Magnetic Interfaces and Nanostructures
Room: Exhibit Hall B2 - Session MI-TuP

Aspects of Magnetism

MI-TuP1 Enhanced Magnetoresistance in Ferromagnetic Vertical Single Electron Transistor, ***S. Haraichi***, *T. Wada*, National Institute of Advanced Industrial Science and Technology, Japan

Recently, such novel phenomena as enhancement of magnetoresistance and magneto-Coulomb oscillation have been found in ferromagnetic single electron transistors (SET). However, because the areas of the ferromagnetic-insulator- ferromagnetic (FIF) tunnel junctions were as large as 0.02 ???, extremely low temperature as 20 mK was required to obtain Coulomb blockade and spin-dependent tunneling transport simultaneously. In order to elucidate the mechanism of those phenomena at relatively high temperatures and to realize such novel devices as spin-memories and spin-transistors, FIF tunnel junctions with 10 nm sizes are necessary. We have developed Si based inorganic electron beam resist process suitable for integration by which 10 nm resolution can be achieved. Using this process, nanometer-scale vertical FIF tunnel junctions are fabricated with high reliability. In this paper, we will report a fabrication process for ultra-small ferromagnetic vertical SET by modifying the above inorganic resist process, and the electrical characteristics especially spin-dependent tunneling transport of fabricated devices. The enhanced magnetoresistance changes over several times in the Coulomb blockade (CB) region in magnetic fields of around 100 mT at 14 K, while that changes only several % in the outside of the CB region. This strong enhancement is explained by the higher-order tunneling process.

MI-TuP2 Iron-silicide Phases Formed in Fe/Si Multilayered Films, ***J.S. Park***, Hanyang University, Korea, *Y.V. Kudryavtsev*, Institute of Metal Physics, Ukraine, *J. Dubowik*, Institute of Molecular Physics, Korea, *J.Y. Rhee*, Hoseo University, Korea, *Y.P. Lee*, Hanyang University, Korea

Fe/Si multilayers films (MLF) can have the interfacial layers of various iron silicides and were recently discovered to have an antiferromagnetic (AF) coupling in the as-deposited state. An ion-beam mixing (IBM) allows us to overcome either thermodynamic or kinetic barriers by employing the energetic particles, to surpass the limit of solid solubility and to achieve the compositional and structural metastability. Fe/Si MLF with various sublayer thicknesses were made by RF sputtering onto glass substrates and an IBM was also performed. The structural properties before and after the IBM turned out to be very different. A study of the optical and magneto-optical (MO) properties of the as-deposited MLF reveal that neither $FeSi_2$ nor ε-FeSi could be considered as the spacer layer providing the strong AF coupling, but that a B2-phase nonmagnetic metallic FeSi compound is spontaneously formed between Fe sublayers during deposition. The IBM of the Fe/Si MLF has been performed at room temperature (RT) by using Ar^+ ions with an energy of 80 keV, a dose of $1x10^{16}$ ions/cm^2 and a flux of $1.5x10^{-6}$ A/cm^2. The magnetic properties were measured at RT by vibrating-sample magnetometry and ferromagnetic-resonance spectroscopy. The ion-beam treatment has led to noticeable changes in the structural and physical properties of Fe/Si MLF : the formation of a new phase, which is characterized by a crystalline silicide structure, a low coercivity and a Curie temperature of about 550 K. The obtained results can be explained if a metastable $FeSi_2$ silicide with a B2-type structure is supposed.

MI-TuP3 Dynamic and Static Measurements on Epitaxial Fe/Si/Fe, ***B.K. Kuanr***, University of Colorado at Colorado Springs, *M. Buchmeier*, Forschungszentrum Juelich GmbH, Germany, *Z. Celinski*, *R.E. Camley*, University of Colorado at Colorado Springs

Strong antiferromagnetic interlayer exchange coupling across an insulating spacer is in increasing demand for high-density magnetic recording. For example such structures can be used as artificial antiferromagnets in spin valves. We report here the interlayer exchange coupling of epitaxial Fe(10 nm)/Si(t)/Fe(8 nm) trilayers as a function of Si thickness studied by Ferromagnetic Resonance (FMR), Brillouin Light Scattering (BLS) and Magneto Optic Kerr Effect (MOKE) measurement techniques. A very strong antiferromagnetic (AF) interlayer exchange coupling (>6 mJ/cm^2) was observed at a spacer Si thickness of 0.7 nm. The bilinear J_1 and biquadratic J_2 coupling constants are determined from (i) the fitting of the angular variation of the resonance field (H_{res}) from FMR (ii) the field variation of the frequencies for the Damon-Eshbach (DE) surface modes (both optic and acoustic with non-zero k) and (iii) the fitting of longitudinal MOKE hysteresis loops. We obtain a higher H_{res} along the easy-axis than along the hard-axis and the magnetizations of the two Fe films are canted. The eight-fold like symmetry of H_{res} as a function of the angle observed at room temperature, is due to the competition between the four-fold anisotropy and AFM interfacial coupling energy. This behavior vanishes at 24 K due to a strong increase of AFM coupling in comparison to four-fold anisotropy. From the fitting of temperature variation of H_{res} curves, we obtain the temperature variation of the bilinear and biquadratic exchange coupling constants. This strong coupling can be related to the highly resistive Si spacer between epitaxial Fe layers.

MI-TuP4 Investigations on the Peculiar Magneto-optical and Magnetic Properties of Au-Fe Alloy Films and Au/Fe Multilayered Films, ***K.W. Kim***, Sunmoon University, Korea, *R. Gontarz*, Institute of Molecular Physics, Poland, *Y.V. Kudryavtsev*, Institute of Metal Physics, Ukraine, *Y.P. Lee*, Hanyang University, Korea

In this study, the peculiar magneto-optical (MO) and magnetic properties of Fe-Au alloy films and Au/Fe multilayered films (MLF) were investigated. (3.0 nm Fe / t_{Au})$_{20}$ MLF (where / t_{Au}= 1.0, 2.0, 2.5 and 3.0 nm) were prepared by rf-sputtering onto glass substrates with a Au buffer layer of 20 nm in thickness. We also prepared Au, Fe and $Au_{1-x}Fe_x$ ($0 < x < 1$) films of about 100 - 150 nm in thickness by face-to-face sputtering onto a glass substrate at room temperature (RT). The structures of Au/Fe MLF and Au-Fe alloy films were analyzed by using the low- and high-angle x-ray diffraction (XRD). The MO equatorial Kerr effect and optical properties of the samples were measured at RT in a spectral range of 248 - 1130 nm (5.0 - 1.1 eV) and 235 - 2500 nm (5.3 - 0.5 eV), respectively. To understand the magnetic properties of $Au_{1-x}Fe_x$ alloy films more quantitatively, the magnetic circular dichroism (MCD) measurement was performed at 2B1 beamline of Pohang Light Source (Pohang, Korea). It was elucidated that alloy-like regions are spontaneously formed near the interfaces between Au and Fe sublayers during the Au/Fe MLF fabrication. The MCD results reveal that the orbital magnetic moment of the constituent Fe atoms in the bcc Fe-Au alloy film is about twice larger than that of pure Fe, which implies a hybridization between Fe and Au atoms. It is thought that the prominent feature observed in the UV range of the MO response of Au/Fe MLF results not from the quantum confinement, but probably from an enhanced magnetic moment of Fe (and/or an induced magnetic moment of Au).

MI-TuP5 Magnetoresistance and Magnetic Behavior of Manganite-based Multilayers, ***M. Sirena***, *M. Granada, L.B. Steren, N. Haberkorn, J. Guimpel*, C.N.E.A., Argentina

We have studied the physical and structural properties of multilayers based on manganite compounds. Different ferromagnetic (FM) spacers, insulator (B1) and metallic (B2), have been used in order to compare the magnetoresistance (MR) effects and interlayer coupling of both kind of systems. Multilayers based on high polarized manganites are specially interesting for developing magnetic devices with high tunneling MR, spin filters, etc. A/B1 and A/B2 multilayers (A: $La_{0.55}Sr_{0.45}MnO_3$, B1: $La_{0.9}Sr_{0.1}MnO_3$ and B2: $La_{0.67}Ca_{0.33}MnO_3$) have been grown by DC sputtering on MgO and $SrTiO_3$ substrates. X-ray diffraction patterns have been fitted to obtain information about the interface and roughness interdiffusion. The results show that the samples grow strongly textured in the c-direction, perpendicular to the sample surface, with a multilayered structure. The similar structure and lattice parameters of the samples make these films specially attractive to build multilayers with interfaces of good quality. We have studied the dependence of the transport and magnetic properties of these systems with the interlayer and top-layer thickness. Both A/B1(B2)/A trilayers present properties similar to those observed for the $La_{0.55}Sr_{0.45}MnO_3$ film. Magnetization vs. field measurements performed in both systems, show a single FM loop indicating that the A layers are always ferromagnetically coupled. The FM nature of the interlayer in the A/B1/A case is probably the origin of the FM coupling. In the A/B2/A trilayers, on the other hand, the FM coupling above its Curie temperature could be mediated by short-range ordered zones in the LaCaMnO interlayer. No extrinsic MR, associated with the multilayered structure was observed in the whole temperature range, probably due to the presence of FM coupling between the metallic layers, as suggested by magnetization measurements.

MI-TuP6 Current Induced Magnetoresistance in Co/Cu/Cu Multilayers, ***J.-D. Suh***, Electronics and Telecommunications Research Institute, Rep. of Korea

We have investigated the magnetic properties fabricated by e-beam lithography from a Co/Cu/Co multilayer. Current induced magnetoresistance properties for current flowing perpendicularly through the layers with a high current density of 10^8A/cm^2 are systematically studied as a function of device size, magnetic layer thickness and temperature. A

current induced magnetic switching is observed in multilayer structures with diameters as small as 100 nm. The results are explained by spin transfer model. In this study, we shall discuss the relation between nanostructured geometry of magnetic Co/Cu/Co multilayer and current induced magnetic switching in detail.

MI-TuP7 Patterned Nanostructures of Permalloy on Al_2O_3 Barrier Grown by an Electrodeposition, ***S. Kenane***, *L. Piraux*, Université Catholique de Louvain, Belgium, *J. Carrey, K. Bouzehouane, J.-M. George*, CNRS/THALES, France

Abstract Dots of Ni80Fe20 were grown by electrodeposition on the top of a thin alumina barrier at preferential nucleation centers. The particle sites were induced by indentation with a conducting tip atomic force microscopy (AFM) on the alumina barrier (figure 1). Figure 1 shows regular spheres of Ni80Fe20 which all have practically the same size. The size of the dots (sphere) can be controlled by varying the time deposition. The behavior of the current has been confronted to a theoretical nucleation-growth model. Using a conducting atomic force microscope, we characterize the resistance of the defects on which the dots nucleate. Preliminary electrical transport measurements were performed on the permalloy dots.

MI-TuP8 Magnetism of Ultrathin Co Films on Flat and Vicinal (001) Surfaces, *S. Pütter, N. Mikuszeit, J. Hoyer*, ***H.P. Oepen***, University of Hamburg, Germany

The magnetic properties of ultrathin Co films on Cu(1 1 13) and Pt(001) have been investigated by means of the magneto-optic Kerr effect (MOKE). Due to the symmetry breaking of the vicinal Cu(1 1 13) a uniaxial magnetic behavior is found. Magnetic anisotropies of first and second order are derived from the hard axis hysteresis curves revealing a field-driven spin-reorientation transition. The thickness dependence of the magnetic anisotropies is explained in the framework of strain relieve. The Kerr ellipticities perpendicular and parallel to the step edges are different. The difference is due to a canting of magnetization that causes a superposition of longitudinal and polar Kerr effect. Utilizing a recently proposed procedure[1] to deconvolute the mixed Kerr signals the canting angle is determined and found to be thickness dependent. By means of MOKE the quasi static magnetic susceptibility is measured during Co growth on Pt(001). The parallel susceptibility was obtained for in-plane orientation of magnetization. Around one monolayer a susceptibility peak indicates the onset of ferromagnetism in the pseudomorphic Co layer. For higher thicknesses the fcc Co film exhibits a fourfold symmetry with <110> as easy axes.

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MI-TuP9 Spin Polarized Vacuum Tunneling in Field Emission from Co-Coated W(111) Tips, ***K.L. Man***, *R. Bryl*, Hong Kong University of Science and Technology, *R. Zdyb*, Arizona State University, *T.C. Leung*, National Chung Cheng University, China, *C.T. Chan*, Hong Kong University of Science and Technology, *E. Bauer*, Arizona State University, *M.S. Altman*, Hong Kong University of Science and Technology

Ultrathin Co films are grown on the W(111) surface as the basis for spin polarized vacuum tunneling in field emission and scanning tunneling microscopy. The growth morphology, structure and magnetism are studied with conventional and spin polarized low energy electron microscopy (LEEM/SPLEEM) and diffraction (LEED) and first principles total energy calculations. Quasi-layer-by-layer growth of thick pseudomorphic Co films is observed at 380K, while Stranski-Krastanov growth and transformation to a (6x6) closed-packed structure are observed at higher temperatures. Pseudomorphic Co/W(111) is ferromagnetically ordered at 380K when film thickness exceeds 7.6 ML. Although only in-plane magnetization is found, a strong influence of substrate atomic steps is seen in the magnetization easy axis and magnetic domain structure. Spin polarization in vacuum tunneling is assessed by a Mott electron spin polarimeter coupled to a field emission microscope. High spin polarization (typically 20%, maximum 50%) in field emission from Co-coated W(111) tips and polarization manipulation achieved by pulsed magnetic field encourage further development.

MI-TuP10 Transition Metal Ion-implanted GaN and Its Magnetic and Structural Properties*, *J.S. Lee, Z.G. Khim*, ***Y.D. Park***, Seoul National University, Korea, *S.N.G. Chu*, Agere Systems, *G.T. Thaler, M.E. Overberg, C.R. Abernathy, S.J. Pearton*, University of Florida

We report on the magnetic and structural properties of Co, Cr, and V ion-implanted epitaxial GaN films on sapphire substrates. Dilute magnetic semiconductors (DMS) with ferromagnetic ordering near or above room temperatures have been reported in Mn doped GaN[1] and Co doped TiO2,[2] subsequent to predictions from a near-field model for GaN doped with a relatively high concentration of Mn.[3] Theoretical treatment of ferromagnetic ordering in DMS systems have progressed to include low carrier density regimes[4] and incorporation of other magnetic impurities.[5] We have found from SQUID magnetization measurements that (Ga,Co)N and (Ga,Cr)N show ferromagnetic ordering below ~ 78 K and ~ 51 K respectively, while (Ga,V)N shows paramagnetic behavior. Structurally from TEM and Selective Area Diffraction Pattern (SADP) data, we have observed that the ion-implantation and subsequent annealing process leaves the expected residual damage in the form of dislocation loops, but no detectable second phases, which corresponds well with the observed modest coercive fields (~100 Oe for (Ga,Co)N) of the samples. By sharp contrast, the presence of ferromagnetic metallic clusters at dimensions below our detection limits would have expected coercivities in the range of thousands of Oersteds.

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MI-TuP11 The Effect of the Ferromagnet/Antiferromagnet Interface on Magnetic Properties of Fe/$KCoF_3$ System, *L.M. Malkinski, T. O'Keevan, R.E. Camley*, ***Z. Celinski***, University of Colorado at Colorado Springs, *D. Skrzypek*, University of Silesia, Poland

The Molecular Beam Epitaxy (MBE) system was used to grow Fe/$KCoF_3$ bilayers, a ferromagnet-antiferromagnet system. Depending on deposition conditions the fluoride can be grown on the single crystal Fe layer in either single crystal or polycrystalline forms. Structural properties of our samples were carefully studied using X-rays, Reflection High Energy Electron Diffraction (RHEED) and tunneling electron microscopy. The structure of the fluoride determines the ferromagnet/antiferromagnet interface and significantly modifies magnetic properties, which were measured using Ferromagnetic Resonance (FMR) and SQUID magnetometry. We observed changes in the exchange bias which correspond to different structural states of the antiferromagnet. This could result in different spin compensations at the Fe/$KCoF_3$ interface in single crystal and polycrystalline samples. The interface also had a dramatic effect on the four-fold magnetocrystalline anisotropy of Fe. For the samples with polycrystalline $KCoF_3$, the anisotropy thickness dependence for the single crystal Fe film, with thickness d ranging from 0.9 to 3 nm, showed a deviation from the usual 1/d dependence. The temperature dependence of the four-fold anisotropy of the samples with single crystal fluoride was typical of single crystal Fe films. However, the films with polycrystalline fluoride exhibited a distinctly different temperature behavior. The anisotropy for these samples increases significantly with decreasing temperature. The enhancement of the anisotropy was most pronounced for the samples with the thinnest Fe film changing by a factor of 3 from room temperature to low temperature. This effect is probably due to a specific morphology of the interface between the ferro- and antiferromagnet. In addition, a large rotational magnetic anisotropy, associated with the interaction between Fe and $KCoF_3$, was evaluated from the temperature dependence of the FMR fields.

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