New Perspective in Spin Conversion Science (NPSCS2020)

3rd Feb (Mon), 2020		
09:30-10:00		Registration
10:00-10:10		**Yoshichika Otani, Hatsumi Mori (ISSP director)** Opening
10:10-10:45	01	**Kang Wang (University of California Los Angeles)** Spin-orbit torque switching in Ferrimagnetics
10:45-11:10	02	**Yoshichika Otani (University of Tokyo)** Nano-spin conversion phenomena in spintronics
11:10-11:45	03	**Hide Kurebayashi (University College London)** Electric/chemical control of magnetism in van der Waals ferromagnets
11:45-12:10	04	**Takashi Kikkawa (Tohoku University)** Spin Seebeck/Peltier effects induced by magnon-phonon hybridization
12:10-13:10		Lunch (60 min)
13:10-15:10		Poster session (120 min)
15:10-15:45	05	**Yaroslav Tserkovnyak (University of California Los Angeles)** Putting magnetic vortices to work in spintronics
15:45-16:10	06	**Kazuya Ando (Keio University)** Spin-Orbit Torques in Metal-Based Heterostructures
16:10-16:45	07	**Burkard Hillebrands (University of Kaiserslautern)** Magnon Josephson oscillations
16:45-17:05		Coffee break (20min)
17:05-17:40	08	**Christopher Marrows (University of Leeds)** Skyrmions in chiral magnetic multilayers
17:40-18:05	09	**Shuichi Murakami (Tokyo Institute of Technology)** Generations and conversions of phonon angular momenta
18:30-20:30		Banquet

4th Feb (Tue), 2020		
08:30-09:00		Registration
09:00-09:35	10	**Xiaofeng Jin (Fudan University)** Spin-charge conversion in Bi/Ag bilayer
09:35-10:00	11	**Masashi Shiraishi (Kyoto University)** Gate-tunable inverse spin Hall effect in ultrathin Pt
10:00-10:25	12	**Gerrit Bauer (Tohoku University)** Spintronics with magnetic insulators
10:25-10:45		Coffee break (20 min)
10:45-11:20	13	**Jairo Sinova (University of Mainz)** Topological spintronics in antiferromagnets and the crystal Hall effect
11:20-11:45	14	**Akira Oiwa (Osaka University)** Conversion of angular momentum, quantum state and entanglement from photons to electron spin using gate-defined quantum dots
11:45-12:10	15	**Shingo Katsumoto (University of Tokyo)** Creation of Two-Dimensional Topological Phases with Perturbations
12:10-13:15		Lunch (65 min)
13:15-13:50	16	**Cheng Song (Tsinghua University)** Ferroelastic strain control of Néel order in antiferromagnets
13:50-14:15	17	**Teruo Ono (Kyoto University)** Ferrimagnetic spintronics
14:15-14:50	18	**Xu Yang (University of Groningen)** Spin-charge conversion by chirality
14:50-15:10		Coffee break (20 min)
15:10-16:45	19	**Theo Rasing (Radboud University)** NEW PERSPECTIVES IN ALL-OPTICAL CONTROL OF SPINS: from fundamentals to brain-inspired computing concepts
14:45-15:10	20	**Takeshi Seki (Tohoku University)** Spin-Charge Conversion in Ferromagnetic Materials
16:10-16:45	21	**Jason Robinson (University of Cambridge)** Pure spin supercurrents
16:45-16:55		Closing

Spin-orbit torque switching in Ferrimagnetics

Abstract

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Antiferromagnetic (AFM) and ferri-magnetic materials (FRM) offer the speed advantage to THz and low energy operation, allowing for information propagation in the form of spin current, spin waves, *i.e.*, magnons [1]. The spin-orbit torque for switching has been demonstrated for ferromagnetic materials but the results of AFM remain uncertain due to thermal effects [2]. The talk will discuss the SOT of AFM and FRM interfaced with topological insulators. First, Topological insulator/AFM heterostructures will be described to show the induced exchange bias via interface proximity effect. A major challenge for SOT switching of the perpendicular anisotropy is that it requires an additional inversion symmetry breaking to become deterministic, which is usually provided by applying an in-plane external magnetic field. We discuss the recent progress for realizing field-free deterministic SOT switching through symmetry breaking using various techniques. Spin-orbit torque and switching of FRM are illustrated in $Bi_2Se_3/Gd_x(FeCo_{1-x})$ for various Gd (x) contents and are compared with prior work on AFM. The energy efficiency of using TI is compared with other materials for various degrees of compensation (Fig. 1). We will also describe the exchange coupling of the two sub-lattices of FRM and AFM, as probed by XMCD (X-ray magnetic circular dichroism), neutron scattering, and anomalous Hall to further ascertain switching. The temperature and layer thickness dependences show the dominant exchange coupling of the Fe sublattice. Preliminary results of dynamic switching of this FRM by the use of an Auston switch excited with a femtosecond laser is also obtained (Fig. 2). The perspective will look into the use of insulating FRM materials for additional advantages of low energy operation, allowing for spin current, but without electrical charge current loss. Likewise, the use of 2-D materials with controlling magnetic properties will be discussed.

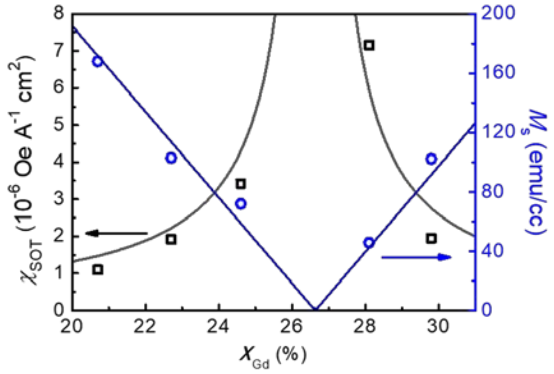

Fig. 1. SOT effective field significantly enhanced near the magnetic compensation (SBiSe/GaCoFe

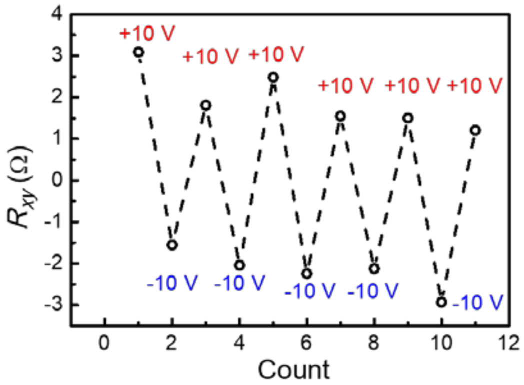

Fig. 2. Using a photoelectric Auston switch, preliminary data indicating repeated ps SOT switching (Ta/GdCoFe)

1. H. Wu, … and K. L. Wang et al., Adv. Mater. 1901681 (2019)
2. C. C. Chiang, S. Y. Huang, D. Qu, P. H. Wu, and C. L. Chien, Phys. Rev. Lett. **123**, 227203, 2019

Nano-spin conversion phenomena in spintronics

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Spintronics research has been evolving and has reached a new phase in which the concept of spin currents, i.e., the flow of spin angular momenta, helps us understand various spintronics phenomena. These include all the recently discovered conversion phenomena, such as the direct and inverse spin Hall effects (SHEs) [1], spin Seebeck [2] and Peltier effects [3], spin pumping, and the inverse Faraday effect. Recently, Rashba interfaces and the surface states of topological insulators were found to exhibit the so-called Edelstein effect, in which spin-momentum locking behavior brings about non-equilibrium spin accumulation [4]. More recently, a novel type of contribution to the SHE (magnetic SHE, MSHE) and the inverse SHE (MISHE) that is absent in nonmagnetic materials can be dominant in some magnetic materials, including antiferromagnets [5].

In this talk, we will summarize our findings in terms of the creation of new spin conversion properties. Firstly, we report Edelstein effects arising at metal/insulator Rashba interfaces [6] and surface states of topological insulators (TIs) as a means of spin-charge interconversion [7], thereby we were able to induce so-called spin-orbit torque (SOT) to switch magnetization of the ferromagnetic TI grown on a non-magnetic TI by applying a current pulse [8]. Secondly, we report a novel MSHE in non-collinear Mn_3Sn [5].

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Electric/chemical control of magnetism in van der Waals ferromagnets

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Two-dimensional (2D) van der Waals (vdW) materials have been intensively and extensively studied in the last two decades. Interesting enough, there exist many magnetic versions of these 2D vdW materials, known for decades in bulk form but only in 2017, a few mono-layers of exfoliated ones were reported to show magnetism [1.2]. Since then, scientists started to seriously explore the physics and materials science of this new class of materials by applying their own research ideas and growth/measurement techniques. The ultimate answer of "are there any unique properties of 2D magnets?" is yet to be answered, if any.

We started to work on one of magnetic 2D vdW materials, $Cr_2Ge_2Te_6$ (CGT), to study its spin dynamics and how to control the magnetism by any external stimuli. In this presentation, I will start with a brief introduction of magnetic 2D vdW materials and then move on to our latest work of controlling magnetism (Curie temperatures and magnetic anisotropies) in CGT by electric field [3] and chemical doping. Both doping techniques show the change of carrier density in CGT by orders of magnitude (from insulator to metallic). As a result, the exchange coupling strength has been greatly enhanced, leading to Curie temperature enhancement. The carrier doping also modifies the spin-orbit interaction within CGT which is measured by a significant change of the magnetic anisotropy parameters. These have been characterized by magneto-transport as well as spin dynamics techniques [4].

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[4] For example, for undoped CGT, Khan et al., Phys. Rev. B 100, 134437 (2019); arXiv:1903.00584.

Spin Seebeck/Peltier effects induced by magnon-phonon hybridization

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The spin Seebeck effect (SSE) [1] refers to the generation of a spin current in magnetic materials by a temperature gradient. In the SSE, a thermally generated magnon spin current in a magnet is converted into a conduction-electron spin current in a metal attached to the magnet via the interfacial spin-exchange interaction. The spin current is detected as an electric voltage via the inverse spin Hall effect in the metal. Recent studies revealed that the SSE provides a sensitive probe for magnon dynamics in magnetic materials [2,3].

In this talk, we report sharp features in the SSE induced by hybridized magnon-phonon excitation (or magnon polarons [4-6]) at the band (anti-)crossings between the magnon and phonon dispersion curves in $Y_3Fe_5O_{12}$ (YIG). We observe anomalous peak structures in the magnetic field dependence of the SSE through a high-resolution field scan. The SSE anomalies appear when the magnon and phonon dispersion curves touch, which maximizes the phase space of magnon-polaron formation. The experimental results are well reproduced by a Boltzmann equation including the magnetoelastic coupling. The sharp structures of the SSE can thereby be attributed to the spin current carried by magnon polarons exhibiting longer lifetimes than pure magnons [4,5]. During the talk, we will show the magnon-polaron features in the spin Peltier effect [7], the reciprocal effect of the SSE, referring to the heat-current generation as a result of a spin current.

The work was done in collaboration with R. Yahiro, R. Ramos, K. Oyanagi, T. Hioki, Y. Hashimoto, Z. Qiu, M. Ishida, K. Uchida, G. E. W. Bauer, K. Shen, B. Flebus, and R. A. Duine.

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Putting magnetic vortices to work in spintronics

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Magnetic vortices in thin (anti)ferromagnetic films can realize mobile objects, which can be injected, manipulated, and detected by electrical currents. We develop a nonequilibrium thermodynamic perspective on the emergent topological hydrodynamics of vorticity, as a new paradigm for yielding spintronic functionality. A flow of vorticity injected across a magnetic strip, which can be controlled by the interfacial spin torques, builds up a magnetic winding density along the strip, which is akin to charging a capacitor by an impinging electrical flow. We thus show how a simple insulating magnetic strip can realize an effective RC circuit for vorticity transport and discuss how it can be used for (topological) energy storage.

Spin-Orbit Torques in Metal-Based Heterostructures

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The fundamental building block of spin-orbitronics is the generation of spin-orbit torques, which enable electric manipulation of magnetization. The source of the spin-orbit torques is spin-orbit interaction in solids. When a charge current passes through a heavy metal with strong spin-orbit coupling, electrons with opposite spins are deflected in opposite directions, resulting in the generation of a transverse spin current, which is known as the spin Hall effect. Another source of the charge-to-spin conversion is the Rashba-Edelstein effect, where a charge flow in a Rashba two-dimensional electron gas results in the creation of a non-zero spin accumulation. The generated spin current and spin accumulation give rise to the spin-orbit torques.

Here, we discuss recent experimental results on the generation of the spin-orbit torques in metal-based heterostructures. We show that the oxidation of metals drastically alters the spin-orbit torques in the heterostructures. We found that the spin-torque efficiency of naturally oxidized Cu is enhanced by more than two-orders of magnitude through natural oxidation [1]. This motivated us to study the spin-orbit torques generated by Cu oxides with controlled oxidation levels. The spin-orbit torque in ferromagnetic-metal/Cu-oxide bilayers is maximized by a fine tuning of the oxidation level of the Cu layer, which is attributed to the enhancement of the interface spin-orbit coupling [2]. We also show that the intrinsic mechanism is responsible for the generation of the spin-orbit torque originating from the ferromagnetic-metal/Cu-oxide interface [3]. The oxidation of the most widely used spintronic material, Pt, also turns the heavy metal into an electrically insulating generator of the spin-orbit torques, which enables to control the spin-orbit torque through voltage-driven oxygen migration [4].

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O07

Magnon Josephson oscillations

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The ac Josephson effect is well known as a rapidly oscillating current that appears between two weakly coupled superconductors subject to an external dc voltage. The Josephson dynamics relies on the existence of two weakly coupled macroscopic quantum states. Therefore, a similar behavior was also expected, and indeed has been observed, in bosonic systems such as Bose-Einstein condensates (BECs), in superfluid ^{3}He, ^{4}He, and in weakly interacting Bose gases. Recently, magnon supercurrents were reported in room-temperature ferrimagnetic films [1] and an existence of the related Josephson effects was predicted [2,3]. Here, I present the discovery of the ac Josephson effect [4] in a magnon BEC carried by a room-temperature Yttrium Iron Garnet ($Y_3Fe_5O_{12}$, YIG) magnetic film. The BEC is formed in a parametrically populated magnon gas [1] around a potential trench created by a dc electric current I_{dc} (see Fig.1a). The appearance of the Josephson effect is manifested by oscillations of the magnon BEC density in the trench (see Fig.1b), caused by a coherent phase shift between this BEC and the BEC in the nearby left and right zones.

Support of ERC within the Advanced Grant 694709 “SuperMagnonics” and DFG through the Collaborative Research Center SFB/TRR-173 “Spin+X” (project B04) is acknowledged.

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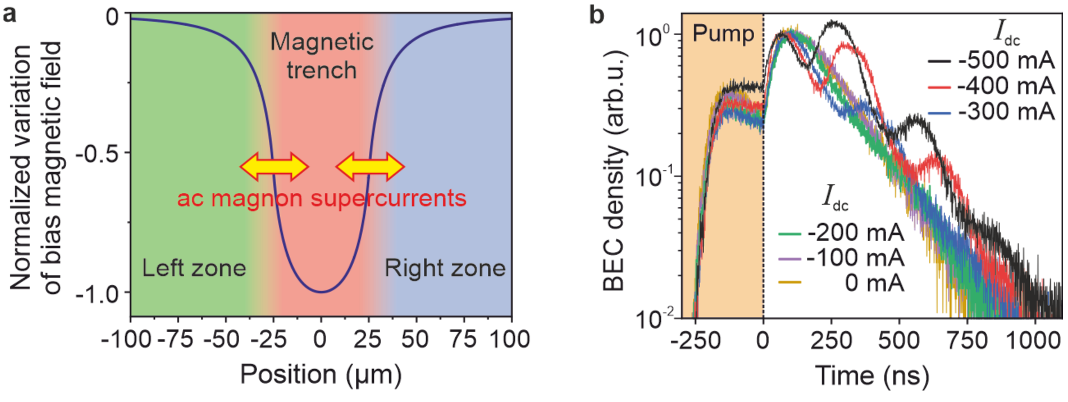

Fig. 1. (a) The calculated profile of a potential trench created by the Oersted field, which is induced by a dc electric current I_{dc}. (b) Josephson oscillations of the magnon BEC in the potential trenches of different depths. The oscillation frequency is proportional to the strength of the applied current.

Skyrmions in chiral magnetic multilayers

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D. Bracher[2], A. Kleibert[2], S. Wintz[1,3], S. Mayr[1,4], T. Weßels[5], A. Sadovnikov[6],
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Magnetic skyrmions are topologically-nontrivial spin textures with particle-like properties [1]. Their size, topological stability, and mobility suggest their use in future generations of spintronic devices, the prototype of which is the skyrmion racetrack [2]. To realise a racetrack requires three basic operations: the nucleation (writing), propagation (manipulation), and detection (reading) of a skyrmion, all by electrical means. Here we show that all three are experimental feasible at room temperature in Pt/Co/Ir or Pt/CoB/Ir multilayers in which the different heavy metals above and below the magnetic layer break inversion symmetry and induce chirality by means of the Dzyaloshinskii-Moriya interaction, defining the structure of Néel skyrmion spin textures [3]. We show deterministic nucleation on nanosecond timescales using an electrical point contact on top of the multilayer [4] (Figure 1), current-driven propagation along a wire in which the skyrmions are channelled by defects in the multilayer [5], and their detection by means of the Hall effect (Figure 2) that reveals an unexpectedly large contribution to the Hall signal that correlates with the topological winding number [6].

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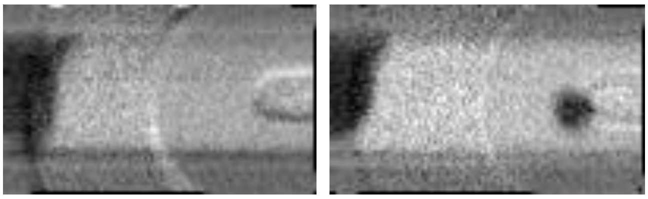

Figure 1. STXM images before and after nucleation of a skyrmion at a 500 nm wide point contact to a Pt/CoB/Ir multilayer.

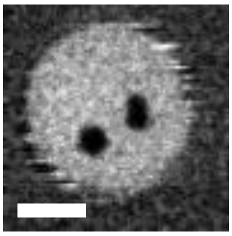

Figure 2. STXM image of two skyrmions in an electrically-connected 1 µm diameter Pt/Co/Ir multilayer dot. 500 nm scale bar.

O09

Generations and conversions of phonon angular momenta

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Phonons in crystals can have rotational motions, and can be associated with angular momenta. It is called phonon angular momenta [1]. Because it has similar symmetry properties with electron spins, one can expect phenomena analogous to those for electron spins, and conversions between the phonon angular momenta and electron spins. We explain our recent theories on predictions of such phenomena.

First we show that in nonmagnetic crystals without inversion symmetry, a heat current induces a phonon angular momentum. In such crystals, each phonon mode has an angular momentum. An example of the nuclei motions for a certain phonon mode in tellurium is shown in Fig.1(a), and one can clearly see that this mode has an angular momentum. In equilibrium, the total phonon angular momentum is zero because the contributions from k and –k cancel. Meanwhile, when the heat current is flowing in the crystal, this cancellation no longer occurs, and there will be a net angular momentum of phonons [2]. We call it phonon Edelstein effect. We propose several experimental setups to measure this effect, including conversion of the phonon angular momentum into a rigid-body rotation of the crystal (Fig. 1(b)). We also propose another way of generating phonon angular momenta, by an electric field onto a multiferroic crystal. In such a crystal, time-reversal and inversion symmetries are broken but their product is preserved. In such a case, an electric field induces a phonon angular momentum, in analogy with the magnetoelectric effect [3].

We also explain our microscopic theory of coupling between the phonon angular momenta with electron spins. In a nonmagnetic system with spin-orbit coupling, we assume that the atoms are rotating due to phonons (Fig. 1(c)), and we show that its spin-polarization is nonzero when the phonons have a rotational motion [3].

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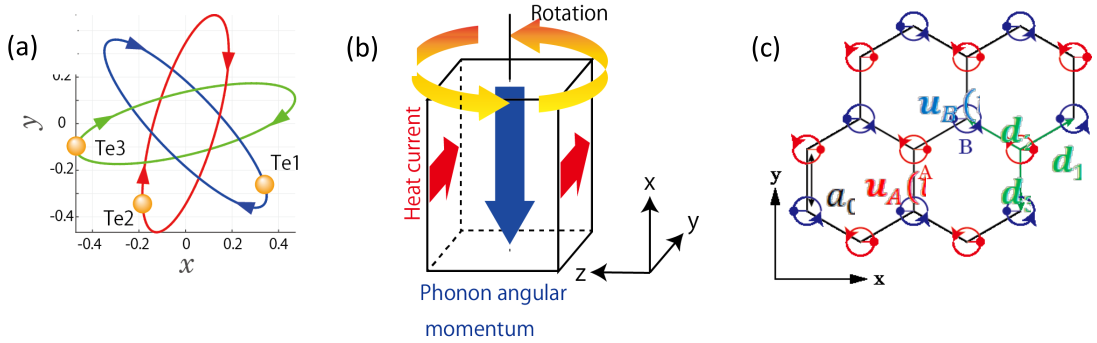

Figure 1: (a) Rotational motion of phonons in tellurium. (b) Proposal for observation of phonon Edelstein effect. (c) Atomic rotational motion by phonons, leading to spin polarization

Spin-charge conversion in Bi/Ag bilayer

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In this talk I will report our recent progress on the mechanism of the spin-charge conversation in Bi/Ag bilayer. We design the sample in such a way that the spin current can be injected from both sides of the Bi/Ag interface, which enables us to distinguish unambiguously the spin Hall effect or the Rashba-Edelstein effect mechanism.

Gate-tunable inverse spin Hall effect in ultrathin Pt

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Electric gating can strongly modulate a wide variety of physical properties in semiconductors and insulators, such as significant changes of conductivity in silicon, appearance of superconductivity in insulator [1], the paramagnet–ferromagnet transition in (In,Mn)As [2], and so on. The key to such modulation is charge accumulation in solids. Thus, it has been believed that such modulation is out of reach for conventional metals where the number of carriers is too large. However, success in tuning the Curie temperature of ultrathin cobalt gave hope of finally achieving such a degree of control even in metallic materials [3].

In this presentation, reversible modulation of up to two orders of magnitude of the inverse spin Hall effect in ultrathin platinum by ionic gating is introduced [4]. The thickness of Pt was changed from 2 to 20 nm, and they were grown on yttrium-iron-garnet (YIG), a ferrimagnetic insulator. An ionic-gate was equipped to the top surface of the Pt, which enables efficient charge accumulation to the Pt. Spin current was injected from the YIG to the Pt and converted to a charge current by the inverse spin Hall effect (ISHE) in the Pt. When a gate-voltage was applied to the 2nm Pt, noticeable modulation of both resistance and electromotive forces due to the ISHE were observed. The modulation vanished when the thickness of the Pt exceeded 5 nm, which indicates that the modulation is attributed to an ultrathin nature. The detailed mechanism is discussed in the presentation.

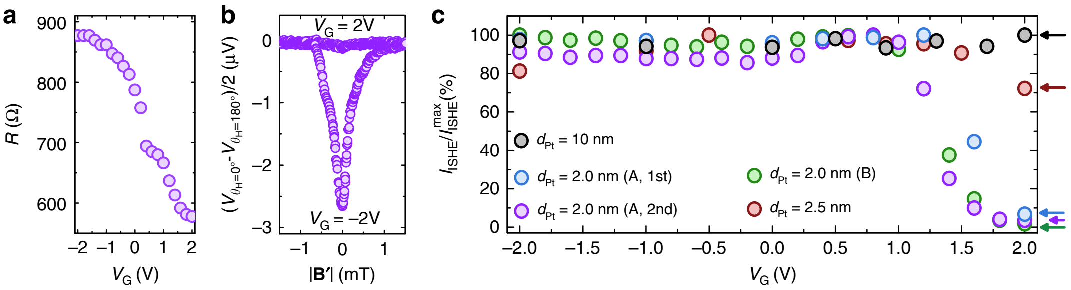

Figure 1. Gate-induced modulation of **a.** resistance and **b.** electromotive forces from the 2nm Pt. c. Detailed results in the modulation of the charge current induced by the ISHE in the Pt films. The thickness was changed from 2 to 10 nm in this figure. No prominent modulation can be seen in the 10 nm Pt.

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Spintronics with magnetic insulators

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Magnetic insulators are versatile materials of great technological importance. They attracted renewed interest from the spintronics community when K. Uchida, E. Saitoh c.s., demonstrated in 2010 thermal and electrical actuation of their magnetization dynamics that allows their integration into conventional electronic and thermoelectric devices.

The most important magnetic insulator is arguably the synthetic yttrium iron garnet (YIG), a ferrimagnet with Curie transition far above room temperature. Its record magnetic, acoustic and optical quality as well as discovery of entirely new phenomena, raises the hope for new applications for a sustainable future electronics. Recent progress includes an understanding of the temperature-dependent spin dynamics, as well as the interaction of the magnetic order with the crystal lattice, lasers, and microwaves.

I will present an overview of recent progress in the theory of the spintronics with YIG and compare results with experiments where available.

Topological spintronics in antiferromagnets and the crystal Hall effect

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The effective manipulation of antiferromagnets (AF), through the recently proposed and discovered Néel spin-orbit torque, has turned AFM into active elements of spintronic devices. This, coupled with the inherent topological properties of their band-structure, makes topological antiferromagnetic spintronics a fruitful area of exploration. A key remaining challenging aspect is the observation of the Néel order parameter. Here we show that the anomalous Hall effect can play a key role, which over a century, continue to play a central role in condensed matter research for their intriguing quantum-mechanical, relativistic, and topological nature. Here we introduce a microscopic mechanism whose key component is an asymmetric spin-orbit coupling originating from lowered symmetry positions of atoms in the crystal. Based on first-principles calculations, we demonstrate a pristine form of this crystal Hall effect in a room-temperature rutile antiferromagnet RuO2 whose Hall conductivity reaches 1000 S/cm. While a collinear antiferromagnetic order of magnetic moments alone would generate zero Hall response, the effect arises when combining it with the spin-orbit coupling due to non-magnetic atoms occupying non-centrosymmetric crystal positions. The crystal Hall effect can also explain recent measurements in a chiral antiferromagnet CoNb3S6, and we predict it in a broad family of collinear antiferromagnets [1].

Please limit your abstract to one page.

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O14

Conversion of angular momentum, quantum state and entanglement from photons to electron spin using gate-defined quantum dots

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Conversion of quantum states from single photons to single electron spins is regarded as an elemental process of optical spin conversions. Such conversion enables the quantum interfaces that bring optically-created quantum correlation, that is, entanglement into solid state devices. We are developing the photon-electron spin quantum interfaces using gate-defined quantum dots (QDs) with a built-in charge sensor [1]. In this talk, we present the recent experimental progresses on the conversions of angular momentum and quantum states from single photons to electron spins in gate-defined GaAs QDs [2,3] and the creation of pairs of single photoelectron in a QD and single photon from entangled photon pairs [4]. Moreover, making the conversion efficient using a nano-cavity in a photonic crystal [5] and a surface plasmon antenna [6] are discussed.

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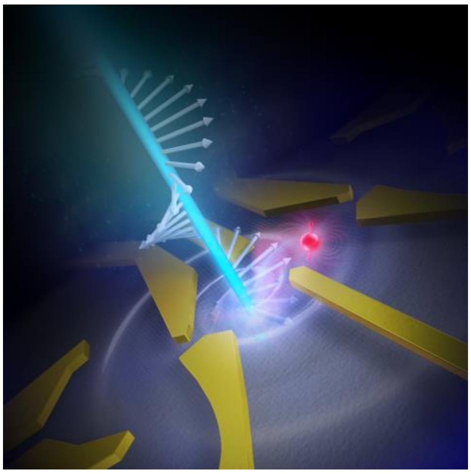

Fig. 1. Schematic illustration of angular momentum conversion from a single photon to a single electron spin in a gate-defined GaAs QD.

O15

Creation of Two-Dimensional Topological Phases with Perturbations

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The first prediction of topological insulator (TI) was done by Kane and Mele in 2005 on a two-dimensional (2D) honeycomb lattice. The first experimental observation of TI was also on a 2D electrons in a quantum well. And now creation of TI phases and control of them in 2D materials are most important issues in topological spintronics.

Here we introduce two ways to create topological phases in 2D materials [1,2]. The first is the introduction of spin-orbit interaction (SOI) into graphene. This was achieved by decorating the graphene surface with fine particles of Bi_2Te_3. Remarkably, multi-terminal resistance measurements suggest the presence of helical edge states characteristic of a quantum-spin-Hall phase; those magnetic-field and temperature dependence, X-ray photoelectron spectra, scanning tunneling spectroscopy, and first-principles calculations further support this scenario. The second is the introduction of different stacking phase 1T' into few layer MoS2 (2H) with laser irradiation. The 1T' phase works as a 2D topological insulator as indicated by the quantized resistance shown in Fig. 2.

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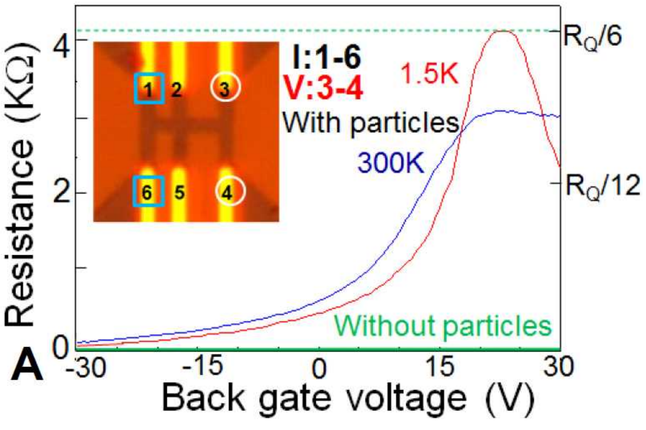

Fig. 1. Inset: AFM image of the sample. The vague dark regions are fabricated graphene with fine particles. The yellow-colored regions are Au electrodes. The blue squares indicate the current electrodes and the white circles the voltage electrodes. At 1.5 K, with varying the back gate voltage, the resistance increases and hits 1/6 of the quantum resistance, which is just expected for the configuration of the electrodes and perfect conductance connection between them.

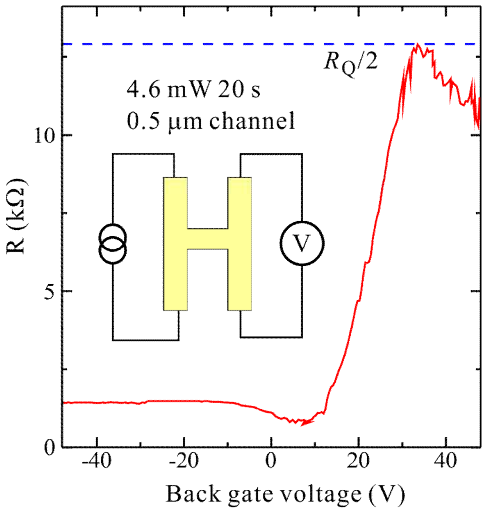

Fig. 2. Inset: Terminal configuration for resistance measurement. The red curve shows thus measured four-terminal resistance as a function of the back gate voltage. With tuning the Fermi energy inside the energy gap, the 1T' phase works as a topological insulator and the resistance is quantized to $R_Q/2$.

Ferroelastic strain control of Néel order in antiferromagnets

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Antiferromagnets with zero net magnetic moment, strong anti-interference and ultrafast switching speed have potential competitiveness in high-density data storage. Electrical control of antiferromagnetic moments is at the heart of their device application. We use ferroelastic strain driven by electric field to switch the Néel order of antiferromagnetic Mn_2Au films grown on piezoelectric $Pb(Mg_{1/3}Nb_{2/3})_{0.7}Ti_{0.3}O_3$ (PMN-PT) (011) substrates. When the electric field is swept, the easy axis of Mn_2Au is switched between [100] and [0$\bar{1}$1] directions of PMN-PT (011) at room temperature, exhibiting a butterfly-like switching feature. This feature indicates that the underlying mechanism is the electric field-induced ferroelastic strain. Such a transition of the easy axis leads to the change of threshold current for the field-like torque switching of Mn_2Au [1]. An atypical spin-charge conversion and spin-orbit torques in Mn_2Au/permalloy bilayers will be also discussed. Spin current whose polarization (δz) and flow directions are parallel or antiparallel to the film normal is allowed when a charge current is passing through Mn_2Au film, and produce an in-plane field torque on the adjacent permalloy [2]. The δz can be modulated by the growth of Mn_2Au/permalloy bilayers on both PMN-PT (001) and (011) substrates, where the ferroelastic strain causes the switching of Néel order and resultant manipulation of the magnitude of δz and spin-orbit torque. Electric field control of Néel order paves the way for all-electrical writing and readout in antiferromagnetic spintronics [3].

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O17

Ferrimagnetic spintronics

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Rare earth-3d transition metal (RE-TM) ferrimagnetic compounds, in which RE and TM magnetic moments are coupled antiferromagnetically, have two distinct compensation temperatures, namely, the magnetization compensation temperature (TM) where the magnetizations of RE and TM sub-lattices cancel each other and the angular momentum compensation temperature (T_A) where the net angular momentum vanishes.

We found the fast field-driven domain wall (DW) motion in ferrimagnetic GdFeCo at T_A [1]. The collective coordinate approach generalized for ferrimagnets and atomistic spin model simulations show that this remarkable enhancement of DW velocity is a consequence of antiferromagnetic spin dynamics at T_A. The antiferromagnetic spin dynamics at T_A results in a peculiar phenomenon; vanishing the skyrmion Hall effect at T_A [2]. We also examined the effect of spin-transfer torque on the motion of DW ferrimagnets and found that adiabatic spin transfer torque changes its sign at T_A and non-adiabatic spin transfer torque shows a peak at T_A [3]. We also found bulk Dzyaloshinskii-Moriya interaction (DMI) in amorphous GdFeCo. This bulk DMI is attributed to an asymmetric distribution of elemental content in the GdFeCo layer, where spatial inversion symmetry is broken throughout the layer. [4].

This work was partly supported by JSPS KAKENHI Grant Numbers 15H05702, 26870300, 26870304, 26103002, 25220604, 2604316, Collaborative Research Program of the Institute for Chemical Research, Kyoto University, and Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University.

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Spin-charge conversion by chirality

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Central to spintronics is the interconversion between electronic charge and spin currents, and this has been demonstrated at molecular scales with the chirality-induced spin selectivity (CISS) effect [1]. This spin-orbit effect has been intensively explored using electronic transport experiments despite that its microscopic theory is still under development. Often, these experiments directly compare CISS to magnetism and use a two-terminal (2T), spin-valve-type of device containing a chiral and a ferromagnetic component, and observe a magnetoresistance (MR) signal—even though such a signal is forbidden by Onsager reciprocity in the linear response regime [2]. In this talk, after a brief introduction of CISS and its current developments, I will highlight the fundamental difference between CISS and magnetism in terms of coupled charge and spin transport, and explain the mechanism that makes the 2T MR signal possible for nonlinear response [3]. I will show how the sign of the MR relates to device properties, and propose a magnet-free spin valve based on chirality.

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O19

NEW PERSPECTIVES IN ALL-OPTICAL CONTROL OF SPINS:

from fundamentals to brain-inspired computing concepts

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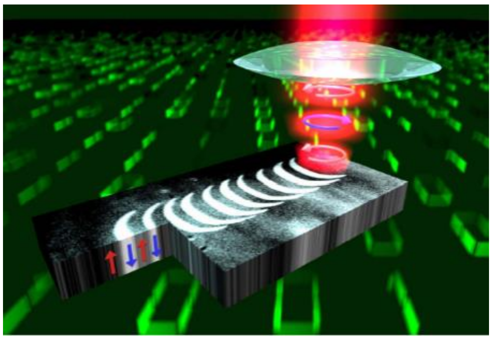
The explosive growth of digital data and its related energy consumption is pushing the need to develop fundamentally new physical principles and materials for faster, smaller and more energy-efficient processing and storage of data. Ultimately, future brain-inspired technology should provide room temperature operation down to picosecond timescales, nanoscale dimensions and at an energy dissipation as low as the Landauer limit (~zJ). Since the demonstration of magnetization reversal by a single 40 femtosecond laser pulse, the manipulation of spins by ultra-short laser pulses has developed into an alternative and energy efficient approach to magnetic recording. In this talk, I will discuss some first results and the potential of ultrafast optical control of magnetism to implement brain-inspired computing concepts in magnetic materials that operate close to these ultimate limits.

We experimentally demonstrated that the cumulative all-optical switching process in technologically relevant Co/Pt materials provides an energy-efficient mechanism for realizing artificial synapses, in which the internal state of the synapse is stored non-volatile and is controlled continuously and reversibly using the helicity of picosecond optical pulses. Moreover, we realize supervised learning of a network of two such opto-magnetic synapses, that together form a single-layer perceptron. Based on our findings we estimate a projected energy dissipation of nanoscale synapses down to 20 fJ/synapse/learning step.



Spin-Charge Conversion in Ferromagnetic Materials

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Highly efficient conversion from charge current (J_c) to spin current (J_s) and vice versa is the key for spintronic devices to improve their performance and to provide them with multi-functionalities. A promising way for spin-charge conversion is to exploit large spin Hall effect (SHE) in nonmagnets (NMs). Thus, the extensive studies on SHE have been done for developing nonmagnetic spin Hall materials. As in the case of SHE in NMs, one can also expect the spin-charge conversion in ferromagnets (FMs). In 2015, our group successfully observed the conversion from J_s to J_c in the ferromagnetic $L1_0$-FePt using the technique of spin Seebeck effect [Ref. 1], which was one of the pioneering studies on the spin-charge conversion in FMs. At the same time, the concept of spin anomalous Hall effect (spin-AHE) was proposed [Ref. 2]. The theory of spin-AHE predicted that AHE also generates J_s in FM and leads to the spin torque exerting on the other FM. Since the quantization axis of J_s can be controlled by the magnetization vector, the large spin-AHE can be used for the field-free magnetization switching of a perpendicularly magnetized free layer. Thus, the spin-charge conversion in FMs is a recent intriguing research topic.

In this talk, we introduce the large spin-AHE in an $L1_0$-FePt ferromagnet [Ref. 3]. By employing the giant magnetoresistance device consisting of $L1_0$-FePt / Cu / $Ni_{81}Fe_{19}$, we have evaluated the spin anomalous Hall angle (α_{SAH}) to be 0.25 ± 0.03 for the $L1_0$-FePt from the linewidth modulation of ferromagnetic resonance spectra by dc current application. This value is much larger than that for CoFeB reported previously [Ref. 4]. In addition, the evaluation of α_{SAH} at different configurations between J_c and magnetization allows us to discuss the symmetry of spin-AHE and gives the unambiguous evidence that spin-AHE provides a source of J_s. Thanks to the large α_{SAH}, we have successfully demonstrated spin-AHE-induced magnetization switching in $L1_0$-FePt / Cu / $Ni_{81}Fe_{19}$.

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O21

Pure spin supercurrents

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Spin currents are fundamental to spintronics, but in the normal state large charge currents are required at device inputs in order to generate sufficiently large output spin current densities. In this talk I will review our group's discovery and progress in generating and controlling superconducting pure spin currents through the transfer of spin angular momentum via proximity-induced equal-spin triplet states in superconducting Nb[1,2]. In agreement with recent theory[3-5] and experiments[2,6], I will show that spin-orbit coupling (SOC) in conjunction with a magnetic exchange field generates spin-polarized triplet pairs. In particular, I will demonstrate that when a perpendicularly magnetized Pt/Co/Pt spin sink is proximity-coupled to superconducting Nb, ferromagnetic spin-pumping efficiency in the superconducting state is tunable by controlling the tilt angle of the Co layer magnetization, thus increasing the degree of orthogonality between the SOC and magnetic exchange field at the Nb/Pt/(Co/Pt) interface. The results are central to the development of superconducting device with charge and spin-degrees of freedom.

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