POSTER PRESENTATION

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RL01

Synchronized modes of in-plane/out-of-plane spin-torque oscillators in MTJ with synthetic ferrimagnetic free layer

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There has been considerable interest in the phenomena of spin-torque oscillators (STO) in magnetic tunnel junctions (MTJs) for device applications, as well as the current induced magnetization switching (CIMS) resulting from the spin transfer torque (STT). In particular, the MTJs with synthetic ferrimagnetic (SyF) free layer is important since we can expect the cooperation and/or competition of the magnetization dynamics due to the interlayer coupling between magnetizations in the ferromagnetic bilayer. We analyze the magnetization dynamics self-consistently in the MTJs with SyF layer by iterative calculation following two steps. The STT in the ballistic regime is estimated, and the magnetization reversal is simulated by the LLG method at the finite temperature. We discuss the effect of the interlayer coupling on the STO. As the interlayer coupling increases, the change of the STO mode is observed, where the STO mode moved from the out-of-plane precession (OPP) to in-plane precession (IPP). From the mapping of the STO behavior on the plane with applied current and interlayer coupling, synchronized mode of STO appears in the region where the effective filed corresponding to the interlayer coupling is larger than the anisotropy field. These results suggest that the STO appears even without external magnetic field.

RL02

Interface material effects on magnetic anisotropy and its electric field induced variation in thin films

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The spintronics has grown up intensively to realistic applications in the technology of magnetic random access memory (MRAM) development. Such development has been remarkable in memory density, reading-writing speed, and non-volatile property in cooperation with the technologies of spin-injection and physics of spin transfer torque. The basic physics about magnetism has been developing in the response to electric field (EF). This has emerged as the connection with low power consumption device and small energy scale of magneto-electric effects. For the thin films [1,2] as a memory, sensitivity and large response may be required in device applications. Due to the limitation of EF penetration into the thin film, interface with a few metallic layers is critical to determine the response to the EF. We have investigated MgO/Fe/M(001) (M = Au, Pt) [3,4] with using the density functional calculation, in which the substrate of Pt was found to enhance the EF effect on magnetic anisotropy. In this work, in order to investigate influences of stacking structure for the interface, we investigate MgO/Fe/Pt/Au(001) and MgO/Fe/Pd/Au(001). In addition, results in MgO/Au/Fe/Au(001) are also discussed in the connection with segregation effects of film preparation, which may be expected in experiments.

[1] Y. Shiota et al., Appl. Phys. Express 2, 063001 (2009). [2] T. Nozaki et al., Appl. Phys. Lett. 96, 022506 (2010). [3] M. Tsujikawa et al., J. Appl. Phys., 109, 07C107 (2011). [4] M. Tsujikawa et al., submitted for publication.

RL03

Effect of spin relaxation rate on the interfacial spin depolarization in ferromagnet/oxide/semiconductor contacts

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The electrical injection and detection of spin-polarized carriers in semiconductors (SCs) has been successfully achieved by employing spin tunnel contacts and the Hanle effects. However, many aspects of the spin phenomena in these systems, e.g., (i) the location, magnitude, and sign of the induced spin accumulation, (ii) the unusual bias and temperature-dependence of the spin signal, and (iii) the unexpected short spin lifetime and its weak variation with temperature, require additional investigation. Here, we report the effect of spin relaxation rate on the interfacial spin depolarization (ISD) from the local fields in ferromagnet (FM)/oxide/SC contacts [1]. The combined measurements of normal and inverted Hanle effects reveal the effect of spin relaxation rate on the ISD [2] in CoFe/MgO/Si and CoFe/MgO/Ge contacts. We have observed, despite the similar amplitudes of the interfacial roughness and local magnetic fields, significant differences of the ISD [2] depending on the host SC; the spin accumulation exposed to similar local fields in different SCs give rise to a clearly different ratio of the inverted Hanle signal to the normal one. This can be understood in terms of two competing mechanisms in the host SCs, namely the spin relaxation and spin precession due to the local fields.

[1] K. R. Jeon et al., arXiv:1110.5978v1. [2] S. P. Dash et al., Phys. Rev. B 84, 054410 (2011).

RL04

Spin-pumping and revelation of inverse spin-Hall effect in n-type Si at room temperature

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Since spin-orbit interaction in n-type Si is very week due to its band structure and lattice inversion symmetry, observation of the spin-Hall effect in n-type Si has been believed to be difficult. Here, we report successful observation of the inverse spin-Hall effect (ISHE) in n-type Si at room temperature. The sample composes of a $Ni_{80}Fe_{20}$/n-type Si film with a doping concentration of 1.0×10^{19} 1/cm^3. The n-type Si surface was etched by hydrofluoric acid to remove the naturally-oxidized Si. A ferromagnetic $Ni_{80}Fe_{20}$ was formed by using electron beam lithography and deposition methods on the n-type Si. Two electrode-pads were attached to the n-type Si layer to detect the electromotive force in the Si. In a ferromagnetic resonance condition of the $Ni_{80}Fe_{20}$, a pure spin current was injected into the n-type Si layer by the spin pumping. If ISHE is induced in the n-type Si, the spin current is converted to a charge current. Here, the ISHE in the n-Si was observed. The output voltage due to the ISHE was estimated to be 0.4μV. The voltage sign was inverted by the magnetization reversal of the $Ni_{80}Fe_{20}$. In this presentation, we discuss details of the inverse spin-Hall effect in the n-type Si.

RL05

Critical current density and domain wall mobility in nanowires with exchange coupled hard-soft magnetic layers

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In this study, critical current density and domain wall mobility of current driven domain wall motion in nanowires composed of TbFeCo and NiFe layers have been studied. TbFeCo layer has perpendicular magnetic anisotropy. Wires and electrode are fabricated by photolithographic method. Current pulses with width less than 100 ns are applied to drive the domain wall in the wires. The domain structure is observed by a high resolution Kerr microscope. We found critical current density decreases in the soft-hard bi-layered structure compared to a single TbFeCo layer. Nanowires of single TbFeCo layer have critical current density of 5×10^6 A/cm^2; however, the critical current density in bi-layered structure has critical current density as small as 2×10^6 A/cm^2. The domain wall mobility is deduced from the dependence of domain wall velocity on the applied current density. We found that the domain wall mobility improved by almost two times with the introducing of the NiFe layer. Of particular interesting is that, micromagnetic simulations show that the Bloch walls in perpendicular TbFeCo wires change to Neel walls with the introducing of NiFe layer. Our experimental results suggest nano-wires composing of soft-hard layers suitable for race track memory.

RL06

Spin Seebeck Effect in SiO_2/Py structures

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Recently, spin version of Seebeck effect, the spin-Seebeck effects (SSE) was observed experimentally at room temperature[1]. For the SSE, it is expected that the voltage sign at the hot end is opposite to that at the cold end and the absolute magnitudes of the voltages at the hot and cold ends are the same. However, it is often observed that an asymmetric magnitude of the voltage at the hot and cold ends [2]. The origin of this asymmetric behavior is attributed to an additional temperature gradient along the thickness direction, which generates an additional voltage signal due to the anomalous Nernst-Ettingshausen effect(ANE) [2]. In this study, we investigated the dependence of the SSE and the ANE on the thickness of the ferromagnetic layer in SiO_2/Py samples. In our results, the sign change in the voltage signal between the hot and cold ends was not observed. Instead, we obtained an offset voltage due to the mixture of SSE and ANE signals. We attribute this offset to the longitudinal SSE caused by an additional temperature gradient along the thickness direction of Py layer. A possible origin of the dependence of offset voltage on Py thickness will be discussed in detail.

[1] K. Uchida et al., Nature, 455, 778-781 (2008). [2] S. Bosu et al., Phy. Rev. B 83, 224401 (2011).

RL07

Domain wall pinning by stray field from NiFe on Co/Ni nano-wire

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Control of a magnetic domain wall (DW) displacement in a ferromagnetic nano-wire is essential in its potential application for nonvolatile magnetic memories. Parkin et al. demonstrated a race track memory device by controlling DW displacement in a NiFe nano-wire with notch structure [1]. However, the structure with notch has two problems such as i) transformation of DW structure and ii) increase of current density due to the change of the wire width between notch and wire part. Here, to make new DW pinning method without the change of wire width, we focus on the DW pinning in Co/Ni nano-wire by the stray field from ferromagnetic stack.We prepared two types of devices; one was a simple wire of Ta/Pt/[Co(0.2 nm)/Ni(0.6 nm)]$_4$/Co(0.2 nm)/Pt/Ta, and the other was a wire of Ta/Pt/[Co(0.2 nm)/Ni(0.6 nm)]$_4$/Co(0.2 nm)/Pt/Ta on which NiFe/SiO_2 was stacked partly. To investigate an influence of the stray field from the NiFe stack, DW depinning field (H_{dep}) was measured for both types of wires. H_{dep} of the wire without the NiFe stack was 200 Oe, while the wire with that had larger H_{dep} of 700 Oe, indicating the effectiveness of the use of the stray field to control the DW position.

[1] S. S. P. Parkin, et al., Science 320, 190 (2008).

RL08

Compositional dependence of critical current density for spin transfer torque switching of amorphous GdFeCo for thermally assisted MRAM

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Spin transfer torque (STT) switching has been demonstrated in magnetic tunneling junctions (MTJ) with perpendicular magnetic anisotropy (PMA), which exhibits a low critical current density compared to their in-plane counterparts [1]. In this paper, we fabricated giant magneto-resistance (GMR) devices consisting of bottom electrode/ [Pd (1.6)/Co (0.4)]$_6$/$Co_{40}Fe_{40}B_{20}$ (0.5)/Cu (3)/ $Gd_x(Fe_{90}Co_{10})$100-x (10)/Cu (5)/top electrode (thickness in nanometer). The R-I loops were measured for 120×180 nm^2 cell with $Gd_x(Fe_{90}Co_{10})_{100-x}$ memory layers, and the STT switching property of these devices was estimated from the resistance measurement after applying current pulses with a duration of 100 ms. In TM-rich compositions, the average value of the critical current density Jc increased from 2.0×10^7 A/cm^2 for x = 22.3 at.% to 4.5×10^7 A/cm^2 for x = 24.0 at.% with increasing x, while the Jc reduced to 1.4×10^7 A/cm^2 for RE-rich $Gd_{28.9}(Fe_{90}Co_{10})_{71.1}$. It is noted that the values of Jc are comparable to the results in conventional MTJs[2]. The difference of Jc values may be due to the difference of the effective perpendicular anisotropy and/or the Curie temperature of the GdFeCo layer. The dependence of Jc on the current pulse width and temperature will be discussed in the presentation.

[1]S. Ikeda, et al. Nature Materials 9, 721-724 (2010). [2]Y. Huai, et al. Appl.Phys.Lett. 82, 222510 (2005).

RL09

Microscopic theory of magnon-drag thermodynamic transport in ferromagnetic metals

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We study the thermodynamic transport carried by magnons in ferromagnetic metals. In this study, the Peltier effect caused by a magnon heat current (magnon-drag Peltier effect) is described in a microscopic model. Magnons can indirectly interact with electric fields via electron-magnon interaction; we evaluate the magnon heat current perturbatively with respect to the electron-magnon interaction in the 2nd order. As a consequence, we found out that the magnon heat current is proportional to the spin current carried by the spin polarized electric current drifted by the electric filed, that is, the magnon-drag Peltier coefficient is governed by the spin polarization of the electric current. This is in contrast to the phenomenological result derived by Grannemann and Berger [1] in which the coefficient is proportional to the electric current directly. In addition, we show the temperature dependence of the Peltier coefficient is $T^{5/2}$ in low temperature. These results indicate that, in the inverse effect (Seebeck effect) of the Peltier effect, the magnon heat current caused by a temperature difference induces the spin current, and the temperature dependence of the Seebeck coefficient is $T^{3/2}$.

[1] G. N. Grannemann and L. Berger, Phys. Rev. B 13, 2072 (1976).

RL10

Electric-field control of magnetic properties in cobalt by means of electric double layer

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Electric-field effect on magnetism using a capacitance structure (gate electrode/insulator/ferromagnetic) has actively investigated to open up a new technology for an electrically manipulation of magnetization [1-10]. Here, we show electric field control of magnetic properties in Co using an electrical double layer (EDL) formed at the interface between the Co layer and a polymer film containing an ionic liquid. The polymer film containing the ionic liquid was put on a 0.4-nm-thin-Co-film and Pt-thin-film was placed on the top of the polymer film as a gate electrode. For the direct detection of the magnetization under the gate-voltage (Vg), superconducting quantum interference device [6] was used. Magnetization curves were measured at 300 K under the application of Vg from -2.0 V to +2.0 V. Dramatic change of coercivity was observed depending on Vg. To investigate the mechanism of this, we measured temperature dependences of the remanent magnetization under the different Vg. The significant increase of Curie temperature from ~320 K at Vg = 0 V to ~370 K at 2.0 V was observed. Thus, the dramatic change in corecivity at 300 K presented here is attributed to this large modulation of Curie temperature [10].

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RL11

Spin-torque magnetic resonance of superparamagnetic Fe nano-particles in Fe/MgO/Fe magnetic tunnel junctions

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During the past decade, electric detection and manipulation of submicron-scale magnet have been conducted by using magnetoresistance (MR) effect and spin-torque. Now, a great deal of interests in manipulating nano-scale magnets (or single-spin) and physics of spin-torque in such a small system are taken. In this study, we employ superparamagnetic Fe nano-particles and the single-crystal MgO based magnetic tunnel junctions (MTJs) [1]. The magnetic resonance of super-paramagnetic Fe nano-particles is electrically excited by spin-torque and detected by the spin-torque diode effect [2,3]. The structure of the MTJs is as follows: MgO(100) substrate/Fe film (50 nm)/MgO (1.35 nm)/Fe nano-particles (2.1 nm)/capping layer. All of the layers were grown by molecular beam epitaxy. The RF detection mechanism is explained as the homodyne detection of the applied RF current because of the oscillation of resistance at the same frequency. In the measurements, the resonant peak was observed around 5 GHz under a magnetic field of 5 kOe at room temperature, for example. This represents that the magnetic resonance of superparamagnetic Fe nano-particles was electrically excited and detected. We thank Y. Shiota, H. Tomita, G. Shiomi for valuable discussions. This work is supported by Grant-in-Aid for Scientific Research (S), MEXT, Japan. (No. 23226001)

[1] S. Yuasa et al., Nature Mater. 3, 868 (2004). [2] A. A. Tulapurkar et al., Nature 438, 339 (2005). [3] S. Ishibashi, S. Miwa et al., submitted.

RL12

Spin Coulomb drag and optical excitations in low dimensional systems

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Within the remit of new quantum technologies, an intense effort is devoted to improving our understanding of spin dynamics, with the aim of building novel spintronics devices. In this context the theory of spin Coulomb drag (SCD) was recently developed. It shows that Coulomb interactions are an intrinsic decay mechanism for spin currents. As confirmed by experiments, SCD can be substantial in semiconductors, and it is bound to become one of the most serious issues in spin polarized transport, since, due to its intrinsic nature, it cannot be avoided even in the purest material. More recently the influence of SCD on optical spin-injection and spin-resolved optical experiments has been considered. Here we report on SCD effects on intersubband optical spin excitations in III-V quantum wells, where SCD may contribute substantially to the linewidth of spin plasmons. By going beyond the usual local density functional approximation and properly including the effects due to the inhomogeneity of the system in the growth direction, we show that the quantization of states in the growth direction may strongly reduce the intrinsic plasmon linewidth.