Abstract

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PS01

Magnetization dynamics with inertia in metallic ferromagnets

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Usually, the magnetization dynamics are described by the Landau-Lifshitz-Gilbert (LLG) equation, which includes only the first-order time derivative of magnetization. However, when the magnetization dynamics are very fast (typically sub-picosecond order for metallic ferromagnets), it is expected that the LLG equation should be generalized to include a term with the second-order time derivative. This term plays the role of the inertia of magnetization [1,2,3].

The appearance of the inertial term is due to the effect of the environmental degrees of freedom surrounding the magnetization. In the case of metallic ferromagnets, they are conducting electrons. Usually, the effects of conducting electrons can be treated at the adiabatic limit, where the spin of the conducting electrons is assumed to align with magnetization vector. This means that the angular momentum vector points in the direction of the magnetization vector, which is the usual gyromagnetic relation. When the inertia is included, this is not the case: the angular momentum vector and the magnetization vector generally point in different directions. Such a generalized gyromagnetic relation will provide rich variety of magnetization dynamics.

We study mainly three points about the inertia of magnetization [4]:
1. A concrete expression of the inertia in terms of the spin polarization of the conducting electrons and the coupling constant between the magnetization and the conducting electrons.
2. The basics of the magnetization dynamics with inertia. In particular, their equivalence to the dynamics of a spinning top, and of a charged particle on a sphere under a monopole background.
3. Typical behavior of magnetization with inertia: effects of the inertia on spin waves, domain wall dynamics and so on. In particular, how magnetization with inertia responds to a large and rapidly changing magnetic field.

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PS02

Coherent control of magnetizations and spin currents in quantum magnets with laser

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Recently periodically-driven quantum states have attracted much attention [1-6]. In particular, thanks to the recent development of laser science, it is gradually possible to realize various periodically-driven nonequilibrium states by applying laser to solid. The control of electron and spin motions by laser is becoming a hot topic. Many theoretical studies for driven systems have concentrated on electric charge dynamics. Remarkably, for example, it is shown [1,2] that when a circularly polarized laser is applied to two-dimensional Dirac electron systems on lattices, a topologically-insulating state with a gapless chiral edge mode emerges. Furthermore, experimental signatures of laser-driven electron states in band-insulating materials have been reported very recently [3].

On the other hand, we have recently explored novel nonquilibrium phenomena in insulating magnetic systems. In particular, we are focusing on magnetic phenomena in quantum antiferromagnets [4,6] and multiferroic models [5]. In this conference, we would like to discuss two of our recent results, i.e., two new methods of (1) controlling magnetizations in a wide class of quantum magnets “without static magnetic field” [4] and (2) generating additional Dzyaloshinskii-Moriya (DM) interactions in a class of multiferroic systems [5] by applying circularly polarized lasers. The control of DM interaction could also be regarded as that of spin current. I will discuss in detail these new theoretical proposals for laser control of physical quantities.

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PS03

Thermodynamics of Mesoscopic Steady-State Heat Engine beyond Linear-Response Regime

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Recently, a new type of heat engine, which we call here the steady-state heat engine, has appeared in the context of research of the efficiency at maximum power [1]. In particular, the mesoscopic thermoelectric steady-state heat engine (Fig.1) is attractive in the following two points. Practically, this engine is realizable experimentally with high efficiency because of the potential of nanoscale thermoelectricity. Theoretically, this engine can be a powerful tool to investigate how quantum mechanics affects thermodynamics.

However, researches on this engine are mostly limited to the linear-response regime [1,2]; its thermodynamic structure beyond the regime is yet to be clarified. Although some researchers have already used the definition of the heat current which we will derive in this Poster beyond the linear-response regime, few discussions have been publicized regarding even its origin and validity.

In this Poster, we will give a thermodynamically consistent definition of the heat current of the steady-state heat engine beyond the linear-response regime, which is the main result of this Letter. We then apply it to the mesoscopic thermoelectric steady-state heat engine, which produces the following two interesting results: the efficiency of the mesoscopic thermoelectric engine reaches the Carnot efficiency if and only if the transmission function is a delta function at a certain energy; the unitarity of the scattering matrix guarantees the second law of thermodynamics, invalidating Benenti *et al.*'s argument in the linear-response regime that one could obtain a finite power with the Carnot efficiency under broken time-reversal symmetry.

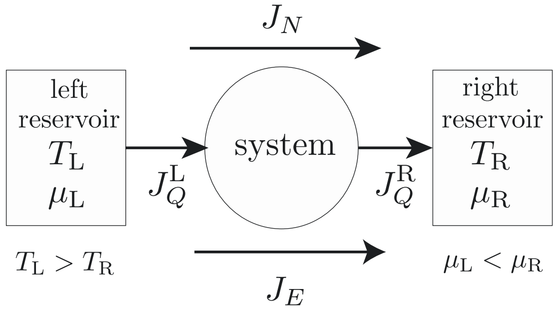

Figure. 1. A mesoscopic thermoelectric engine.

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PS04

Mode engineering with a one-dimensional superconducting metamaterial

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We propose a way to control the Josephson energy of a single Josephson junction embedded in one-dimensional superconducting metamaterial (Fig. 1): an inhomogeneous superconducting loop, made out of a superconducting nanowire or a chain of Josephson junctions. The Josephson energy is renormalized by the electromagnetic modes propagating along the loop [1]. We study the behavior of the modes as well as of their frequency spectrum when the capacitance and the inductance along the loop are spatially modulated. We show that, depending on the amplitude of the modulation, the renormalized Josephson energy is either larger or smaller than the one found for a homogeneous loop. Using typical experimental parameters for Josephson junction chains [2,3] and superconducting nanowires [4,5], we conclude that this mode-engineering can be achieved available metamaterials.

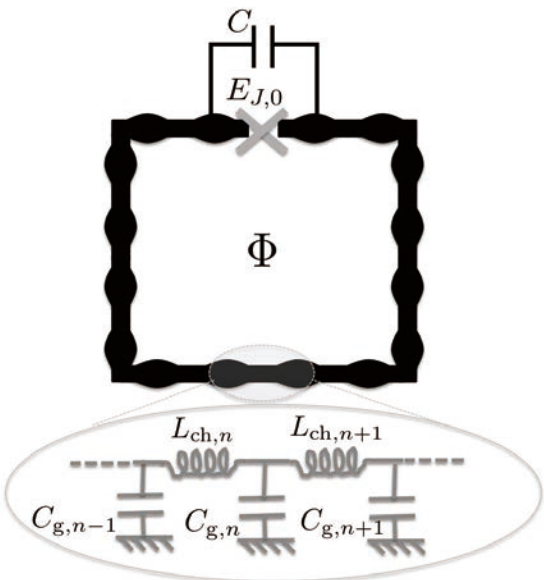

Figure 1: Single Josephson junction with Josephson energy $E_{J,0}$ and capacitance C, embedded in a loop made out of one-dimensional superconducting metamaterial threaded by a magnetic flux Φ. The metamaterial can be either a thin superconducting wire whose parameters (such as cross-sectional area or distance to a nearby screening gate) are spatially modulated, or a chain of Josephson junctions (see inset) with spatially distributed capacitances $C_{\mathrm{g},n}$ and inductances $L_{\mathrm{ch},n}$.

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PS05

Persistant metastability in periodically driven systems

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We investigate the periodic dynamics of isolated quantum many-body systems. Generically, such systems are known to heat up to infinite temperature in the thermodynamic limit, while the behaviors for finite time scales is still a challenging issue. Even if a state goes to the chaotic state under infintite-time periodic dynamics, the state may remain a metastable state with rich structures. Indeed, the existence of such metastable states has been reported in periodically driven Friedrichs models [1]; that is, we still have the possibility to construct the universal Floquet theory at a finite time scale.

Here, we give several universal properties of finite-time Floquet theory. We mathematically prove the existence of the metastable states, whose lifetimes exponentially increases with the driving frequency $\boldsymbol{\omega}$. In the proof, they are given by the eigenstates of a Hamiltonian which comes from the finite-order truncation of Floquet-Magnus expansion; there, we prove that the Floquet-Magnus expansion exponentially converges by a certain order of $\mathbf{O}(\boldsymbol{\omega})$ and then breakdown beyond it. This way, the Floquet Hamiltonian can be well-approximated by the Floquet-magnus expansion for finite-time scale, although it might look completely random for the infinite-time limit. To relate our result to the physically interesting phenomenon, we prove exponentially slow heat absorption for the driving frequency, which is relevant to so called many-body energy localization (or ergodicity breaking).

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PS06

Giant spin Hall magnetoresistance in metallic bilayers

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Recently spin-orbit interaction draws great interests due to its potential to alternative mechanism for magnetization manipulation. As a result, several interesting concepts and phenomena were introduced. Spin Hall magnetoresistance (SMR), which shows distinctive to conventional magnetoresistance, is one of them. The SMR is combined effect with ordinary and inverse spin Hall effect (SHE). So far, the reported SMR was only measured from magnetic insulator/heavymetal system, i.e. $Y_3Fe_5O_{12}$ (YIG)/Pt and YIG/Ta [1,2].

Here we show there is a ten-fold larger SMR in metallic bilayer using with W/CoFeB/MgO heterostructures. The films were prepared using with magnetron sputtering and patterned by photo-lithography and Ar ion-etching. To evaluate the SMR, measurements were given by three kinds of methods: large-field induced method and two methods with small field. We verified that there is few difference of the SMR among the mentioned methods [3]. The measurements were given for several devices with various thicknesses of W layer. As shown in Fig. 1, the SMR is quite sensitive to W layer thickness in accord with theoretical expectation [4]. From the fitting of the SMR, we obtained ~0.2 magnitude of spin Hall angle and 1.4~1.6 nm spin diffusion length for W layer. Similar study was also given for Ta/CoFeB/MgO heterostructures. Further discussion will be given.

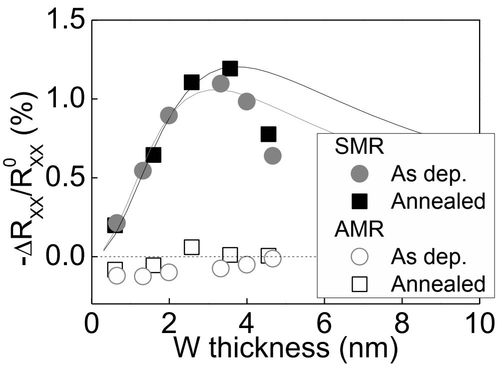

Figure 1: W layer thickness dependence on SMR (solid symbol) and anisotropic magnetoresistance (opened symbol) from annealed (square) and as deposited (circle) W/CoFeB/MgO heterostructures.

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PS07

Topological superconductivity in Dirac semimetals

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Dirac semimetals are a three dimensional (3D) material that possesses a gapless (Dirac) point in a bulk Brillouin zone, whose low energy excitation is effectively described by Dirac fermions. With time-reversal and inversion symmetries preserved, a pair of Dirac points can be formed at the crossing of two doubly degenerate bands in a high symmetric direction and protected by discrete rotation (C_n) symmetry [1,2], which prohibits a band mixing to open a gap. As a consequence of bulk boundary correspondence, a Fermi loop (FL) lives in a surface [2,3]. This is in sharply contrast with a Fermi arc in Weyl semimetals because of the different topological origin.

Most recently, the superconducting transition has been reported on Cd_3As_2 [4] and Au_2Pb [5], both of which support the C_4 symmetry protected Dirac points. A bulk Cd_3As_2 is superconducting around a point contact region on the surface or under the high pressure, and the pressurized Cd_3As_2 involves a structure transition from a Dirac semimetal to a semiconductor [6]. Thus, it is expected that the superconductivity can be accompanied with a breakdown of Dirac point. In addition, the observed tunneling conductance showed a zero-bias conductance peak. Interestingly, Au_2Pb also invokes a structure transition of the crystal before the superconducting transition [5]. Thus, although detailed analysis of the superconductivity is still missing in the Dirac semimetals, it is highly desirable to establish a general criterion for the TSC and a relation to a structure transition of the crystal.

In this poster, we address how the non-trivial topology, involving the Dirac point and the FL, affects the superconducting properties. It is known that topological materials are a promising candidate of the TSC, which stems from the fact that the non-trivial topology of wave function affects its superconducting state. For instance, the Fermi surface topology, which is the simplest topological structure in the normal state, directly influences a TSC for odd-parity superconductors [7].

Key quantities of our theory are a C_4 invariant and a mirror Chern number, which ensure the Dirac point and the FL, respectively. We show that these two topological numbers are intrinsically related and are inherited as a node and a double Majorana fermion in the superconducting state for a type of pairing symmetries. This feature opens a path for realizing a fully gapped TSC and reveals a relationship between the TSC and a structure transition of the crystal. Also, the Majorana fermions are induced by the FL, which is clearly distinguished from one in other TSCs, including superfluid ^{3}He-A [8] and Weyl superconductor [9].

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PS08

Spin Hall effect of Dirac fermions with vanishing spin current operator

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We study Dirac electron systems with spin-mixing alpha-matrices. The spin transport of the system would be quite different from usual spintronics materials due to its spin-mixing linear dispersion. In a spin-non-conserved system, however, the conventional definition of a spin current $\{S_z, \mathbf{j}\}/2$ does not satisfy the continuity equation and sometimes leads crucial problems [1]. Hence it is difficult to judge whether or not we can apply the definition to our system.

Instead of using the conventional definition, we derive a quantum kinetic equation microscopically [2] in a three-dimensional Dirac electron system with $\alpha_i = \sigma_i \times \tau_1$($\sigma$'s: spin Pauli matrices, τ's: orbit Pauli matrices). Then we define the spin current from diffusion equations [2, 3], which can be derived by the quantum kinetic equation. According to the new definition, we find that the spin Hall coefficient has a finite value, though the conventional spin current operator is identical to zero in this system.

We also discuss a relation between anomalous electric current, which originates from the vertex correction of impurities, and the spin Hall coefficient.

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PS09

Electrical transport in three-dimensional cubic Skyrmion crystal

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Two-dimensional magnetic Skyrmions have been well characterized experimentally in the bulk or on epitaxial thin films. Besides, a topologically nontrivial three-dimensional cubic Skyrmion crystal in the bulk, which is essentially a hedgehog-antihedgehog pair structure predicted theoretically, has also been observed. Equipped with a sophisticated spectral analysis method, we adopt finite temperature Green's function technique to calculate the longitudinal electrical transport in such system. We consider conduction electrons interacting with spin-waves of the topologically nontrivial spin texture, whereupon fluctuations of monopolar emergent electromagnetic field enter. We study in detail the behavior of electrical resistivity under the influence of temperature, Skyrmion number and a characteristic monopole motion, especially a novel magnetoresistivity effect tentatively describing some up-to-date experimental observations.

Topological Phase Transitions and Sweep Dynamics of a Generalized Cluster Model in One Dimension

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Quest for topological phases is a hot topic in quantum information science and quantum statistical physics. It has been recognized that topological ordered states can be used for resource states in quantum information processing. In addition, a couple of beautiful relations between some physical properties and entanglement properties have been reported in topological systems and exactly solvable lattice-gas models [1-4].

The cluster model would be one of the simplest models, in which the ground state is a topological state called cluster state [5-7]. The cluster model in one dimension characterizes a string order parameter that is a nonlocal order parameter. By adding the Ising coupling term into the one-dimensional cluster model, a topological phase transition emerges [7]. This suggests that additional terms would involve novel phases and phase transitions.

We consider a generalized cluster model in one dimension [8]. The Hamiltonian of the model is represented by

$$H = \sum_{i=1}^{N} \left(-J^{XZX} \sigma_i^x \sigma_{i+1}^z \sigma_{i+2}^x + J^{YY} \sigma_i^y \sigma_{i+1}^y + J^{YZY} \sigma_i^y \sigma_{i+1}^z \sigma_{i+2}^y \right),$$

where the first, second, and third terms respectively represent cluster, Ising, dual cluster interactions. Since the excitation gap of the model can be obtained exactly, the phase boundaries of the model can be determined. To characterize each phase, order parameters including string order parameters and the entanglement spectra are calculated. We find that nontrivial phases appear in the parameter regions where all coupling constants are comparable. Next, we study dynamic behavior of the model under a sweep of interaction parameter across a critical point. When the interaction parameter changes slowly, the string correlation function and the entanglement entropy have a characteristic spatial structure. The fact would be related with the topological blocking found in topological systems [9,10].

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PS11

Magnetization damping in antiferromagnetically coupled spin valves

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Recently, a new direction in spintronics has been emerging in which antiferromagnets (AFMs) complement or replace ferromagnet (FMs) as active elements of memory or logic devices [1], e.g. because AFMs do not generate unwanted stray fields. On the other hand, it is difficult to control AFMs by an external magnetic field. Moreover, natural AFM materials resonate at a much higher frequencies (THz rather than GHz), which is difficult to match to conventional electronic circuits.

Motivated by experimental results that hitherto have been unexplained [2], we focus on the theory of the simplest of synthetic antiferromagnets, i.e. the antiferromagnetically exchange-coupled spin valve. These devices have the features of natural AFMs but with easily accessible resonance frequencies that are tunable by weak magnetic fields. By rigorous model calculations, we investigate the magnetic damping of synthetic AFMs as affected by mutual pumping of spin currents and spin transfer torques or "dynamic exchange interaction" [3]. We derive the Landau-Lifshitz-Gilbert equations for the coupled magnetizations including the spin transfer torques by spin pumping based on the spin diffusion model with quantum mechanical boundary conditions at the interfaces. We obtain analytic expressions for the linewidths of magnetic resonant modes (acoustic and optical) for magnetizations canted by applied magnetic fields. We find that noncollinear magnetizations induce an additional damping and that FMR linewidths strongly depend on the type of the resonant modes as well as the strength of magnetic fields. Our calculated results compare favorably with experiments [4] as shown in Fig. 1, thereby proving the importance of dynamics spin currents in these devices. Our model calculation paves the way for the theoretical design of synthetic AFM material with an application potential for data-storage technologies in antiferromagnetic spintronics.

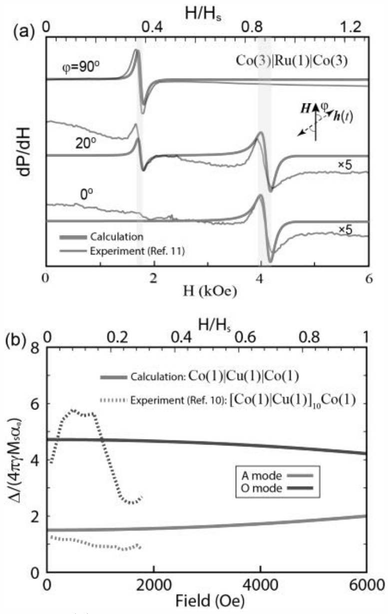

Fig.1: (a) Derivative of the microwave absorption spectrum [5] (b) Computed linewidths of the acoustic (A) and optical (O) modes [2].

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PS12

Majorana fermions with spatially periodic modulation

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Recently, motivated by mesoscopic physics and quantum information science, novel topological phases have been discovered. These phases are characterized by emergent edge excitations and entanglement spectrum (ES). The Kitaev model of one-dimensional spinless *p*-wave superconductor is one of the simplest fermion models exhibiting such a topological phase. In the topological phase, the system possesses Majorana zero modes at the ends of the system, which is responsible for the degeneracy of the lowest levels in the ES of the ground state. The robustness of the Majorana zero modes has attracted both theoretical and experimental attention. The fate of the modes under spatially periodic modulation and disorder has been considered in Ref. 1, where the authors found out the transitions from topological phase to trivial phase.

We numerically analyzed the one-dimensional Majorana fermions with the third-nearest interactions to show the robustness of the Majorana zero modes. We calculated the ES and the string correlation functions using the exact diagonalization method. The model without the periodic modulation has two Majorana zero modes and the ES shows four-fold degeneracy in lowest levels [2]. We impose the chemical potential periodically modulating in space. Varying the amplitude and the phase of the modulation, the number of the Majorana zero modes change. Remarkably, for certain values of the amplitude and the phase, the ground state shows topological phase with *one* Majorana zero mode. Correspondingly, the lowest levels of the ES are two-fold degenerate (Fig.1) and the string correlation functions show characteristic behaviors in the ground state. The above results indicate that the robustness of Majorana zero modes strongly depends on the spatial modulation of the chemical potential.

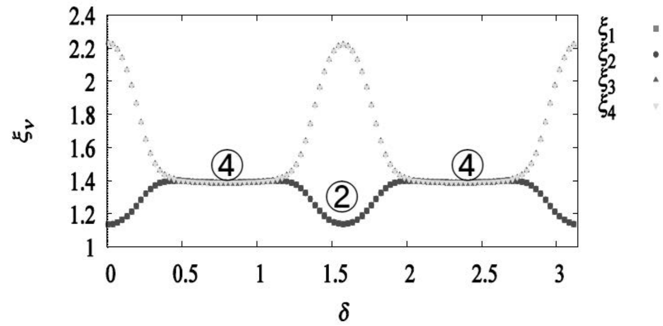

Figure 1: The lowest four ES ξ_ν for each phase δ of the modulation of the chemical potential. The amplitude is $0.5t$ and the wave length is $4a$, where t is the hopping integral and a is the lattice constant. The number enclosed by a circle represents the degeneracy of the lowest levels of the ES.

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PS13

Effect of Rashba spin-orbit coupling in diamagnetic current induced by nonuniform magnetic field

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A dissipative electric current in systems with Rashba spin-orbit coupling is accompanied by a spin polarization. This phenomenon is known as the Edelstein effect. [1] On the other hand, there are permanent currents which do not suffer from dissipation, such as a diamagnetic current induced by a magnetic field. It flows at the edge of the sample for a uniform magnetic field, whereas it flows in the bulk if the magnetic field is nonuniform.

In this work, we examine whether a spin polarization accompanies a diamagnetic current. We calculate the diamagnetic susceptibility and spin susceptibility subject to Rashba spin-orbit coupling. We specifically consider a 2D Dirac electron system, which is known for a large diamagnetism due to the interband magnetic effect [2]. Such a system is realized in graphene on Au substrate, in which a large Rashba constant of order 100 meV was reported [3]. Figure 1 shows the momentum dependence of spin susceptibility. This graph reveals existence of spin polarization. The relation between the spin polarization and the interband magnetic effect is also discussed.

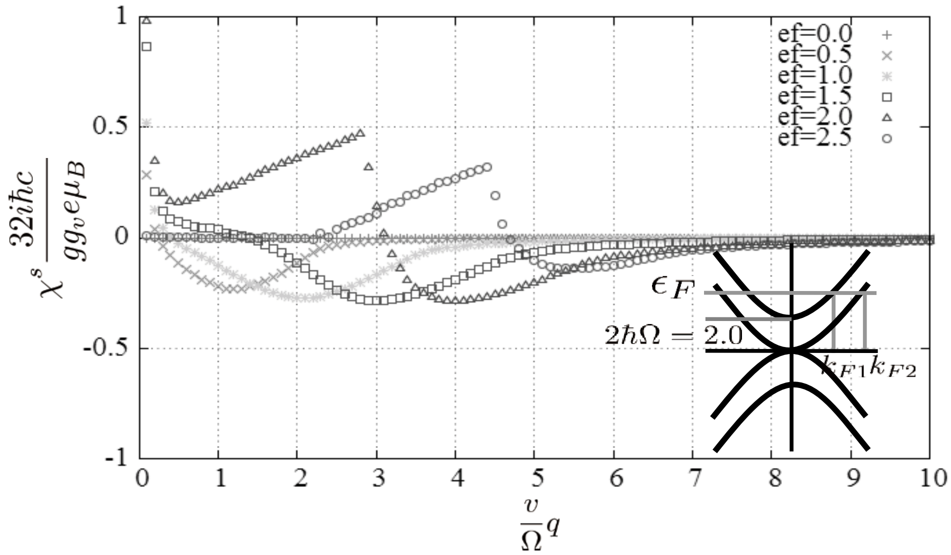

Figure 1

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Cyanide-Bridged Fe_{42} High-Spin Nanocage with $S = 90/2$

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One of the major topics in the molecular magnetism field is the development of high-spin molecules. We synthesized a cyanide-bridged magnetic Fe_{42} nanocage comprising 18 high-spin Fe^{III} ions and 24 low-spin Fe^{II} ions. The magnetic metal centers are ferromagnetically coupled, yielding the highest ground-state spin number (S = 45) of any reported molecule [1].

The reaction of $Fe(CF_3SO_3)_2$, 1,3-di(4-pyridyl)propane (dpp), L-ascorbic acid, and $Li[Fe(Tp)(CN)_3]$ in H_2O led to the isolation of a new $[Fe^{III}{}_{18}Fe^{II}{}_{24}]$ spin nanocage (Fig.1), $[\{Fe^{II\text{-}LS}(Tp)(CN)_3\}_{24}\{Fe^{III\text{-}HS}(H_2O)_2\}_6\{Fe^{III\text{-}HS}(dpp)(H_2O)\}_{12}(CF_3SO_3)_6]\cdot 18H_2O$ (**1**$\cdot 18H_2O$) (LS = low-spin, HS = high-spin), where **1** contains 42 iron ions, the largest number of metal centers in any cyano-bridged cluster reported to date. Crystallographic analysis reveals that 24 $\{Fe(Tp)(CN)_3\}$, 12 $\{Fe(NC)_4(dpp)(H_2O)\}$, and 6 $\{Fe(NC)_4(H_2O)_2\}$ building units are symmetrically disposed in an O space around a central point, providing the cube cage with a separation of 1.96 nm between the most distant Fe ions.

The magnetic properties indicate the existence of predominantly ferromagnetic interactions. The magnetization data in the range of 300–30 K can be fitted to the Curie–Weiss law, yielding $C = 83.2$ cm^{3}mol^{-1}K and $\theta = 6.7$ K. The magnetization (M) at 2 K rapidly increases at low fields and then steadily increases with $H > 15$ kOe to reach a near saturation value of 88.4 μ_B at 50 kOe, which is in good agreement with the expected value of 90 μ_B (with $g = 2.0$) for a ground state of $S_T = 90/2$ (Fig. 2). This magnetization behavior is significantly higher than that shown in the Brillouin curve corresponding to 18 non-interacting S_{Fe} spins ($S = 5/2$), fitting more closely the Brillouin curve for one $S = 45$ center (with $g = 2.0$). These data support the maximum possible spin state $S = 45$, which is the largest spin ground state number of any molecule ever prepared.

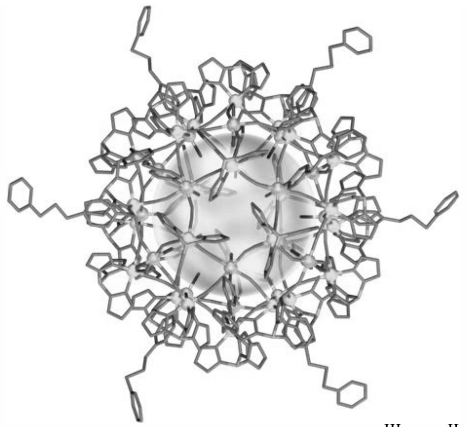

Figure 1: Structure of a single $[Fe^{III}{}_{18}Fe^{II}{}_{24}]$ high-spin (S = 45) nanocage: **1**$\cdot 18H_2O$.

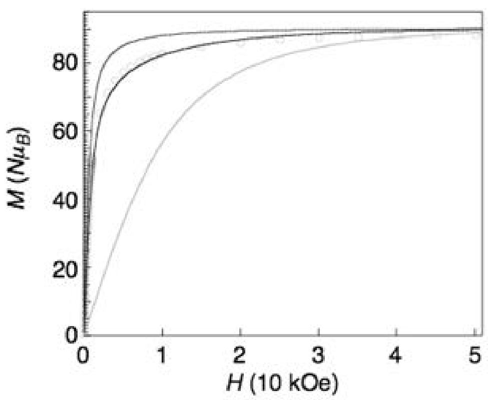

Figure 2: Magnetization *vs*. external magnetic field curve for **1**$\cdot 18H_2O$ at 2 K.

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PS15

Valley coupling, spin-orbit interaction and vernier-scale-like spectrum in finite-length metallic single-wall carbon nanotubes

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Metallic single-wall carbon nanotubes (m-SWNTs) are ideal one-dimensional conductors of nanometer to micrometer length. Due to the confinement in finite-length, energy levels of electrons are quantized. Fourfold degeneracy of the energy levels has been considered as an intrinsic property of SWNTs reflecting the two non-equivalent, degenerate valleys of K and K' in the two-dimensional Brillouin zone together with two spin degrees of freedom. Recent measurements with ultraclean SWNTs have found fine structures of the order of sub-milli-electron-volt in tunneling conductance spectra caused by the spin-orbit interaction. On the other hand, the gate-dependent two- and fourfold oscillations in measurements may imply strong coupling of the two valleys.

We will show that the degeneracy of energy levels of m-SWNTs strongly depends on the chirality, boundary condition, length and the spin-orbit interaction by numerical and analytical calculations [1]. The two valleys are strongly coupled for the so-called metal-2 chiral nanotubes with both ends orthogonal-shaped edges as well as the armchair nanotubes. The effect of strong valley coupling combined with the asymmetric velocities [2] appears as a vernier-scale-like spectrum, showing two- and fourfold oscillations as observed in experiments. For a so-called minimal boundary, which has a geometry removing the Klein-type terminations from the orthogonal-shaped edges, nearly fourfold degeneracy and its lift by the spin-orbit interaction [3] are shown as the result of decoupling of two valleys. For shorter nanotubes, a geometrically induced splitting of the valley degeneracy overcomes the effect of spin-orbit interaction.

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PS16

Novel Coupling between Spin and Electromagnetic Field in a Ferromagnetic Metal with Rashba Spin-orbit Interaction

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In ferromagnetic metals, an effective electromagnetic field emerges due to the presence of the strong *sd* interaction and an inhomogeneous magnetization texture. This emergent field is called the spin electromagnetic field [1]. The spin electromagnetic field couples to conduction electron spins and plays important roles in spintronics. How the ordinary electromagnetic field interacts with the spin electromagnetic field was investigated by the authors [2]. Recently, the emergent spin electromagnetic field arising from the Rashba spin-orbit interaction has been investigated in detail.

The purpose of our study is to clarify how the ordinary electromagnetic field couples to the emergent field induced by the Rashba interaction. In order to achieve our aim, we derive the effective Hamiltonian by integrating out the conduction electrons in the path-integral representation. We show that the product between the momentum of the electromagnetic field and the emergent field (called the Rashba-induced effective vector potential) appears in the effective interaction Hamiltonian. We also discuss how the behavior of the ordinary electromagnetic field and the Maxwell's equations are affected with the Rashba-induced effective vector potential.

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PS17

Detection of ferromagnetic resonance in CoFeB by tunnel anisotropic magnetoresistance

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Spin-torque diode effect [1] is an effective tool for a highly sensitive detection of the magnetization dynamics [2]. The diode effect usually results from a ferromagnetic resonance (FMR) induced by spin-transfer and/or voltage-induced torques and is detected by tunnel magnetoresistance (TMR). Observation of the diode effects therefore needs two ferromagnetic layers, that is, free and reference magnetic layers

In the present study, we tried to detect FMRs in tunnel junctions using just one ferromagnetic layer. We fabricated a $Co_{16}Fe_{64}B_{20}$(1.4 nm)/MgO(t_{MgO} = 1.9, 2.2, 2.5 nm)/Ta(10 nm) multilayer by magnetron sputtering systems since the appearance of tunnel anisotropic magnetoresistance (TAMR) is expected due to an interfacial spin-orbit interaction at CoFeB/MgO interface. The multilayer was post-annealed at 320℃ and patterned into the junction with 5 μm in a diameter (Fig. 1a). The resistance-are product was 2.9 kΩμm^2. The TAMR was measured under perpendicular magnetic field, and one's ratio was 0.3%. Firstly, a microwave current was applied into the junction to excite a FMR in the CoFeB. Then the FMR signal was detected as a DC homodyne voltage measured using a lock-in amplifier. The FMR spectra were clearly obtained as shown in Fig. 1b. The FMR signals (~0.5 μV) are hundreds times smaller than those of the FMRs detected by TMR with similar structure [3], and the decrease in the FMR signals is almost same as that in the MR ratio. The FMRs of the CoFeB can be excited by voltage-induced torque and detected by TAMR. This research was supported by Grant-in-Aid for Scientific Research (No. 23226001, 26103002), Japan.

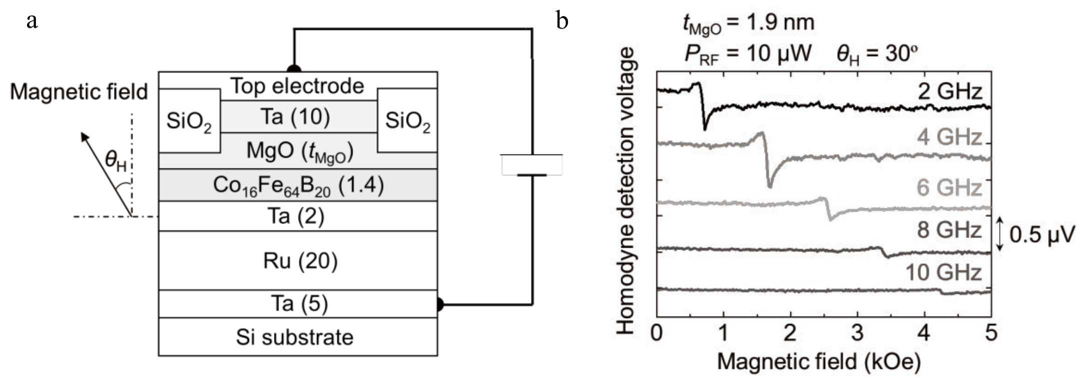

Figure 1 (a) Device structure. (b) Typical FMR spectra of CoFeB detected by TAMR.

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PS18

Shot-noise of a superconductor/nanotube junction in the Kondo regime

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We measured the conductance and the shot noise of a carbon nanotube contacted by Pd/Al superconducting electrodes, in both SU(2) and SU(4) Kondo regime. Varying the gate voltage, two different electronic transport regimes can be observed: if the contacts are symmetric, we observe a multiple Andreev reflections (MAR) regime, governed by the transmission coefficients provided by the Kondo effect [1]. On the other side, if the contacts are asymmetric, the less coupled contact will play the role of a tunnel probe [2]. The conductance the reflects the energy of the Andreev bound states formed in the quantum dot and thus depends strongly on the ratio Δ/T_K , which determines if the ground state of the system is a Kondo singlet or a doublet. We measured the shot noise in both situations.

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PS19

Single-shot readout of electron spins in a quantum dot using spin filtering by quantum Hall edge states

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To prepare and probe an electron spin in a quantum dot (QD) is indispensable for spintronics and quantum information processing. Spin-resolved quantum Hall edge states can be applied for these purposes, since their spatial separation provides spin-dependent tunnel couplings to the QD [1]. Recently, we have improved the spin-filtering efficiency high enough for spin injection and detection by the electrical tuning of the local filling factor near the QD [2].

In this work, we demonstrate the single-shot readout of electron spins in a gate-defined GaAs QD (Fig. 1). We first detect two-electron spin states with a spin angular momentum of $S_z = 0$ and $S_z = 1$. For the transition from these $S_z = 0$ and $S_z = 1$ states to three-electron ground spin state $S_z = +1/2$, a spin-up and spin-down electrons tunnel into the QD, respectively. Because of the highly-efficient spin filtering, the tunnel rate of the spin-up electron is much higher than that of the spin-down electron. We discriminate the two-electron spin states by monitoring such a tunnel-rate difference. The maximum readout visibility reaches 94% (Fig. 2), the highest ever reported for GaAs-based QDs.

Moreover, we apply this spin readout scheme to measure the spin relaxation rates of multi-electron high-spin states, three-electron $S_z = +3/2$ and four-electron $S_z = +2$. These high-spin states are prepared by loading spin-up electrons into the two-electron $S_z = +1$ ground state. For the readout of these states, first they are converted into two-electron spin states by removing one or two electrons. Because spin-up electrons are predominantly removed from the QD due to the spin filtering, the two-electron spin states after the removal have one-to-one correspondence to the multi-electron spin states. Then, the high-spin states are detected from the two-electron spin readout described above. As a result, we find that the spin relaxation rates of the high-spin states are approximately 10 times higher than that of $S_z = 0$ state (Fig. 3).

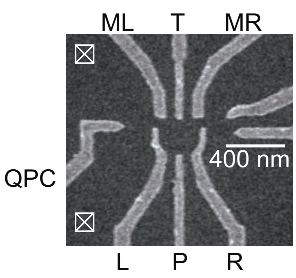

Figure 1: Scanning electron micrograph of the device

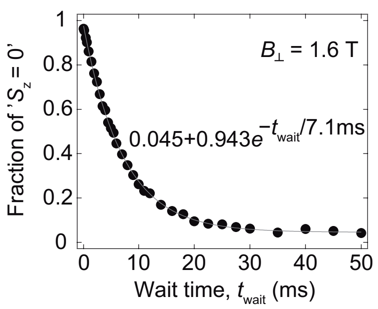

Figure 2: Fraction of the ' S_z = 0' count as a function of wait time

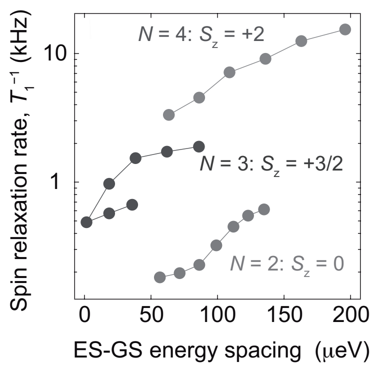

Figure 3: Spin relaxation rates of N = 2, 3 and 4 spin states

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PS20

Enhanced Spin Hall Effect in CuBi Alloys

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Recently, a surprising large spin Hall angle (SHA) of -0.24 with negative sign was experimentally obtained in CuBi alloys [1], and the problem of sign in SHA becomes significant to the physics, where the calculations of the SHA obtained by phase-shift analysis, which has been well tested in many contexts, and by the first-principles simulation are, then, both found to be opposite in sign to the experiment [2]. This confusing situation seems to be a serious challenge to our understanding of the spin and anomalous Hall effects.

Here, we show that the confusing sign problem of SHA in CuBi alloys between the experiment and the established theories was due to the inconsistent definitions of SHA. Once the confusion of definitions is removed there is no contradiction to a skew scattering mechanism, and thus we restore the possibility of properly microscopic understanding of the effects. We find that the SHA can be dramatically enhanced by Bi impurities close to the Cu surface. The mechanisms are two-fold. One is that the localized impurity state on surface has a decreased hybridization and combined with Coulomb correlation effect, this leads to an enhanced SHA. The other comes from the low-dimensional state of conduction electrons on surface, which results in a further enhancement of skew scattering by impurities. Our results [3] may explain the giant SHA experimentally observed in CuBi alloys.

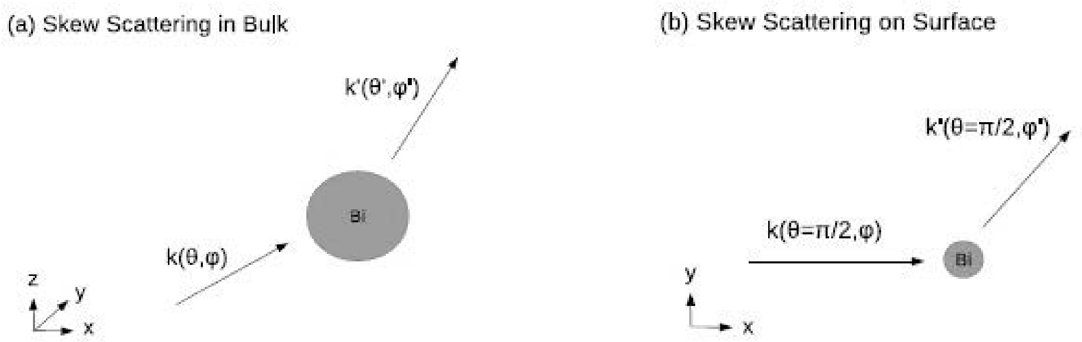

Figure 1: Schematic picture of skew scattering of conduction electrons by the Bi impurity in Cu bulk (a) and on a Cu surface (b). The Bi impurity has very extended state (large circle) in the bulk and a much more localized state (small circle) on the surface. The conduction electron in Cu is described by a three-dimensional wave vector in the bulk, and a two-dimensional wave vector on the surface

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PS21

Artificial Control of Magnetic Phase Transition of B2 Ordered FeRh-based Thin Films

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Controlling magnetic properties without magnetic field is a key issue for improving energy efficiency in spintronic devices. Recently, manipulating the magnetic phases of a material has been demonstrated by using spin polarized current injection and magnetoelectric coupling effect in ferromagnetic (FM)/ferroelectric (FE) heterostructures. It is well known that B2 ordered FeRh alloys show the first-order magnetic phase transition from the antiferromagnetic (AFM) state to the FM state at around 370 K, accompanied by isotropic volume expansion[1]. This clearly indicates that there is a strong lattice-spin coupling in FeRh, and the AFM-FM phase transition could be controlled by external lattice manipulating, accordingly. In this presentation, we will show recent results on strain transfer effect on the magnetic nature of FeRh/FE $BaTiO_3$ (BTO) heterostructures, arising from elastic lattice distortion of BTO[2].

30 nm-thick Ga-doped FeRh thin films (Ga-FeRh)/BTO(001) heterostructures were used for investigating the strain effect. Details of sample preparation are given elsewhere[2]. Figure 1 shows the temperature dependence of magnetization of Ga-FeRh/BTO and Ga-FeRh/MgO. A reference sample on MgO substrate shows a clear AF-FM magnetic phase transition at around 270 K. The magnetic phase transition of Ga-FeRh/BTO, on the other hand, is slightly broader than that of Ga-FeRh/MgO, while sudden changes in the magnetization are seen at 290 and 190 K in the cooling process. The features are clearly associated with the successive structural phase transitions of BTO from the tetragonal (T) to orthorhombic (O), O to rhombohedral (R) phases. Also, magnetization and magnetoresistance data indicate that the feature at the O-R phase transition is likely due to a FM to AFM phase transition induced by the compressive lattice strain transfer from BTO whereas that at the T-O transition arises from a change in the magnetic anisotropy of FM FeRh in the film plane. These results clearly demonstrate that lattice manipulation could provide a promising approach to controlling the magnetic phases of FeRh without magnetic field. Effect of piezoelectric strain on the magnetic phases in FeRh will also be shown at the symposium.

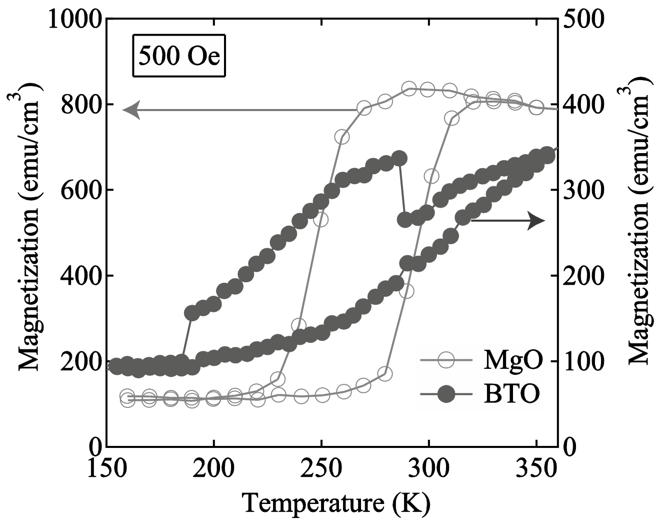

Fig. 1 Temperature dependence of magnetization of Ga-FeRh/MgO and Ga-FeRh/BTO structures.

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PS22

Domain wall of a ferromagnet on a three-dimensional topological insulator

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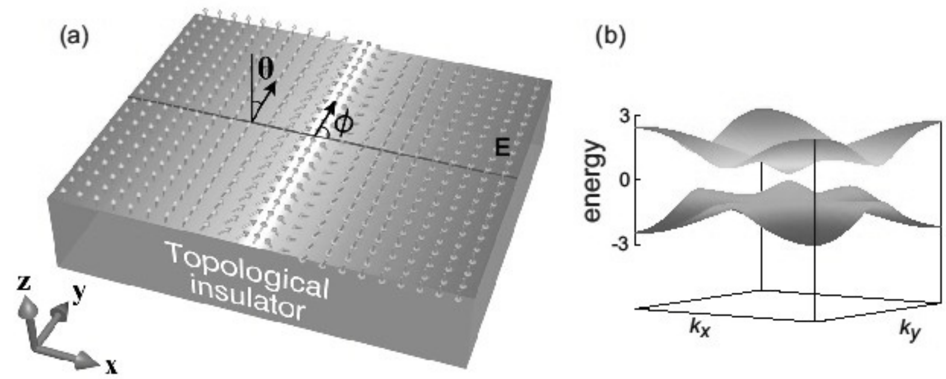
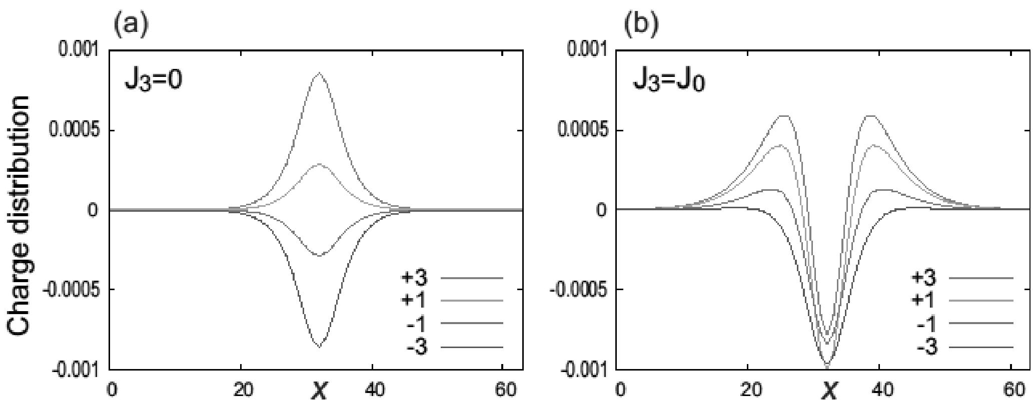
Topological insulators (TIs) show rich phenomena and functions which can never be realized in ordinary insulators. Most of them come from the peculiar surface or edge states. Especially, the quantized anomalous Hall effect (QAHE) without an external magnetic field is realized in the two-dimensional ferromagnet on a three-dimensional TI which supports the dissipationless edge current. Here we demonstrate theoretically that the domain wall of this ferromagnet, which carries edge current, is charged and can be controlled by the external electric field. The chirality and relative stability of the Neel wall and Bloch wall depend on the position of the Fermi energy as well as the form of the coupling between the magnetic moments and orbital of the host TI. These findings will pave a path to utilize the magnets on TI for the spintronics applications.





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PS23

Photon-assisted current noise through a quantum dot system with an oscillating gate voltage

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Photon-assisted transport through mesoscopic conductors has attracted much attention because the quantum nature of transport processes is significantly modified by time-dependent fields. While the photon-assisted transport of the noninteracting electrons has been studied in detail, the interacting case has not been clearly understood. Studying the effect of the Coulomb interaction is an important next step to discuss interesting physics, such as the Coulomb blockade and the Kondo effect.

In this presentation, we discuss photon-assisted transport in a single-level quantum dot system under a periodically oscillating field [1]. Photon-assisted current noise in the presence of the Coulomb interaction is calculated based on a gauge-invariant formulation of time-dependent transport. We derive the vertex corrections within the self-consistent Hartree-Fock approximation in terms the Floquet-Green's functions (Floquet-GFs) and examine the effects of the Coulomb interaction on the photon-assisted current noise. Moreover, we utilize an effective temperature to characterize nonequilibrium properties under the influence of the ac field. The present result provides a useful viewpoint for understanding photon-assisted transport in interacting electron systems.

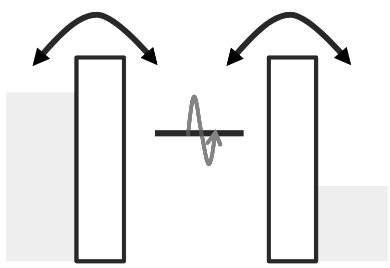

Figure 1: The quantum dot with an oscillating gate voltage.

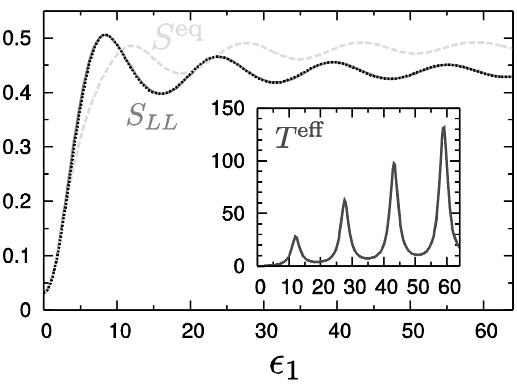

Figure 2: The dependence of the current noise and the effective temperature on the AC amplitude.

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PS24

Quantized Anomalous Hall Effects in Skyrmion Crystal

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Magnetic Skyrmion, a topological spin texture, attracts much attention since it was discovered experimentally in many chiral magnets. The periodic formation of skyrmion is reported and known as skyrmon crystal (SkX) phase. The twisted spin structure of skyrmion can generate an emergent magnetic field felt by conducting electrons which couple to the skyrmions. The Hall effect due to this emergent magnetic field is called topological Hall effect (THE). In SkX, the emergent magnetic field reaches 4000T when we spatially average out the effective flux. Then, it is natural question that can Hall conductance quantize? In periodic system such as complete SkX, Hall conductance is given by the integral of the Berry curvature in momentum space. On the other hand, in strongly disordered system, momentum space description is irrelevant therefore the crossover between real-space and momentum-space Berry curvature must occur. SkX is an ideal laboratory to study quantized anomalous Hall effect (QAHE) since one can change skymion size, mean free path and carrier concentration, to clarify the crossover and stability of quantization as these parameters are changed.

In this poster presentation, we will introduce our theoretical study on QAHE in SkX based on the tight-binding model in 2D square lattice. The obtained band structure (Fig. 1) has finite gaps like Landau Levels and same topology (Chern numbers) therefore the Hall conductance calculated by Kubo formula (Fig. 2) shows the quantized plateaus.

The band gap Δ (red points in Fig. 3) is estimated to be $\Delta = \Delta_0/5$ with Δ_0 being the gap in corresponding uniform magnetic field system (blue line in Fig. 3). However, due to the gigantic emergent magnetic field of SkX, the gap Δ is still large enough to guarantee the robust QAHE.

We also study the conditions to realize QAHE. The disorder V destroys the quantization when $V \gtrsim \Delta_0$ while the thermal effect destroys when . $T \gtrsim \Delta = \Delta_0/5$ This means our system is extremely robust especially against disorder beyond the expectation from the gap size. We also suggest that the QAHE in SkX can be observed even at room temperature when the electron density is of the order of skyrmion density.

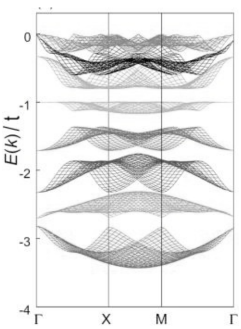

Fig. 1

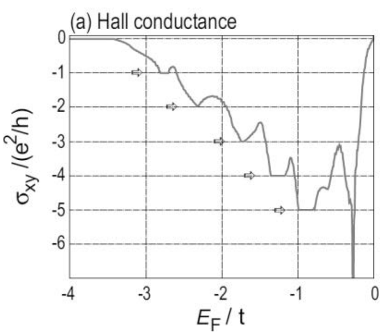

Fig. 2

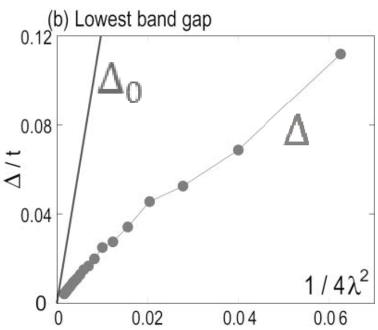

Fig. 3

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PS25

The Cu alloys doped with 5d elements as materials for the control of the sign of spin Hall effect

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The spin Hall effect (SHE), which converts the injected longitudinal charge current into the transverse spin current via the spin-orbit interaction (SOI), is crucial for the development of spintronic devices. The sign of the spin Hall angle (SHA) describes the direction of the induced transverse current.

We perform a systematical analysis of the SHE in the dilute Cu alloys doped with a series of 5d elements, by the combined approach of density functional theory and Hartree-Fock approximation. We find out that not only the SOI in the 5d orbitals, but also the SOI in the 6p orbitals and the local correlations effects in the 5d orbitals of the impurities, are decisive to the sign of the SHA. Including all of these factors properly, we predict the sign of SHA for each alloy in the series, different from the previous theoretical calculations [1,2]. A positive SHA is obtained for CuIr alloys [3,4], which is consistent with experiment [5], while negative SHA are obtained for several alloys including CuOs and CuRe.

Furthermore, to activate the sign of SHA as a new degree of freedom by the external control will give birth to innovative designs of spintronic devices. We analyze the alloys whose sign of SHA are sensitive to the perturbation of the local correlations, which will be considered as materials for the control of the sign of SHE.

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PS26

Cavity optomagnonics in a ferromagnetic sphere

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Vast amount of research on the opto-/electro-mechanical cooling and control of mechanical oscillators have been made in the scope of realizing quantum transducers, ultra-high-sensitivity measurements and macroscopic quantum systems. Cavity cooling, which is realized by enhancing the anti-Stokes scattering and suppressing the Stokes one via optical resonators, paves the way for the ground state cooling of mechanical oscillators and controlling them in the quantum regime[1,2]. Optical whispering gallery mode (WGM) in a dielectric sphere is not only used for these purposes[3] but also expected to become an efficient optical nonlinear element.

We propose that, by extending the idea of optomechanical systems, uniformly precessing ferromagnetic magnon in a sphere of a ferrimagnet, yttrium iron garnet (YIG), can be optically manipulated using whispering gallery mode, i.e., using itself as an spherical optical resonator. Here we show experimental results on the observation of magneto-optical interactions including the non-reciprocal optical effect in a WGM-magnon coupled system.

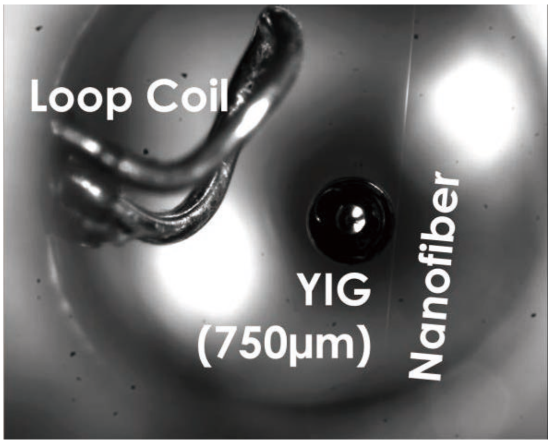

Fig. 1 Spherical optical resonator made of a ferrimagnetic YIG. YIG sphere is optically coupled via the nanofiber and magnon is excited by microwave.

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PS27

Anomalous Hall effect and persistent current due to spin chirality in a diffusive regime

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Anomalous Hall effect (AHE) in ferromagnetic metals has been known to arise as a combined effect of magnetization (exchange splitting) and spin-orbit coupling (SOC) after the works by Karplus, Luttinger and Smit in 1950s [1,2]. Later in 1990s, another mechanism was found by Ye *et al*. for systems with a non-coplanar spin configuration having spin chirality; in such systems, the spin chirality gives a Berry phase to electrons through the exchange interaction and leads to AHE [3].

Subsequently, Tatara and Kawamura showed that AHE can result without the concept of Berry phase by treating the exchange coupling perturbatively [4]. They considered a model with discretely-distributed quenched spins, and calculated the Hall conductivity for the case that the distance r between the localized spins is shorter than the electron's mean free path l (ballistic regime). As a physical picture of this chirality-induced AHE, Tatara suggested a (equilibrium) persistent current around the spin chirality in the ballistic regime [5].

In this work, we extend the previous works [4,5] to the diffusive regime ($r > l$) by considering vertex corrections due to normal impurities [6]. This amounts to electron's diffusive motion as well as spin conservation at each scattering from the normal impurity, and leads to an expression of the AH conductivity which respects spin conservation. We also investigate the persistent current in the diffusive regime, and show that the "typical" value of the persistent current reproduces the AH conductivity in the diffusive regime [6].

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PS28

Spin current transport in a Nb/Cu/NiFe tri-layer structure

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The ferromagnet/superconductor hybrid structures have attracted much attention owing to the Cooper pairs in the ferromagnet, which induce unique transports such as a crossed Andreev reflection and spin-polarized supercurrent[1]. These spin-dependent transport related to a superconductor can be induced also in the nonmagnetic metal under the spin injection because the spin accumulation in the nonmagnetic metal can be treated theoretically as a conduction electron state in a ferromagnet with a certain aspect. However, the experimental studies in these structures have not been performed sufficiently due to the influence of the charge current such as a Joule heating and Oersted field. Here, we investigated spin current transport in a nanopillar-based lateral spin valve structure, in which the aforementioned charge-current-inducing effects are strongly suppressed.

The spin transport properties have been evaluated in the sample consisting of Permalloy(Py)/Cu/Nb trilayer by measuring the nonlocal spin valve signal (Fig.1), which is called as a spin signal. As a results of the measurements, the spin signals below 30 K are almost constant when the Nb is in the normal state. On the other hand, when the Nb becomes superconductor below the superconducting transition temperature 6.8 K, the spin signal increases with decreasing the temperature (Fig.2). This indicates that the spin current is insulated at the Cu/Nb interface because the spin polarized current cannot enter into the superconducting energy gap without forming the Cooper pair, while the spin current in the Cu is absorbed into the Nb in the normal state. From this result, we can estimate the temperature dependence of the superconducting gap magnitude at the Nb/Cu interface. Moreover, around 2.3 K, we observe the superconducting proximity effect in the Cu layer. These results indicate that the spin-polarized electrons and Cooper pairs coexist in the Cu layer around 2.3 K. This may open the new way to the observation of the spin dependent superconducting phenomena.

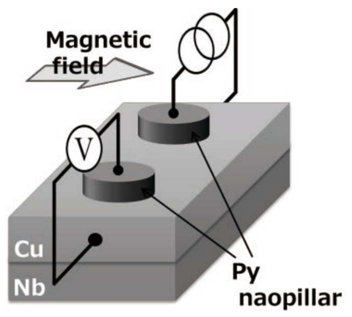

Figure 1: Sample structure and the probe configuration for measuring the spin signals.

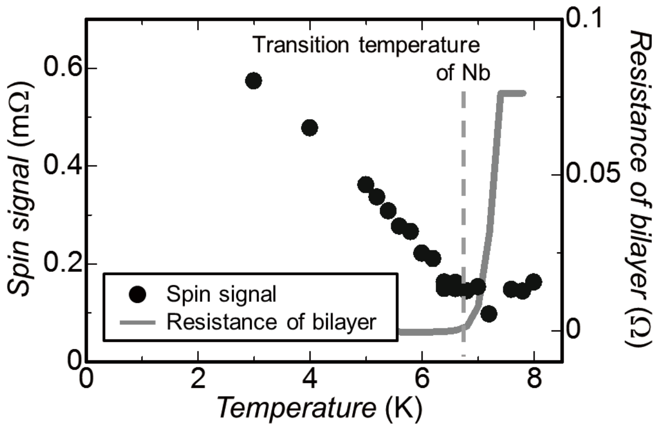

Figure 2: Temperature dependence of the measured spin signals.

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Barnett effect of gadolinium in a paramagnetic state

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The Barnett effect is a phenomenon that a rotating object is magnetized. The effect was discovered in 1915 [1, 2]. We report the first observation of the Barnett effect in a paramagnetic state by mechanically rotating a gadolinium. We developed a magnetic measurement setup comprised of a high-speed rotation system and a fluxgate magnetometer for the measurement (Fig.1). Fig. 2 shows the rotational frequency dependence of the magnetization of the gadolinium sample at 300±0.5 K and that of a blank capsule. We estimate the magnetization of the rotating sample, M_{Ω}, from the stray field measured by the fluxgate magnetic sensor using a dipole model. We find that the magnetization is proportional to the rotational frequency and its polarity changes with the rotation direction. For the blank capsule, no rotation frequency and direction dependence are observed. Thus, the magnetization arises from the rotating Gd sample.

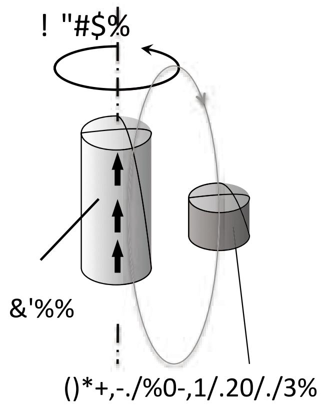

Figure 1: The experimental setup for observation of the Barnett effect.

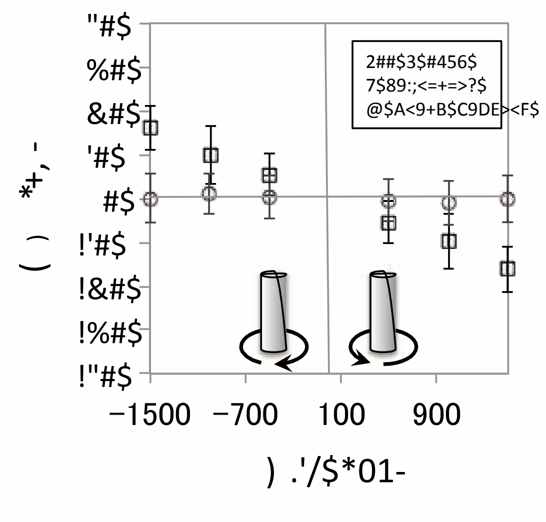

Figure 2: Rotational frequency dependence of the magnetization observed at 300±0.5K for the Gd sample and the blank capsule. Each data point is averaged over three measurements with the error bar in the standard deviation 1σ including the rotational frequency fractionation.

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Universal Conductance Distributions in Disordered Topological Insulator Nanofilms

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The three-dimensional (3D) topological insulators show the specific *surface transport* due to the surface helical Dirac cones. When the 3D topological insulator is cut out in a film geometry, and the thickness (number of layers) is small enough with respect to the film area, it can be regarded as an effective two-dimensional (2D) system and is expected to show the *edge transport* that is a characteristic of 2D topological insulators. Because the finite size effect (aspect ratio) is crucial for this kind of dimensional crossover, the property of the *clean bulk*, such as topological numbers, alone is insufficient for describing the dimensional crossover. However, we have shown that the transport property visualizes both the 2D and 3D topological nature of finite size (and furthermore, disordered) systems [1].

In this work, we employ the Wilson-Dirac Hamiltonian on the cubic lattice with on-site random potential as a typical model for disordered 3D topological insulator nanofilms. We have calculated the conductance by using the transfer matrix method and obtained a kind of phase diagram, the conductance map [2]. It shows the topological insulator to metal transition as well as the shift of the phase boundary due to the disorder effect. At the disorder-induced metal-insulator transition (Anderson transition) point, it is known that the probability distribution function of the conductance shows the universal (scale and model independent, but dimensionality and symmetry dependent) shape. We show that the conductance distributions in the nanofilms converge to the universal shapes for 2D [3] (see Fig. 1).

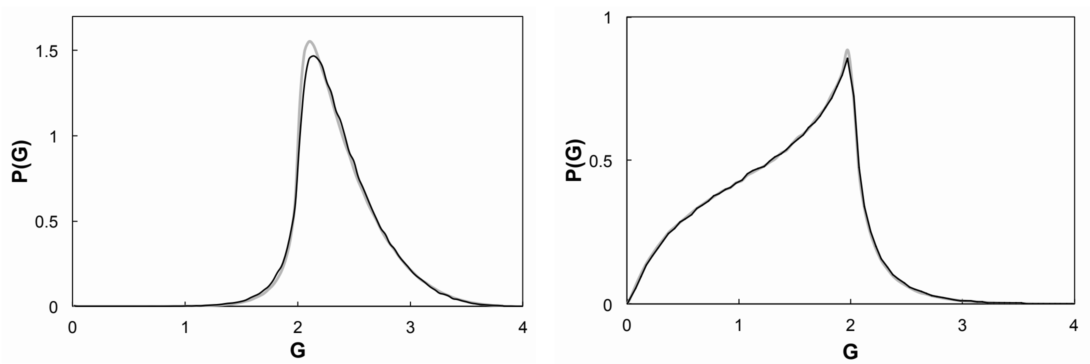

Figure 1: Conductance distribution functions $P(G)$ in disordered topological insulator nanofilms (thin solid lines) and in 2D quantum network model (thick gray lines) [3]. (a) For the number of layers $N_z = 3$, the conductance distribution at the topological insulator-metal transition point converges to the universal critical distribution for 2D quantum spin Hall transition point. (b) For $N_z = 1$, the Hamiltonian is block diagonalized and belongs to the Unitary symmetry class (class A), and the conductance distribution coincides with the universal distribution for 2D integer quantum Hall transition.

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PS31

Electromotive force in a $L1_0$-FePt / $Ni_{81}Fe_{19}$ bilayer element

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Recently, the electromotive force with spin origin, which is called "spinmotive force", has attracted much attention as a new aspect for the generalization of Faraday's law because of the developments of theory [1] followed by experimental observations [2]. However, the systems showing the spinmotive force are limited, and the obtained signals in most cases are transient and small, which is not suitable for practical applications. Thus, a systematic investigation is required to enhance the voltage originating from the spinmotive force. In this study, we investigated the electromotive force generated in a $L1_0$-FePt / $Ni_{81}Fe_{19}$ (Permalloy; Py) bilayer element. The exchange-coupled $L1_0$-FePt / Py bilayer element shows a twisted magnetic structure due to the difference in the magnetic anisotropy energy between $L1_0$-FePt and Py [3]. This difference leads to the spatial modulation in magnetization dynamics, which is suitable to observe the spinmotive force.

The device was microfabricated from a continuous thin film with the stacking structure of MgO (110) sub. // Fe (2 nm) / Au (60 nm) / FePt (10 nm) / Py (100 nm) / Au (5 nm). The FePt layer was deposited at 350 ˚C, leading to the formation of the $L1_0$ ordered structure with the in-plane easy axis along the [001] direction of the MgO substrate. The FePt / Py bilayer was etched into an element with the size smaller than several micrometers. The voltage (V) between the top and bottom of the element was measured using a lock-in amplifier while the radiofrequency (RF) power was constantly applied to the device using a signal generator in order to induce the magnetization dynamics. From the magnetic field dependence of V, several peaks of V were observed. The amplitudes of the peaks were of the order of tens nV. The magnetic field of the peak was shifted as the frequency of the RF power was varied, indicating the signals originated from the magnetization dynamics in the FePt / Py element. We consider that one of the possible origins for the observed V is the spinmotive force.

The authors are grateful to Dr. J. Ieda for valuable discussions.

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PS32

Emergent quantum spin Hall effect in topological insulator nanofilms

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Recently, much effort has been made to grow thin films of a topological insulator (TI) [1-2]. Naturally, its primary purpose was to reduce the contribution of the bulk to transport quantities. In this work, we have performed a theoretical study of such a TI thin film [3].

We consider a standard example of AII symmetry class. We use three-dimensional Wilson-Dirac Hamiltonian as a model of TI and adapt it to the thin film geometry of a finite number of stacked layers. The thin film geometry allows for physically interpolating the two and three dimensions (2D and 3D) limits by changing the number of stacked layers [4-5].

One way to characterize topological properties of the thin film system is to consider 2D type Z_2 index (ν) by regarding the film as an effective 2D system. In this work, we establish Z_2 index maps by calculating the ν as a function of the number of stacked layers (N) and gap parameter (m_0) (see Fig. 1). We also perform numerical study of the conductance of TI thin films. As a result,

1. We have shown that by reducing the number of stacked layers (N), quantum spin Hall phase, which is characterized by non-trivial 2D type Z_2 index (ν=1), can be "emergent" in TI nanofilms.
2. Through numerical study of the conductance of TI thin films, we have revealed how the 2D topological character evolves to its 3D counterpart as the number of stacked layers is increased (see the "conductance maps" in Ref. [3]).

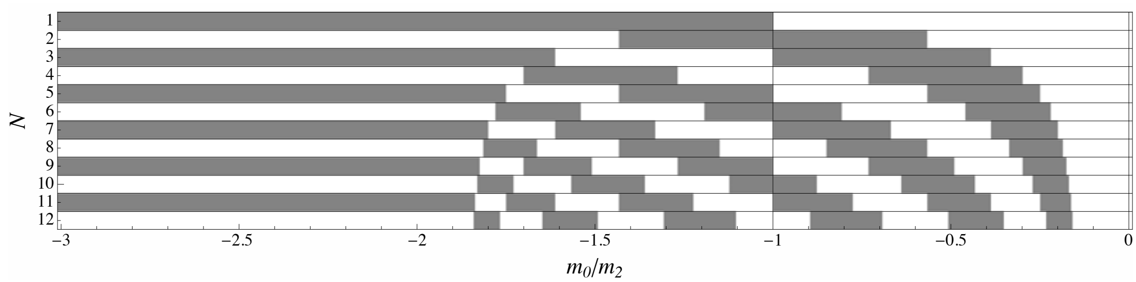

Fig. 1 The Z_2 index map. Painted (unpainted) region corresponds to ν=1 (ν=0)

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PS33

Quantum Entanglement Conservation in Coherent Quantum State Transfer from a Single Photon Polarization to an Electron Spin in a Lateral Double Quantum Dot

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Quantum entanglement is one of the most representative phenomena of quantum physics. Entanglement generation and detection in some kinds of quantum system are well established[1,2,3]. However, whether quantum entanglement can be conserved in coherent quantum state transfer between different quantum systems has not been researched so far. To give an experimental proof for this question, we try to prove that quantum entanglement is conserved through the transfer between polarization entangled photon pairs and spin entangled electron pairs using GaAs/AlGaAs semiconductor[4].

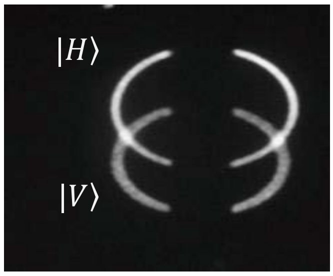

Fig. 1 Optical image of the SPDC

First, we will talk about generation of entangled photon pairs which is based on a non-linear optical phenomenon called spontaneous parametric down conversion (SPDC) in a Type-II BBO crystal. We have succeeded in observing the SPDC using a high sensitive CCD camera (Fig. 1) and also single photon counting modules (SPCM). As a result we evaluated the generation efficiency. We have observed the spatially separated paired photons using an optical aperture.

Second, we will report a way to improve the probability of photo-electron trapping in a quantum dot. We have fabricated a double quantum dot device introducing a GaAs heterostructure with a distributed Bragg reflector cavity structure (Fig. 2 left). We have also attached a solid immersion lens on the surface of the device. Our device has metal gates (Fig. 2 right) which define lateral double quantum dots in a two-dimensional electron gas. We irradiated pulsed photons onto one of the two dots to generate single photo-electrons in the dot. The single photo-electron is detected from observation of real-time charge sensing traces of electron tunneling be tween the two dots upon the photon irradiation.

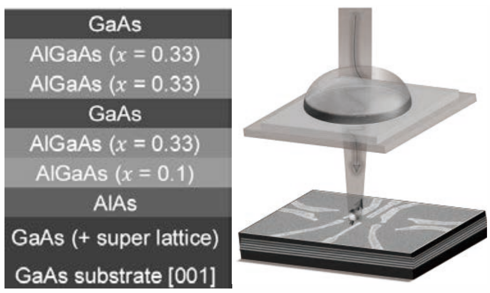

Fig. 2 Layer structure of the wafer (left) and fine pattern fabrication (right)

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PS34

Quantum dot thermometry at millikelvin temperature

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We study a way how to determine the electron temperature using the quantum dot thermometry in millikelvin regime. The temperature can be obtained from a measurement of the current through the sensor dot as a function of gate voltage by fitting the electron Fermi-Dirac distribution function. In this setup, we focus on the role of the mutual Coulomb energy between the dot and the sensor dot with an aim of understanding the feedback effects (or back-action; the measurement itself affects the experimental results) in quantum dot thermometry device.

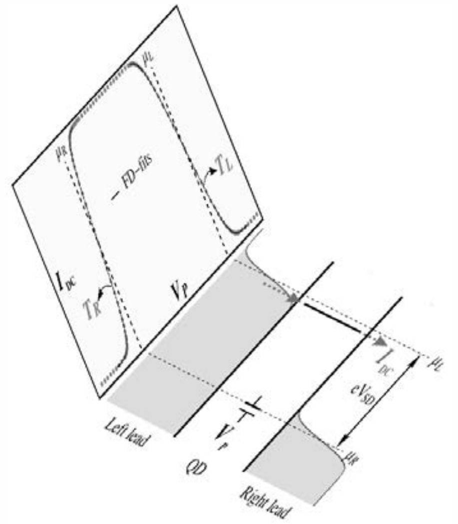

Figure 1: Illustration for the quantum dot thermometry

PS35

How to detect helical order of a one-dimensional magnet

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I consider methods of detection of a helical spin order which arises in the thermodynamical equilibrium in a one-dimensional (semi-)conductor with spin impurities (e.g., nuclear spins, or spins of localized magnetic impurities).[1] The helical order in localized spins is a consequence of the dimensionality, and thus very general, arising in metals, semiconductors, and even gapped phases, like superconductors. Formally, it follows from the resonant peak of the response (spin susceptibility) of a one-dimensional system. Recent low temperature transport experiments with semiconducting wires suggest that such helical order was established in nuclear spins of atoms of the wire.[2] Because of the auto-tuning property, such an order can be useful in the semi-super hybrid platform to stabilize Majorana fermions[3] and to produce even more exotic many body excitations like fractionally charged fermions.[4]

The question therefore arises how to detect unambiguously the presence of helically ordered spins. I will overview the methods suggested theoretically for such detection based on:

- reduction of conductance by a factor of two,[5]
- anisotropic spin susceptibility,[6]
- NMR response at the frequency set by the singular RKKY peak,[7]
- unusual temperature dependence of the nuclear spin relaxation rate,[8]
- dynamical nuclear polarization at zero external magnetic field.[9]

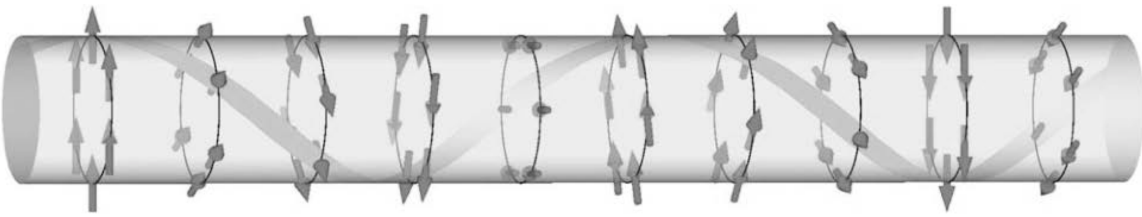

Figure 1: One dimensional conductor (yellow) with helically oriented spins (red).

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PS36

Electrical spin injection and detection across epitaxial Ge/Fe_3Si heterointerfaces

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To date, we have demonstrated the low-temperature epitaxial growth of Ge layers on a ferromagnetic Heusler compound, Fe_3Si, by molecular beam epitaxy (MBE).[1] Although the vertically stacked Ge/Fe_3Si heterostructure will open new perspectives for next-generation Ge-based spintronic devices, spin transport properties across the Ge/Fe_3Si heterointerface have not been clarified yet. Here, we present electrical spin injection and detection in a Cu-based lateral spin valve (LSV) consisting of the Ge/Fe_3Si heterostructure.

Epitaxial Ge(~50 nm)/Fe_3Si(~25 nm) films were grown on a Si(111) substrate (ρ = ~1000 Ωcm) by low-temperature MBE[1] and were processed into two Ge/Fe_3Si electrodes by conventional electron-beam lithography and Ar^+ milling techniques.[2] In order to cover the sidewalls of the electrodes, RF-sputtered SiO_2 films were deposited. After that, Cu strips were fabricated by conventional lift-off techniques. The center-to-center distance between the electrodes is ~300 nm, and the junction size between Ge and Cu is ~150 x 150 nm^2. Nonlocal spin valve measurements were carried out by standard AC lock-in techniques (f_{AC} = 173 Hz).

Figure 1 shows a representative nonlocal spin valve signal measured at 50 K when I_{AC} = 0.75 mA. We can see a clear hysteretic behavior reflecting parallel and antiparallel magnetization states of the electrodes. Although the spin signal is smaller than that for LSV without Ge epilayers,[2, 3] it is noteworthy that pure spin currents flow through the 50 ~ 100-nm-thick Ge epilayers and the ~150-nm-length Cu strip. More detailed information will be discussed in the poster presentation.

This work was partially supported by Grant-in-Aid for Scientific Research on Innovative Areas 'Nano Spin Conversion Science' (No. 26103003) and Grant-in-Aid for Scientific Research(A) (No. 25246020) from JSPS. M.K. and S.O. acknowledge JSPS Research Fellowships for Young Scientists.

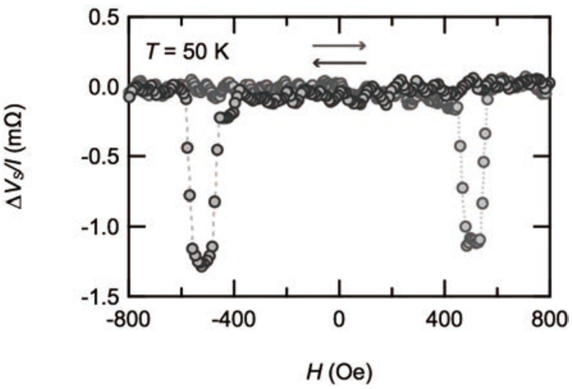

Fig. 1 A nonlocal spin valve signal measured at 50 K.

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PS37

Spin Injection from Epitaxially Grown Fe to Two-dimensional Electrons in InAs Quantum Well

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One of the main interests in electrical spin injection from ferromagnets into semiconductors[1] is the behavior of spins in quantum confined structures like two-dimensional electron systems (2DESs), which usually lie deep beneath the surfaces and the injection efficiencies remain as low as 1-2%.[2] A way to enhance the efficiency is the usage of MgO as a tunneling barrier and 8% efficiency to InAs 2DES was reported.[3] In this poster we report a further improvement of spin-injection efficiency from a ferromagnet (Fe) to a 2DES in an InAs quantum well.

Figure 1(a) shows the layered structure, which is lattice matched to an InP substrate, besides an InAs pseudo-morphic quantum well, which contains an inverted 2DES, the wave-function in which tails up close to the surface. The layers were deposited in an ordinary molecular beam epitaxy and on top of them, an iron (Fe) layer was epitaxially grown in the same chamber at the substrate temperature around 0ºC. Figure 1(b) shows time-evolution of RHEED pattern during the growth of the Fe layer. In the beginning of the growth, the RHEED pattern once almost disappeared and then the pattern for body-centered cubic α-Fe appeared. The streaky pattern changed into bulky after 20nm growth. The surface was covered with a 2nm Al polycrystal film.

The Fe film was fabricated into strips of widths 1 and 2 μm and the final form is shown in the inset of Fig.1(c). The main panel of Fig.1(c) displays magnetic field dependence of the non-local voltage between the 1 μm Fe strip and InAs 2DES when the current was applied between 2 μm strip and another InAs electrode. From the spin-valve magnetoresistance, we estimate the spin-injection efficiency as high as 34 % based on the theory in Ref.4.

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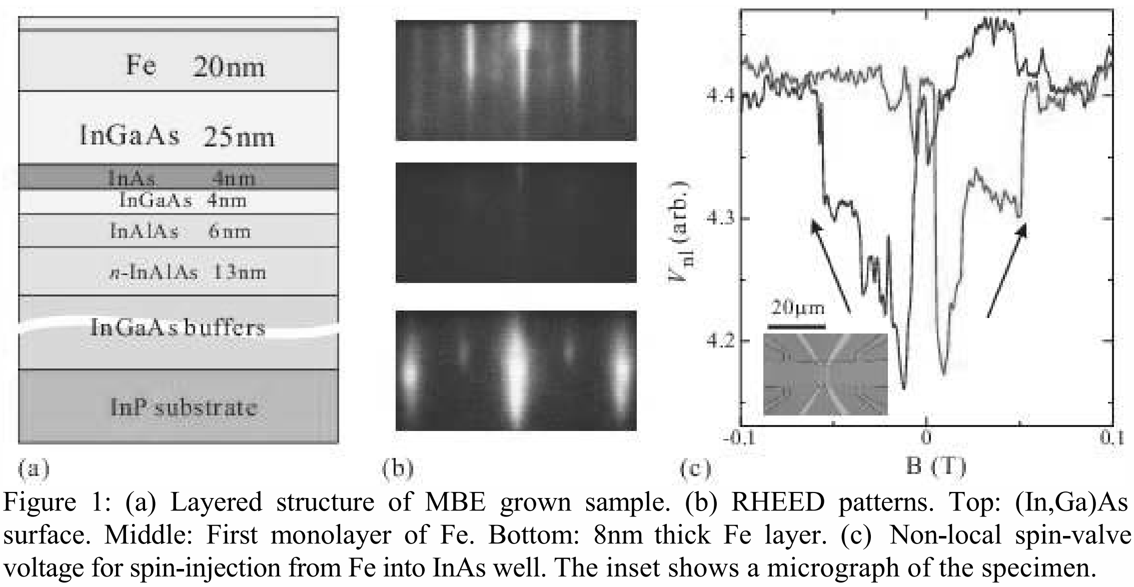

Figure 1: (a) Layered structure of MBE grown sample. (b) RHEED patterns. Top: (In,Ga)As surface. Middle: First monolayer of Fe. Bottom: 8nm thick Fe layer. (c) Non-local spin-valve voltage for spin-injection from Fe into InAs well. The inset shows a micrograph of the specimen.

PS38

Spin-dependent Peltier effect in Co_2FeSi/Cu lateral spin-valve devices

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In a new field of spin caloritronics, the spin-dependent Peltier effect, the conversion of spin current to heat current, was experimentally detected in nanopilar spin-valve structures [1]. If giant pure spin currents are injected from a ferromagnetic material into a nonmagnetic one, one can detect the spin-dependent Peltier effect even in a lateral spin-valve (LSV) structure [2]. Recently, we have developed a technique for generating giant pure spin currents at room temperature by using epitaxial Co-based Heusler-compound Co_2FeSi (CFS) films [3]. Here, we demonstrate the spin-dependent Peltier effect in a LSV with the epitaxial CFS electrodes.

We first confirmed the generation of giant pure spin currents in LSVs [3]. For detecting the Spin-dependent Peltier effect, we used the terminal configuration in Fig. 1(a). When the pure spin current are injected from the Cu side into CFS2, a temperature difference between Cu and CFS2 is created by the spin-dependent Peltier effect. To detect this temperature difference indirectly, we have used a method proposed by Slachter et al. [2] for placing the thermocouple on the CFS2 electrode. As shown in Fig. 1(b), we detected clear spin Peltier signals (V_{1f}^{P}) and obtained the spin-dependent Peltier coefficient of ~ -3.84 mV.

This work was partly supported by CREST from JST and by Grant-in-Aid for Scientific Research on Innovative Areas "Nano Spin Conversion Science" (Grant No. 26103003).

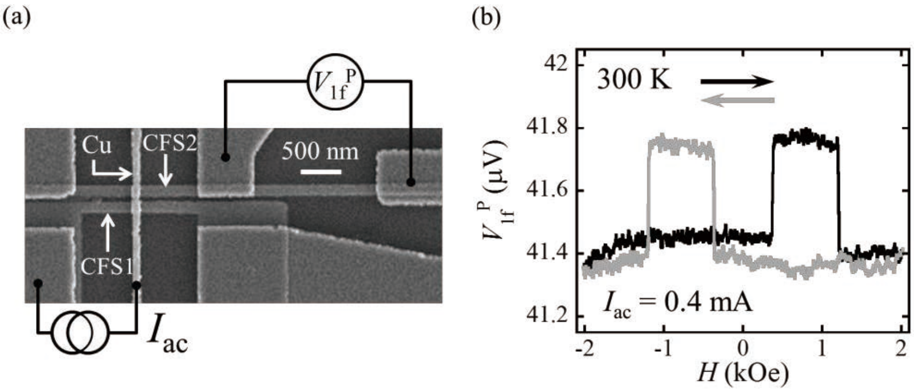

Fig 1: (a) SEM image of a fabricated LSV for the spin-Peltier measurements. (b) Field-dependent nonlocal voltage detected by the Cu thermocouple on the CFS2 wire at 300K under electrical spin injection at I_{ac} = 0.4 mA.

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PS39

First-Principles Study of Spin-Orbit Coupling Parameters and Bult-in Electric Field in $LaAlO_3/SrTiO_3$

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Recently, the oxide interface has attracted much attention since it can be used to realize novel physical properties not found in the bulk system [1]. Heterostructure $LaAlO_3/SrTiO_3$ is one of such systems extensively studied. A high mobility two-dimensional electron gas in the heterostructure of $LaAlO_3/SrTiO_3$ has been reported [2] in contrast to insulating properties of bulk $LaAlO_3$ and $SrTiO_3$.

In this study, we have performed fully-relativistic first-principles density functional calculations for articfical superlattice $(LaAlO_3)_n/(SrTiO_3)_n$. Calculated band structures show interface-induced metallic states for $n \geq 6$. We found electron doping in the TiO_2 layer at LaO interface and hole doping in the AlO_2 layer at SrO interface. Due to the built-in electric field at the interface, the interface states show spin splitting and vortex-like spin textures in momentum space, i.e. Rashba effect. Calculated Rashba coefficient is of the same order as that of the experimental value[3] and theoretical value for n=2[4]. We will discuss tunability of interface metallic states by using magnetic-atom doping and epitaxial strain. The spin-orbit coupling parameters and built-in electric field in related oxide heterostructures are also discussed.

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PS40

Surface Electronic State of Topological Crystalline Insulator in Superconducting State

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There has been a growing interest in topological materials which can be superconducting state since they can host wide variation of surface Andreev bound states (SABSs). Topological crystalline insulator (TCI) whose surface state is protected by crystal symmetry has also received broad attention as a new type of topological material. SnTe is one of the TCI, whose surface states are protected by mirror symmetry [1]. It has been known that Indium doped SnTe become superconducting state. And also, the existence of SABS has been suggested by point contact experiments [2].

Motivated by the experiments, we theoretically study the TCI in the superconducting state. We introduce possible fully-gapped pair potentials to the TCI and calculate the surface spectral function by using the recursive Green's function method.

We find that the superconducting TCI (STCI) can host mirror protected SABSs which has never been seen before. We also reveal that the SABSs twist since they merge with the Dirac cone originating from the normal state. In the superconducting topological insulator (STI), topologically protected zero-energy SABS must across the time reversal invariant momentum. For this reason, the dispersion of the SABS becomes flat like at zero energy when it twists[3]. On the other hand, in the STCI, zero-energy SABS can move along the mirror symmetric line. Therefore, the dispersion of the SABSs in the STCI is not necessary to become flat like at zero energy when it twists.

In order to understand the topological nature of the STCI, we also calculate the mirror Chern number and make a phase diagram as a function of pair potential and the spin-orbit interaction. Consequentry, we find that there are three phases: the mirror Chern number = 0, -2 and -4 in the STCI, instead of three phases: mirror Chern number = 0, -1 and -2 phases in the STI.

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PS41

Theory of Tunnel Conductance in Helical Metal / Superconductor Junction

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Manipulations of spin transports are central issues in spintronics. Recently, spin related transports have been studied in helical metals in which the direction of spin and momentum are linked each other, that is called spin-momentum locking [1,2]. In the helical metal, the spin-momentum locking is realized by a manipulation of the magnitude of Rashba spin-orbit interactions (RSOI) and Zeeman fields (U), when a chemical potential (μ) satisfies $|\mu| < |U|$. There has been works of Josephson currents in the presence of the spin-momentum locking in superconductor/helical metal/superconductor junction [3,4]. However, studies of tunneling conductance have not been, so far.

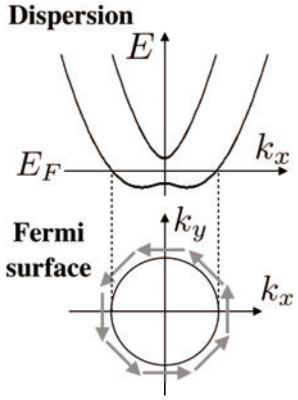

Fig.1:The energy dispersion and the spin sturucture on the Fermi surface in the helical metal.

We study the tunneling conductance for several symmetries of Cooper pairs in helical metal/superconductor junction by using the extended BTK formula and quasi-classical approximation. As results, we find that the zero bias conductance becomes finite, and its origin is caused by RSOI in the case of the two dimensional junction with the spin-singlet superconductor. In the junction with the p_x-wave superconductor, the zero bias conductance depends on not only RSOI, but also the in-plane direction of the d-vector, although the zero bias conductance doesn't depend on the in-plane direction of the d-vector in the ferromagnet/p_x-wave superconductor.

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Conductance Fluctuation versus In-Plane Magnetic Field in an InAs Quantum Corral

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An electron-wavefunction confined in a two-dimensional (2D) plane is directly affected by perpendicular magnetic field through the Aharonov-Bohm (AB) phase while spin-orbit interaction (SOI) works as an effective in-plane magnetic field on spin. Hence an external in-plane magnetic field can be a useful tool to investigate the effect of SOI [1]. Here we report conductance fluctuation (CF) versus in-plane magnetic field B caused by SOI.

The sample was corralled 2D electrons in an InAs quantum well with several quantum point contact (QPC) gateways (Fig.(a)). Mobility 66000 cm^2/Vs, concentration 1.21×10^{12} cm^{-2} and Rashba strength 3.6×10^{-11} eVm were estimated from Shubnikov-de Haas oscillation [2]. When in-plane magnetic field B was applied, conductance between contacts 5 and 2 exhibited clear dip at B=0 and fluctuating but reproducible pattern at high B. The fluctuation diminished with increasing temperature, manifesting that it originated from quantum interference. We observed the CF amplitude increased (Fig.(b) upper panel) when the direction of B was rotated from $\theta = 0$ (*x*-oriented) to $\pi/2$ (*y*-oriented), which clearly appeared in the figures of the conductance variances (Fig.(c)). This can be attributed to the fact that the effective magnetic field B_{SOI} is oriented to y-axis. We also found that the CF amplitude changed with the path of electrons (Fig.(b) lower panel), with the highest CF at the straight path (between contacts 5 and 2) and the lowest at the wound path (between contacts 5 and 4). This presumably resulted from the distribution of B_{SOI} and reflected semi-ballistic nature of the electron propagation.

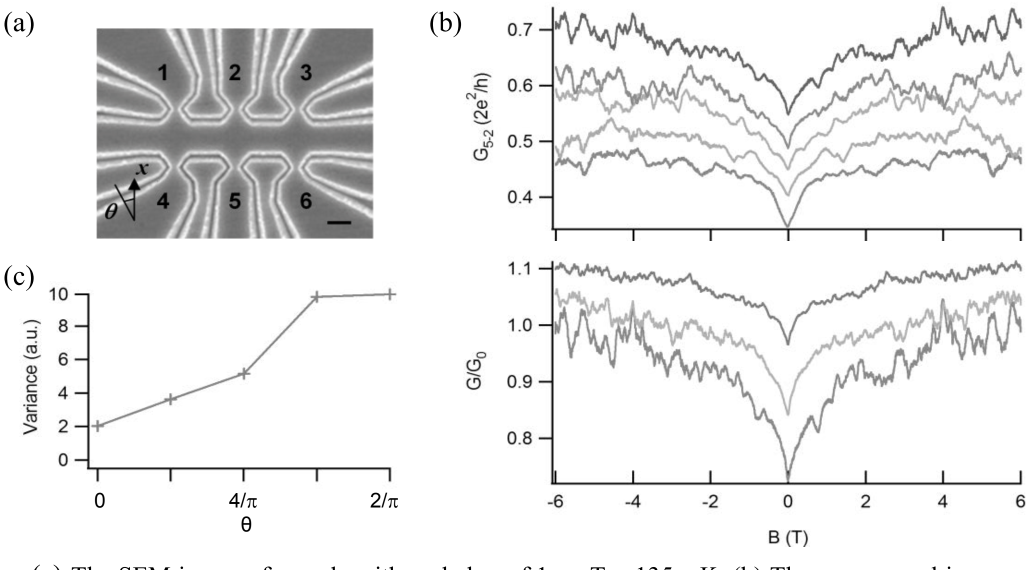

Figure: (a) The SEM image of sample with scale bar of 1μm.T = 135 mK. (b) The upper panel is magnetoconductance *G* between contacts 5 and 2 in the unit of $2e^2/h$. The offset corresponds θ (rotation angle of B) changing from 0 (bottom) to π/2 (top). The lower panel is *G* between contacts 5 and 2 (bottom), 5 and 1 (middle), 5 and 4 (top) with $\theta = \pi/2$, normalized by values at B=-6.0 T (G_0). (c) Conductance variance versus θ calculated from (b). Data from B=-6.0 T to -1.5T were used after subtracting the background.

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PS43

Detection of topological states in two-dimensional Dirac systems by dynamic spin susceptibility

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We discuss dynamic spin susceptibility (DSS) in Landau quantized two-dimensional (2D) Dirac systems with spin-orbit interactions to characterize the topological phases. We show that the imaginary part of DSS appears as absorption rate of a transverse AC magnetic field, just like electron spin resonance experiment for localized spin systems. We found that when a system is in a static magnetic field, the topological state can be identified by an anomalous absorption peak related to transition between the two Landau levels close to the Fermi level, which does not appear in the trivial state.

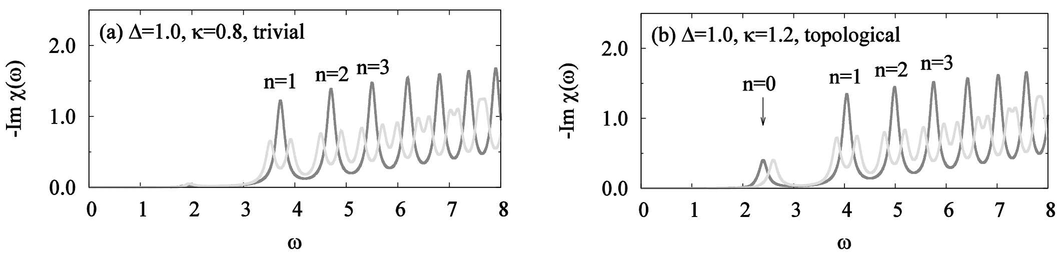

Figure 1: Imaginary part of the dynamic spin susceptibility of a 2D Dirac system with spin-orbit interactions [red (green): without (with) Zeeman effect]. An anomalous peak appears only in the topological phase.

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PS44

Linear response theory of spin torques due to spin waves

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Manipulation of magnetic structures by unconventional means is one of the important topics in spintronics. Among various means, driving a magnetic structure by temperature gradient has received a particular attention. Such phenomena were observed experimentally [1,2], but the relevant mechanism is under discussion. One of the expected mechanisms is the spin torque due to thermally induced spin waves.

There are some studies on the effects of propagating spin waves on magnetic structures [3,4,5]. A temperature gradient can also induce a flow of spin waves, whose spin current will exert spin torques. Ordinary spin torques (in the absence of Dzyaloshinsky-Moriya interaction) have two components, one comes from the conservation of angular momentum (spin-transfer torque), and the other is its dissipative correction (called β-term) which is related to the damping constant α of magnetization. A calculation of spin torques due to spin waves was performed based on a phenomenological equation (stochastic Landau-Lifshitz-Gilbert equation) [6].

In this work, we formulate a theory of spin torques due to spin waves induced by a temperature gradient based on the linear response theory, and calculate the spin-transfer torque and the β-term. To treat temperature gradient, we follow Luttinger and introduce a 'gravitational potential' [7]. We discuss, in particular, the relation of the β parameter to α. Also, we apply the results to some specific magnetization structures, such as a domain wall, and discuss their dynamics.

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PS45

Enhancement of spin-orbit interaction in graphene due to hydrogenation

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Graphene is one of the monolayer materials beyond silicon with weak spin-orbit interaction (SOI) of a few tens of microelectronvolts. It is difficult to modulate the SOI in graphene by applying gate voltage unlike the two-dimensional systems in semiconductor heterostructures[1]. However, functionalization is considerable method to tune the SOI for graphene. Recently, Balakrishnan *et al*. reported that weak hydrogenation greatly enhances SOI in graphene [2]. They discovered anomalous increase of non-local resistance by hydrogenation and estimated the SOI strength of 2.5 meV for 0.05% hydrogenated graphene. This value is three orders of magnitude larger than that of pristine graphene. A plausible mechanism of the enhancement is based on breaking the reflection symmetry across the graphene plane induced by the lattice distortion due to the C-H covalent bonding. But there is also a skeptical view about the enhancement itself because of the lightness of the composition elements.

In order to clarify the enhancement of SOI, we have investigated spin-valve devices using hydrogenated graphene and confirmed spin-charge conversion phenomena caused by the enhanced SOI. The devices were fabricated from exfoliated graphene and $Ni_{0.78}Fe_{0.22}$ ferromagnetic electrodes and gold electrodes were deposited using conventional lift-off process. The graphene was hydrogenated just before measurements using hydrogen silsesquioxane resist and electron beam irradiation [3]. Figure 1(a) exhibits a conventional lateral spin-valve signal, which guarantees successful spin injection. Another type of non-local voltage between non-magnetic electrodes displayed in Fig.1(b) is obtained, and it oscillates by the magnetic fields perpendicular to the ferromagnetic electrodes. This signal is likely to exhibit inverse spin Hall effects induced by the SOI.

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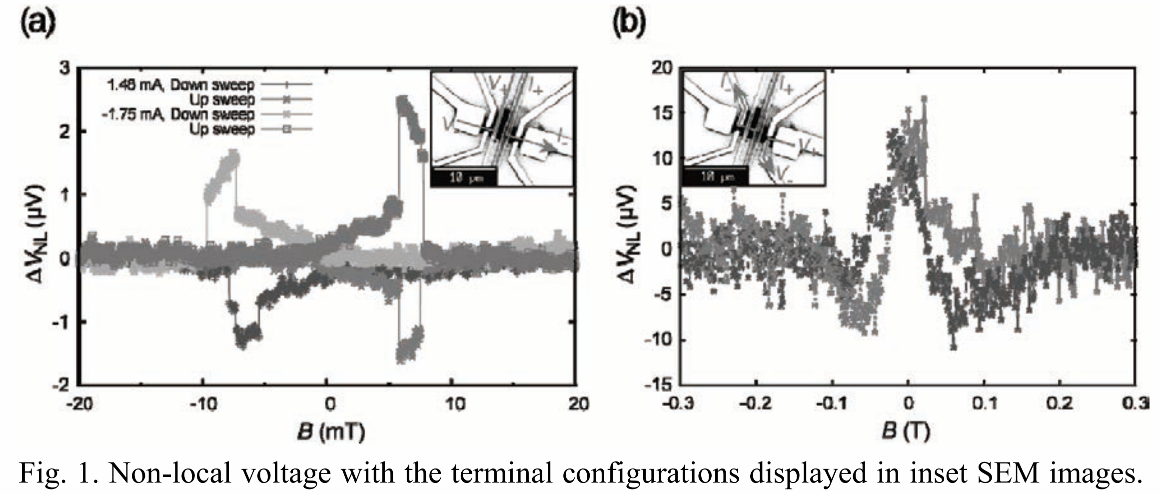

Fig. 1. Non-local voltage with the terminal configurations displayed in inset SEM images. The white, gray and black figures indicate gold, permalloy, and graphene. The magnetic fields are parallel and perpendicular to the permalloy electrodes in (a) and (b), respectively.

PS46

Rotating angle dependence of NMR line structures in various nuclides

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Barnett effect [1], magnetization by body rotation, is one of the fundamental phenomena of the angular momentum conversion between spin angular momentum and mechanical rotation motion. The Barnett effect shows that a rotating body feels an effective magnetic field. Recently, the effective magnetic field called Barnett field has been observed directly in terms of solid state nuclear magnetic resonance (NMR) [2] using a new coil-spinning technique [3] in which a sample and a detector are synchronously rotated.

We report experimental results and theoretical analysis for the angle dependence of the NMR measurement with mechanical rotation in kHz range. By changing the angle θ between rotation axis and an external field, NMR line splitting is found even in nuclear spin I = 1/2 system [4]. We obtain that the θ dependences of NMR line structure and peak intensity are independent of nuclear spin by calculation of dynamic magnetic susceptibility. Figure 1 shows the θ dependences of peak intensities for deuteron (D) nucleus with I = 1. The results are well reproduced by the calculation (solid lines).

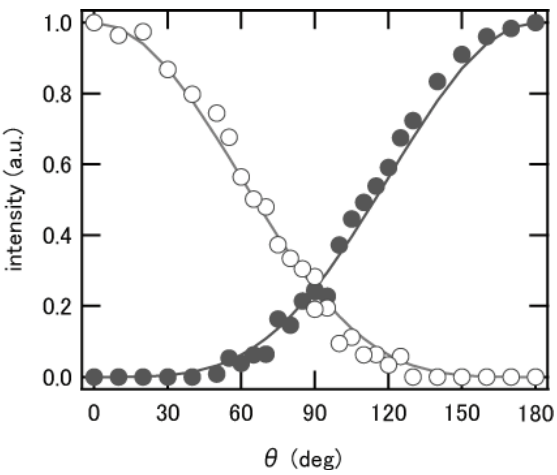

Figure 1: Rotating angle dependences of peak intensities in D_2O NMR measurement.

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PS47

Effects of Dirac Points on Rashba Spin-Orbit Torques

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PS48

Persistent spin helix on the ZnO (10-10) surface: Fully relativistic study

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Recently, spin-orbit coupled systems attracted much scientific interests because they allow manipulation of the electron spin[1]. One of the most interesting physical properties induced by the SOC is the persistent spin helix (PSH) since it enables the long spin life time[2]. However, the PSH is widely studied only for the zinc-blende semiconductors [3,4]. Wurtzite structure semiconductors are promising candidates since the high quality of the two dimensional system has been experimentally observed[5]. In this presentation, we show that the PSH is realized by using wurtzite ZnO (10-10) surface.

We performed fully relativistic first-principles calculation on ZnO (10-10) surface by using the openMX code[6]. We calculate the spin textures of the spin-split surface state and found the quasi-one dimensional spin orientations, which is similar to PSH spin textures. We clarify the origin of the spin textures based on the simplified spin-orbit Hamiltonian. The calculated values of the spin-orbit strength and the wavelength of the PSH are comparable with those observed for various zinc-blende quantum well structures. This findings open the new possibility in the study of wurtzite-based PSH systems.

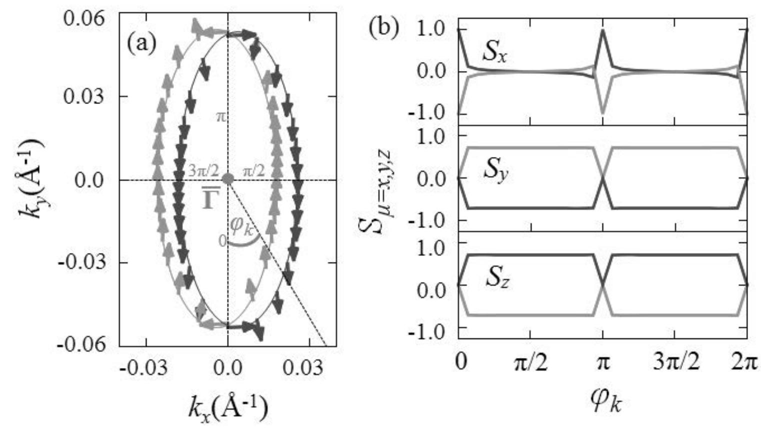

Figure 1. The spin textures on the spin-split surface states of ZnO (10-10) surface

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Topological Transitions in Spin Interferometers

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We calculate nonadiabatic electronic transport in mesoscopic loop-shaped spin interferometers and show topological transition in the interference effects (see Figure 1). Due to complex spin-state structure the dynamic and bare geometric phases [1] show intricate mixing and they lose relevance as separate quantities near the line of transition. Instead, the transition is determined by an effective Berry phase that is observable and related to the topology of the field texture via parity of the windings around the Bloch sphere. The transition manifests as a distinct dislocation of the interference pattern in the quantum conductance [2]. The phenomenon is robust against disorder and can be demonstrated by a controlled manipulation of spin-guiding fields within experimental reach [3]. We find an analogous transition for SO(3) rotations in simulations of magnetic moment dynamics.

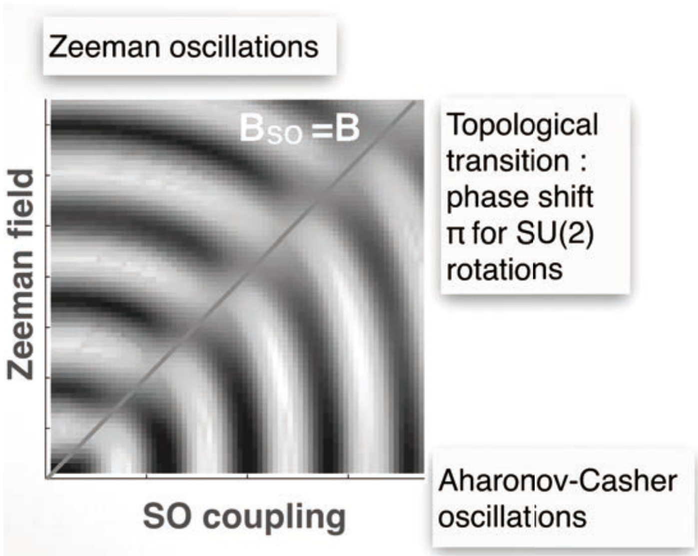

Figure 1. Topological transition in the calculated interference pattern in conductance of a ballistic single-mode loop.

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PS50

Quantum transport through 3D Dirac materials

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We study the quantum transport properties of three dimensional Dirac materials (3DDM) within the framework of Landauer-Buttiker formalism. Bismuth and its alloys provide a paradigm to realize three dimensional materials whose low-energy effective theory is given by Dirac equation in 3+1 dimensions[1, 2]. Charge carriers in normal metal satisfying the Schrodinger equation, can be split into four-component with appropriate matching conditions at the boundary with the 3DDM. We calculate the conductance and the Fano factor [3] of an interface separating 3DDM from a normal metal, as well as the conductance through a slab of 3DDM. As shown in Fig.1, under certain circumstances the 3DDM appears transparent to electrons hitting the 3DDM. We find that electrons hitting the metal-3DDM interface from metallic side can enter 3DDM in a reversed spin state as soon as their angle of incidence deviates from the direction perpendicular to interface. However the presence of a second interface completely cancels this effect.

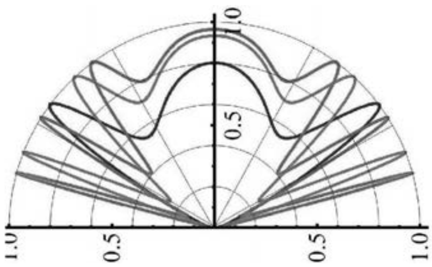

Figure 1: (Color online) angular dependence of quantum transport of an excitation with energy $\varepsilon/\Delta = 2, 3, 4$ corresponding to red, brown and blue curves, respectively. We set Δ=10 meV and $v_D = 10^5$ m/s. The length of junction is L=1μm.

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PS51

Half-metallic ferromagnetism in Mn-doped zigzag AlN nanoribon from first-principles

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Based on first-principles calculations, we investigate the effect of Mn impurity on the electronic and magnetic properties of H-terminated zigzag AlN nanoribbon (ZAlNNR), using the band structure results obtained through the full potential linearized augmented plane wave (FP-LAPW) method within the density functional theory (DFT). The exchange-correlation potential is treated by the generalized gradient approximation (GGA) within the Perdew et al. scheme [1]. The calculated results show that the H-terminated ZAlNNR is semiconducting and non magnetic material with a direct band gap of about 2.78 eV which in good agreement with previous experimental and theoretical reports [2,3]. Density of state (DOS) analyses shows that the top of the valence band for the H-terminated ZAlNNR (bare) is mainly contributed by N atoms, while just beside the conduction band the whole DOS is mainly contributed by Al atoms.

The main result is a transition from non-magnetic semiconducting character to ferromagnetic half-metallic one upon doping. The ZAlNNRs doped with Mn impurity, display strong spin polarization very close to the Fermi level which will result in spin-anisotropic transport. The Mn-doped ZAlNNR shows complete (100%) spin polarization at the Fermi level and the charge transport is totally originated from Manganese spin up electrons in the nanoribbon. These results propose potential application for the development of AlN nanoribbon-based in magneto-electronic devices.

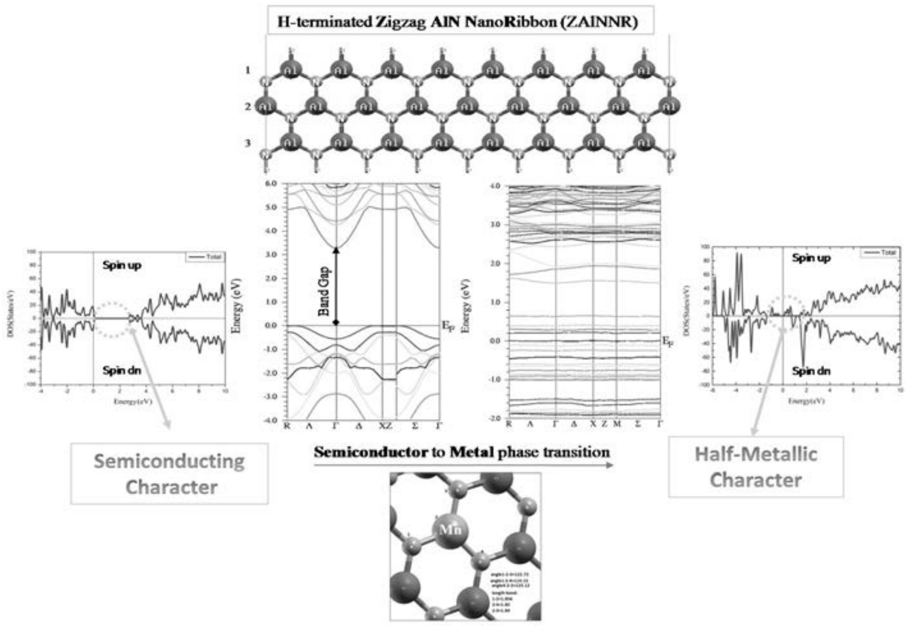

Figure 1: Graphical abstract.

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Kondo effect in a carbon nanotube quantum dot with a finite orbital splitting and a magnetic field

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We study ground-state properties of a carbon nanotube quantum dot, for which high-sensitive current and current-noise measurements have recently been carried out [1,2]. This system shows SU(4) and SU(2) Kondo effects depending on the gate voltages and external fields, and some corresponding situations were examined by Izumida, Sakai and Shimizu in their seminal numerical-renormalization-group (NRG) study of quantum dots [3]. Our purpose is to explore the wide parameter space of this system, especially the realistic regions relevant to the experiments. We calculate the conductance, linear noise, and renormalized local-Fermi-liquid parameters, using the NRG, to clarify effects of a level splitting $\varepsilon_{\rm sp}$ and a magnetic field b which break the SU(4) symmetry.

We consider an impurity Anderson model with two orbitals $\mu = +, -$, and spin $\sigma = \uparrow, \downarrow$

$$\mathcal{H} = \sum_{\mu\sigma} \varepsilon_{d,\mu\sigma}\, d^{\dagger}_{\mu\sigma} d_{\mu\sigma} + \frac{U}{2}\, N_d\,(N_d - 1) + \sum_{\mu\sigma} V\left(d^{\dagger}_{\mu\sigma}\psi_{\mu\sigma} + \text{H.c.}\right) + \sum_{\mu\sigma}\int_{-D}^{D} d\epsilon\, \epsilon\, c^{\dagger}_{\epsilon,\mu\sigma} c_{\epsilon,\mu\sigma},$$

$$\varepsilon_{d,\pm,\sigma} \equiv \varepsilon_d \pm \varepsilon_{\rm sp} - b\ \mathrm{sign}\,\sigma, \quad N_d = \sum_{\mu\sigma} d^{\dagger}_{\mu\sigma} d_{\mu\sigma}\ , \quad \psi_{\mu\sigma} = \int_{-D}^{D} d\epsilon\, \sqrt{\rho}\, c_{\epsilon,\mu\sigma}.$$

Here, $\Delta \equiv \pi\rho V^2$, and $\rho = 1/(2D)$ with D the half-width of the conduction band. Figure 1 shows some results of (left) conductance and (right) occupation number for zero field $b = 0$ at $T = 0$. Typical value of the Kondo temperature in this situation is given by $T_K/(\pi\Delta) \simeq 0.13$ for the SU(4) particle-hole symmetric point $\varepsilon_{\rm sp} = 0$ and $\varepsilon_d = -1.5U$. We see that the unitary limit conductance at this symmetric point decreases as level splitting $\epsilon_{\rm sp}$ increases whereas the average of the total occupation $\langle N_d \rangle$ does not changes so much. We will also dicuss effects of additional magnetic field b and other details.

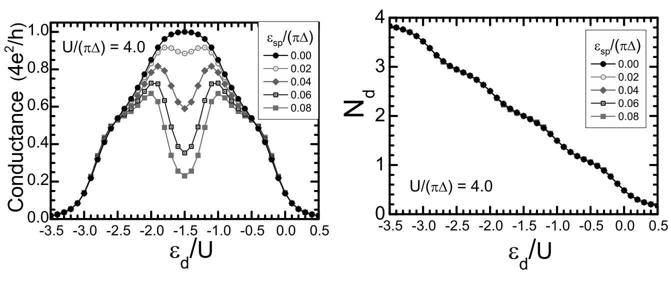

Figure 1: NRG results of (left) conductance and (right) average of N_d for Coulomb repulsion $U/(\pi\Delta) = 4.0$ and zero field $b = 0$, are plotted vs ϵ_d, for several different orbital splittings $\epsilon_{sp}/(\pi\Delta) = 0.00, 0.02, \ldots, 0.08$. Typical energy scale is $T_K/(\pi\Delta) \simeq 0.13$.

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PS53

Phasons and Excitations in Skyrmion Lattice

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Excitations of two-dimensional skyrmion lattice are theoretically studied based on a collective coordinate description[1]. Starting from the representation of skyrmion lattice in terms of three helices, we identify the canonical coordinates describing low energy excitations as phasons. The phason excitation spectra turn out to have one gapless mode with a quadratic dispersion and one massive mode, in agreement with previous studies. We will show that there is another collective mode governing the topological nature and the stability of skyrmion lattice and that the fluctuation of this mode leads to a screening of the topological charge of the lattice. Experimental implications of the screening effect in microwave absorption, topological Hall effect and depinning threshold current in metals are discussed.

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PS54

Application of NV-Center Spin Probe to Spintronics

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Recently, nitrogen vacancy center (NV center) in diamond crystal, single spin state in a pair of carbon defect and substituted nitrogen, is attracting much attention for utilizing it as a magnetometer. NV center can detect stray magnetic field from spins and magnets existing around at single spin sensitivity and nanometer-scale resolution [1, 2].

We focus on applying NV center to sensing and mapping magnets and spins unravelling underlying physics. For instance, magnetic domains and accumulated spins at the interface of ferromagnet and paramagnet of the spintronic device can be imaged by NV center spin probe.

In this study, we detected stray field by NV center from magnetic domains of yttrium iron garnet film (YIG), which is interested in using for magnon-based spintronic devices. Figure 1(a) shows polarization-microscope image of magnetic domains in the YIG film, where vertically magnetized up and down domains are formed. Nanodiamonds, which contains single NV center were spread on the YIG film surface and the stray magnetic fields from magnetic domains were optically detected by the NV center in naodiamonds. Figure 1(b) shows optically detected magnetic resonance (ODMR) signal from one of NV nanodiamonds on the YIG film. The observed data shows broadened ODMR signal which can be explained that the magnetic domains are dynamically oscillated by the microwave field for exciting NV center and the averaged stray fields were detected by NV center. From the broadening of ODMR signal information of domain wall motion can be extracted.

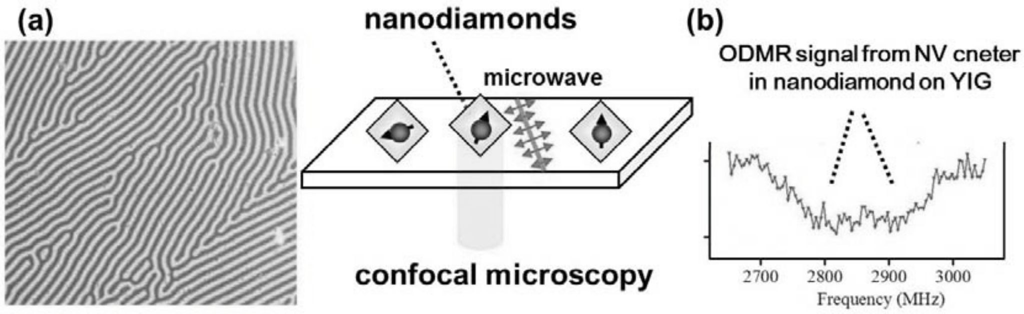

Figure 1: (a) polarization-microscope image of magnetic domains in the YIG film. (b) ODMR signal from NV center in nanodiamond on YIG.

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