. Hence, there are only a few reports regarding the wet chemical synthesis of NdFeB based magnetic materials. We have approached this problem by synthesizing a mixed oxide system of Nd, Fe and B by glycine-nitrate combustion synthesis, followed by reduction using calcium hydride. The X-ray diffraction studies revealed the Nd$_4$Fe$_{14}$B phase formation along with minor amounts of CaO present in it. The magnetic measurements showed that coercivity for the unwashed powder higher than the washed powders. A maximum BH$_{max}$ around 3 MGOe can be successfully obtained for samples synthesized using this novel method. These results will be discussed in detail in the presentation.
anatase phase in the undoped as well as low Fe-doped TiO₂ nanomaterials with no impurity phases. As the concentration rises the XRD line width gets considerably broader, yet maintaining the basic anatase form. Optical studies using UV-VIS spectrometer yield band gap (Eg) of ~ 3.5 eV for undoped case and extended band tailing for the Fe-doped cases. FTIR study gives information regarding O-Ti-O lattice modifications due to Fe-doping. The SQUID data show the absence of ferromagnetism in Fe-doped TiO₂. The nanoparticles were also examined for photocatalysis. These data will be analyzed, presented and discussed.

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A01023-02917

Synthesis of Hexagonal Mesoporous Material from Indonesian Natural Bentonite

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Synthesis and characterization of a Hexagonal Mesoporous Clay (HMC) prepared from Indonesian Natural Bentonite has been studied. The natural bentonite was leached by hydrochloric acid and then suspended in tetradecyltrimethylammonium bromide (C₁₄TMA) surfactant solution and followed by adjusting at pH 12 and stirred for 24 hours. After stirring the suspended solution was adjusted to pH 9 and then refluxed and treated hydrothermally for 48 hours respectively. After filtered the solid particle of the resulted HMC was calcined.

The resulted HMC was characterized by x-ray diffraction (XRD), N₂ adsorption and FTIR. Leaching process by using hydrochloric acid caused dissolution of octahedral layer of clay and produced tetrahedral silicate layer. The silicate was templated by C₁₄TMA surfactant to produce the long range hexagonal mesoporous material (HMC) with basal spacing 41.13 Å. From the isotherm adsorption shows that the resulted HMC has isotherm adsorption type IV, BET surface area of 600 m² g⁻¹, and the framework pore sizes in the supermicropores to small mesopore range (2-4 nm) with average pore sizes of 2.6 nm. The BJH method were found to be closest to the experimental value of the pore size obtained by XRD.

A01027-01795

Suitability of Commercial Colloids in Magnetic Hyperthermia

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There is an obvious and widespread need for an alternative treatment of metastatic cancer that does not rely upon systemic therapies such as chemotherapy or radiotherapy, which can result in adverse side effects. In treating cancer cells, there is often damage sustained to healthy cells inducing increased strain on an already weakened body. One viable solution would be to develop a specific localised treatment that would deliver biomolecular therapeutic agents, preferentially targeting cancer cells, that could then be activated in a controlled manner thus increasing the efficiency of the therapy where needed. One particular method relies upon heat generated from a magnetic nanoparticle under the influence of an externally applied alternating magnetic field. This method, known as magnetic hyperthermia, is ideally suited for treating metastatic cancers which are highly susceptible to cell death as a response to a small increase in local temperature, typically between 3-5ºC. It is crucial to study the calorimetric efficiency of nanoparticles to optimise them for hyperthermic treatment. Commercial nanoparticles from Chemicell, Micromod and Bayer-Schering were characterised on hydrodynamic diameter, total iron content and relative ferrous iron content and crystalline diameter. Additionally calorimetric measurements were taken using a 900 kHz AC magnetic field of 3 kA/m. Our findings conclude that 4 out of the 16 samples containing relatively high (>18%) ferrous content on average generate an intrinsic loss power (ILP, a system-independent parameter) of less than 12% compared to other particles. Highest ILP (11.1 nHm²/kg) was achieved for particles with hydrodynamic diameter of around 70 nm and crystallite diameter of 12 nm. Two Chemicell batches (fluidmag-D 50 nm) that only differ in production date show significantly different ILP as a result of different individual crystal sizes. Results are compared to ILPs of natural and synthetic particles in the literature.
**Ferromagnetic Nanostructures by Atomic Layer Deposition: From Thin Films towards Core-shell Nanotubes**

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A broad range of potential applications of magnetic nanostructures have been developed in the recent years. Magnetic data storage, microelectronics, or biomedical uses such as cell separation or biosensing present a special interest among these applications. Atomic layer deposition (ALD) is a very suitable method for the conformal deposition of magnetic thin films in pore structures of high aspect ratio, while offering the precise tuning of the layer thickness and high uniformity.

For the ALD of Co and Ni, initially a metal oxide film based on CoCp$_2$ (cobaltocene) and NiCp$_2$ (nickelocene) has been grown by the reaction of the precursor with ozone, respectively. Subsequently, the metal oxide film has been reduced in hydrogen atmosphere after the ALD process and converted to the metallic ferromagnetic phase with low-degree of surface roughness. In a similar manner, Fe$_3$O$_4$ films have been grown by the ALD deposition of Fe$_2$O$_3$ films based on the reaction of water and iron(III) tert-butoxide (Fe$_3$(OtBu)$_6$) and followed by a hydrogen reduction after the ALD process. On the other hand, we have observed that direct reaction of a metal-organic precursor and hydrogen during the ALD cycle always yields very granular films with ill-defined magnetic properties and very low deposition rates (<0.1 Å/cycle).

By conformal coating of self-ordered Al$_2$O$_3$ membranes, arrays of magnetic nanotubes with diameters down to 20 nm and wall thicknesses of less than 5 nm have been achieved. The magnetic properties of the nanotube arrays as a function of wall thickness and tube diameter have been studied by using SQUID magnetometry and compared with magnetic simulations. As an outlook we will discuss the properties of magnetic multi-layer nanotubes (core-shell) and the application of conformal magnetic coatings of other template systems and 3D nanostructures.

**Magnetic and Optical Properties of Fe-doped SnO$_2$ Nanoparticles Synthesized by Hydrothermal Method**

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We report the synthesis, microstructures, magnetic and optical properties of Fe-doped Sn$_{1-x}$Fe$_x$O$_2$ nanoparticles. Samples with $x=0, 0.01, 0.05, 0.1$, and $0.2$ were prepared by a simple hydrothermal method using SnCl$_4$·5H$_2$O and FeCl$_3$·6H$_2$O. Samples are characterized using X-ray Diffraction, Rietveld refinement, high-resolution transmission electron microscopy, UV-Visible absorption and Photoluminescence. Magnetic measurements were carried out over a wide range of temperature and magnetic field. Our results show that all the samples have a rutile SnO$_2$ structure with the particle size decreasing from 6 nm to 4 nm when Fe concentration increases from 0 to 20.0%. We did not observe any diluted ferromagnetic state in any of our samples. All the Fe doped SnO$_2$ show a typical paramagnetic feature. The magnetization of samples increases with increasing Fe doping level. The spin state assessment indicates that the Fe takes 3+ with high spin state. A relative intensive UV-violet peak at 388 nm (about 3.20 eV) and a broad blue emission band 440-480 nm (about 2.82 - 2.58 eV) were detected in all samples. These two absorption band edges show a considerable red shift as the Fe level increases. Our first-principles band structure calculations show that the impurity band from Fe 3+ is responsible for the second absorption peak and the observed paramagnetism in our Fe doped SnO$_2$ samples.

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**Symposium E - Nanostructured Magnetic Materials and Their Applications**

**A011123-05001**

**Nanogranular L10 FePt-C-Ta2O5 Composite Media for Perpendicular Recording Applications**

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L10 FePt with large magnetocrystalline anisotropy of 6.6-10x107 erg/cc has attracted much attention due to its potential to reach recording areal densities beyond 1Tb/in2 [1]. To achieve this, small, well-isolated FePt grains which are chemically ordered are highly desired. Attempts to reduce grain size and promote decoupling among grains include the addition of non-magnetic materials to isolate the FePt grains.

In this report, (Fe55Pt45)79C21-(x vol%)-Ta2O5 films (where x = 0% to 20%) were prepared using both low and high power magnetron sputtering on CrRu(30nm)/MgO(2nm) underlayers. The microstructure and magnetic properties were discussed.

Experimental results showed that FePt-C-Ta2O5 films sputtered at low power showed an out-of-plane coercivity of 7.2 kOe even with Ta2O5 content to 20 vol. %. Exchange decoupling improved with increasing Ta2O5 content as evident from the loop slope parameter, α, which showed a monotonic decreasing trend. FePt-C-Ta2O5 films sputtered at high power showed an initial increase in out-of-plane coercivity to 8.2 kOe, as well as improvements in exchange decoupling at Ta2O5 content of 5 vol. %. Subsequent increases in Ta2O5 content to 20 vol. % led to both a decrease in out-of-plane coercivity to below 1 kOe, as well as the deterioration of exchange decoupling.

XRD spectra showed the presence of FePt(001) superlattice peak in films sputtered at low power with Ta2O5 content up to 20 vol. %, suggesting that perpendicular anisotropy was maintained. Films sputtered at high power showed FePt(001) superlattice peak for Ta2O5 content up to 15 vol. %. Perpendicular anisotropy was lost with additional doping of up to 20 vol. %. TEM images for both low and high power sputtered films showed improvement in grain isolation with increasing Ta2O5 dopant content. However, the size and amount of soft FCC FePt secondary nucleation formed on the L10 FePt grains increased as well.

**A01151-02077**

**Superconductivity according to Densification of MgB2 using Spark Plasma Sintering Process**

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Since discovery of MgB2 superconductivity in 2001, much research on MgB2 has been performed in enterprises and research institutions because MgB2 has lower production cost than high temperature superconductor, and can be applied to electric machinery by refrigerator without liquid helium.

Recently, as a new sintering process, the spark plasma sintering process shows the advantages of a very fast heating rate (up to 600 °C/min or more) and short holding time (minutes), and it can obtain fully dense samples at relatively low sintering temperatures, typically a few hundred degrees lower than that of normal hot pressing.

In this study, Mg and amorphous B powders about 8 and 2 micron were used as raw materials, respectively. MgB2 sample was fabricated by spark plasma sintering under various temperature and time conditions after mixing of raw powders. The fabricated MgB2 samples were evaluated with XRD, EDS, FE-SEM, PPMS.

The densification of MgB2 microstructure showed at sintering temperature over 900 °C, and the relative density of sintered sample for 20 min at 1000 °C was about 97 %. Transition temperature (Tc) of sintered samples at 1000 °C was about 37K, and it’s critical current density (Jc) shows over 1.0*10^6 A/cm2 at T=20K, H=2.5T. This result expects that alternating current(A.C) loss was decreased by densification behavior of microstructure.

**A01163-01992**

**Giant Positive Magnetoresistance in (Fe0.2Ni0.8)10C90 Granular Composites**

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Recent studies on micron sized powder compacts of Fe-C, Ni-C, Co-C showed a very large magnetoresistance (MR) values at room temperature under high magnetic field. Xue et al. have reported MR values of 59% at 300 K under 8 tesla magnetic field while 105 % under 5 tesla at 5 K in Co/C granular compacts. On the other hand, 54% and 44% MR values at 300 K in 5 tesla magnetic fields
have been reported for Fe\textsubscript{20}C\textsubscript{80} and Ni\textsubscript{20}C\textsubscript{80} respectively. However, interestingly enough all the above magnetic composites exhibit positive MR values and increase linearly with applied magnetic field, which is contrary to that of conventional granular materials where one observes negative MR values with nonlinear field dependence and attributed it to spin dependent scattering. It is also well known that semimetallic graphite also exhibits positive MR values. Therefore our main objective of this work is to understand whether the magnetic particles embedded in graphite matrix contribute to the large positive magnetoresistance values or not. In order to investigate this, we have replaced the transition metal element by a soft magnetic permalloy particle, which shows maximum magnetoresistance values.

From these studies, it is clear that one can obtain large MR values in the present samples by optimizing the magnetic particle size, though a significant contribution comes from the graphite matrix.

Mixtures of appropriate amounts of Fe (<10 micron, 99.9+%\%) and Ni (200 mesh, 99.9\%) powders corresponding to the nominal compositions of Fe\textsubscript{a.2}Ni\textsubscript{0.8}\textsubscript{10}C\textsubscript{90} were mechanically alloyed using a planetary ball mill (RETSCH- PM 200) with tungsten carbide milling media. As-milled powders of Fe\textsubscript{a.2}Ni\textsubscript{0.8}\textsubscript{10}C\textsubscript{90} under different milling times were thoroughly mixed by mortar and pestle with micrometer size C (graphite) and compacted into 11 mm diameter and 1-1.2 mm thick pellets at a pressure of 3 ton for 5 minutes. All the samples show semiconducting like resistivity behavior in the temperature range 10-300 K. The magnetization of the alloy powders reveals that the samples are ferromagnetic in nature at room temperature. The MR was measured in the samples has been observed using cryogen-free superconducting magnet system. The highest 30.9\% MR(L) whereas 6.8\% MR(T) at room temperature have been observed in 40 hrs ball milled (Fe\textsubscript{a.2}Ni\textsubscript{0.8}\textsubscript{10}C\textsubscript{90} alloy. From these studies, it is clear that one can obtain large MR values in the present samples by optimizing the magnetic particle size, though a significant contribution comes from the graphite matrix.
We have grown NiCoFe/Cu/NiCoFe sandwich onto Si (100) substrates using opposed target magnetron sputter. The growth parameters are: temperature of 100 °C, applied voltage of 600 Volt, flow rate of the Argon of 100 sccm, and growth pressure of 5.2 x 10^{-1} Torr. The NiCoFe target was prepared by solid reaction method with molar ratio Ni:Co:Fe = 60:30:10. The effects of thickness of ferromagnetic and non magnetic layer on magnetoresistance (MR) ratio of GMR materials were studied. At room temperature, we have found that the MR ratio of the samples depend on the thickness of ferromagnetic and non magnetic layer was varied, as consequences of variation in time growth. The MR ratio are: 24.39%, 18.31%, and 0.16% for NiCoFe(70nm)/Cu(60nm)/NiCoFe(70nm), NiCoFe(150nm)/Cu(103nm)/NiCoFe(150nm), and NiCoFe(250nm)/Cu(247nm)/NiCoFe(250nm), respectively. The numbers in parentheses indicate the thickness of the layers. The thickness of the ferromagnetic and non magnetic layer in thin films will have an effect on to the magnetoresistance value.

Use of Polymers to Control the Transport Properties of Sintered Magnanite Samples

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Cobalt films were grown by molecular beam epitaxy on CaF2 buffer layers on silicon and showed a variety of magnetic and optical effects. When the substrate is Si(111), CaF2 grows as flat layer with (111) surface and Co grows on it in face centered cubic lattice. Magneto-optical Kerr effect (MOKE) from these structures is isotropic in plane. When the substrate is Si(100), CaF2 growth direction is [110] due to unique properties of CaF2/Si(100) interface. Then CaF2 surface has grooves with {111} facets and cobalt grown on it has in-plane magnetic anisotropy with easy axis along the grooves. The dependence of remanence magnetisation and coercivity on azimuthal angle (between the grooves and field) follows single domain model except the range between 80 to 90 degrees - there is a peak related to crystalographic anisotropy. MOKE from these structures can have different sign depending on incidence angle; this is consistent with calculations of multilayer model. We found that the sign of MOKE can change also versus azimuthal angle, which was unexpected. Physics behind this phenomenon will be presented.
In this presentation, we shall discuss our investigation on the high coercive field $H_C$ and magnetization reversal associated with its core-shell cum nanotwin in EG reduced n-Ni. High coercive field of 1.44 Koe at 2K, sharp transition to superparamagnetism at ~20K, and magnetization reversal are observed in the Ni$_{core}$NiO$_{shell}$ cum nanotwin driven spherical nickel nanoparticles of average particle size 25nm having nanotwin thickness in the range of 2-5nm. These characteristic properties are explained using a proposed model based on this unique nanostructure that leads to the uncompensated magnetic moment of ferrimagnetic-like Ni nanomultilayers combined with antiferromagnetic NiO shells. These features seem to be interesting from the point of memory effect studies and applications.

Structural and Magnetic Characterization of Multifunctional CoPtAu Nanoparticles

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Nanoparticles of multiple components are constructed as smart nanovehicles to deliver diverse, multifold functionality demanded by converging nanotechnology. In the study of magnetic nanoparticles, surface modification and surface functionalization is of great import for their utilization in versatile potential applications, particularly in drug delivery, cell separation and magneto-transfection. We have initiated a research program to prepare a variety of functional nanoparticles via an efficient, scalable and non-toxic synthesis approach for numerous biomedical applications. On the basis of the previous investigation on CoPt nanoparticles and nanowires, the incorporation of the Au element is remarkable owing to one of its advantages in easy linkage of bio-molecules and organic materials via the mercapto groups. Such alloy nanoparticles amalgamate the magnetic, optical, catalytic, chemical and biological properties of each mono-metallic constituent in a single entity. In experiments, the synthesis of the multifunctional CoPtAu alloy nanoparticles was performed via a modified polyol process. A typical synthesis was carried out in a flask, mixing Au(OOCCH$_3$)$_2$, Co(acac)$_2$ and Pt(acac)$_2$ in an ether with a reducing agent and a polymer surfactant under vigorous stirring to complete the reaction at high temperature. The compositions of CoPtAu NPs were adjusted by controlling the amount of each precursor added and specimens of three nominal compositions, Co$_{0.34}$Pt$_{0.33}$Au$_{0.33}$, Co$_{0.25}$Pt$_{0.2}$Au$_{0.5}$ and Co$_{0.4}$Pt$_{0.4}$Au$_{0.2}$, changing the mole ratio of nickel acetate to EG in the presence (or absence) of sodium hydroxide.
were prepared. The initial results and analysis on the multifunctional CoPtAu alloy nanoparticles as synthesized were reported elsewhere. In this contribution, we focus on the structural and magnetic characterization by means of synchrotron X-ray diffraction and the Physical Property Measurement System (PPMS). The structural analysis by synchrotron radiation further proves in more detail about the formation of the alloy nanostructures consisting of Au-rich and Pt-rich nanophases. The magnetic properties were measured systematically over a wide range of temperature and applied fields. As revealed in the series of the hysteresis curves obtained from room temperature to 4 K, both Co$_{0.34}$Pt$_{0.33}$Au$_{0.33}$ and Co$_{0.4}$Pt$_{0.4}$Au$_{0.2}$ nanoparticles show transition from superparamagnetic to ferromagnetic, in contrast to the soft ferromagnetic behavior of the Co$_{0.2}$Pt$_{0.2}$Au$_{0.6}$ nanoparticles over the range of temperature. In the zero-field-cooling (ZFC) and field-cooling (FC) analysis, the nanoparticles show unconventional properties in the FC M~T curves but broad thermal response in the ZFC M~T curves. Moreover, the M~T curves substantiate the observation in the FC measurements. The composition dependence of parameters such as freezing temperature and blocking temperature were acquired. In the presentation, we elucidate the relation between the magnetic properties and the microstructures.

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A01330-02500
Enhancement of Ferromagnetic Behavior in Cu Doped ZnO:Fe
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Magnetization measurements were performed on a series of Zn$_{0.94}$ Fe$_x$ Cu$_{0.06}$ samples (x<0.15) prepared using solid state reaction and sol-gel methods. Although Cu is non-magnetic, we found that adding Cu concentration not only increases the magnetization but also results on the appearance of the hysteresis loop. Arrott-Kouvel plot reveals the presence of spontaneous magnetic moment at low temperatures (<10K), while hysteresis losses have been observed at much higher temperatures. The inverse DC magnetic susceptibility versus T at high temperature indicates the presence of ferromagnetic (FM) exchange interaction. Moreover, we found that Cu-doping greatly enhance the FM exchange interaction. We also found that samples prepared using sol-gel technique showed enhanced ferromagnetic behavior, higher saturated magnetization and stronger FM exchange interaction.

A01391-02424
Encapsulated Nickel Nanoparticles: Preparation and Characterization
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Nano structured metal carbon composites are emerging as new materials for electromagnetic interference shields, drug delivery, and energy storage. Carbon coated nickel nanoparticles were synthesized by low temperature chemical route. Their structure and magnetic properties were investigated by means of X-ray diffraction, high resolution transmission electron microscopy (HRTEM), micro Raman spectroscopy and vibrating sample magnetometry. The X-ray diffraction pattern reveals the formation of fcc phase of nickel with a grain size of 40nm. The
graphitic planes (d spacing of ~0.34Å) are observed over nickel nano particles from the HRTEM images. The catalytic activity of nickel during the formation of carbon nano fibers is confirmed. These carbon layers keep the highly reactive nano nickel passivated from further reactions. Fingerprint peaks of carbon (D and G peaks) are observed in the Raman spectrum. The shift in the peaks points to the defects occurring due to curling of graphite planes around nickel nanoparticles. The saturation magnetization of 28.6emu/g is observed, which is 52% of that of pure bulk nickel. The reduction in the saturation magnetization can be attributed to the small percentage of non magnetic components like carbon.

Thus highly crystalline, stable and magnetic carbon coated nickel nano structures were synthesized and characterized. Such material can find potential use as microwave absorbing material at high frequency over the Giga hertz range, ascribed to it’s higher Snoek’s limit.


**A01413-02658**

Fabrication and Magnetic Properties of Electrospun TiO₂ and Ti₁₋ₓFeₓO₂ (₀≤x≤0.01) Nanofibers

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Ti₁₋ₓFeₓO₂ (₀≤x≤0.01) nanofibers were fabricated by a simple electrospinning using a solution that contained poly(vinyl pyrrolidone) (PVP), iron (III) nitrate hexahydrate and titanium(diiisoproproxide)bis(2, 4-pentanedionate) 75 wt% in 2-propanol. The Ti₁₋ₓFeₓO₂ nanofibers with diameters of 91–125 nm were successfully obtained from calcination of the as-spun Ti₁₋ₓFeₓO₂/PVP composite nanofibers at 600°C in air for 3 h. The as-spun and calcined Fe-doped TiO₂ composite nanofibers were characterized by TG-DTA, XRD, SEM, and TEM. For comparison, the pure TiO₂ nanofibers were also prepared and characterized using the similar procedures. The results of XRD and selected electron diffraction (SEAD) analysis indicated that the calcined samples of Ti₁₋ₓFeₓO₂ composite nanofibers had the mixed phases of anatase and rutile TiO₂ structure without any significant change in the structure affected by Fe substitution. Room temperature magnetization results revealed a diamagnetic behavior for the undoped TiO₂ sample whereas a weak ferromagnetic behavior for the Ti₁₋ₓFeₓO₂ samples, having their hysteresis loop in the range of -2500 Oe < H < 2500 Oe, while outside this range the specific magnetization increased with increasing field and showed no sign of saturation in the field range investigated (± 10 kOe). The origin of ferromagnetism observed in the Ti₁₋ₓFeₓO₂ nanofibers was also discussed.

**A01427-02611**

Magnetic and Magnetocaloric Properties of Nanocrystalline PR₁₋ₓAₓMN₁₋ₓCOₓO₃ (A = CA, SR) Manganite

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Structural, magnetic and magnetocaloric properties of the hole-doped manganites Pr₁₋ₓAmₐMn₀.₅Co₀.₅O₃ (x = 0.3, y = 0.5) (where A is the divalent cation) can be modified by partial substitution at Mn site. The present work reports the structural, magnetic and magnetocaloric property studies of nanocrystalline perovskite oxides, namely, Pr₁₋ₓCaₓMn₀.₅Co₀.₅O₃ and Pr₁₋ₓSrₓMn₀.₅Co₀.₅O₃. These nanocrystalline samples have been synthesized by sol-gel method. The phase purity and crystal structure of these powder samples have been studied using powder X-ray diffraction and the samples are found to have orthorhombic and cubic structures with space group Pnma and Fm m at room temperature. The crystallite size is calculated using Debye-Scherrer formula. The respective values for the samples are ~24 nm and 15 nm. The surface morphology of the powder samples is studied by scanning electron microscopy and the particles are found to be evenly distributed. High resolution transmission electron microscopy image shows that the particles are spherical in shape and the average particle size is 34 nm and 20 nm. Magnetic measurement is carried out using vibrating sample magnetometer (PPMS, Quantum Design) and it shows the Curie temperature as 153 K and 172 K in applied magnetic field of 100 Oe for Pr₁₋ₓCaₓMn₀.₅Co₀.₅O₃ and Pr₁₋ₓSrₓMn₀.₅Co₀.₅O₃ samples respectively. The paramagnetic susceptibility follows Curie-Weiss behaviour in the temperature range of 180 K – 300 K and a deviation from it is observed in the temperature window of 140 K to 180 K suggesting possible presence of short range magnetic clusters. AC magnetic susceptibility was measured in the temperature range 5 K to 300 K with frequencies 33, 133, 667, 1333 and 9333 Hz. The amplitude of the peak...
values of remanent magnetization and coercive field $H_c$ appearing around 150 K and 167 K for Pr$_{0.7}$Ca$_{0.3}$Mn$_{0.5}$Co$_{0.5}$O$_3$ and Pr$_{0.7}$Sr$_{0.3}$Mn$_{0.5}$Co$_{0.5}$O$_3$ samples is suppressed and the peak position shifts to higher temperature with increasing frequency. For Pr$_{0.7}$Ca$_{0.3}$Mn$_{0.5}$Co$_{0.5}$O$_3$ sample M-H curves registered at different temperatures show significant hysteresis loops below 150 K, with unsaturated magnetization even at higher fields (up to 7 T). At 2 K, the values of remanent magnetization and coercive field $H_c$ are estimated to be 0.28 μB/F.u. and ~ 1 T respectively. The magnetocaloric effect is calculated from magnetization vs. applied magnetic field at various temperatures. Magnetic entropy change shows a maximum near $T_c$ for both the samples.

Magnetron Sputtered Nanostructured Ferromagnetic Shape Memory Alloy Thin Films

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Ferromagnetic Shape Memory Alloys (FSMAs) are a new class of material showing a unique combination of high energy densities, thermoelastic and ferromagnetic properties. These properties enable the simultaneous use of ferromagnetic and shape recovery forces in a single component part. FSMAs show magnetic-field-induced strains at room temperature greater than any magnetostrictive, piezoelectric, or electrostrictive material, and faster frequency response than temperature-driven shape memory alloys. However, the applications of these materials in emerging micro-devices such as magnetically driven microelectromechanical systems (MEMS) would require a high quality of FSM thin films grown on semiconductor substrates. In the present study attempts have been reported to grow highly oriented NiMnSn FSM thick films on silicon substrate using DC magnetron sputtering technique. NiMnSn targets of different compositions were prepared using arc melting technique. X-ray diffraction studies reveal highly crystalline single phase austenite phase with cubic bcc $L_2_1$ crystal structure and lattice parameter $a=0.5977$ nm. Traces of secondary or spurious phases were not detected. Grain size and crystallization extent increases with increase in substrate temperature. Field induced martensite-austenite transformation has been observed in magnetization studies using SQUID magnetometer. The value of transformation temperature is found to be lower in comparison to bulk value, which could be due to strain effect in thin films. Hysteresis loops measured at 5K & 300K underline the ferromagnetic ordering of austenite and martensite. The electrical and magnetic properties of the films reveal that grain size plays an important role in the phase transformation temperature, which is of immense technological importance in MEMS applications.
Phase Transition in YBCO Superconducting Material

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YBCO is well known for its superconducting properties. But all the reason is lying in the detailed investigation of the YBCO. One of the prime factor found to be involved is the phase transition in the various phases of YBCO. To study the effect of the phase transition the material was developed in the laboratory in the controlled environment by the sol-gel method and some characterization technique has been employed to reveal the problem. YBCO shows some interesting results about the properties related to different phases of formation. Various optical and crystal properties during the phase transition was investigated and hence an attempt is done to study the dynamics of phase transition.

Coating non-Magnetic Metals with Fe$_3$O$_4$ - based Magnetic Fluids

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Fe$_3$O$_4$ particles have been synthesized using co-precipitation method without and with poly-ethylene-glycol (PEG) 400 in HCl as dissolving agents and NH$_4$OH as precipitating agents. The particles synthesized without and with PEG 400 have the particle size < 50 nm by analyzing SEM and MFM images. After the particles were solved in tetra-methyl-ammonium-hydroxide (TMAH) surfactant to result in magnetic fluids, those were then spin-coated onto an aluminium substrate. Magnetic properties of the particles were studied by Vibrating Sample Magnetometer (VSM). The result of coating is characterized by AFM/ MFM and SEM, signifying studies on the distribution of nanoparticles and their morphologies in nanoscaled structure, and possibly corrosion factor because of TMAH surfactant in microscaled structure.

Magnetic Behavioural Studies of Nano-particles of Substituted Calcium Hexaferrites

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Nanocrystalline particles of calcium hexaferrite of composition Ca(ZnIr)$_{1-2x}$Fe$_{12+2x}$O$_{19}$ with x = 0 to 1.0 produced by a sol-gel combustion technique using nitrate-citrate gel. The thermal decomposition process of the nitrate-citrate gels and as burnt powders was investigated from DTA/TGA analysis. The results revealed that the nitrate-citrate gels exhibit a self-propagating behaviour after ignition. The phase composition of the samples was investigated by X-ray diffraction. The analysis reveals for all the samples the presence of the hexagonal M-type phase as the main phase. The SEM and TEM investigations confirm that the mean particle size of calcium hexaferrite lies between 20-60nm and dramatically increases with increasing temperature i.e. from 400 to 700°C. The magnetic parameters were measured using vibrating sample magnetometer (VSM), shows that samples synthesized under investigations exhibit higher saturation magnetization in comparison with those synthesized in pure form. In the present investigation the effect of Zn$^{2+}$-Ir$^{4+}$ ions in the calcium ferrites were reported and discussed in detail. The site preference of Zn$^{2+}$-Ir$^{4+}$ and magnetic properties of the ferrites have been studied using Mossbauer spectra and hystereses. The results show that the magnetic properties are closely related to the distribution of Zn$^{2+}$-Ir$^{4+}$ ions on the five crystallographic sites. The saturation magnetization systematically increases.

Fractal System in Polar Magnetic Fluids Studied by Small Angle Neutron Scattering

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The water-based Fe$_3$O$_4$ polar magnetic fluids have been synthesized using coprecipitation method with addition of Polyethylene Glicol (PEG)-400 as a template. The measurement of small angle neutron scattering were carried out to study the fractal structure and dimension as well as size distribution of nanoparticles in magnetic fluids synthesized with PEG and non-PEG. The fractal aggregation of particles in magnetic fluids were identified by their scattering distribution, showing its correlation to the magnetic particle concentration in the fluids. It was found a fractal dimension (D) in the range of 2 < D < 3 in the non-PEG polar magnetic fluids. Meanwhile, the magnetic fluids with PEG shows the fractal aggregate from their scattering distributions in the range of 0.005 < Q < 0.02 Å$^{-1}$ with fractal dimension value of D = 2.03(1), revealing that the particles have tendency to aggregate in 2-dimensional space like elipsoidal or disc-like. The cluster size of particles, $R_c$ ~ 200 Å, was obtained with the building block radius of 30 Å and polydispersity between 0.47 and 0.63.
Magnetic & Electrical Behaviour of Zn Substituted Ferrichromates

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Concentrated disordered magnetic systems with spinel structure are highly attractive as they show wide spectrum of magnetic structures useful for variety of applications. The new cubic spinel system $\text{Zn}_{0.5}\text{Cu}_{0.2}\text{Ni}_{0.3}\text{Fe}_x\text{Cr}_{2-x}\text{O}_4$ ($0.8 \leq x \leq 1.1$) has been prepared by ceramic technique and found to have single phase cubic spinel structure from XRD studies. The concerned cations site distribution for all the values of $x$ can be closed to $\text{Zn}_{0.5}\text{Fe}_{0.5}([\text{Cu}_{0.3}\text{Ni}_{0.2}\text{Fe}_{x-0.5}\text{Cr}_{2-x}]\text{O}_4$. System is investigated for its electrical and magnetic behavior.

The dc resistivity and thermo-electrical measurements were carried out from room temperature to higher temperature for all the samples. From the resistivity – temperature curves, activation energies for all the compounds were found. From the plots of $\Delta V$ vs. $\Delta T$, the variation of Seebeck coefficients as a function of $x$ was also studied. The activation energy ($\Delta E$) of the system was found to vary between 0.62 eV and 0.47 eV. Seebeck coefficients ($\alpha$) for the system are found to vary between $+405 \mu V/K$ and $+326 \mu V/K$ indicating p-type conductivity in all the four compounds.

The ac susceptibility measurements were carried to determine the Curie temperatures [$T_c$] and to study the nature of graph below [$T_c$]. The values of Curie temperatures were confirmed and the paramagnetic behavior above $T_c$ was studied using Gouy’s balance. The magnetic moments are calculated from $\sigma_s$ values at 80K using Galileio’s formula,

$$n_u = (\sigma_s \times MW) / 5585.$$  

From ac and dc magnetic susceptibility, measurements, Curie temperatures were investigated and found to be ferrimagnets. The magnetic hysteresis at 300K and 80K for all the samples were recorded using an electro magnet type loop tracer From higher values of $H$ and $J_u/J_s$ at low temperatures (80 K) and nature of $X$ vs $T$ curves indicate single domain behavior in which magnetic crystalline anisotropy dominates.

Ag-Fe$_2$O$_4$ Nanohybrid Heterodimer: A Novel Nanomaterial for Femtosecond and Nanosecond Optical Limiting

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We present a novel material: Ag-Fe$_2$O$_4$ nanohybrid heterodimer for optical limiting. The new nanomaterial functions effectively from femtoseconds to nanoseconds with ultrafast recovery. In the femtosecond regime, the large two-photon absorption of the semiconductor component (Fe$_2$O$_4$) in the nanohybrid heterodimer is responsible for optical limiting. The two-photon absorption cross-section ($\sigma_2$) is determined to be $1.3 \times 10^{-43}$ cm$^4$ s/photon by open-aperture Z-scans with femtosecond laser pulses. Up to now, this value is the largest $\sigma_2$ reported in the literature. In the nanosecond regime, nonlinear absorption and scattering by the Ag nanoparticle in the nanohybrid heterodimer play a dominant role in optical limiting. The experimental results show the limiting performance is better than SWCNT suspensions, which is a benchmark optical limiter in the nanosecond regime. The total photon excited electron-hole separation time in the Ag-Fe$_2$O$_4$ nanohybrid heterodimer is observed to be 50 ps or less with nondegenerate transient absorption technique.

Nanostructured Magnetite Formation in Borosilicatic Glass

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We investigated the nanostructure and magnetic properties of a series of iron-containing borosilicatic glasses samples with different nucleators and the starting ratio SiO$_2$/Fe$_2$O$_3$ between 1.4 and 1.7. X ray diffraction data revealed the formation of magnetite as the major crystalline phase in a silica matrix for all samples. The presence of the magnetite is confirmed by the magnetization vs temperature data which showed two transitions for all samples: a low temperature crossover around 50 K which we associated with the change in the domain wall dynamics and a high temperature transition around 125 K which is consistent with the Verwey transition. The microscopic morphology and the phase structure were correlated with nature and amount of the nucleators.
Effect of Particle Size on Magnetic and Magneto-optical Properties of CoFe$_2$O$_4$ Nanoparticles

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Coercivity of cobalt ferrite nanoparticles was studied to understand the effect of particle size on magnetic and magneto-optical properties. The nanoparticles were prepared by the co-precipitation method using high purity sulphates. The average particle size was varied from 12 to 15 nm. X-ray photoelectron spectroscopy (XPS) was used to study the chemical properties and the core level binding energies of the constituent atoms of the nanoparticles. Transmission electron microscopy (TEM) images show uniform and narrow particle size distribution. The XPS analyses indicate that the samples are composed of iron (Fe), cobalt (Co) and oxygen (O), with corresponding binding energies of 780.35 eV (Co 2p$_{3/2}$), 796.04 eV (Co 2p$_{1/2}$), 710.55 eV (Fe 2p$_{3/2}$), 724.29 eV (Fe 2p$_{1/2}$) and 529.75 eV (O 1s) respectively. The analysis of the Co 2p, Fe 2p and O 1s peaks gave Co:Fe:O atomic ratios close to 1:2. The valence states were found to be Co$^{2+}$, Fe$^{3+}$ and O$^{2-}$. The analysis of the Co 2p, Fe 2p and O 1s peaks gave Co:Fe:O atomic ratios close to 1:2. The valence states were found to be Co$^{2+}$, Fe$^{3+}$ and O$^{2-}$. The analysis of the Co 2p, Fe 2p and O 1s peaks gave Co:Fe:O atomic ratios close to 1:2. The valence states were found to be Co$^{2+}$, Fe$^{3+}$ and O$^{2-}$.

DC Electrical Resistivity and Curie Temperature Study of Nanocrystalline Mg-Cd Ferrites

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Ferrites with the general formula Mg$_{1-x}$Cd$_x$Fe$_2$O$_4$ (x = 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0) were prepared by oxalate co-precipitation method from high purity sulphates. The pellets were sintered at 1050 °C for 5 h. Chemical phase analysis was carried out by powder X-ray diffraction (XRD) technique, which confirms the formation of single phase cubic spinel structure. The XRD analysis of the samples showed that the peaks were present at 2θ values of 30.8°, 36.3°, 43.1°, 54.3°, and 62.8°, which are in agreement with the reported values for Mg-Cd ferrite. The magnetic properties of the ferrites were studied using a vibrating sample magnetometer (VSM). The magnetization curves showed a decrease in saturation magnetization with increasing Cd content. The Curie temperature (Tc) was increased with applied magnetic field (H) from 0 to 100 Oe. All the results will be presented.

Thermal Induced Magnetic Anisotropy of Fe over Layers on Pt(110) Surface

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Surface morphology including their structures effect due to annealing on the magnetic system strongly induced in the magnetic anisotropy. This kind of ground state properties are dominated the magnetic anisotropy on the FePt nanoparticles or ultrathin layers which is the best candidate for the Tb/ln² high density decoding media for the future generation. Our studies annealing induced magnetic anisotropy Fe over layers on the Pt(110) surface where Pt(110) shows 1x2 missing row reconstruction structure. Fe/Pt(110) system revealed high coercivity along (1-10) missing row direction and low coercivity along (001) direction with magnetization always in plane via square shape hysteresis loop for low dimensional film. In room temperature it exhibited fcc phase and ordering L10 phase at high temperature. On between these two
Room Temperature Ferromagnetism in Co-doped Titania Thin Films

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Development of a stable dilute magnetic semiconductor with a Curie temperature near or above room temperature is a challenging requirement for spintronic applications. Incorporation of cobalt in titania (TiO₂) matrix has recently been reported to exhibit room temperature ferromagnetism (RTFM). However, the origin of the observed RTFM is not yet fully understood. While some research groups have ascribed Co clustering as the possible cause of RTFM, others have completely ruled it out. Some reports have shown weak signature of RTFM in air annealed samples which got enhanced after vacuum annealing To clarify these aspects, therefore, a systematic study of Co-doped TiO₂ thin films has been carried out; and some of the results are presented in this paper.

The films were deposited by spray pyrolysis technique on a quartz substrate. The substrate was heated at ~ 500°C prior to deposition, and nitrogen was used as a carrier gas. The as-deposited films were annealed in vacuum (1x10⁻⁵ Torr) at 500°C for one hour. These films were characterized by glancing angle X-ray diffraction (GAXRD), energy dispersive analysis of X-rays (EDAX), atomic force microscopy, and SQUID magnetometry techniques.

Both the pure and doped thin films were nanocrystalline with a crystallite size of nearly 30 and 20 nm respectively. The as-deposited pure and Co-doped films exhibited only anatase phase, while a small amount of rutile phase had developed in the vacuum annealed 5% Co-doped films. No signature of cobalt clusters could be revealed even by careful and slow scan in XRD (recorded at scan rate = 0.01/sec), suggesting the incorporation of Co in TiO₂ matrix (at Ti-site). While, the as-deposited pure TiO₂ film was diamagnetic in nature, the 5% Co-doped film exhibited the ferromagnetic behaviour with a saturation magnetization (Mₛ) of 5.35 emu/cm³.

On vacuum annealing, Mₛ got enhanced by 100%. In order to investigate the origin of ferromagnetism, M-T measurements were performed on the vacuum annealed sample under both field cooled (FC) and zero field cooled (ZFC) conditions. The field cooled measurements indicated the presence of both FM and paramagnetic contributions to the overall observed magnetization of the sample. The observation of discernible hysteresis in the isothermal MH measurements at 300K, and the XRD data thus rule out the formation of Cobalt clusters (leading to FM). In our view, the PM fraction is a result of non interacting Co²⁺ ions. The electrical resistivity measurements showed that the as deposited as well as vacuum annealed Ti₁₋ₓCoₓO₂ films were highly insulating in nature which suggested that the bound magnetic polarons (BMP) might be the possible cause of the observed RTFM.
Multilayer Films

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Magnetoelastic behavior in ferromagnetic intermetallic nanostructures is of great scientific and technological interest due to their large magneto-crystalline anisotropy constant ($K \approx 10^7$ erg/cm³) that could have potential applications in modern magnetic devices. Little work has been done and paid to the change in the process temperature by shifting the composition of the FePd phase to the Fe or Pd-rich off-stoichiometric region. Therefore in this work, a series of epitaxial FePd films with different Fe concentrations were first prepared in order to systematically investigate the effect between the alloy composition and chemical ordering. And then the FePd films with different compositions deposited with in-situ heating and post-annealing at the same final process temperature was in order to study the correlation between the magnetization behavior and microstructure during different thermal processes. In this work, we fabricated [Fe (1.5–3 nm)/Pd (1 nm)]₁₀ multilayers on MgO (001) substrates by molecular-beam epitaxial technique at different deposition temperatures ($T_D$) ranged from 200 to 500 °C, therefore the composition of Fe was varied in the range of 38–58 at. %.

As Fe increases to 2.5 nm (Fe₅₂Pd₄₈), the intensities of FePd (001) and (003) superlattice peaks reach to the maximum for all $T_D$, while the optimum composition for FePd (001) films with the highest ordering degree was Fe₃₀Pd₇₀. In comparison with different thermal process and buffer layer effects on the microstructure and magnetization reversal behavior, we also prepared Fe₅₂Pd₄₈ films with Pd buffer layer from 5 to 20 nm at 100 °C, and then annealed at the same $T_D$ for 1 hr to study the thermal effects between surface morphology and the magnetic properties. Low-temperature ordering of FePd could be achieved by introducing a Pd underlayer due to optimal strain form the lattice distortion. For the case of Fe₃₀Pd₇₀ films grown at 400 °C, the isolated island-like morphologies were observed and displayed a perpendicular magnetic anisotropy with a coercivity of 8000 Oe, which could be useful for application such as ultrahigh density recording media. On the other hand, the FePd films grown at 100 °C and then annealed at 400 °C showed continuous surface and with a lower remanence corresponded to the alternate up and down orientations of the magnetization due to stripe domains formation. The significant distinction in magnetic exhibition of the FePd films was due to the marked change in magnetic domain and surface structures caused by interfacial energy during different thermal processes.
Magnetic Tunabiling of FeCo and FePt Nanostructures

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Ordered FeCo and FePt nanostructures show great potential in ultrahigh density magnetic recording due to their large magnetic anisotropy energy, K_u. This paper outlines the size, structural and magnetic properties of the FeCo and FePt nanostructures. In this study, FeCo nanoparticles have been chemically synthesized through polyl process; while FePt thin films have been physically deposited by DC magnetron sputtering. As-synthesized FeCo nanoparticles are of body-centred-cubic (bcc) structure. Particles that are subjected to heat treatment show gradual structure transformation. Similar for FePt thin films, where as-deposited films are face-centred-cubic (fcc) in structure, and high temperature annealing either by substrate heating and/or post-anneling is necessary to transform the disordered phase to ordered face-centred-tetragonal (fct) structure. Theoretical simulation predicted both bct structure of FeCo and fct structure of FePt possess very high magnetocrystalline anisotropy energy. The dependencies of the magnetic properties on the two different magnetic alloy materials (FeCo and FePt) and their fabrication methods have been investigated. Morphologies and sizes of the prepared FeCo and FePt nanostructures have been analyzed by Transmission Electron Microscopy (TEM). Structural and phase identification have been carried out by X-Ray Diffractions (XRD), and magnetic properties have been characterized by Vibrating Sample Magnetometer (VSM).
Temperature is above 400 K. It should be noted that the ferromagnetism reported in the so-called Oxide Dilute Magnetic Semiconductors (ODMS) are either thin film or nanoparticles form with critical temperature above 400 K. Moreover, the magnitude of saturation magnetization is comparable to that found in these nanoparticles. Therefore, it appears that the reported ferromagnetism in ODMS has similar origin as these nanoparticles.

**A01726-03008**

**Synthesis and Characterization of Mn-Zn Ferrite Nanoparticles**

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Ferrimagnetic substances exhibit a substantial spontaneous magnetization at room temperature, just like ferromagnetics, and this fact alone makes them industrially important. The large resistivity of ferrites makes it ideal material for high – frequency applications.

High initial magnetic permeability, low magnetic loss and high electrical conductivity are the most advantageous features of Mn-Zn ferrites as the main category of soft magnetic materials. Therefore Mn-Zn ferrites are mainly used for cores of inductors, transformers, recording heads and in switch mode power supplies. The properties of Mn-Zn ferrites depend mainly on technique and condition of preparation which in turn affect cation distribution over the tetrahedral A-site and octahedral B-site. In this work the cation distribution and magnetic properties of $\text{Mn}_1\text{-}_{x}\text{Zn}_x\text{Fe}_2\text{O}_4$ ($x = 0, 0.2, 0.35, 0.6, 0.65$) were studied using X-ray diffraction, electron spin resonance and vibrating sample magnetometer.

Mn-Zn ferrite has been synthesized by sol-gel technique. The crystallite size, X-ray density, lattice parameter and interplaner distance are recorded from X-ray analysis. It has been observed that crystallite size decreases as percentage of zinc addition increases. The crystallite size varies from 20nm to 100nm and lattice parameter varies from 8.50Å to 8.71Å. It has also been observed that crystal density decreases with increase in Mn ion content, which could be attributed to the atomic weight and the radii of constituent ions. The crysal density for the samples varies from 4.65 gm/cm$^3$ to 5.14 gm/cm$^3$. The calculation of the resonance line width, resonance field and effective g-factor has been done by ESR technique.

It has been found that the resonance line width is decreasing with temperature. It has also been observed that resonance field is increasing with temperature. The broadening of line width indicates that sample have more electric loss. The spin-spin relaxation time limits the broadening of line width. The IR-spectra of sample was also recorded by FTIR.

**A01770-03102**

**Novel Glassy FePBNb Alloys with High Magnetization and Excellent Low Loss Characteristic for Inductor Core Material**

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**INTRODUCTION**

The inductor in a power supply is required to be capable of dealing satisfactorily with the high-current supply and to improve the power loss characteristic. Therefore, we focused on glassy metal alloys with low magnetic anisotropy, and developed novel glassy metal alloys with a chemical composition $\text{Fe}_{(0.7-x)}\text{P}_{x}\text{B}_{0.2}\text{Nb}$, $\text{Fe}_{(0.7-x)}\text{P}_{x}\text{B}_{0.5}\text{Nb}$, that have a stable amorphous structure due to a high

**A01755-03067**

**Attacking Cancer Cell by Heat and Drug via Magnetic Nanoparticulates**

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Nanostructured magnetic materials find applications in variety of areas ranging from information technology to bio medical research. I shall present here some aspects of our recent work in this area at IIT, Bombay. Magnetic nano particulates ( MNPs) with different shapes, composites, hybrids, core shell structure and magnetic fluids have been prepared by various soft chemical methods. Such magnetic materials with Curie temperature (Tc) between 42°C and 60°C, with sufficient biocompatibility are the best candidates for effective treatment for cancer by providing heat exploiting the hysteresis, Neel and Brownian losses such that during therapy it acts as in vivo temperature control switch and thus over heating could be avoided. We discuss here, a combined therapeutic approach, i.e magnetic nano particulates based hyperthermia along with chemotherapy for more effective therapy of cancer. For efficient delivery of magnetic nano paticulates and drug to cancer tissue, magnetic fluid based release systems will be discussed with different possibilities of thermosensitive and pH sensitive polymers, gels and lipids. For the targeted and sustained delivery, some of our recent results will be discussed. The mechanism of cell death during controlled experimental conditions will be discussed. We will also address some diagnostic issues using these magnetic nanoparticulates. For example, the advantage of using these MNPs as contrast agent for magnetic resonance imaging will be brought about.

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**Note:** The text above contains some technical details that might require specific knowledge in materials science and physics to fully understand. The document discusses the synthesis and characterization of Mn-Zn ferrite nanoparticles, as well as the properties and applications of glassy FePBNb alloys and magnetic nanoparticulates in the context of cancer therapy. The abstracts and contributions from various authors are highlighted, focusing on the unique characteristics and potential applications of these materials.
glass-forming ability, achieving a large critical thickness of 110-150µm in a wide chemical composition range. Thereby, Fe\textsubscript{(97-x-y)}P\textsubscript{x}B\textsubscript{y}Nb\textsubscript{3}, features both a high saturation magnetic flux density of 1.3T and excellent low core loss characteristic of 650kW/m\textsuperscript{3}, which are suitable for glassy metal powder/resin composite core. In addition, optimum annealing temperature of 573-623K for these alloys also can be lower than that of 773-823K for the ordinary Fe\textsubscript{73}Si\textsubscript{10}B\textsubscript{15}Cr\textsubscript{2}, which is important for the mass production of inductor core using soft magnetic material powder.

EXPERIMENTS

The glassy metal Fe\textsubscript{(97-x-y)}P\textsubscript{x}B\textsubscript{y}Nb\textsubscript{3} and the amorphous Fe\textsubscript{77}P\textsubscript{7}B\textsubscript{13}Nb\textsubscript{3} alloy ingots were prepared by arc melting in an Ar atmosphere. A single-roller melt-spinning method in an Ar atmosphere was used to produce the rapidly solidified ribbons having a width of about 1mm and thickness of about 25-30 µm. The as-quenched ribbons were punched out and laminated into a toroidal shape to be used as samples. The glassy metal alloy powder was made by a water atomize method. The powder, having an average particle size of 15 µm, was mixed with a resin binder, and after granulation, pressurizing molding was done to create the ring shape core with 71-73% packing density. Core loss (300kHz, 50mT) were measured by B-H analyzer.

RESULTS AND DISCUSSION

Fe\textsubscript{x}P\textsubscript{y}B\textsubscript{z}Nb\textsubscript{3} has highest critical thickness (T\textsubscript{max}) of 150µm than conventional amorphous Fe\textsubscript{77}Si\textsubscript{10}B\textsubscript{15}Cr\textsubscript{2} because of having the high glass-forming ability (GFA) relating the existence of the super cooled liquid region (ΔT\textsubscript{x}). A high glass-forming ability was observed in a very wide range of the composition from Fe\textsubscript{x}P\textsubscript{y}B\textsubscript{z}Nb\textsubscript{3} to Fe\textsubscript{77}P\textsubscript{7}B\textsubscript{13}Nb\textsubscript{3}. Since Fe\textsubscript{(97-x-y)}P\textsubscript{x}B\textsubscript{y}Nb\textsubscript{3} alloys has high glass-forming ability, these alloys can be manufactured in the case of making glassy metal alloy powder for inductor. Therefore, Fe\textsubscript{x}P\textsubscript{y}B\textsubscript{z}Nb\textsubscript{3} has excellent low loss characteristic of 650 kW/m\textsuperscript{3} compared with conventional amorphous Fe\textsubscript{77}Si\textsubscript{10}B\textsubscript{15}Cr\textsubscript{2}, Fe\textsubscript{77}P\textsubscript{7}B\textsubscript{13}Nb\textsubscript{3} and Fe\textsubscript{77}P\textsubscript{11}B\textsubscript{9}Nb\textsubscript{3}, also have low optimum annealing temperature which is suitable for practical use of 623K than Fe\textsubscript{77}Si\textsubscript{10}B\textsubscript{15}Cr\textsubscript{2} of 773K.

CONCLUSION

The glassy metal alloy Fe\textsubscript{x}P\textsubscript{y}B\textsubscript{z}Nb\textsubscript{3} has high GFA leading to a ribbon with a critical thickness 150µm due to having a stable amorphous structure in wide range chemical composition. Therefore, glassy metal alloy Fe\textsubscript{x}P\textsubscript{y}B\textsubscript{z}Nb\textsubscript{3} shows excellent lower loss characteristics than the conventional amorphous alloy by approximately 1/3. In addition, lower optimum annealing temperature of the glassy alloy is useful for practical use.
in MHz range. We compare and contrast our results in ferromagnetic metallic manganites \( La_{0.67}Ba_{0.33}MnO_3 \) and insulating antiferromagnetic \( Pr_{0.5}Sr_{0.5}MnO_3 \).

**A01790-03271**

**Estimation of the Size Distribution of Magnetic Nano-particles Using Magnetization Curve by VSM**

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This paper illustrates a method of reconstructing the size distribution of magnetic nano-particles (MNP) using a magnetization curve measured on a water-based MNP. To obtain the size distribution function, the solution of the integral equation describing fine particle magnetization in an external field must be found, without any a priori assumptions on the shape of size distribution \( p(d) \). From an engineering perspective, MNP’s magnetization property can be formulated numerically as

\[
M(H) = A(i,j) p(d) (1)
\]

Singular value decomposition (SVD) methods were previously used by D. V. Berkov to solve Eq. (1) in order to obtain size distribution \( p(d) \). For the sake of eliminating sedimentation and glomeration in a long time measurement, VSM is used instead of SQUID to obtain magnetization curve. Solution procedure consists of two steps. For the starting step a SVD of matrix \( A = U*S*V' \) using singular value threshold \( s_{min} \). Due to the ill-conditioned nature of the problem the estimation quality of depends dramatically on the round-off error and experiment error. Then our next step is: reconstructing size distribution using

\[
p(d) = V*S^{-1}*U'*M(H)
\]

Here * denotes multiply and ' denote matrix transposition. The question is a strong oversmoothing of the reconstructed peaks occurs with oversized threshold. When the threshold is lowered, oversmoothing disappears, yet strong error-induced oscillation is observed. From the computational mathematics perspective, possible reasons for the oscillation could be any, or all, of the following: lack of information, measurement error, and machine accuracy. In this study, a method utilizing up to 60 sample points of magnetization curves obtained from VSM is used to achieve a more favorable solution. This shows that proper sampling, to some extent, can suppress artificial oscillation. However, eliminating oscillation in this manner could be difficult.

Incorporating restrictive conditions according to prior knowledge is normally conducted to attain solutions from ill-posed equations. In order to take advantage of more priori knowledge like nonnegativity nature of grain-size distribution, Tikhonov proposed a regularization method used for ill-posed equation to suppress this artificial oscillation signals. First let

\[
A*A'*p(d) = A*M(H)
\]

and a threshold of \( \epsilon \) is used to obtained a approximate solution of original equation, as

\[
(A*A' + \epsilon*I)'p(d) = A'M(H)
\]

Here I is a uint matrix. For detailed descriptions of Tikhonov regularization method please refer to the related literatures. In this way, we find that size distributions from Tikhonov SVD (TSVD) are stable and in good agreement with the magnetization curve. As predicted in previous theoretical analyses, and based on our estimates, a lognormal-like distribution of MNP can be found in single-origin MNP. The results were found to be in accordance with the size distribution obtained from TEM.

**A01802-03150**

**The Mechanism of Magnetic Moment Enhancement in 1-D Bimetallic Multi-Sandwich Molecular Wires**

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Followed by our pervious studies on 1-D monometal sandwich molecular wire, we extend our study to 1-D bimetallic multi-sandwich molecular wires (MSMWs), (FeCpMCp)\(n\) (M = Sc, Ti, V, Cr, Mn and Cp = cyclopentadienyl). Based on density functional theory calculations, it is found that aforementioned MSMWs to exhibit a large magnetic moment enhancement compared to the corresponding monometallic system (MCp)\(n\). Here, we focus on bimetallic multi-decker system (FeCpVCp)\(n\), which has been studied experimentally and aimed to understand the mechanism of the magnetic moment enhancement. It is revealed that the magnetic moment enhancement is due to an unusual electron transfer between M and Cp as well as between the metals. We combine crystal field theory with DOS and band structure analysis to study the local electron configurations on Fe and V atoms and elucidate the total magnetic moment per unit and the magnetic moment on each metal quantitatively. In addition, we propose a growth mechanism for the decker molecular clusters, V\(n\)(FeCp)\(2(n+1)\) (n=1~3), based on reported experimental
observations and our present theoretical results. Finally, we suggest that \((\text{FeCpMCp})_{5}\) can be semiconducting, metallic, and even half-metallic depending on the metal chosen.

**A01810-03160**

*Magnetization Reversal of (Co/Pd) Magnetic Nano-dots*

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Bit-patterned media (BPM) where magnetic islands “bits” are magnetically separated from each other offers a viable route towards terabits/in² range areal density.

In this study we investigated the correlation between crystallographic texture and switching field and its distribution in BPM. Magnetic nanodots of (Co/Pd) multilayers with 60 nm diameter and 120 nm pitch have been fabricated by electron beam lithography and ion milling. Crystallographic texture of (Co/Pd) multilayer was modified by depositing the films at different Ar-gas pressures ranging from 1.5 to 5 mTorr.

It was observed that (Co/Pd) multilayers have better texture when deposited at high pressure. Rocking curve measurements using X-ray Diffraction (XRD) indicated that the dispersion of fcc(111) peak, \(\Delta \theta_{(111)}\), decreased from 5.2° at 1.5 mTorr down to 3.8° at 5 mTorr. Magnetization switching of the patterned films determined from magnetic force microscopy (MFM) at remanence states, shows almost no difference for films deposited at 1.5 and 3 mTorr while an increase of 2 kOe in mean switching field was observed for films deposited at 5 mTorr. By normalizing remanence magnetization curves by the mean switching field, almost similar switching field distributions were observed for all the films even though the crystallographic texture was different. This suggests that the SFD may not be closely dependent on texture. However, the observation of higher switching field indicates that better texture is desired for thermal stability at high areal density. From these results, the origin for the change in SFD for films deposited at different pressures may be related to other extrinsic and intrinsic factors such dots size distribution and anisotropy distribution from one dot to the other.

Magnetic nanodots with 60 nm diameter are thermally stable due to large \(K_{a}V/k_{B}T\) (\(K_{a}\) is the anisotropy energy, \(V\) is the volume, \(k_{B}\) is Boltzmann constant and \(T\) is the absolute temperature). To evaluate thermal stability dependence on crystallographic texture, MFM measurements at different sweeping rates are conducted and thermal stability comparison with different structures will be presented.

**A01824-03819**

*High Resolution Magnetic Force Microscopy Using Tips with a Narrow Dipole*

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Magnetic nanostructures are interesting from the point of view of fundamental understanding as well as potential applications. Hard disk media, spintronic devices, and magnetic nanoparticles for biomedical applications are just a few among them. For several applications such as hard disk media and spintronics devices, the sizes of such nanostructures keep shrinking in order to improve the performance of the devices. For example, the recording media researchers are aiming at 10 nm sized dots with a pitch of 20 nm for the next generation technology called patterned media. Even in the recording media used in current hard disk drives, the bits are closely packed at a center-to-center spacing of 12-16 nm. Magnetic force microscopy could not be performed to resolve such bits without exhaustive modifications. Magnetic force microscopic tips with an antiferromagnetic coupling has been in the past, to obtain a narrow dipole, which could resolve features as small as 30 nm. In this paper, we have adapted a novel method to obtain pointed dipole which could help to obtain a resolution of 13 nm.

Standard uncoated force modulation tips (NanoWorld Arrow (tm) FM) were sputter deposited CoCrPt thin films under different conditions. The tips have force constants of 2.8 N/m and tip radii of less than 10 nm. MFM scans were obtained with a Veeco Dimension 3100 scanning probe microscope in tapping/lift mode.

To evaluate the spatial resolution of the tips, hard disk media with high-density information are the ideal choice. Therefore, data tracks were written onto CoCrPtSiO₂ perpendicular media at linear recording densities ranging from 800 to 1000 kfc; these correspond to bit lengths of between 20 – 30 nm. Magnetic force images of the data tracks obtained using our tips show clear transitions with well-resolved recording bits. An analysis of the power spectra of the magnetic track profiles show that the resolution of the tips is approximately 13 nm. The effect of sputtering conditions and film thicknesses on the magnetic image resolution is also investigated. The physics of the novel MFM tip and the experimental results will be presented in detail.
Spin and Charge Pumping in Magnetic Tunneling Structures

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Spintronics has attracted much scientific and technological interest in recent years. The spintronic devices evolve from simple spin valve (SV) type structures to magnetic tunnel junctions (MTJ) based on amorphous AlO barriers, and more recently to crystalline MgO barriers. While most static properties have been understood, dynamic properties have become the focal research effort. It is well known that magnetization precession can be induced from spin polarized current, referring to the spin torque transfer effect. On the equal footing, a precessing ferromagnet polarized current, referring to the spin torque transfer effect. Experimentally, high microwave permeability has been realized in soft magnetic thin films and multilayers with bianisotropy. By adjusting the magnetic anisotropy the resonance frequency can be changed in the range of 5 GHz. Furthermore, the microwave magnetic properties of multilayer can exceed that of the thin film. This result is important for the microwave application in planar inductor, micro-transformer, electromagnetic interference suppressor and even in metamaterials.

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Effective Approach for the Remarkable Improvement of Microwave Permeability

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As microwave properties can be significantly affected by the magnetic anisotropy, in order to improve the microwave permeability remarkably, an effective approach from the symmetry analysis of the magnetic anisotropy were given. It is found that a two-fold easy axis system is one good choice. Experimentally, high microwave permeability has been realized in soft magnetic thin films and multilayers with bianisotropy. By adjusting the magnetic anisotropy the resonance frequency can be changed in the range of 5 GHz. Furthermore, the microwave magnetic properties of multilayer can exceed that of the thin film. This result is important for the microwave application in planar inductor, micro-transformer, electromagnetic interference suppressor and even in metamaterials.

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Surface Anisotropy and Tunable Exchange Bias in Magnetic Nanostructures

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Magnetic nanostructures are considered basic building blocks in spintronics and high-density data storage applications. Surface and configurational effects in oxide nanoparticle assemblies have been increasingly found to play significant roles in controlling the magnetic anisotropy. Modification of the surface spin structure in magnetic oxide nanoparticles can be achieved by methods such as controlling the particle shapes, use of mechanical milling or surfactant chemistry to alter the coordination of surface atoms and forming interfaces with non-magnetic metals. We discuss how these effects often lead to novel
magnetic properties, useful for applications, such as tunable exchange bias and enhanced magnetocaloric effect (MCE). Surface terminations in soft ferrite nanoparticles, core-shell structures, composite metal-oxide nanostructures and competing effects due to blocking and intrinsic geometric frustration in garnet nanoparticles can also contribute to significant changes in effective anisotropy. These contributions to magnetic anisotropy are notoriously difficult to resolve using conventional magnetization experiments. Over the years, we have pioneered the sensitive method of radio-frequency (RF) transverse susceptibility that is unique in terms of its ability to precisely probe such phenomena. We will present and discuss novel cooperative magnetic phenomena arising from surface and interface effects as probed by AC and RF dynamic susceptibility experiments in nanostructured materials.

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A01914-03302

Ferromagnetism in Co and F Codoped ZnO and SNO2 Thin Films

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Presence of intrinsic ferromagnetism in wide band gap transparent conducting oxides is the key to their use for spintronic applications. Incorporation of transition metal Co ions in the ZnO matrix has been predicted to yield appreciable room temperature ferromagnetism (RTFM). There have been reports of obtaining robust RTFM in thin films of ZnO and SnO2 doped with 5 -10 at% Co. The magnetic moment of the Co ions in oxide matrix is rather low to meet the requirement of good spintronic material. We have attempted the codoping of the two oxides with Co ions at cation sites and F anions at the O-sites to study enhancement in the RTFM via the increased free carrier density induced magnetic ordering. Thin films of the codoped oxides have been produced by spray pyrolysis at substrate temperatures of about 400°C using aqueous inorganic salt solutions. The concentrations of Co and F up to 10at% can be incorporated without any secondary phases being detected. The highly transparent thin films retain the parent crystallographic structure of the oxides with Co being incorporated as Co2+ ions at the metal ion sites. Magnetic moments per Co ion approaching 1 µB per ion have been possible. We have performed theoretical calculations based on density functional theory within a local spin density approximation to study the magnetic properties of transition metal (Cobalt) substituted SnO2. We compare our results with experimental data available and also with recent theoretical reports on ferromagnetism in ZnO. We investigate the effect of introducing extra carriers in the host material, which would be equivalent to co-doping, on the magnetic properties of the system, and also the conditions under which the ground state would be ferromagnetic. The detailed results will be presented in the paper.

A01917-03310

Synthesis and Characterization of Silver Selenide Particles and Bulk

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A large and linear field dependence of the magnetoresistance (MR) effect even in a high magnetic field has already been found in a non-magnetic material like silver selenide and telluride. This unusual MR effect attracted the interest of people science the potential application of the material for the measure of a high magnetic field. So, many researchers tried to find an appropriate method to synthesize the material. Sodium chloride, selenide powder and ethylenediamine were used as precursors and silver selenide nanometer particles were prepared applying room temperature range of 300-600°C. Combined with X-ray diffraction analysis, scanning and transmission electron microscopy, the phase and the topography were characterized. The results showed that α-phase Ag2Se nanometer particles with a high purity and orthorhombic structure were obtained; the bulk maintain a orthorhombic structure and stoichiometric ratio of Ag to Se was 2:1 which suggested that a Ag2Se bulk was prepared successfully.

A01918-04215

Magnetic, Electronic, Magneto-Transport and Ordering Phenomena in Nanocrystalline Sm0.5Ca0.5MnO3 Manganites

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The rare earth doped manganites with general formula R1-xA_xMnO3 (R= rare earth ion, A= divalent cation) crystallizes in ABO3 type perovskite structure They show some complicated and unusual electronic and magnetic properties like metal- insulator transition, ferromagnetic to paramagnetic transition, colossal magnetoresistance (CMR), electronic phase separation, charge-ordered (CO) state. Double exchange interactions in the Mn3+-O-Mn4+ network is supposed to be responsible for exhibiting ferromagnetism in these manganites. Charge ordering in doped manganites is real alternate space arrangement of Mn3+ and Mn4+ ions. For x = 0.5 charge ordering is
favorable because of the presence of equal proportion of Mn$^{3+}$ and Mn$^{4+}$ ions. Investigations show that charge ordering is the manifestation of charge carrier - phonon interaction where Jahn-Teller interaction is also important. The system Sm$_{0.3}$Ca$_{0.7}$MnO$_3$ is a good candidate for studying charge ordering. The charge ordered phase is also an antiferromagnetic insulating phase. We have attempted to investigate the effect of grain size on charge ordering of Sm$_{0.3}$Ca$_{0.7}$MnO$_3$ down to nanometer scale. We have synthesized our samples through chemical pyrophoric reaction route. To vary the particle size the samples have been sintered at different temperatures. The single phase of the samples has been confirmed by their XRD micrographs. TEM and FESEM micrographs have been utilized to determine the average particle size. Temperature dependent resistivity and ac susceptibility have been measured down to 77 K. We have observed an abrupt change in resistivity around charge ordering temperature $T_c = 270$ K and no metallic phase for the samples with higher particle size. The magnetoresistance (MR) defined as $100(\rho(H) - \rho(0))/\rho(0)$ for the both bulk and nanometric sample is negative although the value, as well as the temperature dependence is qualitatively different. The insulating CO state of the bulk sample is completely suppressed on application of high field. The MR at lowest temperature is very high for bulk sample in contrast of the nanocrystal sample.

**Compositional Dependent Study of Magnetocaloric Effect in La Based Manganites**

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Due to both fundamental as well as significant technological importance, the research on magnetic refrigeration (MR) near room temperature has been very actively developed in recent years. The conventional gas compression technology offers quite low efficiency and working with media such as freon leads to environmental concerns. In contrast, the magnetic solid materials exhibiting large magnetic entropy change (Δ$S_m$) near the Curie temperature $T_c$, crucial to MR, and the energy efficiency of a magnetic cycle can be much higher than that of a gas process. As a consequence, magnetic materials exhibiting large magnetocaloric effect (MCE) are considered as potential candidates for MR. Reports on manganites exhibiting large MCE have attracted considerable attention in the last one-and-half decade. A remarkable feature in manganite systems is that the Curie temperature and magnetic entropy change can be tailored for room-temperature applications through a suitable choice of chemical composition. Keeping in view of the optimal values of Curie temperature and Δ$S_m$, we have investigated magnetocaloric effect in La$_{0.67}$Ba$_{0.33}$Ca$_{x}$MnO$_3$ and La$_{0.67}$Ba$_{0.33}$Sr$_{1-x}$MnO$_3$ ($x=0$, 0.1, 0.25, 0.25 and 0.33) systems. The magnetic transition temperatures for La$_{0.67}$Ba$_{0.33}$Ca$_{x}$MnO$_3$ are $T_c = 317$K, 301K, 281K, 271K and 263K and for La$_{0.67}$Ba$_{0.33}$Sr$_{1-x}$MnO$_3$ $T_c = 317$K, 337K, 354K, 368K and 373K for $x=0$, 0.1, 0.2, 0.25 and 0.33, respectively. With Ca and Sr doping at Ba sites in La$_{0.67}$Ba$_{0.33}$MnO$_3$ the $T_c$ decreases and increases, respectively, $La_{0.67}Ba_{0.33}MnO_3$, $La_{0.67}Ca_{0.33}MnO_3$ and $La_{0.67}Sr_{0.33}MnO_3$ exhibit peak values of 3.32, 6.34 and 3.24 J/kg K, respectively for $\Delta S_m$ under external field variation of 3T and, as expected, the temperatures corresponding to these peak values are close to their respective transition temperatures. The paramagnetic to ferromagnetic transition in La$_{0.67}$Ca$_{0.33}$MnO$_3$ is accompanied by significant lattice changes. This concomitance of structural and magnetic transitions strongly influence the $\Delta S_m$ and hence has highest value compared to La$_{0.67}$Ba$_{0.33}$MnO$_3$ and La$_{0.67}$Sr$_{0.33}$MnO$_3$, where in the transition is purely magnetic. Correspondingly the nature of magnetic transition determined to be first order in La$_{0.67}$Ca$_{0.33}$MnO$_3$ and second order in La$_{0.67}$Ba$_{0.33}$MnO$_3$ and La$_{0.67}$Sr$_{0.33}$MnO$_3$ as suggested by Banerjee. A comparison of values of $\Delta S_m$ as a function of temperature at different doping concentrations of Ca and Sr in La$_{0.67}$Ba$_{0.33}$MnO$_3$ reveals that $\Delta S_m$ value increases with Ca doping at Ba sites in La$_{0.67}$Ba$_{0.33}$MnO$_3$ with its peak position shifted to lower temperatures whereas, there is no observable change in the peak value of $\Delta S_m$ of Sr doped La$_{0.67}$Ba$_{0.33}$MnO$_3$, except that peak position shifts to higher temperatures.

**Nanostructured SmCo$_5$ Thin Films with Perpendicular Anisotropy**

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SmCo$_5$ alloy has the highest magnetic anisotropy constant ($K_u = 1.1 \times 10^6$ erg/cm$^3$) among all of the ferromagnetic materials. Recently, SmCo$_5$ thin films with a (0001) texture exhibiting perpendicular anisotropy have attracted great attentions for the application as a perpendicular recording medium. The (0001) texture of SmCo$_5$ can be induced by the (111) texture of the Cu underlayer because of the small lattice mismatching between SmCo$_5$ (0001) and Cu (111). There is only 2% along the edge of hexagonal lattice. Recent studies indicate that a good (111) texture of the Cu underlayer requires a certain thickness (>100nm) By introducing a Ti or a Ru seedlayer, the critical thickness of Cu can be reduced. However, there is no obvious SmCo$_5$ (0001) texture observed.

In this work, we prepared SmCo$_5$ thin films with a high perpendicular coercivity up to 20kOe. We found a very thin seedlayer (4nm) of Ta can improve the crystallinity and texture of (111) Cu underlayer. The high quality Cu underlayer can result in high magnetic performance of SmCo$_5$ thin films. From the XRD results, the half
maximum of the rocking curve of SmCo₅ (0001) peak was as small as 3.4° and the high-index SmCo₅ (0003) diffraction peak was clearly observed. The SmCo₅ (000l) peaks were shifted to the smaller angle compared to the standard powder sample which may indicate the formation of SmCoCu alloy through the Cu diffusion. SIMS and EDX results confirmed the Cu diffusion into SmCo layer. The magnetic properties of SmCo₅ thin films were found to be dependent on deposition temperature. 400°C is the optimized temperature for the magnetic properties of SmCo₅ thin films and 325°C is the minimum temperature demand for the crystallization of the SmCo₅ phase.

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Study of Magnetic and Electrical Properties of Nanocrystalline Mn Doped NiO

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Diluted Magnetic Semiconductors (DMS) are intensively explored in recent years for its applications in spintronics, which is expected to revolutionize the present day information technology. Nanocrystalline Mn doped NiO samples were prepared using chemical co-precipitation method with an aim to realize room temperature ferromagnetism. X-ray diffraction (XRD) patterns confirm the phase pure formation of Ni₁ₓMnₓO up to 2 % doping of Mn. Scanning electron microscopy (SEM) and Energy dispersive X-ray analysis (EDAX) results reveal the nanocrystalline nature of the samples, agglomeration of the particles, considerable particle size distribution and the near stoichiometry. Vibrating Sample Magnetometer (VSM) measurements indicate paramagnetic behavior at room temperature for the phase pure samples. The lack of free carriers is expected to be the reason for the absence of ferromagnetism, which is in agreement with the resistivity measurements using impedance spectroscopy. Arrhenius plot show the presence of two thermally activated regions and the values of activation energies for the nanocrystalline Mn doped samples were found to be greater than that of undoped NiO. This is attributed to the doping effect of Mn. However no significant change could be observed in the dielectric property of the samples because of the introduction of Mn ions in to NiO.

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Magneto-optical Investigation of Local Magnetic Properties and Micromagnetic Structure of As-cast and Annealed Nanocomposite NiFe/Cu and 81NMA/Nb microwires

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Results on the magneto-optical investigations of the near-surface local magnetic properties and the micromagnetic structure (equilibrium distribution of magnetization) of the as-cast and annealed NiFe/Cu and 81NMA/Nb microwires are presented. The above wires of the diameters D = 50, 100 and 140 µm were produced by pressing the rod blank, its continuous drawing and subsequent annealing. The blank consisted of Cu (Nb) rod in NiFe (81NMA) tube. The diameters of the inner nonmagnetic core, d, and the magnetic outer shell were in the 40-100 and 10-27 µm range, respectively. A ratio of D/d was practically identical for all samples. The pieces of the above wires were annealed at temperature T = 750 and 780 °C for 1, 2 and 3 h under pressure P = 10⁻⁵ Torr. The length of studied samples was 15 mm. An alternating magnetic field H of frequency f = 80 Hz was applied parallel to the sample length L. By scanning the light spot of 2-µm diameter along L, the distributions of the near-surface magnetization components (both parallel, M₊, and perpendicular, M₋, to the applied magnetic field) and also local magnetization curves were measured by using magneto-optical micro-magnetometer with a surface sensitivity of about the 15-nm thickness depth and a spatial resolution up to 0.3 microns.

The local values of the saturation field, Hₛ, were discovered to depend on the disposition of the measured microparts and on the thickness of the magnetic outer shell, tₛ. It was found that Hₛ increases with increasing tₛ. In particular, the local values of Hₛ for the central microparts of the as-cast NiFe/Cu wires with D = 50, 100 and 140 µm are equal to 9, 14 and 20 Oe, respectively. The magnitudes of Hₛ for the end microparts are larger (about 3 times) in comparison with Hₛ of the central ones that were ascribed to the influence of variations of local demagnetizing factors. The strong influence of annealing on the local magnetic properties was revealed. For example, in the 81NMA/Nb wires, annealed at T = 750 °C for 1 and 3 h, the local values of Hₛ were found to be respectively 2 times smaller and larger as compared with Hₛ of the as-cast sample. These data were explained by structural peculiarities of the above samples.

The distributions of magnetization components along L were found to be periodic. It was found that the local magnetization components M₊ have the same sign, and
the circumferential components $M_r$ have oscillatory, alternating-sign behavior. These data indicate that there are the near-surface circular domains with alternating left- and right-handed magnetization in the neighboring domains. The near-surface domain widths, $W$, were determined by using the $M_r (L)$ dependences. The magnetic field behaviour of the near-surface components shows that the dominant magnetization reversal mechanism of the microwires in the axial magnetic field is the rotation of local magnetization vectors.

**Effect of Current Density on Magnetoimpedance of Electrodeposited NiFe/Cu**

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Since the discovery of giant magnetoimpedance (GMI) effect in soft magnetic materials there has been consistent effort to understand the phenomena in order to in order to tailor its value towards an optimum limit at relatively lower applied magnetic fields. Such a viability where tailoring of GMI depends on external parameters may be an attractive approach. It would permit tenability of GMI and enables us to exercise desired control over the properties of the material for application in magnetic sensors. In general, MI can be defined as the change of impedance of a magnetic element carrying an alternating current, as a function of the external dc magnetic field. The MI effect is generally attributed to the skin effect, and can be related to the change of magnetic permeability when an axial magnetic field is superimposed on a high frequency AC circumferential field created by a current flowing along the sample. Therefore soft magnetic films are needed to tune the skin depth easily on application of small external magnetic field. Electrodeposition method is a simple and cost effective method for the preparation of thin films of binary/ternary alloys. It permits an effective approach to control of uniformity, thickness, microstructure and magnetic properties by tuning the deposition parameters such as deposition time, current density etc.

In the present manuscript, we report the GMI response of ferromagnetic NiFe films electrodeposited onto 100 μm diameter copper wire. The electrodeposition bath composition was kept unchanged for all samples deposited. However the current density of deposition was varied systematically from 10 mA/cm² to 60 mA/cm². The time of deposition was accordingly adjusted so that thickness of magnetic film remains the same in all the electrodeposited thin films. The magnetoimpedance of the coated wires were measured by Agilent 4294A impedance analyzer. A maximum magnetoimpedance response ($\Delta Z / Z_{\text{MAX}}$) was observed in electrodeposited sample with a current density of 20 mA/cm². SEM micrographs suggested a reasonably smooth surface microstructure of all the films i.e. almost independent of the current density of deposition (within the range used in the experiment). The magnetic measurement indicated that optimum softness was achieved at a current density of 20 mA/cm². The EDX analysis confirmed a composition of Ni$_{0.5}$Fe$_{0.5}$ was achieved for a current density of 20 mA/cm². It is concluded that by changing the current density only, we can easily tune the magnetic property of electrodeposited wires without changing the bath composition.

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**Large-Area Fabrication of Nano-network to Nano-dot Arrays for High Density Magnetic Recording**

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A non-lithographic fabrication method is demonstrated to fabricate magnetic nanostructure with gradual change from nano-network to isolated nanodots covering a large area. The nanostructures are fabricated by depositing perpendicular Co/Pt multilayers (MLs) on pre-patterned substrate. The whole work can be divided into three parts:

In the first part, nano-network of Co/Pt MLs is fabricated by depositing them on anodized alumina (AAO) formed on Si wafer where the pores (∼10 nm) act as the pining sites and the areas between adjacent pores are the Co/Pt networks. The fabricated structure can be considered as percolated perpendicular media (PPM). Coercivity and switching field is engineered by changing pore density from 2.5 to 12.1 ×10¹⁰ cm⁻² in association with the variation of network width 41 nm to 9 nm. The media exhibit strong perpendicular anisotropy and more than one order $H_c$ enhancement and switching fields remain unchanged at its minimum up to an angular deviation of 50° from the easy axis. A better tolerance of switching-field distributions can thus be achieved, which may help to achieve a high signal-to-noise ratio.

In the second part, the gradual change of magnetization process from domain wall motion to S-W rotation or the gradual change of network structure to dot structure is achieved by changing the aspect ratio of AAO. The (Co/Pt)/AAO/Si films show altered reversal mechanisms depending on the aspect ratio of the AAO templates. For high aspect ratios (A ∼ 7.0 and 3.2) the Co/Pt primarily lies on top of the AAO and the reversal is dominated by the highly pinned motion of domain walls. This structure can be good
Magnetic and Electrical Properties of Nickel Nanoparticles Prepared by Polyol Method

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Face centered cubic structure nanocrystalline nickel (Ni) nanoparticles were prepared by polyol method using nickel chloride as a precursor and ethylene glycol with hydrazine hydrate as protective agent. Transmission electron microscopy (TEM) shows spherical morphology of Ni nanoparticles with average size of 20 nm. Vibrating Sample magnetometer (VSM) analysis reveals prepared Ni nanoparticles are superparamagnetic. Magnetic saturation (Ms) and Corecivity (Hc) of prepared Ni nanoparticles is found to be 40 emu /g and 86 Oe respectively at 300 K. He increases to 252 Oe at low temperature (10 K). Electrical resistivity of Ni nanoparticles in low temperature range 83 – 300 K is measured using four-probe technique. It is found to be 9 x 10^3 Ω cm at 83 K and 12 x10^3 Ω cm at 300 K.

On the Ferromagnetism in Nanocrystalline ZnO:Ni

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The existence of room temperature ferromagnetism in transition metal (Co, Ni, Fe) doped zinc oxide is still under controversy. While a large number of reports on ZnO suggest the intrinsic nature of the ferromagnetic character, some of the reports support the presence of secondary phase leading to the observed ferromagnetism. The Ni doped ZnO system is particularly interesting. The solubility limit of nickel in zinc oxide is quite low as compared to Co, Mn and Fe and it decreases as the processing temperature is increased. In the present paper, we present the structural and magnetic properties of nickel doped zinc oxide system. The ZnO:Ni samples were prepared by chemical method. The samples were prepared using zinc acetate tetrahydrate, nickel acetate dihydrate and polyvinyl pyrrolidane. The precursor in the desired amount were dissolved in DI water and heated at 90°C. The so formed mass was then calcined at 500°C for 1 h and then sintered at higher temperature of 600, 700, 800 and 900°C for 12h at each temperature. These pellets were characterized after annealing at each temperature by x-ray diffractometer (XRD) for phase analysis and by vibrating sample magnetometer for the magnetic properties. The XRD data suggests that in addition to the wurtzite ZnO, some secondary phases are present. As the sintering temperature is increased, a systematic change in their relative amount of these phases is clearly evidenced. The magnetization studies support these findings, and clearly show that the samples sintered at different temperatures exhibit different magnetization behavior depending upon the processing conditions.

Giant Magneto-resistance and X-ray Reflectivity Studies in Ion-beam Sputtered Co/Cu Multilayers

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Since the Discovery of Giant Magnetoresistance, the new era of high-density data storage devices is booming very rapidly. The basis of this technological revolution is the highly sensitive magnetic field sensors, comprising of ultra
thin magnetic layers separated by a non-magnetic spacer layer. In electrical transport the electrons with different spins undergo different amount of scattering in magnetic layers and at the interface leading to a structure having different resistance states depending upon the orientation of the magnetizations of two adjacent magnetic layers. It has been reported that the interface plays crucial role in deciding magnetic and electrical transport properties.

The Co/Cu multilayer structure is widely studied system but most of the work is concentrated on samples deposited by RF and DC sputtering, but very less work is reported on GMR studies in multilayers grown by Ion beam deposition technique. In the present work, we report the study of GMR in Co/Cu multilayers deposited by ion beam sputtering technique. We have grown a series of Co/Cu multilayers by keeping Co thickness fixed and varying the Cu layer thickness. While the base pressure is kept $\sim 3 \times 10^{-6}$ torr, the working pressure is kept $\sim 1.3 \times 10^{-4}$ torr. This pressure is two orders of magnitude lower than that employed in RF/DC sputtering. While the as deposited multilayers exhibited Cu-layer thickness dependent GMR $\sim$ 2-3%, the post deposition annealing is found very effective in stabilizing higher GMR values. Over 400% increase in GMR has been evidenced in multilayers deposited on Si and glass grown at room temperature. The effect of annealing temperature on the GMR of Co/Cu multilayers has been studied in detail. The saturation field in these multilayers is observed to increase monotonically with temperature. It is found that annealing beyond 300°C is very detrimental to GMR. A detailed investigation of the X-ray reflectivity (XRR) is preformed on these multilayers to understand the correlation between interface morphology and the observed GMR. The XRR simulation reveals the formation of very thin alloy layer between the adjacent Cu and Co layers. The densities of these layers are relatively smaller compared to their bulk counter part. It appears that diffusion of Cu in Co layer is taking place owing to positive surface energy of Cu. The detailed studies will be presented in the conference.

Phase, Morphology and Magnetic Characterisation of Aluminium Substituted Yttrium-iron Garnet Nanoparticles Prepared Using Sol Gel Technique

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Aluminium substituted yttrium iron garnet nano particles with compositional variation of $\text{Y}_{3-x}\text{Al}_x\text{Fe}_5\text{O}_{12}$, where $x$ was 0, 0.5, 1, 1.5, 2, 2.5 and 3 were prepared using the sol gel technique. The x-ray diffraction results showed that the best garnet phase appeared when the sintering temperature was 800°C. Nano-crystalline particles with high purity and sizes ranging from 20 to 100 nm were obtained. It was found that the aluminium substitution had resulted in a sharp fall of the d-spacing when $x = 2$, which, we speculated is due to the preference of the aluminium
Highly Textured Growth of Mn1-xZnxFe2O4 Film on Glass Substrate

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Mn1-xZnxFe2O4 is one of the soft magnetic materials for the applications of magnetic sensor, reading head for magnetic recording media and microwave engineering. The film with high quality can only be achieved by depositing the film on single crystal substrate, which is not economical. In this work, Mn1-xZnxFe2O4 film was deposited on normal glass substrate at a temperature of 400 °C by pulse laser deposition (PLD) in a vacuum of 10^-6 torr. The deposited film showed a saturation magnetization around 100 emu/g and a coercivity of 50 Oe. Under the examination of XRD, only one peak indexed (311) was found in the film spectrum, indicating highly textured growth of the film. The film was deposited under different conditions, such as different substrate temperatures, different oxygen partial pressures and different thicknesses. The results showed that highly textured growth could be achieved at a temperature as low as 200 °C when the film was deposited in vacuum. With increasing the oxygen partial pressure, the highly textured growth began to be deteriorated. In addition, the saturation magnetization of the film was strongly decreased. However, the coercivity of the film was also decreased. The highly textured growth is not dependent on the film thickness. Detail analysis of the film by XRD and TEM suggested that the stress induced during the film deposition may be attributed to the highly texture growth on glass substrate. This work may provide a new way for growing high quality oxide films on cheap substrate, i.e. glass.
Preparation of Biocompatible Iron Oxide Nanorods: In Vivo Study on Bio-Distribution and Pharmacokinetics

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Biocompatible, monodispersed iron oxide nanorods of diameter 25-30 nm and length 150 nm were successfully synthesised by a low temperature solution growth, without any template or surfactant. The forced hydrolysis of iron (III) chloride, in the presence of mild mineralizer urea, played a key role in determining the pH of the reaction and controlling the particle morphology. Structural and morphological analysis of the sample obtained by refluxing for 12 hours showed the formation of nanospindles of akagenite. The as-prepared akagenite nanospindles were calcined at 300 °C to obtain iron oxide nanorods. The X-ray diffraction analysis, Fourier transform Infrared analysis and thermogravimetric analysis also confirmed the complete transformation of akagenite to hematite on calcinating at 300 °C. The prepared hematite nanorods had an aspect ratio of around 6 with preferred growth along (104) plane. A protocol was identified to evaluate the biocompatibility of the prepared nanorods without any surface modification by polymerizable surfactants. Thorough and systematic analyses were made on blood parameters and histopathological studies were conducted on the liver to assess the acute and chronic toxicity. The in vivo cytotoxicity study show excellent biocompatibility of the prepared nanorods even up to a concentration of 500 ppm. The prepared capsule-like nanorods, on appropriate chemical modification, could serve as nanocarrier for controlled release of drugs.

Concentration Dependent Magnetism Induced by Hydrogen Adsorption on Graphene and Single-walled Carbon Nanotubes

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We performed first principles calculations to study the magnetic properties of hydrogenated graphene and single-walled carbon nanotubes (SWNTs) with different hydrogen concentrations. The hydrogen adsorption on a graphene and SWNTs generates localized states and accordingly a flat band near the Fermi level, opening substantial gaps. The magnetic properties of the compounds depend on hydrogen concentration. At high hydrogen concentration, the flat band split into spin-up and spin-down branches locating above and below the Fermi level, respectively, making the systems spontaneous magnetic. However, the spin-up and spin-down branches of the flat band are energetically degenerated at low hydrogen concentration and the systems are therefore nonmagnetic. This result is understandable from the point of view of the direct interaction between the unpaired electrons of adjacent hydrogen-adsorption defects.

Effect of Cation Substitution on Magnetic and Magnetoelectric Properties of the BiFeO₃ Perovskite

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Multiferroic materials that are simultaneously ferromagnetic and ferroelectric are currently attracting great attention because the possibility of modulating electrical polarization with a magnetic field and magnetization with an electric field in these materials can pay away new technologies which will exploit both electrical and magnetic polarizations to store and manipulate information.

BiFeO₃ is a good candidate for studying this kind of materials since it simultaneously possesses a magnetic ordering and a ferroelectric polarization well above room temperature (Neel temperature $T_N \sim 370$ °C and Curie temperature $T_C \sim 830$ °C). However, the large magnetic moment and strong ferroelectric performance is required for BiFeO₃ for magnetoelectric device applications. It is believed that the above limitations can be overcome by doping BiFeO₃; for example, a proper substitution for Bi
can improve the magnetic moment in BiFeO₃. Although the temperature dependence of structural and magnetic order parameters of BiFeO₃ has been studied long ago, the magnetic measurements over a wide range of temperature (10 K – 700 K) as well as magnetoelectric coupling in BiₓₐₐₓFeO₃ have not been reported and these are the driving factors for the work reported here.

We report the effect of divalent cation (A) substitution on magnetic and magnetoelectric properties in BiₓₐₐₓFeO₃ (A = Sr, Ba and SrₓBaₓ; x = 0 and 0.3). The rapid increase of magnetization below 100 K and a peak at the Neel temperature Tₐ = 642±2 K found in BiFeO₃ is suppressed in the co-doped sample (A = SrₓBa₁₋ₓ). All the divalent cation doped samples show enhanced magnetization with a well defined hysteresis loop compared to the parent compound. Both longitudinal (L= dc) and transverse (T= ac) magnetoelectric coefficients with dc magnetic field parallel and perpendicular to the direction of induced voltage, respectively, were measured using dynamic lock-in technique. It is found that the T-αME increases in magnitude and exceeds the L-αME with increasing size of the A cation. The maximum T-αME = 2.1 mV/cmOe in the series is found for A = SrₓBa₁₋ₓ, though it is not the compound with the highest saturation magnetization. The observed changes in the magnetoelectric coefficient are suggested to possible modification in the domain structure and magnetoelectric coupling in these compounds.

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**Observation of a Cubical-like Microstructure of Strontium Iron Garnet (Sr₃Fe₅O₁₂) and Yttrium Iron Garnet (Y₃Fe₅O₁₂) Prepared via Sol-gel Technique**

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This is our initial response towards preparation of nano-inductors garnet for high operating frequencies strontium iron garnet (Sr₃Fe₅O₁₂) denoted as SrIG and yttrium iron garnet (Y₃Fe₅O₁₂) denoted as YIG. The garnet nano crystals were prepared by novel sol-gel technique. The starting solution was a mixture of iron nitrate Fe(NO₃)₃·9H₂O, yttrium nitrate Y(NO₃)₃·6H₂O and strontium nitrate Sr(NO₃)₂·9H₂O. All the starting powder were dissolved in 150 mL of citric acid, C₆H₈O₇·H₂O. The mixtures were stirred continuously, at about 250 r.p.m, in room temperature until the formation of a gel was observed. The gel was dried at 110 °C in an oven to remove the unneeded water. The dried powder was calcined at 700°C for the Sr₃Fe₅O₁₂ and 800°C for the Y₃Fe₅O₁₂ samples for 3 hours in air. It was then wet crushed using a Fritsch Planetary Micro mill for 6 hours to obtain the fine green nano-particles powder. The phase and crystal structure of the prepared samples were identified by using x-ray diffraction analysis. SEM images were done to reveal the surface morphology of the samples. The magnetic properties of the samples namely initial permeability (µi), relative loss factor (RLF) and quality factor (Q-Factor) were done by using LCR meter. From the XRD profile, both of the Y₃Fe₅O₁₂ and Sr₃Fe₅O₁₂ samples showed single phase garnet and crystalization had completely occurred at 900°C for the SrIG and 950°C for the YIG samples. It should be noted that this is about 30% lower than those prepared via conventional method. The YIG sample showed extremely low RLF value (0.0082) and high density 4.6239 g/cm³. Interesting however is the high Q factor (20 – 60) shown by the Sr₃Fe₅O₁₂ sample from 20 -100 MHz. This high performance magnetic property is attributed to the homogenous and cubical-like microstructure.

**Tunable Multi-magnons Interactions in Nanocrystalline NiOₓ Granular Films**

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Nanocrystalline NiOₓ granular films have been formed by annealing Ni grid in a quartz tubular furnace in the temperature range 400 to 800 °C in a stream of oxygen at atmospheric pressure. The morphology and structures of the prepared granular films were characterized using field-emission scanning electron microscopy, transmission electron microscopic, and high-resolution transmission microscopic images were obtained to study the crystalline structure. Raman spectroscopy has the high spatial resolution and sensitivity necessary for probing the local atomic vibrations of nanowires. This offers us direct observations of the influence of oxygen concentration with which to investigate the coupling strength resulting from the competition of phonon and two-magnons.

We have observed a phonon (LO) and two magnons (2M) excitations by confocal Raman scattering in nanocrystalline NiOₓ granular films. The Raman spectra reveal three main peaks in a granular NiO film with annealing temperature 400 °C, at 540, 1086, and...
1410 cm⁻¹, corresponding to the LO, 2LO and 2M symmetries, respectively. The intensity of 2M modes and LO mode are changed sensitively with annealing temperature. The decreasing 2LO and increasing magnitude of 2M with the increment of annealing temperature were ascribed by the increase of antiferromagnetic spin correlations, while the strong magnetic Raman response caused by a Ni-O superexchange mechanism was associated with the concentration of oxygen due to the annealing.

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Single-Crystal Magnetic MFe₂O₄ Nanotubes/Nanorings Fabricated via Thermal Transformation

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Transformation of phase and structure from an inorganic material to another via gas-solid or solid-solid reaction is a common approach for fabrication of the novel functional materials. Unfortunately, however, it usually results in the loss of their structural characteristics and single crystal nature, which is mainly attributed to the local strain/stress induced by grain to grain contact of heterogeneous phase during the transformation process. Compared to bulk materials, single crystal nanocrystals have less volume defect and better flexibility (enhanced yielding strength) which allow them to undergo a phase transformation and simultaneously maintain the structural and single crystal characteristics. In this work, we elaborate controlling the gas-solid and solid-solid reaction conditions in the experiments, we demonstrate that the single crystal trigonal Fe₂O₃ nanotubes could be rationally transformed into single crystal magnetite Fe₃O₄, maghemite γ-Fe₂O₃, metal spinel ferrites MFe₂O₄ (M=Co, Mn, Ni, Cu) and metallic bcc-Fe nanotubes without the loss of their tubular morphology. The size, composition and shape of the nanotubes can be easily tuned. These nanotubes can be used as a high effective catalyst or as a general nanocapsule for luminescent QDs for magnetic separating and optical probing lung cancer cells. In addition, this transformation process has been successfully applied to other transition metal nano-oxides, showing the potential as a general technique for the synthesis of transition metal-based nanotubes/nanorings.

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Heat Treatment Effect on Magnetic and Magnetoresistance of Mn-doped Si Thin Films

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In the field of spintronics, one of the major focuses is the attempt to inject spin-polarized electrons, ultimately at room temperature. Diluted magnetic semiconductors (DMSs) are the materials which exhibit spontaneous ferromagnetism mediated by the carriers in the valence band and thus they are promising candidates for the applications in spintronics. Although all of DMSs are very interesting from a technological point of view, it would be extremely prospective if Si-based DMSs could be realized, since Si plays an important role in electronic devices. Study systematically both the magnetic properties of Si_{1-x}M_{x} thin films were grown on Si (001) substrates at 200 °C by MBE. Firstly, a thin SiO₂ layer on the surface of Si substrates was removed by heating up to 1100 °C for 30 minutes. After that, the system was cooled slowly to 200 °C with a rate of 1 °C/second. During the deposition procedure, the substrate temperature was maintained at 200 °C for 60 minutes. To fabricate films with different Mn concentrations, the atomic Mn flux was controlled by changing the Mn-effusion-cell temperature. Finally, the fabricated films were measured the thickness by an Alpha-Step (500 Profiler). After deposition, the films were respectively annealed at 400, 600 and 800°C in high vacuum MBE chamber for 30 minutes.

The films have a thickness of about 63 nm. By means of Rutherford backscattering microscopy, we obtained the Mn concentration in the sample to be 3.0 at.%. X-ray diffraction measurement shows that the as-grown samples and annealed samples were crystal without any secondary phases. The result of magnetization measurement by alternating gradient magnetometer reveals that the as-grown samples and annealed samples all have room
temperature ferromagnetism. The magnetic and transport properties of annealed samples at 400°C do not change remarkably compared with as-grown samples. However, magnetization and magnetoresistance (MR) ratios were enhanced very much when annealing temperature was increased to 800°C. Furthermore, the MR exhibits interesting angle and field dependence behavior at room temperature. The MR reached to 46 % at 300 K for the samples annealed at 800°C.

Enhanced Magnetic Properties of Polymer Lanthanum Yttrium Iron Garnet Composite

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This is our initial response towards fabricating a magnetic filled polymer composite samples potentially used as wave absorber. Samples of Y3+0.5LaXFe5O12 (where x = 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0) were synthesized by conventional solid state technique. Oxides of yttrium, lanthanum and iron with purity of about 99.99% were milled with distilled water in a milling machine for 18 hours. They were then filtered, dried and pre-sintered at 1200°C for 10 hours in air. After the final sintering which was done at 1300°C for 10 hours. We used simple casting technique to fabricate the Y3+0.5LaXFe5O12-PVA composite. The samples were mixed with PVA solution for 48 hours to form composite suspension. The phase and crystal structure of the prepared samples were identified by using x-ray diffraction analysis. From the XRD characterization, the sharp peak spans from 32.61° to 32.29°, indicating the transition from yttrium to lanthanum based iron garnet. Scanning Electron Microscope (SEM) revealed the sample Y3+0.5La0.5Fe5O12 have a mean grain size of about 4 μm, which is largest as compared to other samples. The 0.5 mole fraction of lanthanum substitute in the dodecahedron sub-lattice were found to be exhibit the highest initial permeability values. The high initial permeability value exhibited by Y3+0.5La0.5Fe5O12 sample was attributed due to large grain size. Atomic Force Microscope (AFM) was used to observe the surface morphology. The sample Y3+1.5La0.5Fe5O12 showed much smoother surface and with a maximum surface height of only 263.6 nanometres and gave a good Q-factor value due the relative thin surface. As a conclusion, Lanthanum helps in constituting larger grain size and better magnetic properties in forming the garnet-PVA composite.

Control of Growth and Ordering Process in FePt(001) Film with Reduction of Diffusion Length at 300 °C

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L1_2-ordered FePt(001) film is a most promise material for future recording media owing to its outstanding magnetic and chemical properties. It have been reported that the preparation condition is crucial to structural and magnetic properties of the FePt film. In this paper, the effect of diffusion length on (001)-texture and ordering in FePt films are presented. The FePt layer is alternately deposited on textured Cr(200) film on 300°C-heated glass substrate by sequential planetary sputtering of Fe and Pt targets. The thickness of Cr and FePt layers are fixed at 200 and 20 nm, respectively. The planetary rotational speed is changed from 1 to 20 rpm. The sputtering rate of Fe and Pt layers are identical, sets to 1 nm/min. Therefore, the thickness of each Fe and Pt layer is adjusted within the range from 0.05 to 1.0 nm as the rotational speed was reduced from 20 to 1 rpm. X-ray diffraction results show a high order parameter of ~0.8 in the sample with 20 rpm and a disordered phase of FePt in the film with 1 rpm. Both films also exhibit diamentically different microstructures. In the film with 20 rpm, the mean grain size of FePt is about 60 nm and the orientation of lattice aligns along FePt(001) which grows from the Cr(200) plane. In the films with 1 rpm a much smaller average size of around 20 nm with an isotropic orientation is observed in FePt layer. In the case of slower rotational speed, the growth of the film is dominated by surface diffusion, a low activation energy path for thin film growth. During the deposition process the adatoms deposit on the surface randomly and subsequently relax to nearby positions where the binding is strongest. Consequently, the lattice orientation of the FePt layer grown under this condition tends to align along the texture of the underlayer throughout the whole thickness. In the contrast, the speed rotation nucleates isotropically due to the rapid solidification from gas state. The ordering is caused by grain boundary diffusion and the activating barrier is about an order of magnitude larger than that of surface diffusion. Therefore, disorder structure and isotropic orientations are expected. In this study, it has been found that growth and ordering mechanism of the FePt layer can be well controlled with the adjustment of planetary rotational speed. Different rotational speed can generate significant differences in chemical ordering and the development of (001) texture. FePt layers with well-developed (001) texture and high chemical ordering can be fabricated via surface diffusion mechanism even at a temperature as low as 300°C. Our results may provide useful information
for the development of magnetic recording media in the future.

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Nanostructured Multiferroic Double Perovskite Thin Films
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Highly oriented thin films of LaNiMnO₄, a ferromagnetic semiconductor, have been fabricated on different substrates by pulsed laser deposition. The x-ray diffraction studies reveal that the films are single crystalline and have an orthorhombic structure. The out of plane lattice parameter, c-axis, has been shown to be influenced by nature of substrate and substrate temperature. Atomic force microscope (AFM) reveals the uniform grain growth and increase in surface roughness with increasing the thickness of the film. The magnetic properties of the films, including the coercive field, remanent magnetization, and Curie temperature, are found to be strongly dependent on the nature of the substrate. The optimized films exhibit a magnetic moment of 4.32μB/f.u. at 5 K, with a Curie temperature close to 250 K. Dielectric properties of the films were studied at various frequencies and temperature. The film characteristics are promising for potential device applications in information storage, and sensors.

A02230-03871
Nanoscale Spin Torque Transfer Materials, Devices and Systems: From Memory to Computation
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This talk will discuss the key issues and solutions for designing and building future practical spin torque transfer devices, with a focus on the engineering aspects of magnetic materials, emphasizing spin torque transfer device design and fabrication. The discussion will start with a review of the re-emergence of magnetic random access memory (MRAM) and end with our recent effort to build magnetic computation systems.

For the STT memory, the talk will mainly discuss how to make storage elements with low critical switching current, yet adequate thermal stability. Topics include perpendicular anisotropy magnetic materials, the use of new magnetic structures such as exchange coupled composite material, and new recording schemes such as heat assisted magnetic recording. The talk will demonstrate these, based on the author group’s successful research on lowering the critical switching current density for STT RAM cell by 1) composite free layer with nano-current-channel; 2) perpendicular STT RAM; 3) spin accumulation effect in STT RAM cell through an efficient double antiferromagnetically pinned structure; 4) successfully switching the synthetic antiferromagnetic structure through a heat assisted scheme; 5) a practical design on multilevel spin RAM.

In the second part of the talk, kinds of spintronic logic devices for computation will be reviewed. The talk will focus on the early efforts on this topic by the author’s group including 1) the experimental demonstration of programmable logic components, including AND, OR, XOR, NAND, and NOR gates, based on a single MTJ cell; 2) the design of a full adder using only seven MTJ elements; 3) the design of an arithmetic/logic unit (ALU) using a series of MTJ cells; 4) the design and demonstration of spintronic logic devices; 5) recent demonstration of communication between STT cells based on the spin torque transfer switching mechanism.

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Study of the Phase Evolution, Microstructure and Magnetic Properties of Directly Quenched Sm(Coₓ₋ₓHфₓ)ₓC₁₋ₓ (x=5-9; y=0-0.1) Ribbons
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Intermetallic Sm-Co compounds with SmCo₅ and/or SmCo₁₇ or metastable SmCo phase have received intensive attention because of their superior magnetic intrinsic properties, including Curie temperature (Tc), uniaxial magnetocrystalline anisotropy field (Hk), and saturation magnetization (4πM). Dopant elements normally have a large influence on the intrinsic properties, especially Hk of SmCo ribbons, whereas Hf was found to be the most effective element in stabilizing SmCo₅ phase and enhancing its anisotropy field. In this paper, firstly, we would like to show how the (Co, Hf)/Sm ratio, i.e. x, on the magnetic properties of melt spun Hf-substituted
Sm(Co0.97Hf0.03)x ribbons quenched at the wheel speed of 40 m/s. X-ray diffraction analysis shows that the main phases exist in Sm(Co0.97Hf0.03)x ribbons are 1:5 phase for x = 5 and 5.5; 1:5 and 1:7 phases for x = 6-6.5; 1:7 phase for x = 7-7.5; 1:7 and 2:17 phases for x = 8; and 2:17 phase for x = 8.5-9, respectively. The grain size of 100-400 nm for this series ribbons is almost unchanged when x is increased from 5 to 9. Besides, the energy product ((BH)max) is increased from 21.3 kOe for x = 5 to 2.6 kOe for x = 9. Besides, the energy product ((BH)max) is increased from 3.8 MGOe for x = 5 to the maximum respective values of 7.1 MGOe for x = 6.5, beyond which it then decreased to 2.4 MGOe for x = 9. To further improve the microstructure and magnetic properties of Sm(Co0.97Hf0.03)x ribbons, effect of C addition on the magnetic properties of Sm(Co0.97Hf0.03)xC (x = 5-9; y = 0-0.1) ribbons are also studied. It is verified that a slight C addition in Sm(Co0.97Hf0.03)x ribbons refine the grain size from 100-400 nm for C free ribbons to 30-80 nm for C added ribbons, leading to the improved magnetic properties of Bc = 7.0 kG, Hc = 11.8 kOe and (BH)max = 11.0 MGOe in Sm(Co0.97Hf0.03)xCd0.1 ribbons.

Effect of Dopants on the Soft Magnetic Properties and High Frequency Characteristics of FeCoBM Thin Films (M= Ti, Nb, Hf, and Ta)

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Fe-Co alloys have received intensive interest due to their high saturation magnetization and magnetostrictive constant. In order to develop magnetic materials used in GHz range, the soft magnetic properties and high frequency characteristics were examined in the as-deposited FeCoB thin films. The magnetic properties required for high frequency applications are large saturation magnetization (4πM) and high in-plane magnetic anisotropy field (Hk) because the ferromagnetic-resonance frequency (fMR) of the films is proportional to the root of the multiplication of the 4πM and Hk. In addition, to lower the eddy current loss, high resistivity (ρ) is one of the important requirements. In this study, the FeCoB thin films with the thickness of 180 nm were prepared by an oblique deposition method together with an external in-plane magnetic field of 1.2 kOe during the sputtering process. For (Fe0.55Co0.45)100-xBx (x = 0-20) thin films, with the increase of B content, the resistivity was increased because B could decrease the crystallinity of the films. The (Fe0.55Co0.45)90B10 thin film showed the optimum properties, where 4πM = 16.1 kG, Hk = 64.2 Oe, Hc = 13.5 Oe, Hr = 310 Oe and ρ = 338 μΩ-cm. In order to enhance the soft magnetic properties, the elements M, including Ti, Nb, Hf, and Ta, were selected to substitute for B in the (Fe0.55Co0.45)100-xBx (x = 0-10) series films. The experiment results showed that the coercivity of the hysteresis loop along easy-axis was decreased drastically. On the other hand, multiple elements substitution could further decrease the crystallinity of the films and improve the soft magnetic properties and high resonance frequency. Finally, effect of annealing treatment on the magnetic properties of the thin films was also studied. When the annealing temperature was increased, the magnetic anisotropy field increased first to reach a maximum value and then rapidly decreased. The (Fe0.55Co0.45) x Ti, Nb thin film after annealing at a temperature of 200 °C for 30 min showed the optimal properties, where 4πM = 15.8 kG, Hc = 4.8 Oe, Hr = 3.6 Oe, Hc = 224 Oe and ρ = 290 μΩ-cm. The theoretical ferromagnetic resonance frequency of the developed films can be higher than 5 GHz.

Study of the Solidification Process of Melt-spun α-Fe/NdFeα5B Nanocomposite Magnets

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Melt-spun Nd12Fe81Zr3B6.5 ribbons are prepared under different quench rate. The rapid solidification process of the alloy is investigated by X-ray diffraction, differential scanning calorimeter, transmission electron microscopy observations, and magnetization measurements. It is indicates that melt spinning at different wheel velocities caused the as-quenched ribbons to have distinctive structure. The microstructure characteristics of the ribbons at various distances from the ribbon wheel side are obviously different, indicating strong internal variations in quench rate across the ribbon thickness. A qualitative solidification model is presented that details the evolution of microstructures related to the thermal gradient during solidification of rapidly solidified Nd12Fe81Zr3B6.5 alloys.
Magnetic Properties, Phase Evolution, and Microstructure of Melt Spun MM$_{9.5}$Fe$_{78.5}$Ti$_{2}$B$_{10}$ (MM= Mischmetals) Nanocomposites

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Recently, the demand for the R$_2$Fe$_{14}$B-based magnets (R=Nd or Pr) is rapidly increased, and it leads to the shortage of pure Nd and Pr metals. Because Mischmetal (MM) is a cheaper natural ore and contains the combination of light rare earth metals, such as Nd, Pr, La, and Ce, it is motivated to adopt Mischmetal to replace the pure rare earth Nd or Pr to fabricate nanocomposite ribbons for bonded magnet application. In our previous study, the R-lean and B-enriched R$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ nanocomposites with Ti substitution exhibited both high coercivity ($H_c$) and high $(BH)_{max}$ due to proper volume fraction of magnetically soft and hard phases and uniformly fine grains. Among them, Pr$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ nanocomposites exhibited both high $H_c$ of 12.8 kOe and high $(BH)_{max}$ of 16.3 MGOe. Therefore, in this study, three different MM alloys, including MM(A): 71wt% Pr, 27 wt%Nd, and 25 wt% Ce; MM(B): 25% wt Pr and 75 wt % Nd; and MM(C): 8 wt % Pr, 32 wt % Nd, 4 wt % Ce, and 56 wt % La, were adopted as the main rare-earth elements to develop melt spun MM$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ nanocomposites. Besides, in order to explain the change of magnetic properties of the above ribbons, effect of various rare earth elements on the magnetic properties, phase evolution, and microstructure of melt spun R$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ (R = Pr, Nd, Ce, and La) nanocomposites were also compared. Based on the results of thermal magnetic analysis, only 2:14:1 and $\alpha$-Fe phases appear for the alloy ribbons with $R = MM(A)$ and Pr, and an additional Fe$_3$B phase is present for $R = MM(B)$, MM(C), Nd, and Ce, but only magnetically soft phases, containing amorphous, Fe$_3$B and $\alpha$-Fe phases, are present for the ribbon with $R = La$. Besides, uniformly fine grain size of 20-40 nm is almost unchanged for the ribbons with various rare earth elements. Accordingly, magnetic properties of MM$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ nanocomposites are mainly dominated by the composition of MM alloys and are consistent with the outcome for the combinations of magnetic properties of their corresponding R$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ nanocomposites. The optimal magnetic properties of $B_r = 9.3$ kG, $H_c = 12.1$ kOe and $(BH)_{max} = 18.0$ MGOe can be achieved for MM(B)$_{9.5}$Fe$_{78.5}$Ti$_2$B$_{10}$ nanocomposites.

Investigation of Magnetic Properties and Microstructure of Ultrathin Co Films Grown on Si(111)-7×7 Surface

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Recently, the combination of magnetic matter with semiconductor has drawn much attention because this field involves abundant science and potential applications in the development of ultrahigh density media. In the past decades, magnetic and interfacial properties of ultrathin Co films grown on the Si surface have been investigated. However, the detailed growth mechanism and magnetic properties of ultrathin Co/Si(111) films are still missing. Therefore, magnetic properties and growth mechanism of ultrathin Co films grown on Si(111)-7×7 surface have been studied by using both surface magneto-optic Kerr effect (SMOKE) and scanning tunneling microscopy (STM), respectively. STM results show that the existence of three dimensional islands in x ML Co/Si(111) ultrathin film at room temperature without annealing has been observed with Stranski-Krastanow (SK) growth mode. Due to formation of CoSi, layer, no magnetic signal could be detected by SMOKE for 1-4 ML Co deposited on Si(111) surface. Because of rougher surface, both longitudinal and perpendicular magnetic anisotropy configuration appear for 5-10 ML Co/Si(111) films. When the Co thickness is increased to 11 ML, only longitudinal anisotropy configuration exists, which might result from the contribution to the volume anisotropy. Furthermore, in-plane coercivity increases with Co coverage because of enhancement of ferromagnetic coupling with Co thickness, out-of-plane coercivity increases with Co coverage due to the increment of demagnetized field, induced by rougher Co surface.
Current-induced Electroresistance in Nd$_{0.5}$Ca$_{0.5}$Mn$_{0.95}$Ni$_{0.05}$O$_3$

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We have investigated the dc and pulsed current-induced electroresistance in phase separated manganite Nd$_{0.5}$Ca$_{0.5}$Mn$_{0.95}$Ni$_{0.05}$O$_3$ as a function of temperature and magnetic field. It is shown that the negative differential resistance which appears above a threshold current ($I_c$) and hysteresis in the $I$-$V$ progressively vanish with increasing period of the current pulses. However a strong non-linearity in $I$-$V$ exists even for a pulse period of 6s. The peak voltage at $I_c$ decreases in magnitude and shifts towards higher current values with increasing strength of the magnetic field. All the above results suggest that the negative differential resistance in the dc current sweep primarily arises from the rapid increases of the sample temperature. While the Joule heating assists electroresistance in the high current regime, it is shown that the resistance can be switched between a high and low value by controlling the width and period of pulses in the current regime of negligible Joule heating which needs better explanation.

Composition Dependence of Magnetocaloric Effect in Sm$_{1-x}$Sr$_x$MnO$_3$ (x = 0.3-0.5)

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We investigated magnetic and magnetocaloric properties in Sm$_{1-x}$Sr$_x$MnO$_3$ (x = 0.30-0.5). We report a magnetic field driven first-order metamagnetic transition in the paramagnetic state in x = 0.4 and 0.5 and a second-order transition in x = 0.3. The highest magnetic entropy ($\Delta S_m = 1.41$ J/mol K for $\Delta H = 5$ T at $T = 125$ K) that occurs in x = 0.4 is associated with the metamagnetic transition resulting from the field-induced growth and coalescence of ferromagnetic nano clusters preexisting in the paramagnetic state. Our results suggest that manganites with intrinsic nanoscale phase separation can be exploited for magnetic refrigeration.

An Optical Limiter Based on Ferrofluids

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A passive optical limiter is a device that can protect susceptible targets from accidental exposure to intense beams of light. An ideal optical limiter should be transparent to low intensity light and opaque to high intensity light, so that it can protect human eyes and optical sensors from harmful optical radiation. Several organic and inorganic compounds and metal and semiconductor nanoparticles have been investigated for their optical limiting properties. However, optical limiting studies had not been reported for ferrofluids so far.

Ferrofluids are stable colloidal suspensions of nanomagnetic materials, typically magnetite or cobalt, suspended in a suitable base fluid. Magnetite ferrofluids have good thermal stability and stability against agglomeration, which are desirable properties for optical limiting media. These smart fluids have been extensively used in many engineering applications such as in loud speaker coils and pressure sensors. The magnetic field induced structural anisotropy of ferrofluids leads to many special magneto-optical properties like field induced optical birefringence, linear and circular dichroism, Faraday rotation and ellipticity.

For the optical limiting measurements we used colloidal ferrofluid suspensions containing nanosized particles of approximately 80 Å diameter, with a number density of the order of 10$^{22}$/m$^3$. From absorption spectra, the optical bandgap was determined to be around 2.19 eV. Measurements were carried out using laser pulses of 7 ns (7 x 10$^{-9}$ s) as well as 100 fs (100 x 10$^{-15}$ s) durations, at 532 nm and 800 nm wavelengths respectively. Samples taken in 1 mm pathlength cuvettes, having a linear transmission of 50% at the respective wavelength, were used for the investigations. The intensity dependent light transmission was measured using the standard open aperture z-scan technique. The normalized transmittance of the samples (transmission normalized to the linear transmission of the sample) was then plotted as a function of the incident laser fluence. At both excitation wavelengths the samples showed an efficient optical limiting behavior. In the best case the net transmission dropped from 50% to 7.5%, at the highest input laser fluence used (4 x 10$^4$ J/m$^2$).

The optical nonlinearity was found to fit to a three-photon type absorption process, and the three-photon absorption
coefficients were calculated from numerical simulations. For 100 fs laser excitation it is in the order of $10^{-30}$ m$^3$/W, and the nonlinearity arises from genuine three-photon absorption. For 7 ns excitation it is in the order of $10^{-22}$ m$^3$/W, and the nonlinearity arises essentially from two-photon absorption followed by excited state absorption, which can be considered as an “effective” three-photon absorption process.

In conclusion, in this work we have shown experimentally that ferrofluids are potential candidates for fabricating optical power limiting devices. The good thermal stability, resistance against agglomeration and long shelf life make them attractive for this application. A specific advantage of ferrofluids is that the optical properties in these materials are tunable by an applied magnetic field. In typical device applications, such magnetic tunability can turn out to be very useful.

**A02346-04027**

**Electrical Spin Injection from TiO$_2$:Co into Si(100)**

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Oxide ferromagnetic semiconductor TiO$_2$:Co thin films were grown on Si(100) substrates by MOCVD method using titanium (IV) isopropoxide [Ti(OCH(CH$_3$)$_2$)$_3$] and tris (2,2,6,6-tetramethyl-3, 5-heptanedionato) cobalt (III) [Co(TMHD)$_3$] as sources of Ti and Co. Oxygen gas was used as O source. The Co(TMHD)$_3$ powder was dissolved in a tetrahydrofuran (THF) solvent to form a source solution of 0.1 mol concentration of Co(TMHD)$_3$. Solutions of precursors were stored in separate bubblers. The bubblers were heated at temperature of 50°C and 100°C to vaporize the TTIP and Co(TMHD) solutions, respectively. Its vapor was then transported into reactor using argon carrier gas. At the optimum growth conditions, the grown films had a Rutile structure as confirmed by XRD measurement. The Co concentration in the TiO$_2$:Co films depends on the flow rate of Co(TMHD)$_3$ vapour transported into the reactor.

The TiO$_2$:Co thin film with a Co content of 0.3% had been used as contacts in a configuration of non-local Hanle effect measurement. This configuration was used to investigate the electrical spin injection into Si(100), by means of electrical detection of spin transport. The distance between injection and detection contacts were 30µm and 55µm, respectively, while the external applied magnetic fields were in the range of -400 mT and 400 mT. The experimental Hanle curves were observed at room temperature. This curves confirmed the spin injection from TiO$_2$:Co into Si(100). We analyzed the curves using a drift diffusion equation model.

**A02378-04071**

**Preparation of Quaternary Ammonium Group Functionalized Magnetic Nanoparticles**

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The silica-coated magnetic nanoparticles were prepared by co-precipitation of ferrous and ferric iron electrolytic solutions, followed by hydrolyzing tetraethylothsilicate (TEOS) in a 2-propanol solution in the presence of ammonium hydroxide. XRD diffraction indicated that the magnetic particles were mainly composed of Fe$_3$O$_4$. Transmission electron micrographs showed that the nanoparticles of iron oxide with the size ranging from 5 to 10 nm were dispersed in amorphous silica. The surface of magnetic silica nanoparticles was modified by grafting of aminopropyltriethoxysilane (APTS) followed by quaternarization of nitrogen with various alkyl iodies. In addition to the antibacterial properties, the functionalized magnetic nanoparticles were capable of adsorbing anion biopolymers. The adsorption capacity was affected by the length of hydrophobic chains in the quaternary ammonium groups. The novel magnetic nanomateials are promising for bioseparation applications.

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**NiW/Ru Underlayer for CoPt-SiO$_2$ Perpendicular Recording Media**

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Perpendicular magnetic recording has replaced longitudinal recording as the new generation recording technology used in hard disk drives. Granular CoPt-SiO$_2$ magnetic film is one of the promising candidates for perpendicular recording media, as it has a relatively high anisotropy constant of around 1-2×10$^7$ erg/cc. Higher magnetic anisotropy enables higher areal density without compromising the thermal stability of the recorded information. Although some recording materials like L$_1$ phase FePt and CoPt with higher anisotropy constant are hot for research, CoPt-SiO$_2$ has its advantages because no heating or annealing is required to generate its desired texture. As have been
reported frequently, Ru is the best underlayer material to induce the Co hcp (0002) texture with its easy axis normal to the film plane. However, Ru is rather expensive, and its resource is limited. So to reduce the product cost, it is very beneficial to reduce the Ru layer thickness or even find new underlayers for CoPt-SiO₂.

In current work, we proposed a NiW underlayer to reduce the Ru layer thickness but at the same time generate an equally good Ru (0002) texture. Ni crystal has an fcc phase, and its (111) plane has the same atomic arrangement as Ru hcp (0002) plane. So Ru (0002) texture can epitaxially grow on Ni (111) texture under a reasonable lattice mismatch. As pure Ni film is a soft magnetic material, the increasing of media noise is concerned. To solve this problem, we alloyed W atom to Ni to destroy its magnetic property, and mean well reduced its lattice mismatch with Ru layer, as W has larger atomic lattice than both Ni and Ru. To induce small grains and smooth surface due to the high melting temperature of W are the other reasons that we chose W as the alloying element to Ni.

Magnetic sputtering deposition was used to fabricate the samples with the structure of W(3nm)/Ni₁₄₋₀ₓWₓ/Ru(10nm)/CoPt-SiO₂(15nm). The influence of W content in NiW film and the film thickness on Ru layer texture, recording layer microstructure and the magnetic properties were investigated. The results showed that NiW film magnetization decreased dramatically to 0 as the W content was over 10 vol%. As the W content increased, the lattice mismatch between NiW layer and Ru layer reduced. And rocking curves showed that FWHM of Ru (0002) peak decreased with the increasing of W content. The addition of Ni₈₀W₂₀ layer made the magnetic grains more isolated and decreased inter-granular exchanging coupling. Our results demonstrated that the thickness of Ru underlayer for CoPt-SiO₂ based magnetic recording media can be reduced to below 10nm through epitaxial growth on NiW layer.

FePt is one of the candidate materials for future ultrahigh density recording, as fully ordered FePt L₁₀ phase has a very large anisotropy constant Kₚ of 7×10⁷ erg/cc. And as has been reported that C additive can enhance grain isolation and reduce inter-grain exchange coupling to obtain a high SNR. Hence, FePt-C composite material was chosen as the recording material. And the ordering of FePt L₁₀ phase is affected by many parameters, like deposition atmosphere, deposition temperature and film thickness. In this work, the dependence of FePt texture, magnetic properties and microstructure on temperature and film thickness were investigated.

The samples were prepared by using magnetic sputtering deposition, and followed the layer structure of Corning glass/CrRu(30nm)/MgO(2nm)/FePt-C. CrRu and MgO underlayers were to promote FePt L₁₀ phase. The deposition temperature of FePt-C layer varied from 290°C to 390°C. FePt (001) texture improved as the deposition temperature increased, and relative good texture formed from 340°C and above. Out-of-plane coercivity increased significantly from 2kOe to 12kOe as deposition temperature increased from 290°C to 390°C. And TEM planar view images showed that the film grain size increased with the increasing of deposition temperature. Then FePt-C films with different thickness were studied. The results showed that large out-of-plane coercivity and well isolated magnetic grains were obtained. And interestingly, there was a critical thickness of FePt-C film to demonstrate the desired texture and anisotropy constant. The results showed that FePt-C film texture, grain size and magnetic properties can be controlled by both temperature and film thickness. And this may help us to design the FePt-C based ECC or graded media for future research.

FePt-C Granular Perpendicular Recording Media

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The main task of hard disk industry in the next few years is to achieve a recording areal density of 1 Tbits/in² and beyond. Now for perpendicular recording to approach this destination, the only way is to reduce the recording bit size. However, by concerning the signal-to-noise ratio (SNR) and the thermal stability of the magnetic grains, materials with extremely large uniaxial anisotropy constant Kₚ are required for the recording media.

Room-Temperature Ferromagnetism of Undoped and Transition Metal Doped TiO₂ Nanobelts Grown by Metalorganic Chemical Vapor Deposition

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One dimensional (1-D) TiO₂ diluted magnetic semiconductor (DMS) nanostructures are one of intense interest for fundamental research and promising spintronic device applications. Among potential DMS materials, transition metal-doped TiO₂ has been extensively studied as one of the most promising candidates since cobalt (Co)-doped TiO₂ (Ti₁₋ₓCoₓO₂) was shown to be ferromagnetic with T_C up to 400 K. However, litter information is available on the synthesis and characteristics of 1-D
Ti_{1-x}Co_{x}O_{2} nanostructures. Synthesis methods of 1-D Ti_{1-x}Co_{x}O_{2} nanostructures have been limited to template-assistant fabrication and solution-based techniques such as hydrothermal treatment so far. Moreover, the origin of the room-temperature ferromagnetism (RTFM) of Ti_{1-x}M_{x}O_{2-δ} DMS is the most important issue, but, whether it is due to an intrinsic or an extrinsic effect (transition-metal clusters) remains controversial. Recently, we reported the synthesis of Ti_{1-x}Co_{x}O_{2-δ} nanobelts by metalorganic chemical vapor deposition and their room-temperature ferromagnetic properties. In this study, we mainly focus on the ferromagnetic properties of undoped TiO_{2-δ} and lightly Fe, Co-doped Ti_{1-x}M_{x}O_{2-δ} nanobelts (x<1 at. %). The nanobelts were synthesized without using any metal catalysts by metalorganic chemical vapor deposition. The nanobelts consisted of ~10-20 nm size nanocrystallites, which were dominantly rutile structure. The undoped and Fe, Co-doped TiO_{2-δ} nanobelts showed ferromagnetic behaviour at room temperature. We will further discuss the growth mechanism and the origin of the room-temperature ferromagnetism of the nanobelts.

Magnetic Properties of CoPt/Ag and SiN_{x}/CoPt/Ag Thin Films

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Recently, FePt and CoPt alloy films with L1_{0} ordered structure are proposed to apply in the ultra high density magnetic recording medium due to their high magnetocrystalline anisotropy and high coercivity. These two as-deposited films have face-centered-cubic (FCC) phase which could be transferred to face-centered-tetragonal (FCT) phase by high temperature annealing. The preferred crystal oriented FePt or CoPt film can be obtained by introducing a proper under-layer. In this study, CoPt/Ag and SiN_{x}/CoPt/Ag thin films with different thicknesses of Ag under-layer are prepared by magnetron sputtering. The effects of Ag under-layer thickness and the addition of SiN_{x} capped layer on the microstructures and magnetic properties of the CoPt film are investigated.

The CoPt/Ag and SiN_{x}/CoPt/Ag thin films with different thicknesses of Ag under-layer were deposited on glass substrates at room temperature by magnetron sputtering. All films were annealed at 700°C for 30 min in vacuum. The thickness of the films were measured by using an atomic force microscope (AFM). The structure of the films was analyzed by a x-ray diffractometer (XRD) with Cu Kα radiation. Magnetic properties of the films were measured by using a vibrating sample magnetometer (VSM) with a maximum applied field of 20 kOe.

The I_{001}/I_{111} ratio is usually used to describe the degree of (001) texture, where I_{001} and I_{111} are the peak intensities of (001) CoPt and (111) CoPt, respectively. It is found that the I_{001}/I_{111} values are decreased as the thickness of Ag under-layer increases from 25 nm to 200 nm, and the I_{001}/I_{111} values of CoPt(20 nm)/Ag(x nm) films are always higher than those of SiN_{x}(32 nm)/CoPt(20 nm)/Ag(x nm) films. The perpendicular coercivity (H_{⊥c}) values of the CoPt(20 nm)/Ag(x nm) films are all higher than that of SiN_{x}(32 nm)/CoPt(20 nm)/Ag(x nm) films, and the maximum H_{⊥c} value of the CoPt(20 nm)/Ag(x nm) films is 13525 Oe.

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Effect of Bi doping on the Electrical, Magnetic and Magnetocaloric properties of La_{0.7-x}Bi_{x}Sr_{0.3}MnO_{3}

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We report the effect of Bi doping on magnetic, electrical, magnetotransport and magnetocaloric properties in the ferromagnetic La_{0.7-x}Bi_{x}Sr_{0.3}MnO_{3}. It is shown that with increasing Bi content (x), ground state of La_{0.7-x}Bi_{x}Sr_{0.3}MnO_{3}, transforms from a ferromagnetic metal (x = 0) to a spin glass insulator (x = 0.2), with further increase (x > 0.4), it transforms into an antiferromagnetic charge ordered insulator. Evidences for mixed phases with coexistence of ferromagnetic and antiferromagnetic phases were found between x = 0 and 0.2. The x = 0.2 compound shows unusual magnetic-field induced first order metamagnetic transition which results in colossal magnetoresistance. The largest magnetocaloric effect, characterized by magnetic entropy (AS_{m} = 5 J/KgK ) in this series was found close to T_{c} in x = 0.05 and it decreases with increasing Bi content.
Annealing Atmosphere Effect on the Microstructure and Magnetic Properties of Fe(Co)Pt-TiO$_2$ Nanocomposite

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L$_{1.9}$-FePt and L$_{1.9}$-CoPt nanostructured films have received much attentions as the potential candidates for ultrahigh density magnetic recording media due to their high anisotropy. In this work, the annealing atmosphere effect on the microstructure and magnetic properties of the FePt-TiO$_2$ and CoPt-TiO$_2$ nanocomposites has been investigated. The FePt-TiO$_2$ and CoPt-TiO$_2$ nanocomposites were prepared by alternate sputtering of Fe (Co)Pt and TiO$_2$ layers and then post-annealed at 700 °C in Ar atmosphere and in Ar+4%H$_2$ atmosphere respectively.

Results show significant differences of the microstructures and magnetic properties between samples annealed in Ar and those annealed in Ar+H$_2$. XRD results show that for FePt-TiO$_2$ nanocomposite, the chemical ordering of FePt is improved when the annealing atmosphere changed from Ar to Ar+H$_2$. For CoPt-TiO$_2$ nanocomposite, both samples annealed in Ar and in Ar+H$_2$ show L$_{1.9}$-ordering. TEM results show that for samples annealed in Ar, there are slightly coalesced magnetic particles separated by the amorphous TiO$_2$ matrix. But there is large coalescence between magnetic particles annealed in Ar+H$_2$. And the degree of coalescence is greater in CoPt-TiO$_2$ nanocomposite than in FePt-TiO$_2$ nanocomposite. VSM results show that samples annealed in Ar+H$_2$ have larger coercivity than those annealed in Ar. And this difference is much larger for CoPt-TiO$_2$ nanocomposite than for FePt-TiO$_2$ nanocomposite. On the other hand, CoPt-TiO$_2$ nanocomposite has a larger coercivity than FePt-TiO$_2$ nanocomposite. The differences of the microstructures and magnetic properties between samples annealed in Ar and in Ar+H$_2$ can be understood by diffusion-limited ordering and grain growth which resulted from the slight oxidations of Fe atom Co atom in Ar which are evidenced by the XPS results. The difference between FePt-TiO$_2$ nanocomposite and CoPt-TiO$_2$ nanocomposite can be understood by more oxidized Fe atoms than Co atoms which resulted from the lower formation energy for Fe oxides than for Co oxides. The above results suggest that the annealing atmosphere could be considered as a parameter to control the ordering and microstructure of L$_{1.9}$-FePt or L$_{1.9}$-CoPt nanostructured thin film.

CoPt-SiO$_2$ Perpendicular Magnetic Recording Media with Ru/Ru-SiO$_2$ Interlayers

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One of the major challenges for future increasing the areal density of perpendicular magnetic recording media is to reduce grain size so as to improve the signal to noise ratio and optimize the magnetic transition parameters. In this work, the Ru/Ru-SiO$_2$ underlayer was used to reduce the grain size of the CoPt-SiO$_2$ magnetic layer. The effects of the SiO$_2$ volume fraction of the Ru-SiO$_2$ underlayer and the sputtering pressure on the microstructure and magnetic properties of the CoPt-SiO$_2$ magnetic layer were studied. The films with the structure: glass/Ta (4 nm)/Ru (low pressure, 15 nm)/Ru-SiO$_2$ (10 nm)/CoPt -SiO$_2$ (15 nm) were deposited at room temperature. The Ru-SiO$_2$ underlayers were deposited at low and high pressure with SiO$_2$ varied from 0 to 20%.

Full width at half maximum (FWHM) of XRD rocking curves of Ru/Ru-SiO$_2$ underlayer were of 3.4° and 3.55° for Ru-SiO$_2$ deposited at low pressure and high pressure respectively. The FWHM of Ru deposited at both low and high pressures increases slightly and then decreases with the SiO$_2$ volume fraction. TEM results show that the average grain sizes of Ru-SiO$_2$ underlayer decrease with the increase of SiO$_2$ volume fraction. But the grain size distributions increase with the SiO$_2$ volume fraction. Average grain size around 6 nm with narrow grain size distributions are observed in the CoPt. Though the poorer (0002) texture for the Ru-SiO$_2$ underlayer deposited at high pressure, the hysteresis loops of the CoPt-SiO$_2$ film show a much higher coercivity and remanence ratio than those deposited at low pressure. The higher coercivity and remanence ratio at higher pressure were due to the improvement of lateral exchange decoupling as shown in the angular dependent coercivity results and the higher anisotropy constant as shown in the results calculated from the Sharrock’s equation. The best grain isolation, highest anisotropy constant around 3.9×10$^6$ erg/cm$^3$ and best thermal stability are obtained at Ru-SiO$_2$ with SiO$_2$ volume fraction of 5% deposited at higher pressure. The above results show that utilizing the composite underlayer of Ru/Ru-SiO$_2$ could reduce the grain size of CoPt-SiO$_2$ films without much deterioration of magnetic properties.
Co Doped ZnO by Diffusion Method and its Magnetic Property

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Diluted magnetic semiconductors have attracted much attention in recent years for their potential application in spintronics. Room temperature ferromagnetism in TM (transition metal) doped ZnO have been theoretically predicted. However, the experiments showed controversial results, indicating that the magnetism greatly depends on the preparation method and condition. In this study, Co doped ZnO is prepared by diffusing Co atoms into subsurface of ZnO. We first evaporate Co atoms onto clean ZnO (0001) surface and the sample is annealing at 700°C under ultra high vacuum (UHV) conditions. The Co atoms form clusters on the ZnO (0001) surface, then after annealing, the surface reverts to atomic flat one, but the surface reconstruction becomes disordered, indicating Co clusters have been diffused into the ZnO subsurface. The Co doped ZnO shows weak ferromagnetism at room temperature. Cross-section HRTEM and XPS are used to identify the Co bonding in ZnO and the mechanism of ferromagnetism will be discussed.

Interlayer Exchange Coupling Effect of L1₀ CoPt Based Exchange Coupled Composite Media

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The L₁₀ CoPt media has generated great interest for ultra high density magnetic recording due to its large magnetocrystalline anisotropy energy to delay the onset of superparamagnetism. However, the current write heads cannot produce sufficiently large field to reverse the extremely hard magnetic grains. Exchange coupled composite (ECC) media with a magnetically hard layer and a magnetically soft layer has been proposed to reduce the switching field. Since CoPt can be produced as a high-anisotropy L₁₀ phase and as a low-anisotropy fcc phase, it is an ideal homocomposite system to investigate exchange coupling effect between hard and soft layers. In this work, the magnetic media with the structure of MgO (001) single crystal substrate/L₁₀ CoPt-10 vol.% SiO₂, 10nm/fcc CoPt-10vol.%SiO₂, x nm (x=0, 2, 4, 6) were prepared by magnetron sputtering. The formation of this ECC media was achieved by co-sputtering equiatomic CoPt and 10 vol.% of SiO₂ from Co₅₀Pt₅₀ composite target and SiO₂ target under different deposition temperatures, 700 °C for L₁₀ ordered CoPt-SiO₂ hard layer and room temperature for fcc CoPt-SiO₂ soft layer. Nonmagnetic SiO₂ was added in CoPt because it can help the magnetic decoupling in the film and hinder the grain growth. After introducing the soft layer, the ratio of the intensity of the (001) peak to the (002) peak decreased, which suggested fcc CoPt (200) component increased in the films with increased soft layer thickness. The grains in the CoPt-SiO₂ soft layer deposited at room temperature were fcc (200) grown epitaxially on L₁₀ CoPt (001) grains. With increasing the thickness of the magnetically soft layer, both the coercivity and magnetization squareness of the film decreased. The reversal mechanism was explored by determining the angular dependence of coercivity and remanent coercivity for the single hard layer perpendicular media and ECC media. The experimental results indicated that the angular dependence of Hc for L₁₀ CoPt single hard layer and ECC media were both consistent with that of Stoner-Wolfarth mode. But more incoherent switching behavior was observed with increasing soft layer thickness. The results also indicated a much lower switching field and a large tolerance of the angle dispersion for the ECC media than that for the single hard layer. The ECC media developed in this study has the potential to be used as future perpendicular magnetic recording media.

Ferromagnetism Induced by Amorphous Phase in Zn₁ₓAlₓO Film

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In the research area of dilute magnetic semiconductor (DMS), it is essential to develop semiconductor materials that possess the room temperature ferromagnetism such that the spin as well as the charge of the carriers can be coupled by the external magnetic field. ZnO, being a potential candidate of DMS, have received extensive attentions due to its applications in electronic and optical devices. Dietl et al predicted that the Curie temperature (Tc) of ZnO doped with transition metals (TM) is well above room temperature. On the other hand, Coey et al found room temperature ferromagnetism (RTF) in non-transition-metal-doped ZnO. The mechanism of the ferromagnetism is explained by the formation of the impurity band interacting with the localized d orbital. Furthermore, undoped ZnO films show RTF as well. The mechanism of RTF was explained by the defects in ZnO triggering magnetic order. Moreover, several other mechanisms have been proposed to explain the origin of room temperature ferromagnetism in ZnO.
such as the secondary phase segregation (clusters) and the formation of bound magnetic polarons. However, the origin of ferromagnetism is still unclear.

In this paper, we present that Zn$_{1-x}$Al$_x$O film showed room temperature ferromagnetism at a certain Al doping concentrations. The Zn$_{1-x}$Al$_x$O target was fabricated by sintering of ZnO and Al$_2$O$_3$ powders (Good Fellow, 99.99%). The atomic concentration of Al (x) is in the range from 2at% to 40at%. The Zn$_{1-x}$Al$_x$O film was prepared by the pulse laser deposition (PLD) on quartz substrate (110) at 800°C under an oxygen partial pressure of 10$^{-4}$ torr.

Zn$_{1-x}$Al$_x$O film shows ferromagnetism when the Al at% reaches 12 at% with $M_s$=2.55 emu/cc. The ferromagnetism is enhanced with increase in the doping concentration of Al into ZnO film. The maximum $M_s$ is obtained when Al at% reached 20 at%. However, the ferromagnetism disappeared when the Al at%'s further increases to 40 at%. Therefore, the ferromagnetism is possibly correlated with the Al doping concentration in ZnO film. The structure characterization of the Zn$_{1-x}$Al$_x$O film showed that ZnO (002) disappeared when the Al at% reached 20 at% and there was no other phase observed. It was suggested that the amorphous phase presented in the film with high concentration of Al (> 12 at%) induced ferromagnetism. It was also found that the film possessing ferromagnetism was highly resistive. HRXRD showed that the FWHM of ZnO (002) peaks increased with Al doping concentration. XPS showed that only Al$^{3+}$ phase presented and there was no metal cluster in the film. Therefore, it is concluded that this room temperature ferromagnetism found in the Zn$_{1-x}$Al$_x$O film is highly probable due to the amorphous phase in the film. Furthermore, this work also provides a method to induce ferromagnetism in ZnO.

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The Study on the Electromagnet Wave Absorbent Effectiveness of the Honey-comb Structure by the Electronless Nickel Plated Method

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This research utilizes the electronless nickel plated method on the honey-comb to discuss the electromagnet wave absorbent. The honey-comb structure is non-conductive material, so we use different condition to causes it has the electrical conductivity and the magnetic conductive material, such as the pH value and temperature of the solution, and also change the size of honey-comb to increase the electromagnet wave absorbent. From this study, we can understand the different pH value and temperature will affect the nickel on the honey-comb surface structure and the different honey comb size will also influence the electromagnet wave absorbent, such as the thickness and hole of honey-comb structure.

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Transport and Magnetotransport Properties of the Diluted Magnetic Semiconductor Mn-doped GaAs with a Quantum Well InGaAs

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Diluted magnetic semiconductors which include Mn-doped GaAs are promising as materials for spintronics focusing on spin-dependent transport phenomena and related devices. We have investigated the thermodynamic, transport and magnetotransport properties of free charge carriers in a diluted magnetic semiconductor with a quantum well InGaAs in the GaAs with delta-doped by C and Mn. In order to determine the density of the holes in a quantum well, we carried out thermodynamic calculations of the system of free holes and partially ionized Mn impurities. We calculated the temperature dependence of resistance and magnetoresistance of holes in the quantum well. The contributions of various scattering mechanisms of holes to the resistance were analyzed. The negative magnetoresistance are explained as the reduction of spin-flip scattering by aligning spins of the magnetic field.

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Effect of Structural Characteristics on Ferromagnetism of Nano-scale Metal-oxides

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The origin of ferromagnetism in metal-oxides, especially in un-doped ones, is a mysterious issue. In these several years, it has been proposed that the change of electronic structure may play an important role in inducing ferromagnetism in metal-oxides, particularly in nano-materials. In order to reveal spatial dependence of electronic structure in nano-materials, in this study, well-crystallized and circular metal-oxides particles (CeO$_2$) was synthesized by using chemical method (thermal decomposition). With modulating the synthesis process, the size distribution can be controlled precisely (from several to several tens of nano-meters). In addition, oxygen vacancies were introduced by post annealing process. With the characterization of SQUID, TEM, and STEM/EELS, the relationship between
ferromagnetism and structural characteristics of these particles (e.g. size, crystallization, concentration of oxygen vacancy, and distribution of defects, etc.) was established. At last, the density of states (DOS) of metal-oxides particles for different concentration of vacancies and with different crystalline sizes will also be calculated in this study.

Nanomagnets: Poles or no Poles

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Although magnets have been known since antiquity, the intriguing phenomena in nanomagnets have been revealed only in recent years after the advent of advanced fabrication, magnetic imaging and measurements, theory and micromagnetic simulations. Nanomagnets are small magnets with well-defined shapes in the submicron size range with competing exchange, anisotropy and magnetostatic energies. By tuning the size and shape of the nanomagnets, one can realize a variety of spin structures, some of which have no macroscopic counterparts. Nanomagnets that contain vortices and antivortices also display fascinating dynamics under a magnetic field or an electric current. Patterned nanomagnets are exploited in read-heads and MRAM, where the size and shape of the nanomagnets are as important as the intricate effects that enable the technologies.

One-dimensional Nanostructured Magnonic Crystals

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A magnonic crystal is a periodic composite structure of at least two magnetic materials with different magnetic properties. Such a crystal exhibits frequency bandgaps within which the propagation of spin waves (magnons) is forbidden. Magnonic crystals form the basis of magnonics, an emerging field which aims to control the generation and propagation of information-carrying spin waves by means analogous to the control of light in photonic crystals. As such, synthetic magnonic crystals are expected to show great promise in applications such as in magneto-electronic devices. Despite their importance, experimental data on synthetic magnonic structures are very scarce. Here we report the first experimental observation of frequency bandgaps in synthetic nanostructured magnonic crystals. The samples, fabricated with advanced lithographic techniques, are in the form of one-dimensional periodic arrays comprising alternating ferromagnetic Permalloy (Ni$_{80}$Fe$_{20}$) and cobalt nanostripes of rectangular cross section. Brillouin light scattering, a spectroscopic technique, has been employed to map the dispersion relations of the spin waves in these samples. The centre frequency and width of the bandgaps are found to be tunable by an applied magnetic field. Dispersion relations calculated based on the finite element method are in agreement with the measured data. Our findings are expected to stimulate further development of the theory and applications of magnonics.

Control of Magnetization Dynamics Using Patterned Structures

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High power absorption phenomena in ferromagnetic resonance provides familiar examples of threshold processes, such as subsidiary absorption. The threshold for this, and other important low order processes, is determined by rates of microwave absorption and dissipation. These rates are largely determined by intrinsic material parameters, nevertheless possibilities exist for strongly modifying process thresholds by patterning and multilayering of films.

We discuss factors impacting spin wave interaction processes in constrained geometries, and during magnetization reversal. In particular, we describe how patterning of magnetic films into wire arrays and elements can be used to modify spin wave dispersions and low order interaction thresholds. We also consider how transient dynamics, such as occur during precessional reversal, can give rise to high order processes affecting reversal rates and dynamics.

High frequency spin wave dynamics are intrinsically linked to underlying magnetic configurations. Other examples of element shape modified threshold behaviours, not directly related to spin wave dynamics, are therefore also important. Relevant cases include magnetic domain wall depinning in wires and patterned films. In these examples, we discuss briefly how low frequency magnetic dynamics and quasistatic configurations can be controlled through geometrical constraints and patterning techniques.

We gratefully acknowledge the Australian Research Council and FAST. PJM acknowledges support under a Marie Curie Fellowship.
Patterned magnetic recording media is considered as a potential technology for hard disk drives to take over the current perpendicular recording technology. In such media, the magnetic islands are uniformly patterned lithographically or by other means. In the extreme case of a single bit, where magnetization of all the neighbours are in the opposite/same direction, a reduction/increase in switching field will be seen. Thus, magnetostatic interactions in patterned media are responsible for increasing the switching field distribution (SFD) and reducing the thermal stability of patterned media. One way to reduce the bit-to-bit interactions is to reduce the remanence magnetization, $M_r$, without changing $M_s$. In that case, materials with high $M_s$ and high anisotropy energy $K_u$ can be used without much worry about writability because the anisotropy field of the bit is equal to $2K_u/M_s$. In this study, we show that the antiferromagnetically coupled (AFC) structure can provide a reduction of $M_r$ which will help to minimize interactions between the magnetic dots, consequently resulting in a narrower SFD.

For the experimental studies, the two magnetic layers were made of CoCrPt-SiO$_2$ with perpendicular anisotropy and patterned in array of dots using electron beam lithography and ion milling. The switching field $H_{sw}$ and SFD were determined by magnetic force microscopy (MFM) for samples with 60 nm dot-size and 60 nm and 40 nm spacing. The thickness of the first magnetic layer $t_1$ was fixed to 15 nm while the thickness $t_2$ of the top layer, called stabilizing layer, was varied from 3 nm to 6.7 nm. For nonpatterned films, it was observed from magnetometry measurements that the AFC coupling at remanence state occurs only when for the thickness of stabilizing layer is smaller than 5.5 nm. For larger $t_2$, both layers have their magnetizations parallel at remanence state which is not desirable for reducing the interactions.

MFM images taken from patterned films at different magnetic fields show that the SFD was wider for 40 nm spacing than 60 nm case. This is mainly due to an increase in the stray field originating from neighbouring dots as the spacing between the magnetic dots is reduced. The $H_{sw}$ was increased with $t_2$, for both 40 and 60 nm spacing. The SFD for 40 nm spacing array was reduced for the AFC structure with $t_2$ of about 5.3 nm. From these results, it can be seen that there is an optimal $t_2$ which both the antiferromagnetic coupling at remanence state between the two recording layers and increase $H_{sw}$ can be achieved. This will help to reduce the bit-to-bit interactions and stabilize the recorded data. In conclusion, a systematic study of patterned AFC media has been made and will be presented in detail.
Magnetism Study of p and n Type Doped ZnO Thin Films by Sol-gel Method
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Co co-doped with other p or n type impurity based ZnO thin films were prepared by sol-gel spin-coating method. Single phased thin films were confirmed by various characterization techniques. Electrical and magnetic behaviors for both p and n type doped thin films were investigated under different rapid thermal annealing (RTA) ambient, ---Ar, N\textsubscript{2} and O\textsubscript{2}. Anomalous Hall effect was studied to clarify the interaction of carriers and magnetism, with the conclusion that ZnO based ferromagnetic semiconductors could be realized by proper introduction of carriers, although defect-related ferromagnetism could not be completely excluded.

Exchange Bias in Co-Cr\textsubscript{2}O\textsubscript{3} Nanocomposites
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The phenomenon of exchange bias is the shift of the magnetization hysteresis loop along the field axis and occurs due to interfacial coupling of ferromagnetic and antiferromagnetic spins. Magnetic nanocomposites of ferromagnetic cobalt (Co) nanoparticles (average size 3 nm) embedded in antiferromagnetic chromium oxide (Cr\textsubscript{2}O\textsubscript{3}) have been synthesized using the sol-gel method. The objective was to explore the effects of Co concentration and Co particle size of the exchange bias of the nanocomposites. The Co concentration was varied between 20 and 80% and the samples were annealed at different temperatures to obtain different particle sizes.

The structure, composition and particle size have been analyzed using x-ray diffraction (XRD), transmission electron microscopy (TEM) and energy dispersive x-ray spectroscopy (EDX). Magnetic characterization has been done using a vibrating sample magnetometer (VSM). The exchange bias and coercivity have been carried out at different temperatures ranging from 5 K to 295 K using a specially devised technique which removes effects of thermal instabilities in the antiferromagnet. At very low temperature the spin freezing effect have been observed. It has been found that for comparable particle sizes the exchange bias at low temperatures demonstrates a non-monotonic dependence on cobalt concentration, whereas the coercivity decreases with increasing cobalt concentration. We interpret our results within the framework of the independent antiferromagnetic particle model.
Synthesis of Dense/Hollow Superparamagnetic Silica Composite Microspheres via an Oil-in-DEG Microemulsion Route

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Silica-based superparamagnetic composite nanospheres have been widely investigated due to their promising applications in various biomedical and environmental fields. However, the weak magnetic response of the silica-based composite spheres due to their low loading density of superparamagnetic iron oxide nanoparticles (SPIONs) has been a major limitation for real applications. In this work, a novel oil-in-DEG (diethylene glycol) microemulsion technique has been developed for fabricating superparamagnetic silica composite microspheres with ultra-high loading density of SPIONs. Through this method, the loading density of SPIONs in the resultant composite microspheres can reach as high as 80 wt%. More importantly, hollow microspheres with SPIONs loaded in the shells were also obtained by purposely increasing the amount of the unreacted solvent, i.e. toluene. Through holes with typical size larger than 50 nm were observed in the composite shell, which were resulted from the increase of liquid pressure during the reaction. The obtained dense/hollow composite microspheres possess well-defined superparamagnetic properties and demonstrate strong response to external magnetic field, allowing them to be used in various applications, such as magnetic separation and removal of contaminants from water.

Effect of Interlayer Diffusion on Magnetic and Transport Properties of Co/Pd-based Pseudo Spin Valves

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Giant magnetoresistive (GMR) devices based on layers with perpendicular magnetic anisotropy (PMA) are receiving increasing interest as they provide better thermal stability and uniform magnetisation switching compared to in-plane anisotropy devices. (Co/Pd)_n multilayers have been intensively investigated as ferromagnetic electrodes for both soft and hard layer in GMR spin valves. By changing the thickness ratio between Co and Pd layers it is possible to change the magnetic anisotropy and other properties such as GMR ratio, which makes the system extremely flexible for the optimisation of PMA. On the other hand, magnetic tunnel junctions (MTJ) with crystalline MgO barriers exhibit giant tunneling magnetoresistance (TMR) values that are much higher than MTJ with amorphous barriers such as AlO. However, high temperature annealing of MgO-MTJ above 300°C is necessary for better crystallisation and ordering of the tunnel barrier and ferromagnetic electrodes. Unfortunately, Co/Pd-based devices show significant degradation of their transport properties above 200°C due to significant inter-diffusion between the Co and Pd layers, which is undesirable in the case of MgO-MTJ.

We have previously achieved current-in-plane (CIP) GMR of up to 10% in Co/Pd-based spin valves, and showed that vacuum annealing at 230°C for 1 hour increases the coercivity of the magnetic layers but reduces the GMR by more than 50%. This is due to the reduction of the magnetic layer spin polarisation as a result of layer inter-diffusion. We studied magnetic and transport properties of Co/Pd-based pseudo spin valves under rapid thermal annealing (RTA) at different temperatures and annealing time (in the order of seconds to several minutes) to determine if the magnetic properties of the spin valve can be improved without degradation in the GMR signal. Pseudo-spin valves with the structure Substrate/Ta30/Pd50/(Co6/Pd8)_2/Co6/Cu20/Pd6/(Pd8/Co3)10/Ta50 (thicknesses in Å) were deposited on thermally oxidised Si wafers using ultra-high vacuum dc magnetron sputtering at base pressures below 5x10^-9 Torr. The as-deposited films exhibit CIP-GMR of about 5% before annealing. A detailed study of the effect of annealing on both magnetic and magneto-transport properties will be presented. By using RTA, we observed sharper magnetisation reversal of the Co/Pd multilayers up to 300°C without significant increase in the coercivity of both magnetic layers, suggesting reduced inter-diffusion in the magnetic layers.

Effect of Vanadium Content on Magnetic Properties of Doped ZnO Thin Films

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A series of ZnO thin films doped with various vanadium concentrations were prepared on silicon wafer by direct current reactive magnetron sputtering and the properties were discussed from the effect of various vanadium concentration on the structure, morphology and magnetic properties of ZnO:V films in details. The X-ray diffraction (XRD) patterns show that the wurzite structure does not change with lower doping concentration. Furthermore, we could not find any V cluster or phase separation in the
X-ray diffraction patterns. The residual stress, estimated by fitting the XRD diffraction peaks, and the grain size also have been calculated from the XRD results. The surface morphology of the ZnO:V thin films were examined by atomic force microscopes (AFM). The photoluminescence of ZnO:V thin films with different V dopant concentration were investigated. The room temperature photoluminescence spectrum indicates that the films have purple band with 370nm and the bands with 475nm and 490nm, the peak intensity of room temperature photoluminescence spectra was affected by vanadium contents and its position remained stable. The intensity of band with 370nm decreases with raising the vanadium concentration. However, the intensity of the band with 475nm and 490nm changed little. The hysteresis behavior was examined by superconducting quantum interference device (SQUID). The results indicate that films were ferromagnetic at 50K. Ferromagnetism was observed for the film with lower doping concentration, which exhibited a ferromagnetic behavior at Curie temperature higher than 300K. The results implied that the doping concentration and crystalline microstructure influence strongly the film’s magnetic characteristics. All the results have been discussed in relation with doping concentration.

The Fe3O4 nanoparticles were synthesized with FeCl3·6H2O (2.587 g), FeCl2·6H2O (7.033 g), ethanol (50 ml), ethylene glycol (50 ml), and ammonia solution (14 ml). The ultrahighsonic was used during 60 minutes of the synthesis reaction. When the reaction completed, the product was washed there times by distilled water and four times with ethanol, respectively. After washing, Oleic acid (8.5 ml) and Oleylamine (7.5 ml) was injected as the surfactant. By dispersed in Hexan, monodisperse Fe3O4 nanoparticles were finally obtained.

The morphology and crystalline structures of Fe3O4 nanoparticles were characterized using a field-emission scanning electron microscopy (FESEM), a field-emission transmission electron microscopy (FETEM), and X-ray diffractometer (XRD). The magnetic properties were measured with a vibrating sample magnetometer (VSM). This preparation process can provide successfully the superparamagnetic Fe3O4 nanoparticles of about 4 nm with high crystallinity and very low coercivity (9 Oe). We will further discuss the mechanism of synthesis and monodispersion of Fe3O4 nanoparticles.
BaW Hexaferrite Precursor in Presence of CTAB and Tween 80: Dielectric and Magnetic Properties

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The preparation of BaW hexaferrite by a Stearic acid gel route with and without surfactant (CTAB, Tween 80) has been investigated at 650°C, 750°C, 850°C, 950°C and 1050°C. The prepared BaW hexaferrite samples were characterized using various experimental techniques: XRD, SEM, DTA-TG, FTIR and VSM. The effect of sintering temperature on the Magnetic and Dielectric properties has been investigated. It was observed that type of surfactants plays a crucial role in deciding morphology of particles. The value of saturation magnetization (Ms) depends on types of surfactant used. The sample prepared in the presence of polyoxyethylene (20) sorbitan monooleate (Tween 80) shows low saturation magnetization (Ms = 15.10 emu/g), whereas the other sample prepared in the presence of a surfactant cetyltrimethylammonium bromide (CTAB) exhibits high saturation magnetization (Ms = 24.60 emu/g) compared to the normal sample.

Perspectives for 10 Tbits/in² Magnetic Recording

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Hard disk drives (HDD) have come a long way, from occupying a small room with 5 MBytes capacity (1956) to fitting in your packet with 500 GBytes of capacity (2008). HDDs have remained as the dominant devices for storing lots of information coupled with faster speeds and cheaper prices. This has been possible due to continuous efforts to innovate and implement. Several physical and engineering limitations have been proposed in the past and HDD disk technology has consistently broken those limits. The latest limit for areal density of 40 Gbits/in², estimated around 1997, was broken within the next 5 years and hard disk drives with ten times this areal density are in market now. Just six years back, a milestone of 1 Tbits/in² was considered as a significant task for the research community in HDD technology. With the recent demonstration of areal densities above 800 Gbits/in², 1 Tbits/in² is achievable within the next one year or two. The research community has focused its attention now on 10 Tbits/in² areal density as the next major milestone to be achieved.

10 Tbits/in² simply translates into an area of about 64 nm² per bit. In the conventional scaling method - where the number of grains and the grain size are scaled with respect to areal density - a simple calculation would indicate 4 to 16 grains with a diameter of 4 to 2 nm. For significant signal-to-noise ratio, 16 grains are desired, indicating the need for a grain diameter of 2 nm. While achieving 2 nm grains would be a considerable engineering challenge by itself, it is not known if a 2 nm grain could still maintain a high anisotropy to have a thermally stable magnetization. An alternative method would be to store the information in patterned magnetic islands, which are lithographically or otherwise isolated from each other. In this case, a magnetic island of about 4 nm x 4nm using a high anisotropy constant material would store the information. This approach poses several challenges in terms of lithography, writing information on the smaller bits (strength of the field as well as positioning the writer over the islands precisely) and reading information from the bits. In any of the possible approaches, there are several mechanical engineering challenges too, such as precisely aligning the head over the tracks with a track mis-registration close to a few atoms in length. In alignment with the theme of the symposium, I would present the challenges of 10 Tbits/in² for the nano-magnetics community and present some possible approaches by which the magnetic nanostructures can help to overcome these challenges.

FeTaC Magnetic Soft Underlayer for L1₀ FePt based Perpendicular Recording Media

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As the increase of the magnetic recording media areal density, the conventional magnetic recording technology is finally facing the superparamagnetic limit due to the thermal instabilities of the magnetic grains in the longitudinal magnetic recording. The perpendicular magnetic recording technology is capable to defer the density limit beyond what is achievable with longitudinal recording.

In perpendicular magnetic recording, the writing field generated between a soft magnetic underlayer (SUL) and a single pole head increases nearly twice in comparing with the longitudinal recording. SUL acts as virtual write head pole to return the magnetic flux to the head so that recording bit is positioned along the flux direction and increase the writing efficiency. Higher writing efficiency enables the utilization of the media material with much higher magnetic anisotropy, which allows higher areal density without compromising the thermal stability of the recording data.
ordered FePt having high magnetic anisotropy is one of the promising candidates for perpendicular magnetic recording. The development of $L_1_0$ ordered FePt on (200) textured CrRu underlayer for recording media application had been reported in our previous works. Due to the lower noise characteristic in comparing with other SUL candidates, FeTaC was chosen as SUL for $L_1_0$ ordered FePt based recording media. The integration of SUL into FePt based recording media structure imposes several issues such as noises in read back signal and the texture development for recording layer. Furthermore, the effect of the high temperature process for the formation of the $L_1_0$ FePt on FeTaC SUL needs to be addressed. In this paper, we are going to investigate the effect of the high temperature process on magnetic properties and the surface morphology of FeTaC SUL. The development of the (200) textured CrRu on FeTaC layer was also demonstrated.

Two sets of samples, FeTaC (100 nm)/CrRu (30 nm) and FeTaC (100 nm) without CrRu, were prepared on corning glass in magnetron sputter system with in-situ substrate heating and RF bias capability. For both sets of samples, optimized atomic compositions for FeTaC were Fe=79 %, Ta=9 % and C=12 % respectively. For FeTaC/CrRu samples, FeTaC was deposited at room temperature and CrRu at 350°C. Before CrRu deposition, sample was held for 15min at 350°C for temperature uniformity. For samples without CrRu, FeTaC was deposited at room temperature and annealed in the same sputter chamber at 350°C with different annealing durations, 15min and 40min.

Decrease in coercivity ($H_c$) and increases in magnetic induction ($B_s$) were found for FeTaC with increasing annealing duration. High temperature, however, increased the FeTaC surface roughness due to the grain coarsening and/ or crystallization, consequently, deteriorated the crystallographic texture development of the CrRu layer on top of FeTaC. RF plasma etching was applied to eliminate the surface roughness of FeTaC and improved the CrRu (200) texture. RF plasma etching and CrRu deposition on FeTaC was found to have impact on changing FeTaC properties. These changes in magnetic properties might be due to the elemental compositional change in FeTaC layer.
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