Abstracts of Poster Session

①

Oct 13, 17:45-19:45

N-1

Spin-related phenomena detected by spin current

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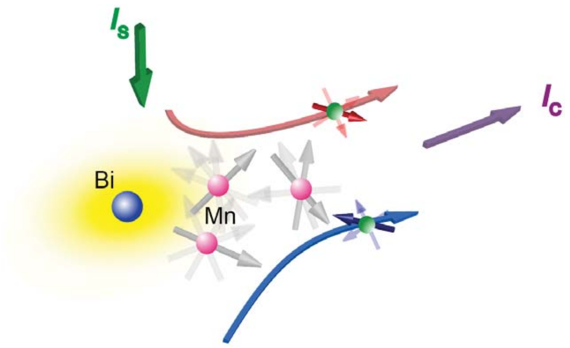
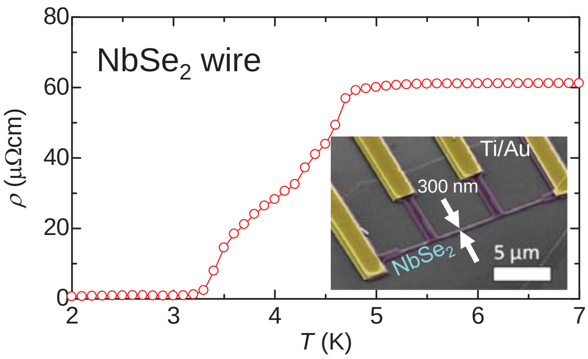
The generation and manipulation of spin current, flow of spin angular momentum, are at the heart of modern spintronics. The spin Hall effect (SHE) and its inverse (ISHE) are the most promising methods to enable the interconversion between charge and spin currents. In the research group, we aim to utilize the spin current as a new probe to detect electrically spin-related phenomena via the SHE and ISHE. In this presentation, we will detail our recent result on the SHE in spin-glass, which is a typical frustrated spin system. We will also show current status on the SHEs in several types of superconductors (conventional *s*-wave, possible *p*-wave, and layered superconductors).





N-2

detection of antiferromagnetic phase transition by spin current

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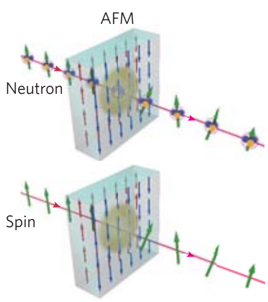
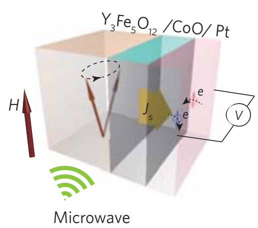
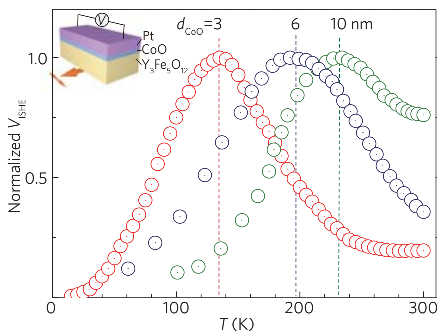
Spin fluctuation and transition have always been one of central topics of magnetism and condensed matter science. To probe them, the spin fluctuation is found transcribed onto scattering intensity in the neutron scattering process, which is represented by dynamical magnetic susceptibility and maximized at phase transitions. Importantly, a neutron carries spin without electric charge, and it can bring spin into a sample without being disturbed by electric energy, although large facilities such as a nuclear reactor is necessary. Here we show that spin pumping, frequently used in nanoscale spintronic devices, provides a desktop micro probe for spin transition; spin current is a flux of spin without an electric charge and its transport reflects spin excitation. We demonstrate detection of antiferromagnetic transition in ultra-thin CoO films via frequency dependent spin-current transmission measurements, which provides a versatile probe for phase transition in an electric manner in minute devices.







N-3

Large spin-to-charge conversion in Pt/graphene lateral nanostructures

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Electrical generation and detection of pure spin currents without the need of magnetic materials are key elements for the realization of full electrically controlled spintronic devices. Here we exploit the spin Hall effect (SHE) and the inverse spin Hall effect (ISHE) by using Pt, a non-magnetic metal with strong spin-orbit coupling, to inject and detect pure spin currents in a 2D graphene channel. Figure 1 shows the detection of the spins flowing in graphene with Pt using the ISHE. This promising approach prevents the use of interfacial barriers, needed when ferromagnetic metals are employed, which suffer from low reproducibility. Furthermore, the outstanding properties of graphene, with long spin transport with relatively high electrical resistivity, allows us to achieve in our graphene/Pt lateral nanostructures the largest spin-to-charge voltage signal, ΔR_{SCC}, reported so far in the literature at room temperature (see Fig. 2), opening up exciting opportunities towards the implementation of spin-orbit-based logic circuits.

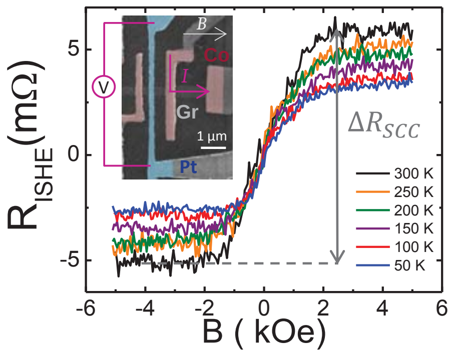

Fig. 1: ISHE resistance (V/I) as a function of the magnetic field *B* at different temperatures. Inset: SEM image of the Pt/graphene lateral nanodevice with the ISHE measurement configuration.

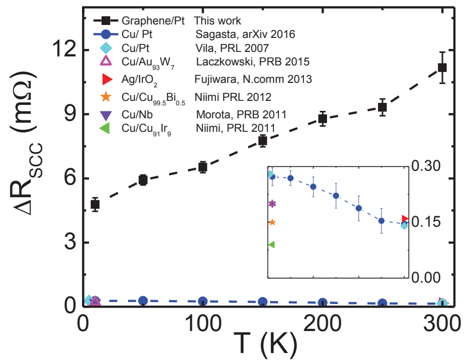

Fig. 2: Experimentally measured ΔR_{SCC} as a function of temperature for different spin Hall metals employing different spin channels. Inset: Zoom of the previous plot showing the data of the devices with metallic spin channels.

N-4

Observation of charge-to-spin current conversion by Dirac surface state of topological insulators

K. Kondou[1], R. Yoshimi[1,2], A. Tsukazaki[3], Y. Fukuma[1,4], J. Matsuno[1], K. S. Takahashi[1], M. Kawasaki[1,2], Y. Tokura[1,2] and Y. Otani[1,5]

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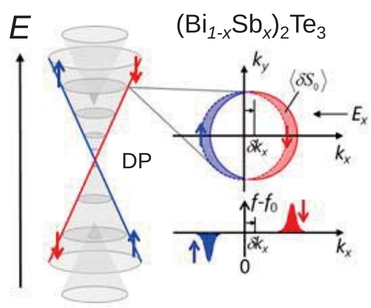
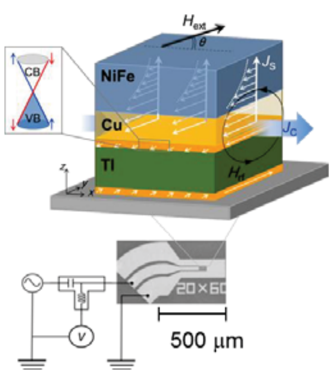
The spin-momentum locking in the surface state offers a possibility of a highly efficient charge-to-spin current (C-S) conversion compared with ordinary spin Hall effect in paramagnetic metals. By applying spectral analysis based on spin-torque FMR to topological insulator (TI) /non-magnetic metal/ferromagnetic-metal tri-layer films, we succeeded in determining the C-S conversion efficiency of a surface state of TIs.

C-to-S conversion in surface state of TI



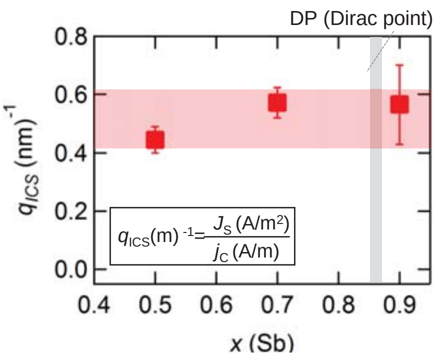
- Spin accumulation <δS_0>due to Fermi circle shift at surface state

Spin torque FMR



- Spin current J_S flows into NiFe (FM layer) from TI surface.

C-to-S conversion coefficient



- Conversion coefficient in surface state of TI shows almost constant value.

N-5

Large unidirectional magnetoresistance in magnetic topological insulator

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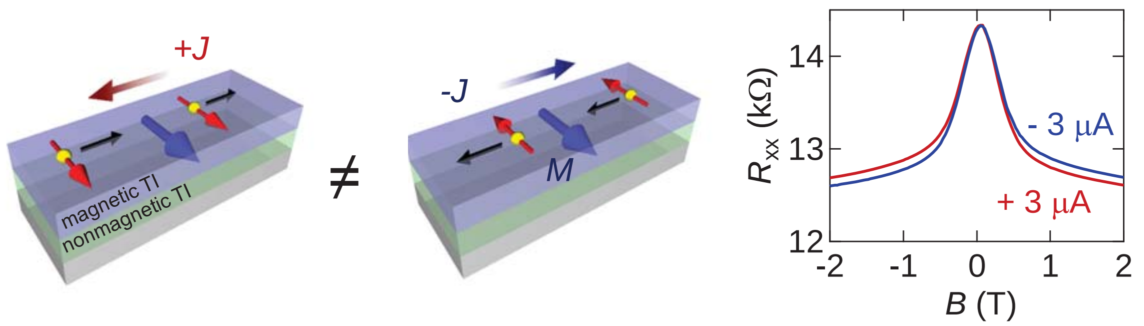
Interactions between conduction electrons and magnetization perceive various kinds of magnetoresistance. Among them, current-direction dependent or unidirectional magnetoresistance (UMR) has recently been found as a nonlinear current-voltage characteristic for heterostructures composed of ferromagnet and normal metal. Here, we report on the UMR in magnetic/nonmagnetic topological insulator (TI) heterostructures, $Cr_x(Bi_{1-y}Sb_y)_{2-x}Te_3/(Bi_{1-y}Sb_y)_2Te_3$, that is shown to be several orders of magnitude larger than those in other previously reported systems. From the angular, magnetic field and temperature dependence, the UMR is identified to originate from the asymmetry in scattering of surface Dirac electrons by magnons. Fermi energy dependence of the UMR is also discussed.



N-6

Magnetization Switching via Charge Transfer in a [CrCo] Complex

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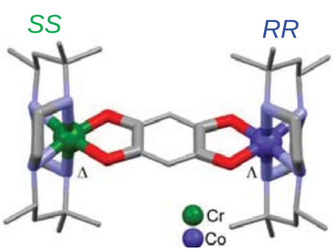
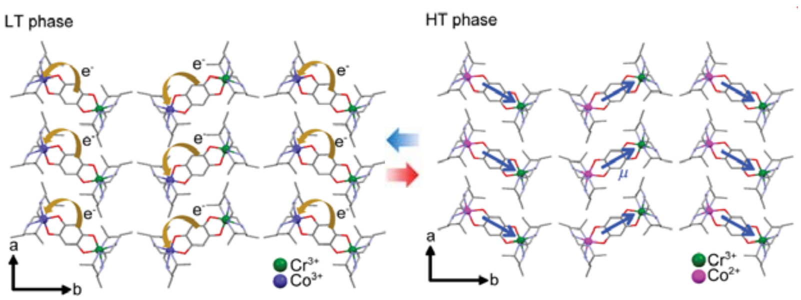
Molecular materials possessing reversibly switchable physical properties are attracting considerable interest in view of their potential applications as multifunctional molecular devices, including ultra-high-density data storage technologies and sensors. Various switchable compounds have recently been reported such as valence tautomeric compounds and multinuclear mixed-valence compounds, where thermally- and photo-induced charge transfers occur between the two redox-active sites. We devised a synthetic and crystal engineering strategy that enables the selective synthesis of a [CrCo] heterometallic valence tautomeric complex with a polar crystal structure, wherein magnetization and polarization changes stem from intramolecular charge transfer between Co and the ligand. Magnetization and polarization can be modulated both by visible-light irradiation and temperature change.



[CrCo] Complex



Thermally- and photo-induced directional electron transfer

N-7

Direct observation of spin accumulation at Rashba-like interface

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Spin Hall effect and Rashba effect describe how electrons moving in an electric field experience a momentum dependent magnetic field that couples to the electron angular momentum (spin). This physical phenomena permits the generation of spin polarization from charge current, which in turn leads to the build up of spin accumulation. Spin Hall effect produces spin polarization with opposite sign on opposite edge of the sample, which was detected in bulk semiconductors by using Kerr rotation microscopy. In contrast to the Spin Hall effect, the spin polarization due to Rashba effect is expected to be uniform and oriented in plane, which has been suggested for applications as spin filter device. However, so far the direct detection of uniform in-plane spin accumulation has been elusive. Here, we report the direct observation of spin accumulation at the Rashba interface formed between non-magnetic metal (Cu, Ag) and insulator (Bi_2O_3). We show that the spin accumulation as predicted is in-plane and uniform all over the interface area.

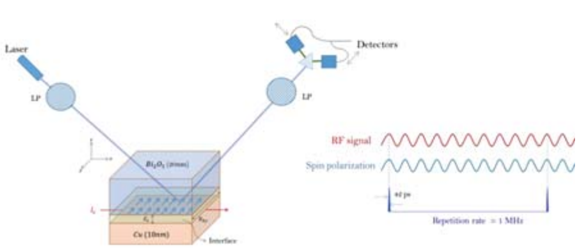

Fig. 1. Longitudinal magneto-optical Kerr effect setup for optical detection of spin accumulation.

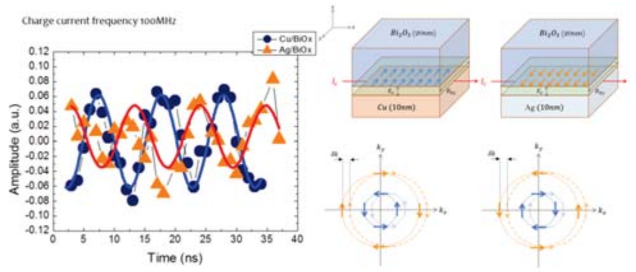

Fig. 2. Optical detection of spin accumulation at Cu/Bi_2O_3 (blue) and Ag/Bi_2O_3 (orange) interface. Right hand side, shows schematics of the expected spin accumulation for Cu/Bi_2O_3 and Ag/Bi_2O_3 interfaces, and their corresponding Fermi contour representations.

N-8

Spin transport in *n*-Ge and *p*-Ge

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Germanium (Ge) is expected to be utilized as a next generation channel material in CMOS because of high electron and hole mobility and the compatibility with existing Si large-scale integration technology. To integrate spintronics with Ge, we need to observe and understand the spin transport in Ge.

We experimentally explored pure spin current transport in ferromagnetic Heusler alloys/Ge lateral spin-valve devices (LSVs) shown in Figs. 1(a) and 2(a). For both electrons and holes, spin transport was clearly observed at low temperatures, as presented in Figs. 1(b) and 2(b). From the comparison between experimental data and the one-dimensional spin diffusion model, spin relaxation times were estimated to be several hundreds ps for electrons and several tens ps for holes in Ge. Temperature dependence of spin signals will be discussed in detail.

This work was partly supported by a Grant-in-Aid for Scientific Research on Innovative Areas 'Nano Spin Conversion Science' (No. 26103003) from MEXT and a Grant-in-Aid for Scientific Research (A) (Nos. 25246020 and 16H02333) from JSPS. M. Kawano and Y. Fujita acknowledge JSPS Research Fellowships for Young Scientists.

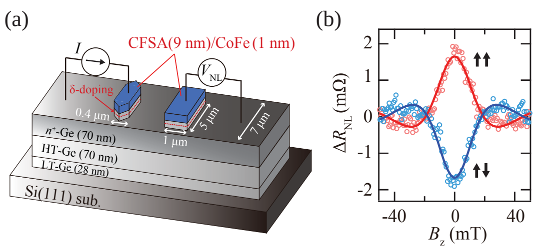

Fig. 1 (a) Schematic of a $Co_2FeSi_{0.5}Al_{0.5}/CoFe/n^+$-Ge LSV. (b) Nonlocal Hanle effect curves at 8 K.

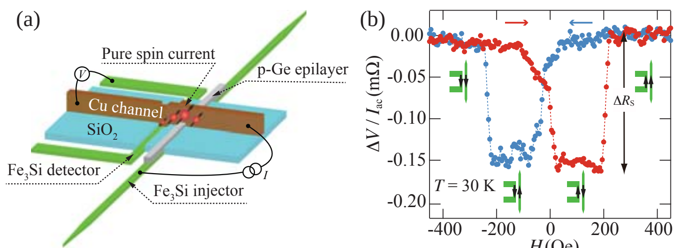

Fig. 2 (a) Schematic of a $Fe_3Si/Cu/p$-Ge/Fe_3Si LSV. (b) A nonlocal magnetoresistance curve at 30 K.

N-9

Laser–induced spin-wave in metals under microscope

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Spin-wave or its quantum, magnon, is studied with renewed interest as a basis for wave-based classic information processing without electric charge. Even though there are many fundamental issues, it is interesting to seek a way for an efficient excitation of spin-wave and to know how to transfer information between light and spin-wave. Here we study on the laser-induced spin-wave in magnetic metals under microscope (Fig. 1) because spin-wave dispersion in metals can be tuned by the interfacial anti-symmetric exchange interaction and also the externally applied electric field. The pulse laser-induced coherent spin-wave propagation was clearly observed and its propagation were highly symmetric or reciprocal (Fig. 2). We discuss symmetry and non-reciplocity of laser-induced spin-wave in metals.

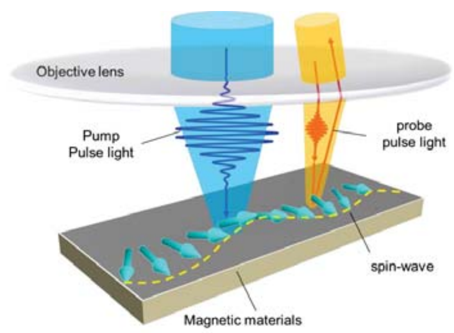

Fig. 1 The cartoon of the experiment.

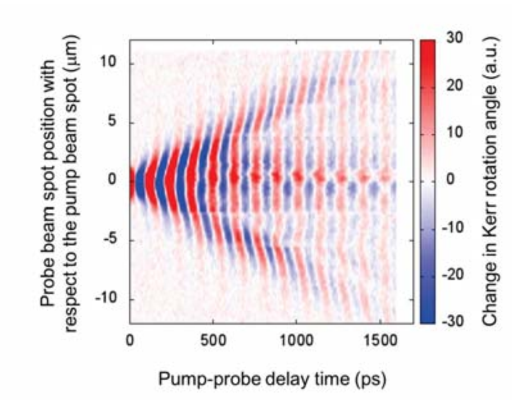

Fig. 2 Laser-induced spin-wave in CoFeB.

N-10

Spin Conversion from Spin Waves into NV Centers in Diamond

T. An

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Nitrogen vacancy center (NV center) in diamond crystal, spin states in a pair of carbon defect and substituted nitrogen, are attracting much attention for utilizing it as a magnetometer. The NV center can detect stray magnetic field from spins and magnets existing around at single spin sensitivity and nanometer-scale resolution.

We focus on to utilize the NV center as a nano spin detector converting spin signal into the NV center. In this study, spin waves is excited in a yttrium iron garnet (YIG) magnet, and the spin signal from spin waves propagating from one side is converted to a nanodiamod hosting the NV center at the other side of sample (Fig. 1(a)). Figure 1(b) and (c) show confocal image nanodiamonds hosting the NV centers spread on the YIG sample, and the stray magnetic fields from magnetic domains were detected by optically detected magnetic resonance (ODMR) (Fig. 1(c)).

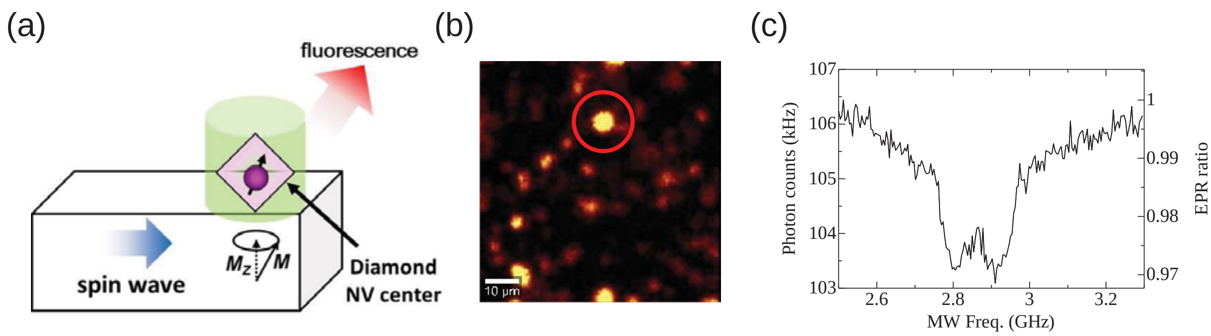

Fig. 1

Spin conversion at interface of metal and dielectric

N-11

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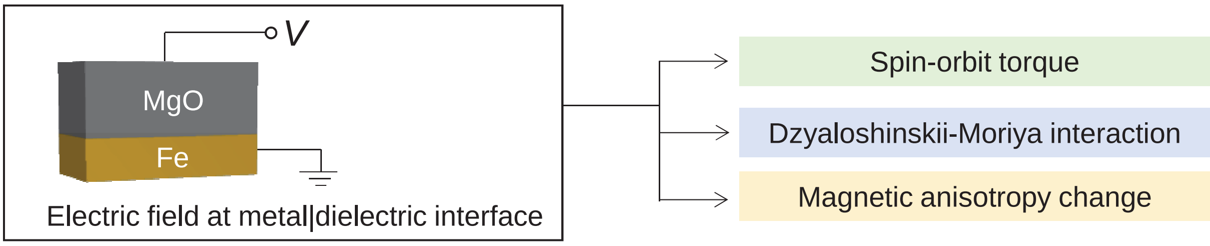
Coauthors: P. Risius, K. Nawaoka, K. Matsuda, K. Tanaka, M. Goto, F. Bonell, E. Tamura, Y. Suzuki (Osaka U) M. Suzuki, T. Nakamura, Y. Kotani (JASRI), M. Tsujikawa, M. Shirai (Tohoku U), T. Ohkubo, K. Hono (NIMS), T. Nozaki, S. Yuasa (AIST)

Electric fields at surface or interfaces provide useful phenomena such as switching function in field-effect transistors through electron accumulation and/or electric dipole induction. In this poster, we show electric field induction of magnetic properties at interface of Fe and MgO.

At Fe|MgO interface, a large interfacial spin-orbit torque can be generated. An Fe|MgO|V system shows large spin-torque about 4×10^{9} (1/Vs) which is comparable to the spin-transfer torque in magnetic tunnel junctions with low resistance area product. We also show electric-field induces electric-dipole and generates interfacial Dzyaloshinskii-Moriya interaction. In addition, at metal|dielectric interface, electric field is atomically inhomogeneous due to the strong electrostatic screening effect in metals. Such field enables us to access electric-quadrupole. We found that the electric-quadrupole induction is correlated to the magnetic anisotropy energy change at metal|dielectric interface.



This work was supported by Grant-in-Aid for Scientific Research and ImPACT program, Japan.

N-12

Graphene spin-charge converter controlled by gate voltage

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Graphene—a single layer of carbon atoms arranged in honeycomb lattice—has a thickness 6 times smaller than the diameter of DNA helix in human body or 300000 times thinner than the human hair. Surprisingly, on this short distance, graphene is able to scatter electrons to opposite directions depending on their spin. Thus, graphene works as an extremely thin spin-to-charge converter, but how exactly does it happen—is still a big question.

In this study, we used microwaves to pump spins into the single-layer graphene from the adjacent yttrium iron garnet ferrimagnetic insulator layer. After that we controlled conversion of the pumped spins by using ionic gel top gate. We showed that efficiency of the spin-to-charge conversion in graphene is independent of the applied electric field: a previously missing step that was necessary to determine the spin-charge conversion mechanism. Our result also showed that graphene can work as a stable spin-charge converter, while other electric properties can be tuned by the applied electric field: a promising feature for the future magneto-electric devices. [S. Dushenko et al., Phys. Rev. Lett. **116**, 166102 (2016)]

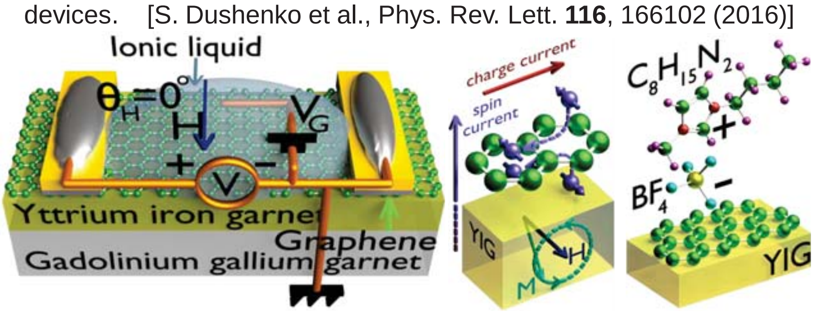

Fig. 1. (Left) Layout of the spin-charge conversion experiment. (Center) Under the ferromagnetic resonance pure spin current was transferred through the ferrimagnetic insulator / graphene interface and converted into an in-plane charge current. (Right) Schematic view of an electric gate using ionic gel.

N-13

Majorana Bound States in Magnetic Skyrmions

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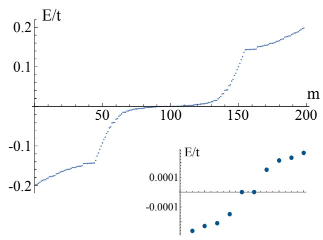
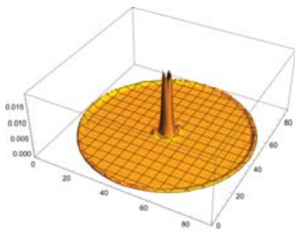
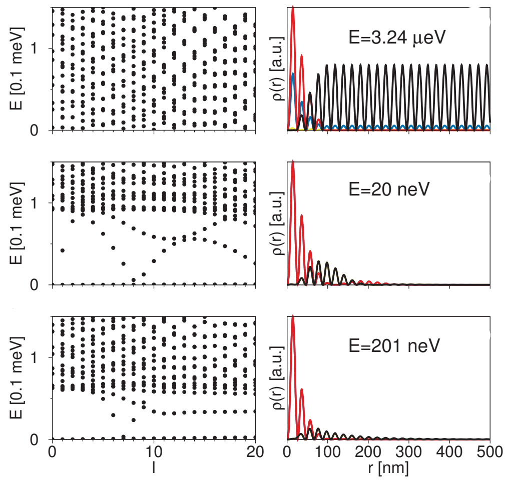
Magnetic skyrmions are highly mobile nanoscale topological spin textures. We show, both analytically and numerically, that a magnetic skyrmion of an even azimuthal winding number placed in proximity to an s-wave superconductor hosts a zero-energy Majorana bound state in its core, when the exchange coupling between the itinerant electrons and the skyrmion is strong. This Majorana bound state is stabilized by the presence of a spin-orbit interaction. We propose the use of a superconducting tri-junction to realize non-Abelian statistics of such Majorana bound states.







N-14

Magnon instability driven by heat current

Y. Ohnuma[1,2], H. Adachi[3], E. Saitoh[1,2,4-6] and S. Maekawa[1,2]

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Gilbert damping constant is known to determine the efficiency of reversal of magnetization in ferromagnets and is important for applications. Recently, suppression of the Gilbert damping constant by temperature gradient has been observed in a ferromagnet/paramagnet bilayer system [1] and other systems.

In this presentation, we report the analytical result on the Gilbert damping constant in the ferromagnet/paramagnet bilayer system under a temperature bias and explain the experiment in [1]. We show that phonon heat current has remarkable influences on the magnon lifetime in the bilayer via the phonon drag mechanism. The magnon instability driven by heat current (Fig. 1) is also discussed.

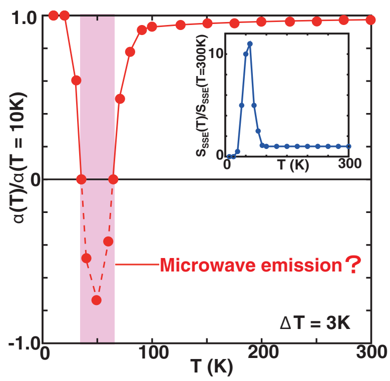

Fig. 1. The temperature dependence of the Gilbert damping constant calculated for a YIG/Pt under a temperature bias ΔT=3K [1]

[1] L. Lu *et al*., Phys. Rev. Lett. **108**, 257202 (2012)

[2] Y. Ohnuma *et al*., Phys. Rev. B **92**, 224404 (2015)

N-15

Non-reciprocal responses in Rashba system

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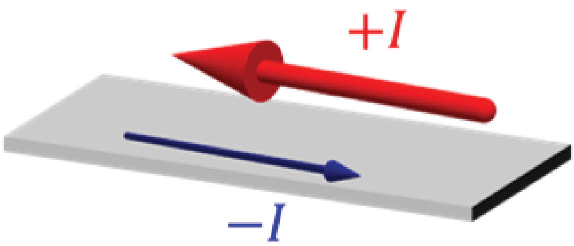
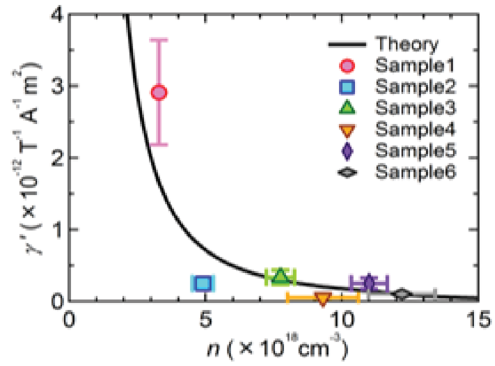
Non-reciprocal responses are consequences of the inversion symmetry breaking where lots of physical responses have directivity. The electrical resistivity, which is the most fundamental physical property of materials, also shows the non-reciprocity**: the resistivity depends on the direction of the current** as $R(j) = R_0(1 + \gamma' B j)$. In this research, the **non-reciprocal electrical response in polar semiconductor BiTeBr** is investigated. The measured non-reciprocity coefficient γ' is quantitatively reproduced by simple model: **Boltzmann equation for Rashba Hamiltonian with in-plane magnetic field**. In this presentation, we explain mainly about the theoretical model and the analysis of the non-reciprocal electrical responses.





N-16

Efficient domain wall transport and pinning in magnetic nanowires and synthetic ferrimagnets

S. Lepadatu,[1,2] H. Saarikoski,[3] R. Beacham,[4] M. J. Benitez,[4,5] T. A. Moore,[1] G. Burnell,[1]
S. Sugimoto,[1] D. Yesudas,[1] M. C. Wheeler,[1] J. Miguel,[6] S. S. Dhesi,[6] D. McGrouther,[4]
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Domain walls in ferromagnetic nanowires are potential building-blocks of future technologies such as racetrack memories, in which data encoded in the domain walls are transported using spin-polarised currents. However, the development of energy-efficient devices has been hampered by the high current densities needed to initiate domain wall motion. We show that an order of magnitude reduction in the critical current density to 1.0×10^{11} Am^2 can be achieved for in-plane magnetised coupled domain walls in CoFe/Ru/CoFe synthetic ferrimagnet tracks [1]. Theoretical modelling indicates that this is due to nonadiabatic driving of anisotropically coupled walls. Moreover, for memory applications, techniques to *stop* a moving wall at intended positions precisely and without delay is essential. We propose that an array of locally-embedded Rashba interaction can be used as pinning centers for current-driven domain walls (see Fig. 2 and Ref. [2]).

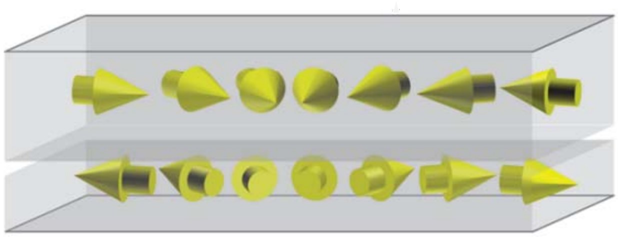

Fig. 1 Domain wall in a synthetic ferrimagnet.

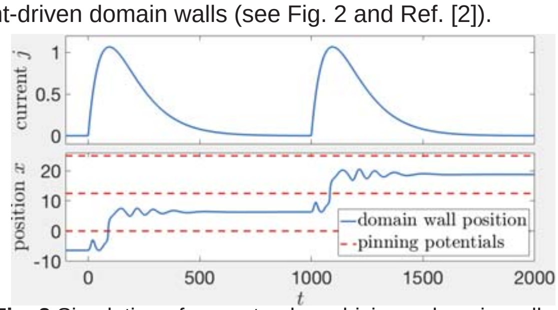

Fig. 2 Simulation of current pulses driving a domain wall.

[1] S. Lepadatu *et al.*, arXiv:1604.07992 [2] G. Tatara, H. Saarikoski, C. Mitsumata, arXiv:1608.06044

N-17

Detection of voltage excited spin wave by ps-TRMOKE

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We report detection of voltage excited spin wave by pico-second time-resolved magneto-optical Kerr-effect (ps-TRMOKE) microscope. The spin waves are excited by modulating perpendicular magnetic anisotropy of $Co_{20}Fe_{60}B_{20}$ with rf voltage (V_{rf}) and measured by a linearly polarized pico-second (ps) pulsed laser beam focused with a spot size of about 600 nm in longitudinal MOKE geometry. The decay length (λ_d) of excited magnetostatic surface spin waves (MSSW) is about 2.1 μm and group velocity (v_g) is about 0.35 $\mu m.ns^{-1}$ at 10 mT bias magnetic field (H). We got reasonably good agreement of these values with the micromagnetic simulations and theoretical values. For voltage excitation, spin wave amplitude monotonically increases with the increase of H, whereas for Oersted field excitation, the amplitude reaches to maxima and starts to decrease after that. These behaviors are supported by our micromagnetic simulations. We think our results have a large impact for the development of future spin wave based logic devices.

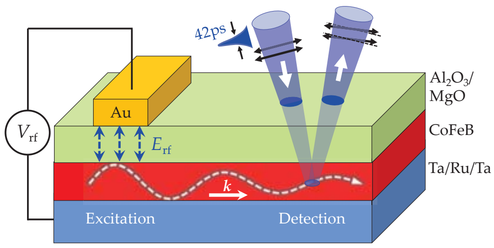

Fig. 1: Schematic of device and experiment

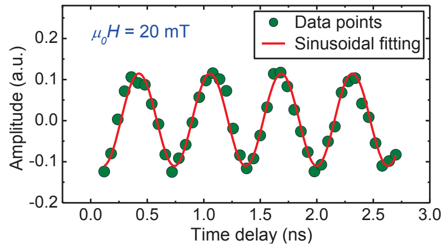

Fig. 2: Spin wave signal as a function of time

N-18

Doppler shift picture of the Dzyaloshinskii-Moriya interaction

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In our work [1], we showed that the origin of the DM interaction is the Doppler shift due to an intrinsic spin current induced by the spin-orbit interaction. As the result, the DM coefficient is given as the expectation value of the spin current of electrons. We examined our claim by performing first-principle calculation for the magnitudes of the equilibrium spin current in $Mn_{1-x}Fe_xGe$ and $Fe_{1-x}Co_xGe$. For comparison, we also calculated the DM coefficient D as the first derivative of E(q) = Dq+Jq^2, where E(q) is the total energy of electrons as a function of the magnetization wave number q. The numerical results of the DM coefficient by the two different approaches agreed well with each other (Figure below). Moreover, the experimental values of x where the DM coefficient changes its sign are well reproduced. These results show the numerical accuracy of our identification of the DM coefficient as the magnitude of the spin current.

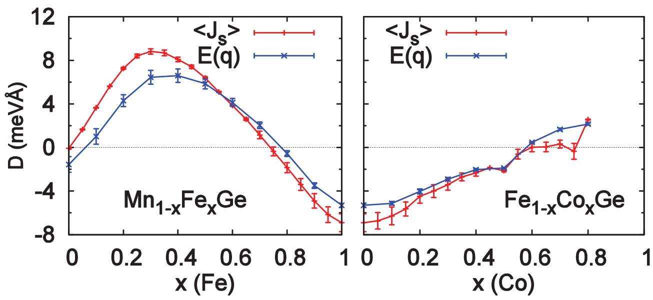

Fig: The numerical results of the Dzyaloshinskii-Moriya coefficient D. One is calculated as the intrinsic spin current D=<Js>, and the other is by the total energy of electrons E(q)=Dq+Jq^2.

[1] T. Kikuchi, T. Koretsune, R. Arita, and G. Tatara, Phys. Rev. Lett. 116, 247201 (2016)

N-19

Electrical modulation of damping constants in (Ga,Mn)As

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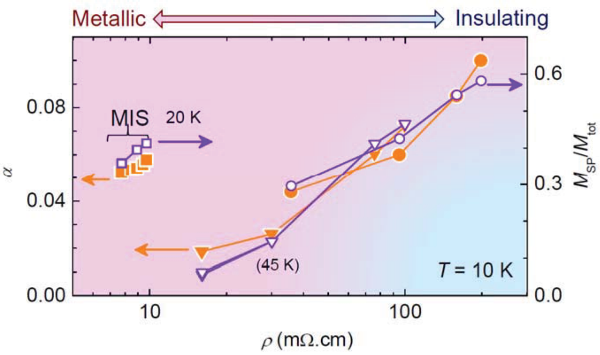
The damping constant α is a fundamental parameter, which governs the magnetization dynamics, and determines the performance of spintronics devices. In this work, we investigate a possible control of α of (Ga,Mn)As by applying an electric field E.

We fabricate capacitance structures with a 4-nm-thick (Ga,Mn)As as one of the electrodes to apply external electric fields. From the linewidths of ferromagnetic spectra under E up to 4 MV/cm, we find that α of (Ga,Mn)As can be modulated by 5%. The modulation ratios of other magnetic material parameters, such as saturation magnetization, magnetic anisotropy, and g factor, are much smaller.

Figure shows the comparison of the electrical resistivity dependence of α with that of magnetization, which indicates that the magnetic disorder induced by carrier localization plays a measure role in determining the magnitude of α in (Ga,Mn)As [1].



The work was done with L. Chen and H. Ohno, and was supported in part by a Grant-in-Aid for Scientific Research on Innovative Areas (No. 26203002) and R&D Project for ICT Key Technology to Realize Future Soceiry of MEXT.

[1] L. Chen, F. Matsukura, and H. Ohno, Phys. Rev. Lett. **115**, 057204 (2015).

N-20

Spin Hall effect in ferromagnetic FePt alloy

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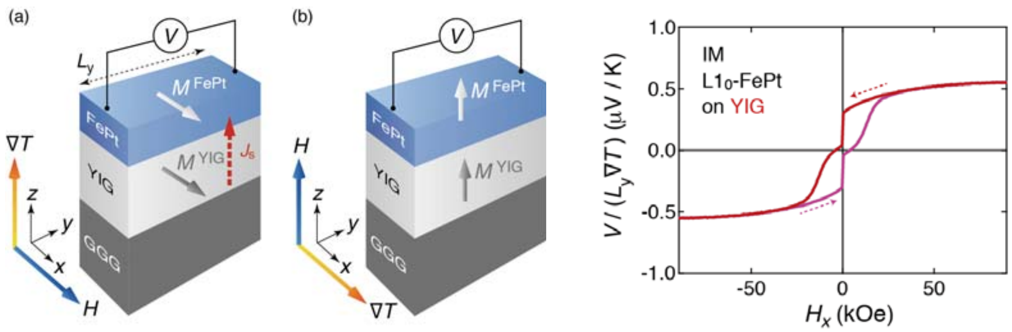
Spin Hall effect (SHE), which converts charge current (J_q) to spin current (J_s), has recently been examined not only in nonmagnetic metals and semiconductors but also in ferromagnetic metals, and the unified understanding for the above phenomena is of importance to design spintronic devices.

In this study, we experimentally observed the inverse SHE (ISHE) of ferromagnetic FePt alloys. Spin Seebeck effect due to the temperature gradient generated the J_s in the FePt | $Y_3Fe_5O_{12}$ (YIG) structure, and J_s was injected from YIG to FePt and converted to J_q through ISHE of FePt. The significant difference in magnetization switching fields for FePt and YIG led to the clear separation of the voltage of ISHE from that of anomalous Nernst effect in FePt. We also investigated the effect of ordering of FePt crystal structure on the magnitude of ISHE voltage in FePt.



N-21

Phase modulation of supercurrent in the multi-layer-based lateral Josephson junction

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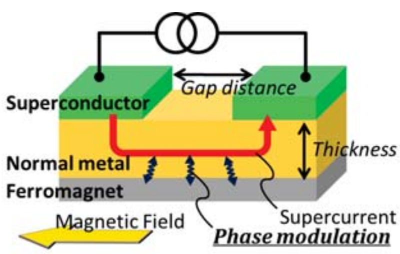
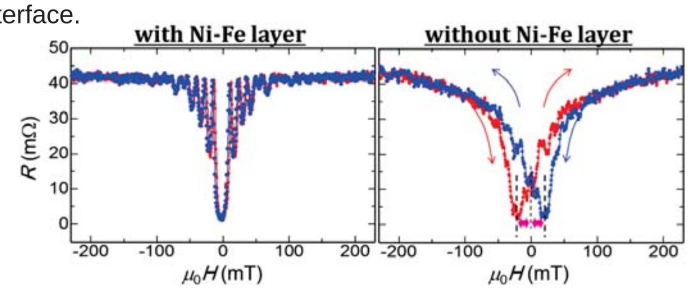
Exchange interaction between Cooper-pair and spin-polarized electrons is expected to provide intriguing phenomena in ferromagnet/superconductor hybrid structures. One of these phenomena is a spin-triplet Cooper pair, which is recently reported to be realized through the phase modulation from the singlet Cooper. However, such a interaction has not intensively investigated because of the difficulty of the experimental setup. Here, we have developed a novel Josephson junction with a nonmagnetic/ferromagnetic bilayer film as a supercurrent channel. To understand and modulate the exchange interaction, we investigate the magneto-transport property of the Josephson junction.

The sample used for the present study is a Josephson junction consisting of the Nb superconducting leads with Cu/Ni-Fe channel. In order to observe the phase modulation of the supercurrent due to the exchange interaction from the ferromagnet Ni-Fe layer, we investigated the magnetic field dependence of the superconducting properties of the Josephson junction with and without the Ni-Fe layer. Although we observed the Fraunhofer-pattern-like oscillation of the critical current in both of the Josephson junctions, the peak positions are different. This result implies the possibility to control the phase modulation by the exchange interaction at the normal metal/ferromagnet interface.





N-22

Magnetic Anisotropy due to Interplay of Curvature and Dipolar Interaction

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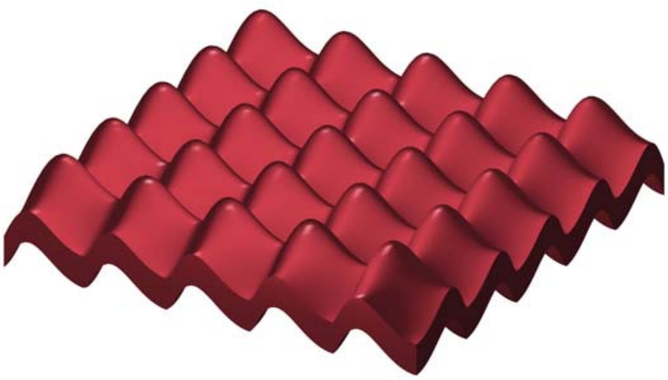
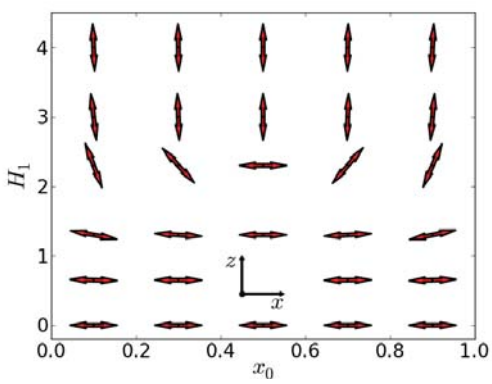
The large curvature effects on micromagnetic energy of a thin ferromagnetic film with nonlocal dipolar energy are considered. We predict that the dipolar interaction, due to its nonlocal nature, and surface curvature can produce perpendicular anisotropy, which can be controlled by engineering a special type of periodic surface shape structures. Similar effects can be achieved by a significant surface roughness in the film. We show that in general the anisotropy can point in an arbitrary direction depending on the surface curvature. We provide simple examples of these periodic surface structures to demonstrate how to engineer particular anisotropies in the film.





N-23

A Holographic Dual of Ferromagnets

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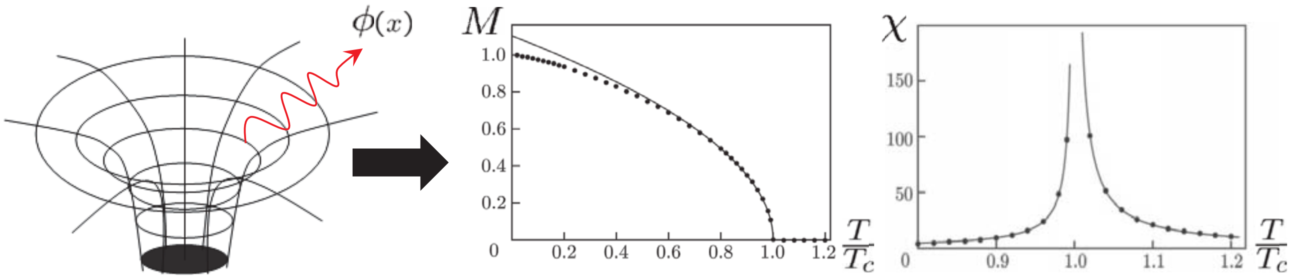
We propose a dual description for ferromagnetic systems based on the holographic duality, which relates *D*-dimensional quantum many body systems to (*D+1*)-dimensional gravitational theories.

The holographic dictionary between physical quantities of the ferromagnetic systems and dual gravitational theory is developed. Utilizing the dictionary and black hole background as a thermal bath, we obtain relevant thermodynamic quantities such as magnetization M, magnetic susceptibility χ, and free energy F. The holographic model reproduces the critical behavior of the mean field theory near the Curie temperature. Furthermore, the results automatically incorporate the contributions from spin wave excitations and conduction electrons at low temperatures. Our model provides a bridge between the gravitational theory and magnetic systems, and the methods and findings in general relativity and black hole physics can be transferred into the field of spintronics as novel guidelines. This is based on the publication, Phys. Rev. D 93, 026002 (2016).



Magnetization and susceptibility obtained from the holographic duality

N-24

Spin Wave Transmission in FeRh Thin Films

T. Taniyama[1], T. Usami[1], and M. Itoh[1]

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FeRh is now drawing great attention for its intriguing magnetic properties and antiferromagnetic spintronic applications. Our focus in this study is to investigate how magnetostatic spin waves transmit in FeRh. In order to characterize the spin wave transmission in FeRh, we first study the spin wave attenuation in ferromagnetic FeRh, showing that the spin waves transmit over a distance ~56 μm, which is comparable to that for NiFe. The long attenuation length is likely associated with the B2 ordering and the resultant induced ferromagnetic moments of Rh. We also investigate the spin wave transmission across ferromagnetic NiFe/antiferromagnetic FeRh/ferromagnetic NiFe junctions (Fig. 1). In spite of the high magnon energy of antiferromagnetic FeRh in the THz range, we find that spin waves transmit across the junction (Fig. 2), presumably due to the magnon tunneling through the antiferromagnetic FeRh or magnetostatic coupling between the two NiFe layers. More detailed discussion will be given at the meeting.

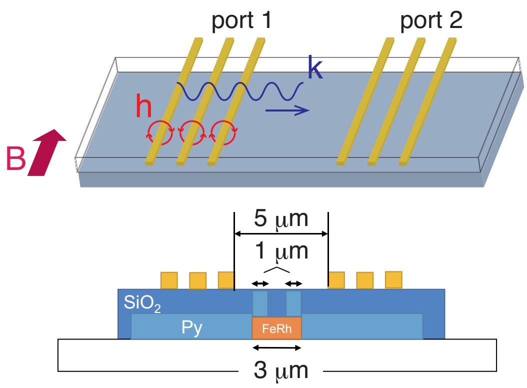

Fig. 1 NiFe/FeRh/NiFe junction structure.

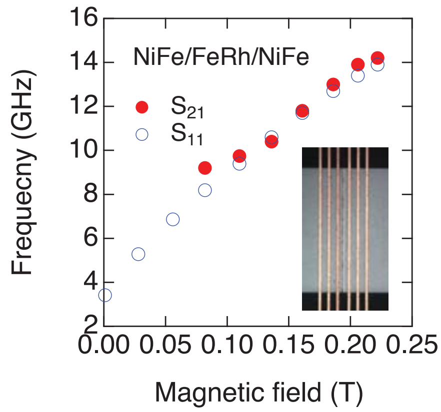

Fig. 1 Dispersion relationships for S_{11} and S_{21}.

N-25

Time-resolved imaging of spin wave transmission

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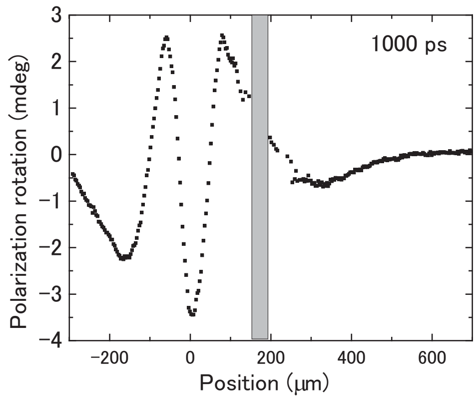
Magnetization control using ultrashort optical pulses has been extensively studied in recent years. One of the nonthermal control of magnetization is based on the inverse Faraday effect, where circularly polarized pulses generate the effective magnetic field along the propagation vector in a transparent material, leading to spin wave generation). Spin wave reflection at the sample edge or transmission through an air gap has been reported in finite-size samples). In the present study, we report on time- and phase-resolved imaging of photo-induced spin wave's transmission through an air gap using pump-probe technique with a CCD camera.

In the experiment, a bismuth-doped rare earth iron garnet crystal with a thickness of 110 μm was used as a sample. Circularly polarized pump pulses with a time duration of 150 fs were employed to excite the sample via the inverse Faraday effect. Faraday rotation of time-delayed probe pulses was measured. Figure shows the transmission of spin wave excited in the left hand sample through an air gap to the right hand sample, where the gap width was 40 μm and the time delay was 1000 ps. The center wavelength of the spin waves was observed to be 100-200 μm meaning that the spin waves were dipolar-dominated magneto-static waves. The relation between transmission, phase and the gap width was analyzed. The experimental results were compared with simulation results.



N-26

Effective Hamiltonian theory for nonreciprocal light propagation in magnetic Rashba conductor

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[2]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan*

In spintronics, spin-orbit interaction plays an important part in the context of a mixing of electric and magnetic degrees of freedom. It was reported that a strong spin-orbit interaction, Rashba interaction, is observed at surfaces containing heavy metals in the absence of space inversion symmetry [1]. It is known that the Rashba interaction leads to various electromagnetic cross correlation effects such as Edelstein effect and inverse Edelstein effect [2]. Recently, in the case where there is a magnetization or a magnetic field, it is pointed out theoretically that Rashba conductors exhibiting the cross correlation effects induce an anomalous light propagation (directional dichroism) due to the presence of toroidal and quadrupole moments like in insulator multiferroics by calculating an optical conductivity using linear response theory [3].

In present work, we investigate the directional dichroism in the magnetic Rashba conductor by deriving an effective Hamiltonian based on an imaginary-time path-integral formalism. We show that the effective Hamiltonian describing the directional dichroism consists of two terms, one representing the Doppler shift induced by the toroidal moment and the other denoting the cross correlation effect induced by the quadrupole moment. It is found that the toroidal moment affects the light propagation as a result of the Doppler shift irrespective of polarization, while the quadrupole moment results in a magneto-optical phenomenon such as Faraday effect for circularly-polarized waves.

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N-27

Spin injection into the topological crystalline insulator SnTe using spin pumping

S. Ohya[1,2], A. Yamamoto[1], T. Yamaguchi[3], R. Ishikawa[3], R. Akiyama[4], Y. K. Wakabayashi[1], S. Kuroda[3], and M. Tanaka[1,2]

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Topological crystalline insulators (TCIs) possess gapless metallic surface states (SSs) that are protected by the mirror symmetry of the crystal, and thus TCIs are promising for spintronics applications. In this study, we have carried out spin-pumping experiments with a typical TCI SnTe using a Fe (20 nm) / SnTe (70 nm) bilayer structure grown on a GaAs substrate by molecular beam epitaxy (Fig.1.(a)). The measured derivative of the absorption and electromotive force (EMF) as a function of a magnetic field showed two peaks due to the magnetic anisotropy of the Fe film (Figs. 1(b) and 1(c)). To derive the component of the inverse spin Hall effect from the EMF spectra, we separated the EMF peak at the higher magnetic field into the symmetric (V_{sym}) and asymmetric (V_{asym}) components. The temperature dependence of V_{sym} was completely different from that of V_{asym} (Fig. 1(d)), which indicates that the spin current was successfully injected in SnTe from Fe for the first time. This work was supported by Grants-in-Aid for Scientific Research No. 26103003, Center for Spintronics Research Network (CSRN), and the Project for Developing Innovation Systems of MEXT. Part of this work was carried out under the Cooperative Research Project Program of RIEC, Tohoku University.

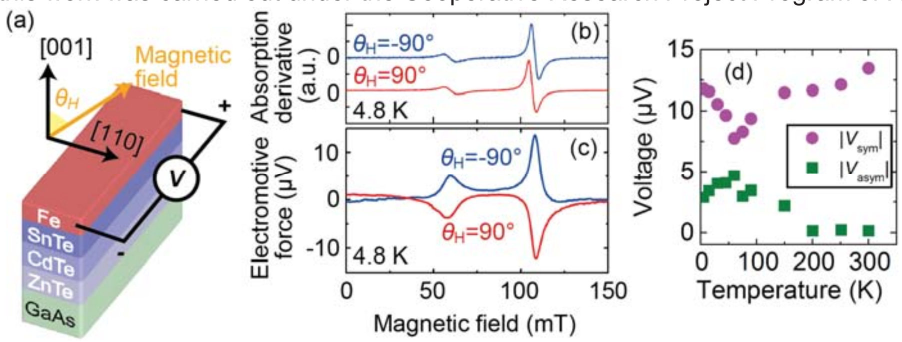

FIG. 1 (a) Schematic illustration of the device structure and the measurement alignment used in this study. (b)(c) Absorption derivative (b) and the EMF (c) as a function of a magnetic field at 4.8 K. (d) Temperature dependence of $|V_{sym}|$ and $|V_{asym}|$ with the magnetic field direction θ_H = 90º.

N-28

Size effect of electrical transport properties in NiS_2

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NiS_2 is a pyrite-type material which shows non-coplanar antiferromagneitc (NCAF) spin structure below 38 K. In addition to this NCAF spin structure, the weak ferromagnetic moment corresponding to ~0.02 m_B/Ni coexists below 30 K. Thio *et al*. proposed that tiny ferromagnetic moment is due to the small structural distortion [1], but the spin structure in this weak ferromagnetic (WF) phase has not been clarified yet. In this WF phase, the magnetic susceptibility differs between field-cooling and zero-field cooling processes, suggesting the existence of magnetic domains [2]. Anomalous magnetoresistance which might be related to magnetic domains in the WF phase have been observed[3]. Moreover, the presence of surface conduction has been proposed from the Hall resistivity measurements in NiS_2 [4].

In this work, we performed micro fabrication of NiS_2 single crystals to investigate the effect of magnetic domain structures and the surface conduction using the Focused Ion Beam (FIB). The temperature dependences of resistivity is quite different between Bulk sample and FIB-fabricated sample as shown in Fig. 1. In this poster session, we will report the effect of sample size on the electrical transport properties of NiS_2 and discuss the surface conduction and the magnetic domain structure with the resistivity, magnetoresistance and Hall measurements.

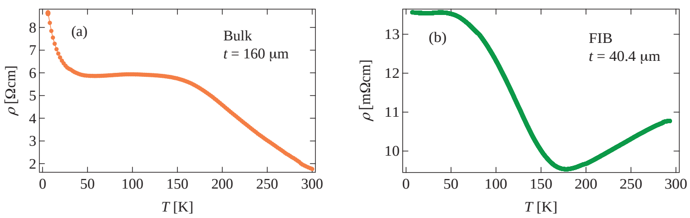

Fig. 1. Temperature dependence of resistivity (a) t = 160 μm, (b) t = 40.4 μm.

Reference
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[4] T. Thio and J.W. Bennett, Phys. Rev. B 50, 10574 (1994).

N-29

Proximity-induced magnetoresistance in two-dimensional Dirac electrons on ferromagnetic insulators

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We theoretically study the magnetoresistance (MR) of massless Dirac two-dimensional electrons as found on the surface of three-dimensional topological insulators (TIs) [1] on top of a ferromagnetic insulator (FI). We calculate electron and spin transport by Boltzmann and Kubo theories, taking into account the in-scattering and ladder-vertex corrections due to disorder. In contrast to the spin Hall (or Rashba-Edelstein) magnetoresistance [2,3], the induced exchange splitting is found to generate an electric resistance that depends on the magnetization orientation. For in-plane magnetizations, the MR vanishes identically in the TI/FI bilayer. By contrast, in the out-of-plane magnetizations, we predict a large MR ratio. We also predict the MR in in-plane magnetizations is emerged in the case of the magnetic impurity that is aligned to FI magnetizations. Our results may help understand recent transport measurements with TIs [4].

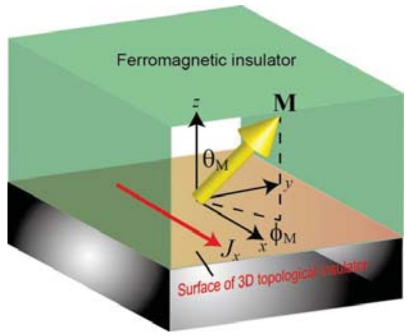

FIG. 1. Schematic picture of the system consisting of a three-dimensional topological insulator with a ferromagnetic insulator. Electric currents only flow at the interface between both insulators

Reference
[1] M. Z. Hasan & C. L. Kane, Rev. Mod. Phys. **82**, 3045 (2010).
[2] H. Nakayama *et al.*, Phys. Rev. Lett. **110**, 206601 (2013.
[3] H. Nakayama *et al.*, Phys. Rev. Lett. **117**, 116602 (2016).
[4] A. R. Mellnik *et al.*, Nature **511**, 449 (2014).

N-30

Electric-field-induced magnetic resonance in topological antiferromagnetic insulators

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An interesting phenomenon predicted in topological insulators is the magnetoelectric effect characterized by a topological action called the θ term [1], which comes from a topology of the electronic band structure. Such ME effects have also been proposed in antiferromagnetic (AF) insulators with strong spin-orbit coupling [2]. A candidate AF phase has been experimentally observed in the magnetically doped Bi_2Se_3 [3].

Here we present a theory to realize an ac electric-field-induced antiferromagnetic resonance in three-dimensional AF insulators with the θ term which couples the electric field and the Néel field under magnetic fields [4]. By solving the Landau-Lifshitz-Gilbert equation in the presence of the θ term, we show that the AF resonance is driven by ac electric fields. We also discuss a possible experiment to observe our proposal, which utilizes the spin pumping from the AF insulator such as a magnetically doped Bi_2Se_3 into a heavy metal (HM) such as Pt shown in Fig. 1. Our study opens a new direction in possible applications of topological materials in spintronics.

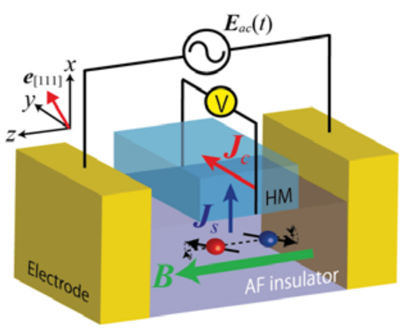

FIG. 1. Schematic figure of a possible experimental setup to observe the electric-field-induced AF resonance in this study.

Reference
[1] X.-L. Qi *et al.*, Phys. Rev. B **78**, 195424 (2008).
[2] A. Sekine & K. Nomura, Phys. Rev. Lett. **116**, 096401 (2016).
[3] S. W. Kim *et al.*, Appl. Phys. Lett. **106**, 252401 (2015).
[4] A. Sekine & T. Chiba, Phys. Rev. B **93**, 220403(R) (2016).

N-31

First-principles Approach for Skyrmion-driven Thermoelectric Conversion

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The magnetic skyrmion, a topological object made up of spins in condensed matter, exhibits many peculiar properties, among which we target the anomalous Nernst effect (ANE), heat-to-electricity conversion in transverse direction, driven by an emergent magnetic field **B** originating from its spin texture. We have so far found from computations on some models that, in the so-called 2D SkX phase (Fig.1), where skyrmions are crystallized in two dimensions, the crystal-momentum component of **B** gives rise to the band structure that could generate large ANE when chemical potential μ is properly tuned (Fig.2). Although this behavior was most clearly confirmed★ in the simplest model of square SkX with single *s*-orbital per site, our subsequent computations on more realistic models of transition-metal oxides also showed possible large ANE.

In this presentation, such intriguing results, the details of our first-principles computational procedures, as well as the problems to be solved will be discussed.

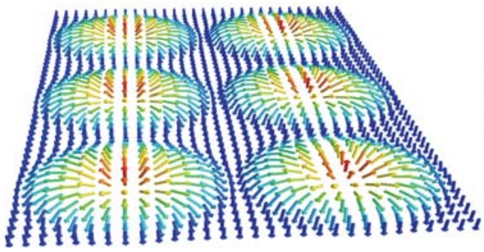

Fig.1 square SkX (15×15 size)

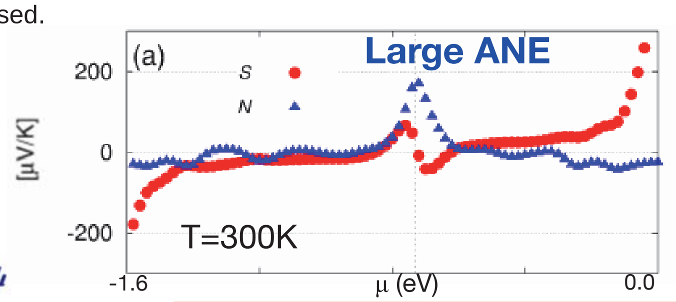

Fig.2 Large ANE coefficient (blue) at specific μ in a SkX (6×6 size)
(from Figure 3 in Ref.★)

★ Y. P. Mizuta and F. Ishii, *Scientific Reports* **6,** Article number: 28076 (2016)

N-32

Edelstein magnetoresistance in $CoFe/Cu/Bi_2O_3$

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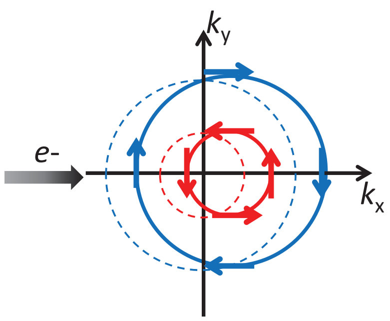
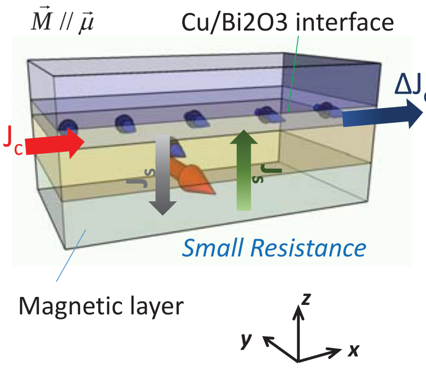
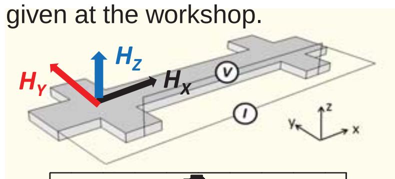
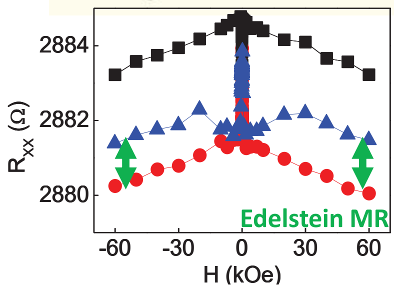
It can be expected that interconversion between spin and charge current originated by Edelstein effect can modulate the resistance similar mechanism with spin Hall magnetoresistance (SMR). Here we studied modulation of the resistance originated from the Edelstein effect at Cu/Bi_2O_3 interface. Hall-bar patterned $CoFe/Cu/Bi_2O_3$ heterostrucructure was prepared with electron beam evaporation and photo-lithography. The resistance measurement was carried out with applying external magnetic field. We found characteristic decrease of resistance when magnetization of the CoFe layer was parallel with spin direction of spin accumulation originated from the Edelstein effect. Further discussion will be given at the workshop.









N-33

Thermal generation of spin current in antiferromagnets

S. Seki[1], T. Ideue[2], M. Kubota[1], Y. Kozuka[2], R. Takagi[1], M. Nakamura[1], Y. Kaneko[1], M. Kawasaki[1,2], and Y. Tokura[1,2]

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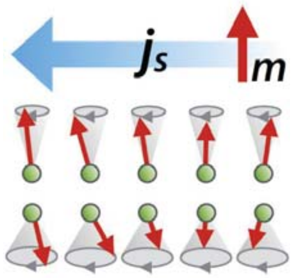
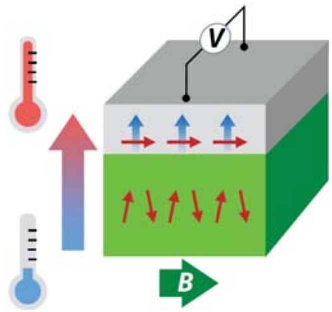
The longitudinal spin Seebeck effect has been investigated for a uniaxial antiferromagnetic insulator Cr_2O_3, characterized by a spin-flop transition under magnetic field along the c axis. We have found that a temperature gradient applied normal to the Cr_2O_3 /Pt interface induces inverse spin Hall voltage of spin-current origin in Pt, whose magnitude turns out to be always proportional to magnetization in Cr_2O_3. The possible contribution of the anomalous Nernst effect is confirmed to be negligibly small. Similar behaviors are also observed for frustrated helimagnet $Ba_{0.5}Sr_{1.5}Zn_2Fe_{12}O_{22}$. The above results establish that an antiferromagnetic spin wave can be an effective carrier of spin current [1,2].

[1] S. Seki *et al*., Phys. Rev. Lett. **115**, 266601 (2015). [Highlighted in Nature Nanotechnology 11, 308 (2016).]

[2] R. Takagi, S. Seki *et al*., APL Mater. **4**, 032502 (2016).





N-34

Microscopic derivation of spin current in topological insulator/magnetic insulator heterostructure

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Topological insulator(TI)/ferromagnet(FM) heterostructures have attracted much attention in spintronics. Recent experiments have shown that spin current injected by spin pumping is converted to the electric current on the surface state. Since the material is effectively a two-dimensional system, while usual spin current injection is performed in three-dimensional systems, it is important to understand the microscopic origin of the conversion.

In the light of the situation, we investigate electrical transport in a TI/FM heterostructure (Fig.1). We consider a model of the heterostructure in which a three-dimensional magnon gas is coupled with a two-dimensional Dirac electron system at the interface. We calculate microscopically the spin current induced by an inplane electric field.

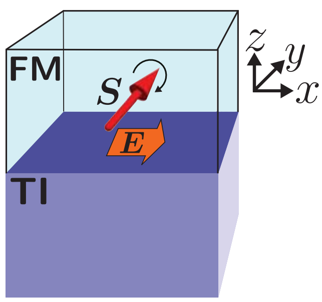

Fig.1. A ferromagnet deposited on the surface of a topological insulator.

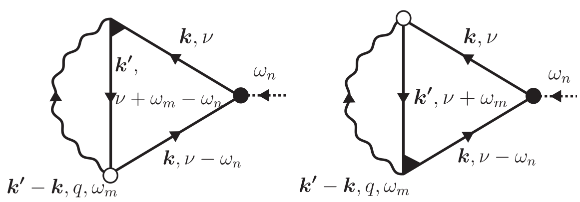

Fig.2. The lowest-order Diagrams contributing to the spin current.

N-35

Conservation of angular momentum in DMI spin textures

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The lack of inversion symmetry in the interface between a thin ferromagnetic film and a non-magnetic substrate with strong spin orbit coupling results in an important contribution from the Dzyaloshinskii-Moriya interaction (DMI) to the energy of the system[1]. Due to the origin of the DMI it is necessary to revise the conservation law for angular momentum in such films.

We identify the symmetries of the system and calculate, by means of Noether's Theorem, the energy-momentum tensor of a thin ferromagnetic film under the influence of the DMI. We find that spin angular momentum and orbital angular momentum are not conserved separately due to the DMI. However, because of the rotational symmetry of the system we find that the total (spin plus orbital) angular momentum is conserved. This formalism allows us to clearly identify the contributions from spin and orbital angular momentum to the total angular momentum current.

We apply this conservation law to spin textures stabilized by the DMI such as N'eel domain walls [2] and magnetic skyrmions [3] and determine the role of orbital angular momentum in the magnetization dynamics.

[1] A. Bogdanov, et. al, PRL, 87, 037203, (2001)

[2] A. Thiaville, et. al, EPL ,100,5, (2012)

[3] S. Heinze, et. al, Nat. Phys., 7, 713-718, (2011)

N-36

Role of interfacial exchange field in the spin-current modulation with ferromagnetic insulator

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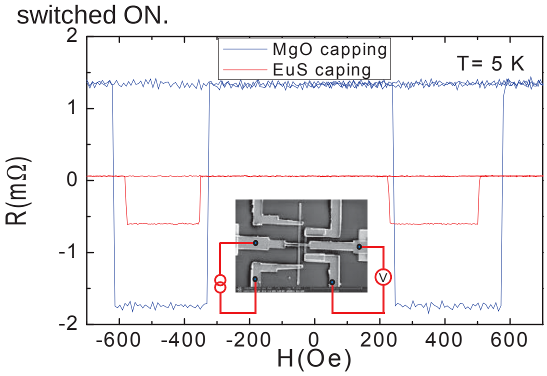
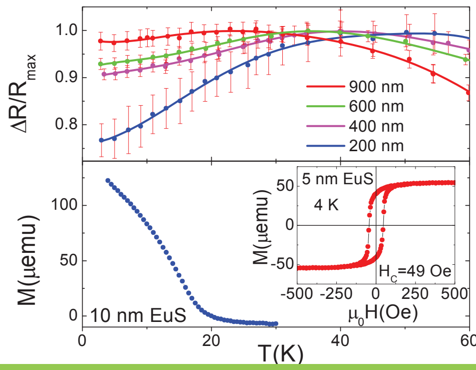
Recent experiments have shown that the spin-current flowing through a nonmagnetic metal (NM) in intimate contact with a ferromagnetic insulator (FI) can be manipulated with the magnetization direction of the FI even though no current flows through the FI. We study the effect of interfacial exchange field on spin-current by capping $Ni_{80}Fe_{20}$/Cu nonlocal spin-valve devices (NLSVs) with ferromagnetic insulator; EuS. The nonlocal spin-valve signal is about 5 times lower when NLSV is capped with magnetic EuS compared to nonmagnetic MgO due to enhanced surface spin-flip probability in the former. We present detailed study on the effect of spin-flip probability from Cu-EuS interface by measuring NLSV signal as a function of temperature for varying injector-to-detector distances. We probe the role of interfacial exchange field on spin current modulation with NLSV measurements done close to the Curie temperature T_C of EuS when interfacial exchange field is switched ON.



(a) NLSV signal measured at 5 K for 3 nm MgO (blue) and 5 nm EuS (red) capping. Inset shows SEM picture of NLSV with nonlocal measurement arrangement.



(b) Temperature dependence of normalized NLSV signal for different injector-to-detector distances (c) Temperature and field dependence of magnetization for 10 nm and 5 nm thick EuS film, respectively.

N-37

Spin-hydrodynamic Conversion Effect

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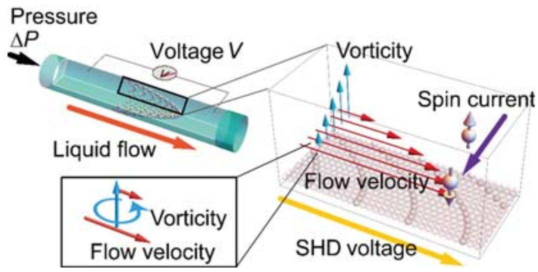
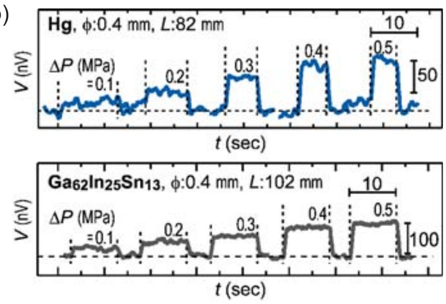
Generation and utilization of spin currents are essential for the field of spintronics, dealing with spin-based transport in condensed matter systems. The key is angular-momentum conversion from/to spin degrees of freedom. Several forms of the angular momentum are utilized but there existed an angular-momentum carrier remaining to be used, namely macroscopic mechanical rotation. Especially, we focused on the vorticity, local rotation in fluid motion, and consequently we demonstrated that the fluid-mechanical motion enables us to generate spin currents, which is a novel spin-current generating method "Spin Hydrodynamic (SHD) Generation" [1]. Our experimental results and its consistency with theoretical predictions will be discussed in this presentation. Besides that, our recent experimental progress in this spin-hydrodynamic conversion phenomenon will be discussed.

[1] R. Takahashi *et al.*, Nature Phys. **12**, 52 (2016).

(a)


(b)


(a) Concept of fluid-mechanical spin-current generation.
(b) Time evolution of SHD voltage signals for various values of applied pressure in mercury and gallium alloy.

N-38

Transition behavior in Pd-doped FeRh wire

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R. Temple[2], C. Marrows[2], Y. Otani[1,3]

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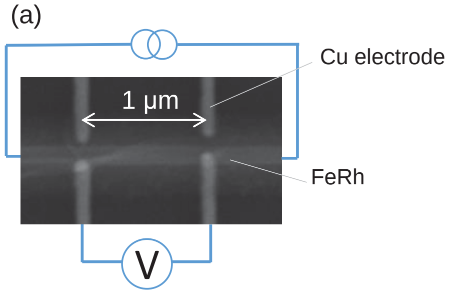
FeRh alloy shows a first-order phase transition from an antiferromagnetic (AF) phase at low temperature to a ferromagnetic (F) phase above 370 K [1]. This material is a candidate for a room-temperature resistivity controllable device because of the abrupt change in resistivity during phase transition. Recently a discontinuous change of resistivity on F to AF phase transition is observed on a submicron wire [2]. On our research, we fabricated submicron wires from a Pd-doped FeRh thin film and measured their transport properties as shown in figure1. We will discuss the anomalous transition behavior in fabricated wires.

(a)


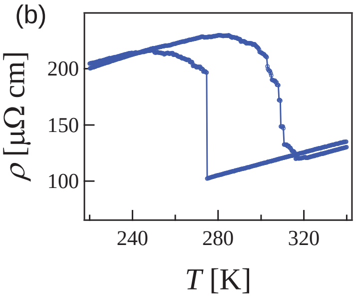
(b)


Figure 1. (a) SEM picture and (b) temperature dependence of resistivity of a Pd-doped FeRh wire.

[1] J. S. Kouvel and C. C. Hartelius, J. Appl. Phys. **33**, 1343 (1962). [2] V. Uhlíř *et al*, arXiv, 1605.06823 (2016).

N-39

Supercurrent-induced Skyrmion dynamics and Tunable Weyl points in Chiral Magnet with Superconductivity

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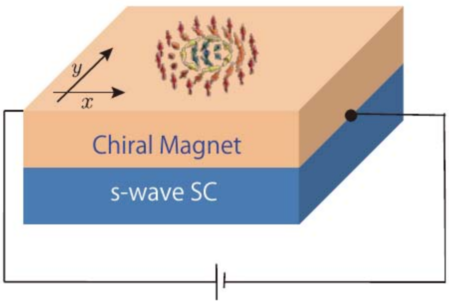
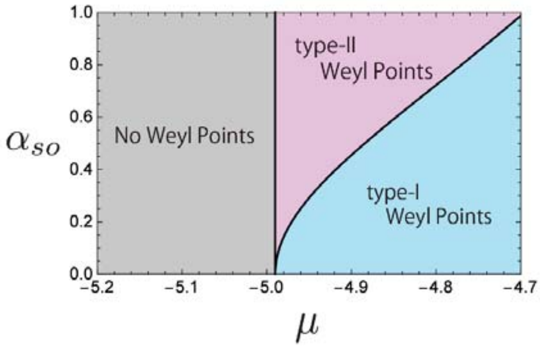
Recent studies show superconductivity provides new perspectives on spintronics. We study a heterostructure composed of an s-wave superconductor and a cubic chiral-magnet that can stabilize a topological spin texture, a skyrmion. We propose a supercurrent-induced spin torque that originates from the spin-orbit coupling, and we show that the spin torque can drive a skyrmion in an efficient way that reduces Joule heating.
We also study the band structure of Bogoliubov quasiparticles and show the existence of Weyl points, whose positions can be controlled by the direction of the magnetization. This results in an effective magnetic field acting on the quasiparticles in the presence spin textures. Furthermore, the tilt of the Weyl cones can also be tuned by the strength of the spin-orbit coupling, and we propose a possible realization of type-II Weyl points.

arXiv: 1607.02336





N-40

First-principles calculation of Rashba parameters in surface alloys of bismuth and noble metals

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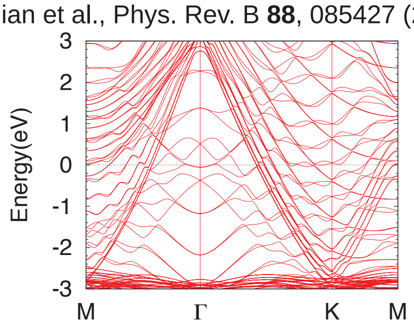
Bismuth is a material with a strong spin-orbit coupling. Rashba effect is due to spin-orbit splitting, and Rashba parameters are key parameters for spintronics [1]. Recently, the interfaces of the heterostructures consisting of bismuth and metal have been extensively studied [2]. Those interfacial systems can be candidates for spintronic materials. In this study, we focused on Rashba effect and have investigated its parameters and the spin structure for the heterostructures of Bi/*M* (*M*=Cu, Ag, or Au) using first-principles calculations. The figure on the left shows a calculated band structure for a Bi/Ag(111) surface alloy, and the table on the right Rashba parameters for Bi/*M*(111) surface alloys, where k_R is the Rashba momentum offset, E_R the Rashba energy, E_Γ the energy at the degenerate point, and α_R the Rashba coefficient, estimated from the spin-orbit splitting around Γ-point for each 10-atomic-layer model. Our calculated α_R for Cu and Ag are consistent with experimental ones, and we predicted for Au. We will also discuss a trend of the Rashba parameters.

[1] J. C. Rojas Sánchez et al., Nat. Commun. 4, 2944 (2013).
[2] G. Bian et al., Phys. Rev. B **88**, 085427 (2013).



M	Cu	Ag	Au
(Upper splitting)			
k_R(Å^{-1})	0.029	0.077	0.067
E_R(eV)	0.052	0.146	0.081
E_Γ(eV)	1.481	0.509	0.833
α_R(eV·Å)	3.51	3.75	2.43
(Lower splitting)			
k_R(Å^{-1})	0.036	0.113	0.020
E_R(eV)	0.015	0.159	0.009
E_Γ(eV)	0.212	-0.373	-0.418
α_R(eV·Å)	0.83	2.82	0.857

N-41

All – optical magnetization switching in GdFeCo stacked on different metallic layers

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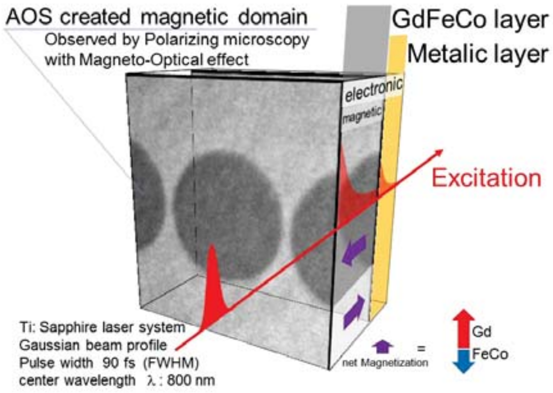
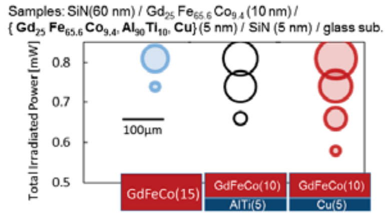
Only tens fs of laser pulse are sufficient to induce the non-adiabatic and non-equilibrium energy dissipation process of electron in metalic thin films. All – Optical magnetization Switching (AOS) is originated from the non-adiabatic and non-equilibrium energy dissipation process of electron, spin and lattice systems of ferrimagnetic metallic thin films in short time scale after the laser excitation. In this report, we stacked GdFeCo ferrimagnetic films on different metallic layers. These metal has different specific heat *C* and electronic specific heat C_{el}. we observed the dependency of AOS in these films, considering the relation between non-local energy dissipation of 3d electron and the AOS phenomena. From these experiments, we suggest AOS depends on the non-local energy dissipation which relate in sub-ps time scales with electrons. It means that a sample on low C_{el} metalic films has low irradiated power threshold for exciting AOS.





Specific heat *C* [J / kg K]	Fe: 444 Co: 434	Al: 900 Ti: 519	Cu: 385
Electronic specific heat C_{el}[mJ / mol K^2]	Fe: 5 Co: 4.7	Al: 1.35 Ti: 3.5	Cu: 0.688

The Japan Institute of Metals and Materials: "revised 4th edition Metals data book", (Maruzen, Japan, 2004) p 17. [in Japanese]

N-42

The fluctuation of charge, heat and spin currents

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Department of Physics Engineering, Mie-University, Mie, Japan

We investigate the effect of fluctuating charge, heat and spin currents flowing through a tunnel junction on the efficiency of thermo-magneto-electric device [Fig. 1]. In the framework of full counting statistic, we derive the joint cumulant generating function of the charge, the heat and the spin transfer obeying the Bidirectional Poisson process. We also reproduce the linear response theory of thermo-magneto-electric transport [1] within the Gaussian approximation. Furthermore, based on the resulting joint probability distribution, we consider the efficiencies of heat transfer (cooling) and spin transfer. In addition, we derive the average of coefficient of performance (COP), which is defined as the heat current over the spin current. We found that the COP depends on time [Fig. 2]. In the short time regime, the average of COP possesses either minimum or maximum depending on the parameters, and approaches to the macroscopic value in the long time limit.

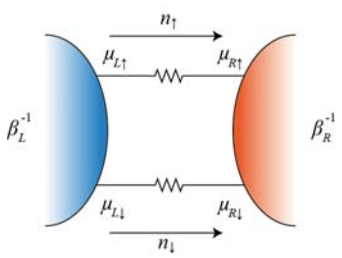


Fig. 1. Schematic picture of thermo-magneto-electric device

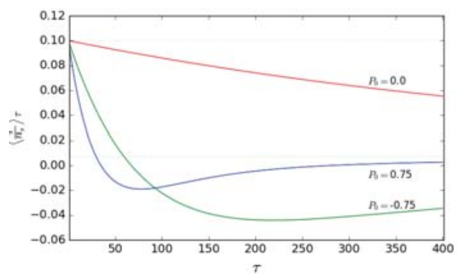


Fig. 2. Time dependence of the COP

[1] M. Johnson, R. H. Silsbee, Phys. Rev. B. **35**, 4959 (1987)

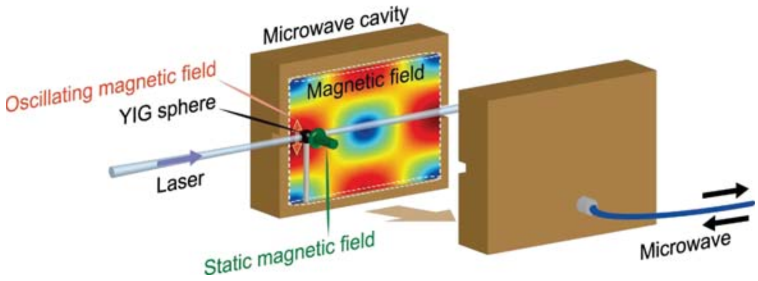
N-43

Bidirectional conversion between microwave and light via ferromagnetic magnons

R. Hisatomi[1], A. Osada[1], Y. Tabuchi[1], A. Noguchi[1], R. Yamazaki[1], K. Usami[1], Y. Nakamura[1,2]

[1]*Research Center for Advanced Science and Technology (RCAST), The University of Tokyo, Meguro-ku, Tokyo 153-8904, Japan*
[2]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan*

To build working quantum networks that allow for transfer of quantum information between remote superconducting qubits, coherent conversion between microwave and optical photons is required. We have recently demonstrated in the microwave domain the coherent control of magnons in a hybrid quantum system consisting of a superconducting qubit and a millimeter-scale ferromagnetic sphere made by yttrium iron garnet(YIG) and made a breakthrough in the field of “quantum magnonics” [1]. On the other hand, magnons interact with light through the Faraday and inverse Faraday effects. Here we realize bidirectional conversion between microwave and optical signals in the classical regime [2]. In particular, for the conversion from optical to microwave signals via magnons, we use two phase-coherent continuous-wave lasers, in contrast to the femtosecond lasers used in many experiments achieving optical manipulation of magnons.



[1] Y. Tabuchi *et al*., Science **349**, 405 (2015); C. R. Phys. **17**, 729 (2016).
[2] R. Hisatomi *et al*., Phys. Rev. B. **93**, 174427 (2016).

N-44

Anomalous Nernst effect in Co / Ni multilayers

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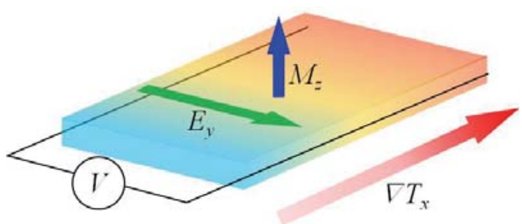
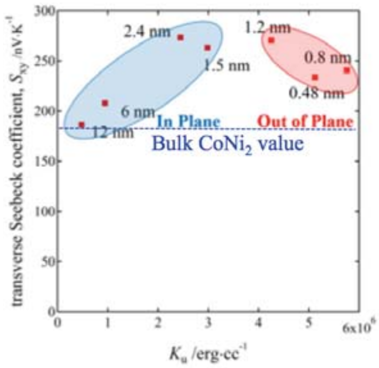
The Nernst effect is a common thermomagnetic effect, that has been known for a long time. When a temperature gradient is applied on a material with spontaneous magnetization, an electric field is induced in the perpendicular direction to both the temperature gradient and the magnetization, which is called anomalous Nernst effect. The interaction between a spin current and a heat current has been studied in a new field of spin-caloritoronics since the discovery of the spin Seebeck effect, and a number of thermomagnetic effects related to spin current have been investigated. In this paper, anomalous Nernst effect in Co / Ni epitaxial multilayer films with various stacking thicknesses was measured and discussed in relation to the interface magnetic anisotropy. All the Co / Ni multilayers showed larger transverse Seebeck coefficients than that estimated for bulk Co-Ni, implying that interface magnetic anisotropy strongly contributed to anomalous Nernst effect.





N-45

Barnett effect in rare-earth metals

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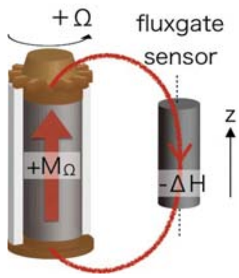
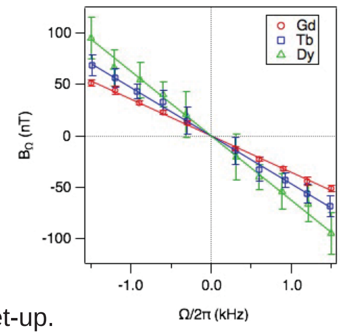
The magnetomechanical factor *g'* of Gd, Tb, and Dy metals were determined by measurements of the Barnett effect using homemade apparatus, which consists of fluxgatesensor, magnetic shield, and high speed rotar. We performed mechanical rotation experiments up to 1.5 kHz at room temperature. The emergent magnetic field (Barnett field) in sample caused by mechanical rotation linearly depends on the rotational frequency as shown in Fig. (b). The *g'* factor of Gd, Tb, and Dy samples were estimated to be 2.00±0.08, 1.53±0.17, and 1.15±0.32, respectively, from the slopes of the rotation dependence of the Barnett field. This study provides a new technique for determination of the g factor even under zero magnetic field.

(a)



(b)



(a) A schematic illustration of the experimental set-up.
(b) Rotational frequency dependence of the Barnett field for Gd, Tb, and Dy samples.

N-46

Rashba-Edelstein magnetoresistance in metallic heterostructures

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The change of electrical resistance of ferromagnetic films and multilayers in a magnetic field, magnetoresistance, has been studied for a long time, providing a fundamental understanding of spin-dependent transport in solids. Recently, magnetoresistance due to a nonequilibrium proximity effect has been observed in a heavy metal/magnetic insulator bilayer, where no charge current flows in the magnetic layer [1]. This magnetoresistance is commonly referred to as the spin Hall magnetoresistance (SMR). The physics behind the SMR is the spin-current reflection and the reciprocal spin-charge conversion caused by the simultaneous action of the spin Hall effect and inverse spin Hall effect.

Here we report the observation of magnetoresistance originating from Rashba spin-orbit coupling (SOC) in a metallic heterostructure: the Rashba-Edelstein (RE) magnetoresistance [2]. We show that the simultaneous action of the direct and inverse RE effects in a Bi/Ag/CoFeB trilayer couples current-induced spin accumulation to the electric resistance. The electric resistance changes with the magnetic-field angle, reminiscent of the spin Hall magnetoresistance [1], despite the fact that bulk SOC is not responsible for the magnetoresistance. We further found that, even when the magnetization is saturated, the resistance increases with increasing the magnetic-field strength, which is attributed to the Hanle magnetoresistance [3] in this system.

References

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