International workshop on nano-spin conversion science & quantum spin dynamics

Oct 12-15, 2016, Tokyo, Japan

ABSTRACT BOOK

Organizers and Supported by :

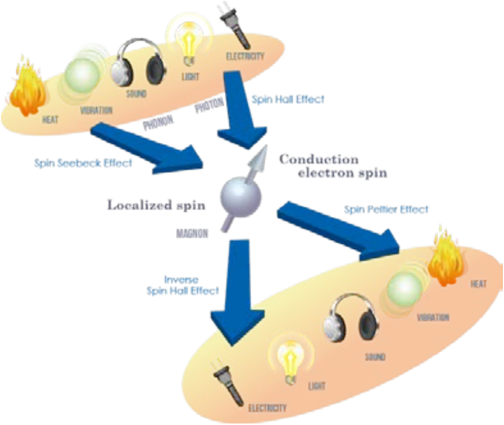
Grant-in-Aid for Scientific Research on Innovative Areas, MEXT, Japan
"Nano Spin Conversion Science“
Y. Otani, S. Murakami,M. Shiraishi, A. Oiwa, E. Saitoh

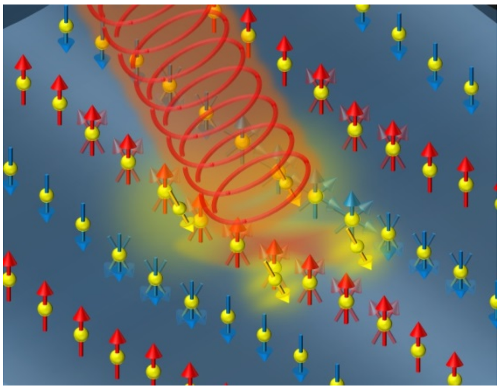
RIKEN Center for Emergent Matter Science
S. Tarucha, K. Ishibashi, K. Kono, G. Tatara

The aim and scope

The international workshop on Nano-Spin Conversion Science and Quantum Spin Dynamics (NSCS-QSD 2016) is co-sponsored by KAKENHI on Innovative Area "Nano-Spin Conversion Science" and Quantum information electronics division, CEMS RIKEN. Nano-spin conversion science deals with all the interconversion phenomena among electrons, phonons, magnons, and photons mediated by spins.

The aim of the workshop is to provide an international/global forum for discussions of interdisciplinary issues on "spin torque induced dynamics of spin structures such as domain walls and skyrmions", "spin to charge conversion phenomena due to spin Hall effects and spin momentum locking at the surface and interface states", "optically induced collective and also coherent quantum spin dynamics" and "thermally and mechanically created spin currents".





NSCS-QSD 2016

PROGRAM

WEDNESDAY, 12 OCTOBER

08:30-09:15	Registration & Opening		
	CHAIR : Eiji Saitoh		
09:15-10:00	W1	**Kang Wang** (University of California Los Angeles)	Spin Dynamics and Textures via Interfacial Spin-Orbit Coupling
10:00-10:30	W2	**YoshiChika Otani** (University of Tokyo, RIKEN CEMS)	Spin to charge interconversion at the interfaces with strong SOI
10:30-11:00		Coffee Break	
11:00-11:45	W3	**Juan Carlos Rojas Sanchez** (CNRS)	Rashba interfaces and Topological Insulators for efficient spin-to-charge current conversion at room temperature
11:45-12:15	W4	**Masashi Shiraishi** (Kyoto University)	Spin transport and conversion in semiconductors and topological insulators
12:15-13:00	W5	**Felix Casanova** (CIC Nano GUNE)	Spin Hall effect in heavy metals: mechanisms and optimization
13:00-14:30		Lunch	
	CHAIR : Masashi Shiraishi		
14:30-15:15	W6	**Se Kwon Kim** (University of California Los Angeles)	A Realization of the Haldane-Kane-Mele Model in a System of Localized Spins
15:15-15:45	W7	**Takahiro Moriyama** (Kyoto University)	Antiferromagnetic spintronics and recent results
15:45-16:15		Coffee Break	
16:15-17:00	W8	**Hyunsoo Yang** (National University of Singapore)	Flexible magnetic tunnel junctions and spin-orbit torque dynamics

17:00-17:30	W9 **Eiji Saitoh** (Tohoku University)	Spin Current Generators
17:30-18:15	W10 **Xiaofeng Jin** (Fudan University)	Spin Hall effect in epitaxial Cu(111) films with δ-doped Bi measured by H-Pattern

THURSDAY, 13 OCTOBER

CHAIR : YoshiChika Otani

09:00-09:45	T1 **Yoshinori Tokura** (RIKEN CEMS, University of Toyo)	Meta-stable skyrmions in chiral magnets
09:45-10:30	T2 **Christopher Marrows** (University of Leeds)	Chiral interactions in thin film magnets
10:30-11:00		Coffee Break
11:00-11:45	T3 **Vladislav Demidov** (University of Münster)	Magnetization oscillations and waves driven by pure spin currents
11:45-12:15	T4 **Gen Tatara** (RIKEN CEMS)	Transport, magnetic and optical properties induced by emergent spin electromagnetic fields in metallic ferromagnet
12:15-13:00	T5 **Theo Rasing** (Radboud University)	Femtosecond optical control of magnetism : Towards THz spintronics
13:00-14:30		Lunch

CHAIR : Akira Oiwa

14:30-15:15	T6 **Timothy Phung** (IBM)	Spin-orbitronic materials and devices
15:15-15:45	T7 **Shuichi Murakami** (Tokyo Institute of Technology)	Current-induced magnetizations in chiral systems
15:45-16:15		Coffee Break
16:15-17:00	T8 **Jairo Sinova** (Johannes Gutenberg University of Mainz)	Antiferromagnetic spin-orbitronics
17:00-17:45	T9 **Dieter Weiss** (University of Regensburg)	Spin injection into two-dimensional electron systems

17:45-19:45	Poster Session : Bierstube	

FRIDAY, 14 OCTOBER

CHAIR : Takis Kontos

09:00-09:45	F1 **Sam Carter** (US Naval Research Laboratory)	Cavity-enhanced Raman spin flip emission from single and coupled quantum dots
09:45-10:15	F2 **Akira Oiwa** (ISIR,Osaka University)	Photon-electron spin Poincaré interface using gate-defined quantum dots
10:15-10:30	Coffee Break	
10:30-11:15	F3 **Matthew Sellars** (Australian National University)	Spin wave storage of light using rare-earth doped crystals
11:15-11:45	F4 **Yasunobu Nakamura** (RIKEN CEMS, RCAST University of Tokyo)	Quantum magnonics in a ferromagnetic sphere
11:45-12:15	F5 **Franco Nori** (RIKEN CEMS, University of Michigan)	Parity–Time (PT)-symmetry in optics and the quantum spin Hall effect of light
12:15-13:45	Photo + Lunch	

CHAIR : Sam Carter

13:45-14:30	F6 **Christian Schönenberger** (University of Basel)	Magnetoresistance of quantum dots with ferromagnetic split-gates
14:30-15:15	F7 **Charles M. Marcus** (Niels Bohr Institute, University of Copenhagen)	Majorana zero modes in Coulomb islands
15:15-15:30	Coffee Break	
15:30-16:00	F8 **Russell S. Deacon** (RIKEN CEMS)	Signatures of 4pi periodicity in the dynamics of HgTe Josephson Junctions
16:00-16:30	F9 **Daniel Loss** (RIKEN CEMS, University of Basel)	From Majorana- to Para-Fermions in Nanowires and Helical Edge States

16:30-17:15	F10 **Silvano De Franceschi** (CEA Grenoble)	Electrically driven hole-spin resonance in silicon devices
17:15-18:45	Poster Session	
19:00-21:00	Banquet	

SATURDAY, 15 OCTOBER

CHAIR : Akira Oiwa

09:00-09:45	S1 **Tristan Meunier** (CNRS Institut Néel)	Coherent long-distance spin displacement of individual electrons
09:45-10:15	S2 **Seigo Tarucha** (University of Tokyo)	Distance-independent Dephasing of Phase-controlled Spin Entanglement
10:15-10:45	Coffee Break	
10:45-11:30	S3 **Bill Coish** (McGill University)	Decoupling and decoherence for spin-resonator state transfer
11:30-12:00	S4 **Yoshiro Hirayama** (Tohoku University)	Interaction between electron and nuclear spins in GaAs and InSb quantum systems
12:00-12:45	S5 **Menno Veldhorst** (Delft University of Technology)	Quantum logic in silicon
12:45-14:15	Lunch	

CHAIR : Daniel Loss

14:15-14:45	S6 **Kouichi Semba** (NICT)	Stable ‘Molecular’ State of Photons and Artificial Atom
14:45-15:30	S7 **Takis Kontos** (CNRS/ENS)	Cavity quantum electrodynamics with carbon nanotubes
15:30-16:00	Coffee Break	
15:00-15:45	S7 **Hongqi Xu** (Peking University)	Topological superconducting devices made from semiconductor nanostructures
15:45-16:15	S8 **Yukio Tanaka** (Nagoya University)	Control of odd-frequency s-wave Cooper pairs in double quantum dots

Closing & Departure : Tarucha

1st Poster Session (NSCS) : October 13th

Poster #	Name	Affiliation	Title
N-1	NIIMI Yasuhiro	Osaka University	Spin-related phenomena detected by spin current
N-2	QIU Zhiyong	WPI-AIMR, Tohoku University	detection of antiferromagnetic phase transition by spin current
N-3	SAGASTA Edurne	CIC nanoGUNE	Large spin-to-charge conversion in Pt/graphene lateral nanostructures
N-4	KONDOU kouta	RIKEN CEMS	Observation of charge-to-spin current conversion by Dirac surface state of topological insulators
N-5	YASUDA Kenji	University of Tokyo	Large unidirectional magnetoresistance in magnetic topological insulator
N-6	SATO Osamu	Kyushu University	Magnetization Switching via Charge Transfer in a [CrCo] Complex
N-7	PUEBLA Jorge	RIKEN CEMS	Direct observation of spin accumulation at Rashba-like interface
N-8	OKI Soichiro	Osaka University	Spin transport in n-Ge and p-Ge
N-9	MIZUKAMI Shigemi	WPI-AIMR, Tohoku University	Laser-induced spin-wave in metals under microscope
N-10	TOSHU An	Japan Advanced Institute of Science and Technology	Spin Conversion from Spin Waves into NV Centers in Diamond
N-11	MIWA Shinji	Osaka University	Spin conversion at interface of metal and dielectric
N-12	DUSHENKO Sergey	Kyoto University	Graphene spin-charge converter controlled by gate voltage
N-13	YANG Guang	RIKEN CEMS	Majorana Bound States in Magnetic Skyrmions
N-14	OHNUMA Yuichi	Japan Atomic Energy Agency	Magnon instability driven by heat current
N-15	HAMAMOTO Keita	University of Tokyo	Non-reciprocal responses in Rashba system
N-16	SAARIKOSKI Henri	RIKEN CEMS	Efficient domain wall transport and pinning in magnetic nanowires and synthetic ferrimagnets
N-17	RANA Bivas	RIKEN CEMS	Detection of voltage excited spin wave by ps-TRMOKE
N-18	KIKUCHI Toru	RIKEN CEMS	Doppler shift picture of the Dzyaloshinskii-Moriya interaction
N-19	MATSUKURA Fumihiro	WPI-AIMR, Tohoku University	Electrical modulation of damping constants in (Ga,Mn)As
N-20	SEKI Takeshi	IMR, Tohoku University	Spin Hall effect in ferromagnetic FePt alloy
N-21	OHNISHI Kohei	Kyushu University	Phase modulation of supercurrent in the multi-layer-based lateral Josephson junction
N-22	TRETIAKOV Oleg	IMR, Tohoku University	Magnetic Anisotropy due to Interplay of Curvature and Dipolar Interaction
N-23	YOKOI Naoto	IMR, Tohoku University	A Holographic Dual of Ferromagnets
N-24	TANIYAMA Tomoyasu	Tokyo Institute of Technology	Spin Wave Transmission in FeRh Thin Films
N-25	SATOH Takuya	Kyushu University	Time-resolved imaging of spin wave transmission
N-26	KAWAGUCHI Hideo	Tokyo Metropolitan University, RIKEN CEMS	Effective Hamiltonian theory for nonreciprocal light propagation in magnetic Rashba conductor
N-27	OHYA Shinobu	University of Tokyo	Spin injection into the topological crystalline insulator SnTe using spin pumping
N-28	UCHIDA Yusuke	ISSP, University of Tokyo	Size effect of electrical transport properties in NiS2
N-29	CHIBA Takahiro	IMR, Tohoku University	Proximity-induced magnetoresistance in two-dimensional Dirac electrons on ferromagnetic insulators
N-30	CHIBA Takahiro	IMR, Tohoku University	Electric-field-induced magnetic resonance in topological antiferromagnetic insulators
N-31	MIZUTA Yo Pierre	Kanazawa University	First-principles Approach for Skyrmion-driven Thermoelectric Conversion
N-32	KIM Junyeon	RIKEN CEMS	Edelstein magnetoresistance in CoFe/Cu/Bi2O3
N-33	SEKI Shinichiro	RIKEN CEMS	Thermal generation of spin current in antiferromagnets
N-34	OKUMA Nobuyuki	University of Tokyo	Microscopic derivation of spin current in topological insulator/magnetic insulator heterostructure
N-35	BORYS Pablo	RIKEN CEMS	Conservation of angular momentum in DMI spin textures
N-36	MUDULI Prasanta Kumar	ISSP, University of Tokyo	Role of interfacial exchange field in the spin-current modulation with ferromagnetic insulator
N-37	TAKAHASHI Ryo	Japan Atomic Energy Agency	Spin-hydrodynamic Conversion Effect
N-38	MATSUMOTO Kenta	ISSP, Univ. of Tokyo	Transition behavior in Pd-doped FeRh wire
N-39	TAKASHIMA Rina	Kyoto University	Supercurrent-induced Skyrmion dynamics and Tunable Weyl points in Chiral Magnet with Superconductivity
N-40	YAMAGUCHI Naoya	Kanazawa University	First-principles calculation of Rashba parameters in surface alloys of bismuth and noble metals
N-41	YOSHIKAWA Hiroki	Nihon University	All-optical magnetization switching in GdFeCo stacked on different metallic layers
N-42	OKADA Hiroki	Mie-University	The fluctuation of charge, heat and spin currents
N-43	HISATOMI Ryusuke	RCAST, University of Tokyo	Bidirectional conversion between microwave and light via ferromagnetic magnons
N-44	MIZUGUCHI Masaki	Tohoku University	Anomalous Nernst effect in Co / Ni multilayers
N-45	OGATA Yudai	Japan Atomic Energy Agency	Barnett effect in rare-earth metals
N-46	NAKAYAMA Hiroyasu	Keio University	Rashba-Edelstein magnetoresistance in metallic heterostructures

2nd Poster Session (QSD) : October 14th

Poster #	Name	Affiliation	Title
Q-1	LAMBERT Neill	RIKEN CEMS	Bistable Photon Emission in Hybrid-QED
Q-2	LAMBERT Neill	RIKEN CEMS	Non-perturbative and non-Markovian environments: exact solvers and applications
Q-3	FRISK KOCKUM Anton	RIKEN CEMS	Quantum optics with giant artificial atoms
Q-4	LI Zhou	RIKEN CEMS	Second harmonic generation in topological insulators
Q-5	WAKATSUKI Ryohei	University of Tokyo	Nonreciprocal Transport in Noncentrosymmetric Superconductors
Q-6	SHITADE Atsuo	RIKEN CEMS	Anomalous Thermal Hall Effect in a disordered Weyl ferromagnet
Q-7	HSU Chen-Hsuan	RIKEN CEMS	Antiferromagnetic nuclear spin helix and topological superconductivity in ^{13}C nanotubes
Q-8	MATSUO Sadashige	University of Toky	Equal-spin Andreev Reflection between Spin-resolved Quantum Hall Bulk State and Superconductor
Q-9	STANO Peter	RIKEN CEMS	Fractional charge in one-dimensional quantum dots array
Q-10	BARKER Joseph	IMR, Tohoku University	Atomistic spin dynamics with a semi-quantum thermostat
Q-11	IBA Satoshi	AIST	Development of (110) GaAs quantum wells for emission layers of spin-controlled lasers
Q-12	CIRIO Mauro	RIKEN CEMS	Ground State Electroluminescence
Q-13	KUROYAMA Kazuyuki	University of Tokyo	Single photon-electron pairs generation from polarization entangled photon pairs
Q-14	OTSUKA Tomohiro	RIKEN CEMS	Charge and spin dynamics in a quantum dot-lead coupled system
Q-15	NOIRI Akito	University of Tokyo	Measuring the time dependence of a Rabi oscillation of an electron spin in a semiconductor quantum dot
Q-16	KAMATA Hiroshi	RIKEN CEMS	Transport properties of InAs nanowires on hexagonal boronnitride
Q-17	NAKAMURA Taketomo	ISSP, University of Tokyo	Proximity induced triplet supercurrent in Nb/(In, Fe)As/Nb junctions
Q-18	MORIYA Rai	IIS, University of Tokyo	Construction of van der Waals magnetic tunnel junction using ferromagnetic layered dichalcogenide
Q-19	SUZUKI Michi-To	RIKEN CEMS	Cluster-multipole-driven Anomalous Hall Effect in antiferromagnets
Q-20	GIAVARAS Giorgos	RIKEN CEMS	Spin resonance effects in parallel-coupled quantum dots
Q-21	FUJIMOTO Junji	ICR, Kyoto University	Effects of skew scattering on non-dissipative transport properties
Q-22	SAWAHATA Hikaru	Kanazawa University	Large Chern number in films of transition metal oxides
Q-23	ALLISON Giles	RIKEN CEMS	Lowering electron temperature for measurement of spin relaxation in quantum dots
Q-24	BOJESEN Troels	RIKEN CEMS	Quantum Monte-Carlo study of quantum spin ice under a [111] magnetic field
Q-25	NAKAJIMA Takashi	RIKEN CEMS	High-Fidelity Readout of Two-Spin Correlations Using a Metastable Charge State in Triple Quantum Dots
Q-26	TAKEDA Kenta	RIKEN CEMS	Centre resonance frequency shift of a strongly driven silicon quantum dot spin qubit
Q-27	YONEDA Jun	RIKEN CEMS	High-fidelity spin control in an enriched Si/SiGe quantum dot with a micromagnet
Q-28	NAKOSAI Sho	RIKEN	Magnetic Analogue of Superconductivity in Quantum Spin Ice
Q-29	MARX Marian	University of Tokyo	Hybrid cQED architecture as a model system for non-equilibrium physics in condensed matter
Q-30	ITO Takumi	University of Tokyo	Detection and control of the charge states of a quintuple quantum dot in a scalable multiple quantum dot architecture

Abstracts of Oral Presentation

W1

Spin Dynamics and Textures via Interfacial Spin-Orbit Coupling

Kang L. Wang

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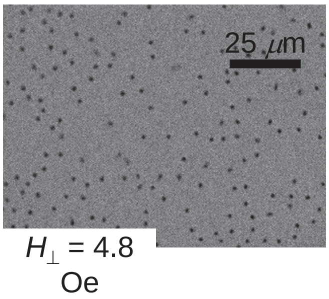
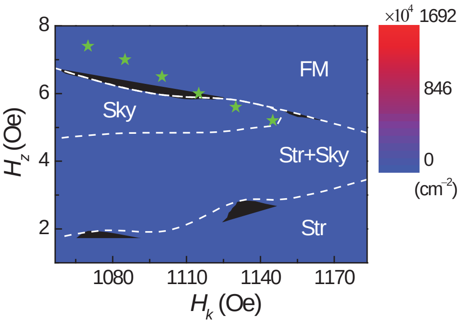
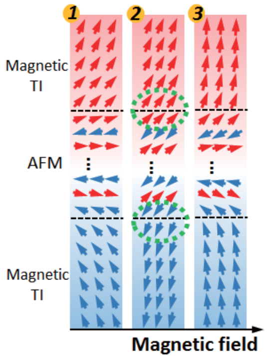
The engineering of interfacial spin-orbit interaction will be discussed for a few cases. First, spin orbit coupling (SOC) will be illustrated for the efficient electric field control of magnetic moment or magneto-electric (ME) effect. Magnetic memory arrays based on this ME effect, referred to as magnetoelectric RAM (MeRAM), are shown to have orders of magnitude lower energy dissipation compared with spin transfer torque memory (STTRAM). The principle of operation, the dynamics of switching and the benefits of energy scaling in technology nodes as well as the readiness of the technology implementation and manufacturing will be discussed. Next, magnetic skyrmions are shown to be manipulated at room temperature through SOC via tuning the magnetic anisotropy. Also to be discussed includes a method for room-temperature skyrmion creation, their manipulation by spin-orbit torque and the dynamics of motion in magnetic thin films. This talk will also describe other related physics of SOC at the interface of anti-ferromagnetism/topological insulator and show the control of exchange bias as well as high speed memory switching. THz speed electronics may be possible.







W2

Spin to charge interconversion at the interfaces with strong SOI

Y. Otani[1,2] S. Karube[1], J. Kim[2], K. Kondou[2]

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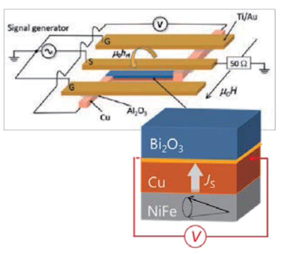
[2]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan*

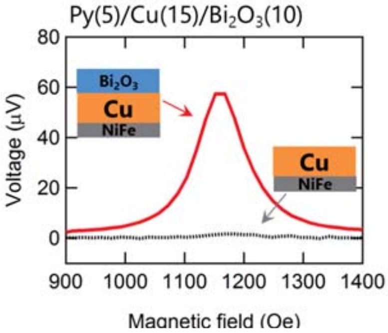
As an alternative mechanism to the spin Hall effect (SHE), we found that the spin to charge conversion took place at Cu/insulating Bi_2O_3 interfaces similarly to the Ag/Bi interface. The ferromagnetic resonance (FMR) of Py layer is excited by using the coplanar wave guide with applying an external magnetic field, so that the FMR of the Py layer induces the spin pumping to the adjacent Cu layer through which the spin current flows towards the Cu/Bi_2O_3, and then converted into charge currents. This was clearly observed as characteristic absorption peaks at the resonance field in the dc voltage spectrum. In contrast the Py/Cu bilayers prepared as a reference exhibit no peaks at the resonance field in the dc voltage spectrum, indicating this conversion is due to the presence of the Bi_2O_3 layer. Both Cu and Bi_2O_3 thickness dependences showed that the IREE length λ_{IRE} varied as a function of the Cu thickness, reflecting the thickness dependent resistivity of a Cu layer. Rashba parameter α_R was estimated to be -0.46 eV Angstrom, about 50% of the reported value for Bi/Cu(111) interface. Interestingly this Cu/Bi_2O_3 interface can be used to detect spin Seebeck effect and also modulate significantly the angular dependent magnetoresistance of an adjacent ferromagnet like spin Hall magnetoresistance.

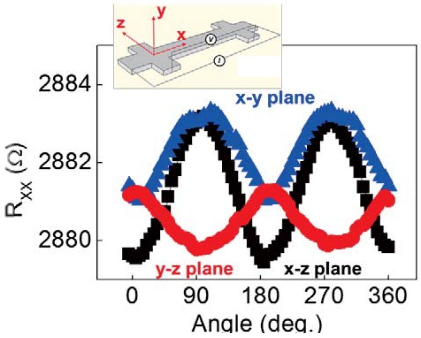
Spin pumping method



//NiFe(5nm)/Cu(0-34nm)/Bi_2O_3(100nm)

Py(5)/Cu(15)/Bi_2O_3(10)





W3

Rashba interfaces and Topological Insulators for efficient spin-to-charge current conversion at room temperature

J-C Rojas-Sánchez[1,2], A. Fert[1], A. Barthélémy[1], M. Bibes[1], J-M. George[1], H.Jaffres[1], E. Lesne[1], H. Naganuma[1], N. Reyren[1], D.C. Vaz[1] , L. Vila[3], J.-P. Attané[3], Y. Fu[3], S. Gambarelli[3], M. Jamet[3], A. Marty[3], S. Oyarzun[3], L. Vila[3], Y. Ohtsubo[4], P. LeFevre[5], F. Bertran[5], A. Taleb-Ibrahimi[5]

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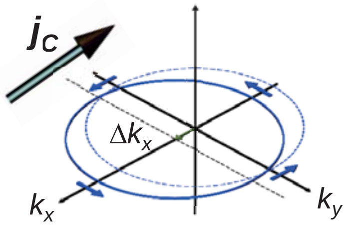
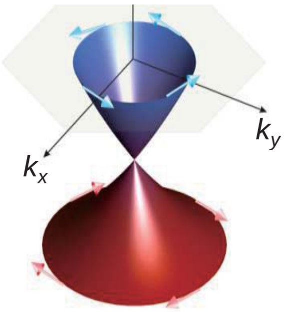
[2] IJL-CNRS/U. Lorraine, F-54506 Vandoeuvre-Les-Nancy, France
[3]CEA, Grenoble, F-38000 France
[4]Osaka Univ., Suita 565-0871,Japan
[5]Synchrotron SOLEIL, Gif, France

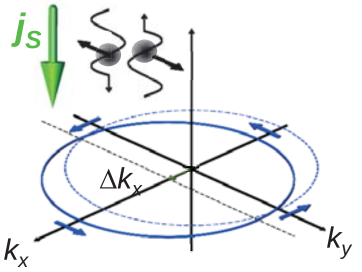
My talk focuss on the conversion between spin and charge currents by exploitation of the spin-orbit coupling (SOC) in the 2DEG states at Topological Insulator or Rashba Interfaces and the resulting perspective for low power spintronic devices.

I will show results of spin to charge conversion in spin pumping experiments on **Bi/Ag Rashba interfaces** and thin films of the **newly discovered topological insulator α-Sn**, and their analysis in term of **inverse Edelstein Length**. I will also discuss additional example of conversion between spin and charge at **LAO/STO** interfaces.

I will use the conversion parameters obtained at room temperature with α-Sn to demonstrate the very large **advantage of the SOC effects in 2D interface states** with respect to the SHE of 3D metals.







W4

Spin transport and conversion in semiconductors and topological insulators

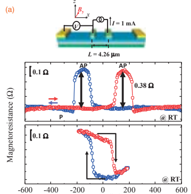
Masashi Shiraishi

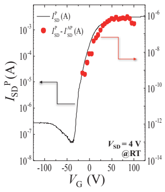
Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan.

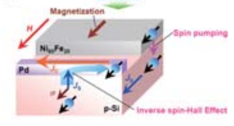
Spin transport and conversion in solids attract significant attention in condensed matter physics. Realization of room temperature electric and dynamical spin transport and its detection by electric spin conversion in Graphene [1,2], Si [3,4], Ge [5] and GaAs [6,7] at room temperature pioneered spin physics in semiconductors and also enabled expanding the research field to an application of spin-based devices, such as spin MOSFETs [7,8]. In addition, topological insulators, where topologically-protected edge (spin) current appears, also garners tremendous attention, and a number of studies has been implemented about detecting the spin current in BiSe [9], BiSbTeSe [10] and BiSbTe [11].

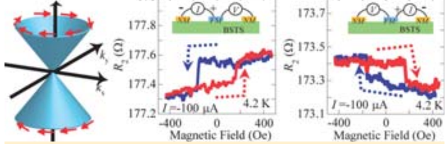
In this presentation, electrical and dynamical spin currents in semiconductors and topological insulators are introduced and discussed.

[1] N. Tombros et al., Nature 448, 571 (2007). [2] Z. Tang, M. Shiraishi et al., Phys. Rev. B87, 140401(R) (2013). [3] T. Suzuki, M. Shiraishi et al., APEX 4, 023004 (2011). [4] E. Shikoh, M. Shiraishi et al., Phys. Rev. Lett. 110, 127201 (2013). [5] S. Dushenko, M. Shiraishi et al., Phys. Rev. Lett. 114, 196602 (2015). [6] T. Uemura et al., APL 99, 082108 (2011). [6] A. Yamamoto, M. Shiraishi et al., Phys. Rev. B91, 024417 (2015). [7] T. Sasaki, M. Shiraishi et al., Phys. Rev. Applied 2, 034005 (2014). [8] T. Tahara, M. Shiraishi et al., APEX 8, 113004 (2015). [9] C. Li et al., Nature Nanotech. 9, 218 (2014). [10] Yu. Ando, M. Shiraishi et al., Nano Lett. 14, 6226 (2014). [11] J. Tang et al., Nano Lett. 14, 5423 (2014).









W5

Spin Hall effect in heavy metals: mechanisms and optimization

Fèlix Casanova[1,2]

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The discovery of new spin-to-charge conversion effects (spin Hall effect (SHE), Rashba-Edelstein effect, spin-momentum locking) is expanding the potential of applications such as the magnetization switching of ferromagnetic elements for memories [1] or the recent proposal of a spin-orbit logic [2] which can have a strong technological impact. Finding routes to maximize the SHE is not possible as long as it remains unclear which is the dominant mechanism in a material. I will present a systematic study in Pt, the prototypical SHE material, using the spin absorption method in lateral spin valve devices. We find a single intrinsic spin Hall conductivity in a wide range of conductivities, in good agreement with theory. By tuning the conductivity, we observe for the first time the crossover between the moderately dirty and the superclean scaling regimes of the SHE, equivalent to that obtained for the anomalous Hall effect (see Fig.1). Our results explain the dispersion of values in the literature and find a route to maximize this important effect [3]. We also studied the mechanisms in Ta and W, materials with a claimed giant SHE. Finally, we show how to achieve larger spin-to-charge voltage output at room temperature by combining Pt with a graphene channel, opening up exciting opportunities towards the implementation of spin-orbit-based logic circuits.

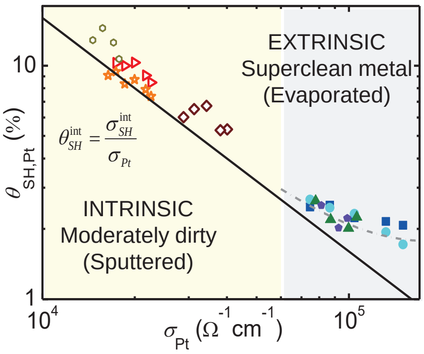


FIG.1. Conductivity dependence of the spin Hall angle of Pt.

[1] C. K. Safeer *et al.*, Nat. Nanotech. **11**, 143 (2016)
[2] S. Manipatruni *et al.*, arXiv:1512.05428
[3] E. Sagasta, Y. Omori *et al.*, arXiv:1603.04999 (PRB, *in press*)

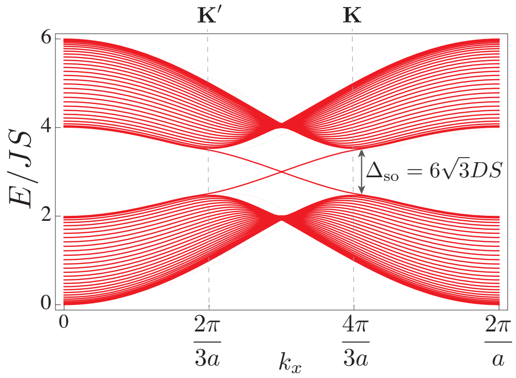
W6

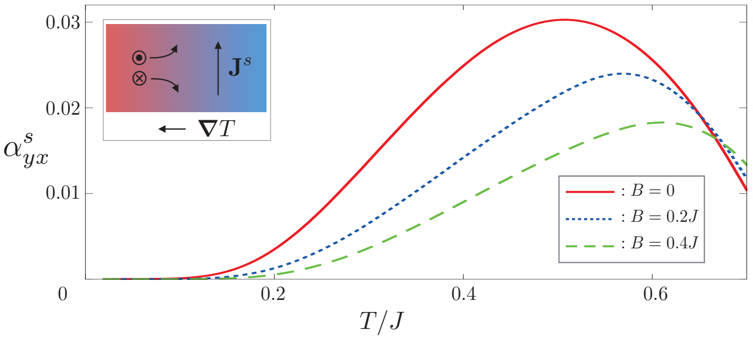
A Realization of the Haldane-Kane-Mele Model in a System of Localized Spins

Se Kwon Kim

University of California, Los Angeles, USA

We study a spin Hamiltonian for spin-orbit-coupled ferromagnets on the honeycomb lattice [1]. At sufficiently low temperatures supporting the ordered phase, the effective Hamiltonian for magnons, the quanta of spin-wave excitations, is shown to be equivalent to the Haldane model for electrons, which indicates the nontrivial topology of the band and the existence of the associated edge state. At high temperatures comparable to the ferromagnetic-exchange strength, we take the Schwinger- boson representation of spins, in which the mean-field spinon band forms a bosonic counterpart of the Kane-Mele model. The nontrivial geometry of the spinon band can be inferred by detecting the spin Nernst effect. A feasible experimental realization of the spin Hamiltonian is proposed.





[1] S. K. Kim et al., arXiv:1603.04827 (accepted for PRL)

W7

Antiferromagnetic spintronics and recent results

Takahiro Moriyama and Teruo Ono

Kyoto University, Institute for Chemical Research, Kyoto 611-0011

Spintornics yields novel electronic devices by utilizing both charge and spin degrees of freedom in a solid. We have seen a flourish of spintronic applications such as hard disk drives (HDD) and magnetic random access memory (MRAM). However, majority of the spintronic researches and applications has so far been dealing with ferromagnetism and much less attention has been paid to antiferromagnetic materials. Although it has no net magnetization, its microscopic magnetic moments can in principle exhibit a similar spintronic effect as seen in ferromagnetic materials. In this talk, we will show our recent experimental results of the magnetoresistance and the spin torque effect in antiferromagnets, possibly leading to novel antiferromagnetic spintronic applications.

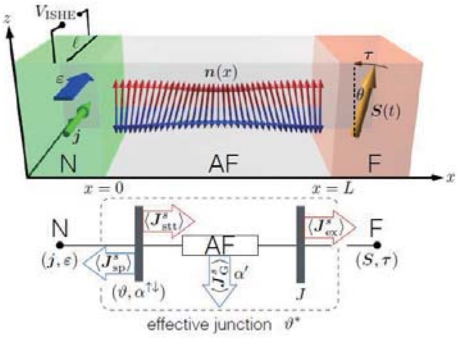


Figure 1 Spin current transmission in antiferromagnetic NiO.

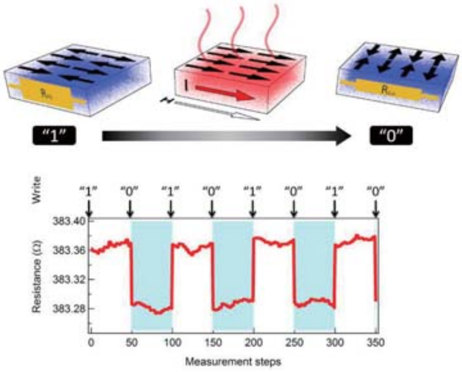


Figure 2 Sequential write-read in FeRh antiferromagnetic bit.

W8

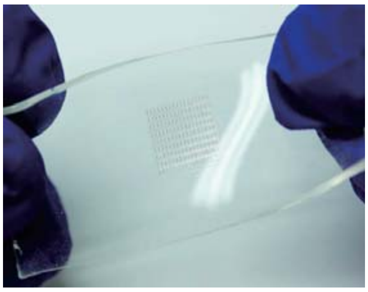
Flexible magnetic tunnel junctions and spin-orbit torque dynamics

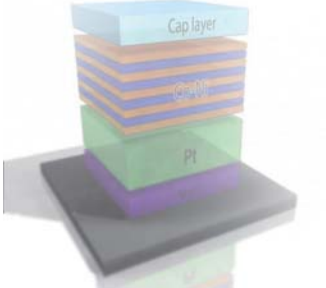
Hyunsoo Yang[1]

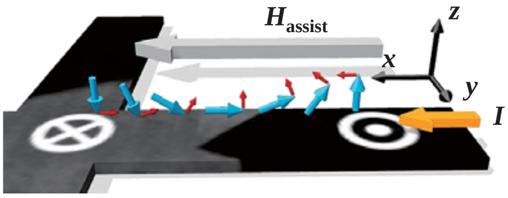
[1]*Department of Electrical and Computer Engineering, National University of Singapore, Singapore*

The magnetic tunnel junction (MTJ) is a central element for the magnetoresistive random access memory (MRAM). We show that the tunneling magnetoresistance (TMR) of the MTJ is strongly influenced by strain in the tunnel barrier and ferromagnets, and demonstrate flexible MTJs on various substrates, which can be utilized for future flexible MRAM.

Current induced spin-orbit torques (SOTs) in a heavy metal/ferromagnet provide a new way to manipulate the magnetization. We examine the role of oxygen bonding in Pt/CoFeB/MgO, and find that as the oxygen bonding level increases, a full sign reversal of SOTs occurs, which goes beyond the bulk spin Hall effect and evidences a new SOT mechanism. We also report the angular and temperature dependence of current induced spin-orbit effective fields from Ta/CoFeB/MgO nanowires. In addition, we show current induced spin-orbit torques from multilayer nanowires such as Co/Pd and Co/Ni as well as oxide heterostructures such as LAO/STO. Finally, we discuss the role of the Dzyaloshinskii-Moriya interaction for spin orbit torque switching and SOTs in a topological insulator Bi_2Se_3, which may be able to generate strong spin currents to switch the magnetization in SOT MRAM.







W9

Spin Current Generators

Eiji Saitoh[1,2,3,4]

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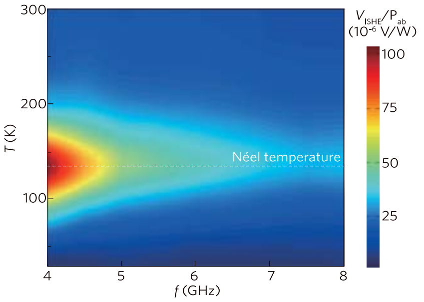
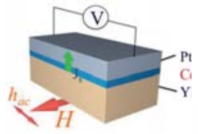
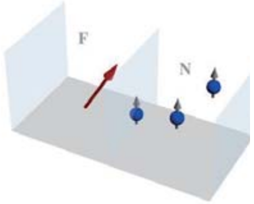
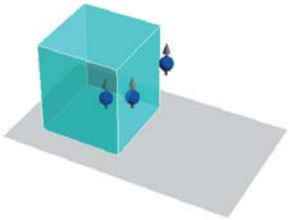
I will give an introduction to the concept and various fascinating phenomena of spin-current science. Generation and utilization of spin current, a flow of spin angular momentum of electrons in condensed matter, are the key challenge of today's nano magnetism and spintronics. The discovery of the inverse spin Hall effect has allowed researchers to detect and utilize spin current directly, and, since then, many spin-current driven effects have been discovered, including spin Seebeck effects, light-spin conversion, sound-spin conversion, and motion-spin conversion. Spin Seebeck effects refer to spin-current generation from a temperature gradient, where spin's non reciprocity allows it to rectify thermal fluctuation into unidirectional spin current; spins, working as a natural rectifier in magnets, may thus provide a versatile mechanism of energy conversion in condensed matter. Spin micro mechanics, one of more recent topics, will also be covered.









W10

Spin Hall effect in epitaxial Cu(111) films with δ-doped Bi measured by H-Pattern

Xiaofeng Jin

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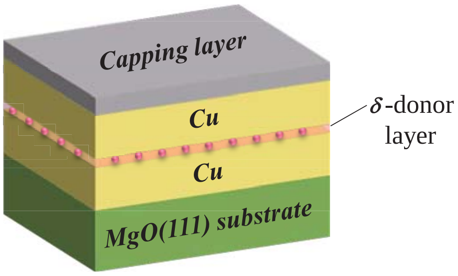
The spin Hall effect (SHE) has recently attracted a great deal of attention in the spintronics community because of its potential applications utilizing spin current. Various methods have been developed to produce and detect the SHE, and search for materials with larger spin Hall angle. Despite these efforts, however, reliable and accurate determination of spin Hall angle remains challenging. All the established methods including (1) non-local spin injection, (2) spin transfer torque, (3) spin pumping, and (4) spin Seebeck effect, contain a bilayer structure in which the spin current is generated in one material and the converted charge current is detected in the other, thereby inevitably would involve complications from the shunting and interface effects. Based on our understanding of the microscopic mechanisms of the anomalous Hall effect and the intricate properties of ultrathin Bi films [1-3], we have developed a new method to measure quantities inherent to the spin Hall effect. We first epitaxially grow Cu(111) films including the δ-doped Bi inside by MBE on clean and ordered MgO(111), then cap it with MgO *in situ* to prevent oxidation. We then patterned the blank film into H-patterns by e-beam lithography for the nonlocal spin Hall effect measurement in a single material without the complications of other materials and interfaces. Using the H-patterns, we obtain a giant spin Hall angle of 12% in this Cu(111) with δ-doped Bi. The present method is much simpler, with far less complications, and hence more reliable, than those listed



T1

Meta-stable skyrmions in chiral magnets

Y. Tokura[1,2]

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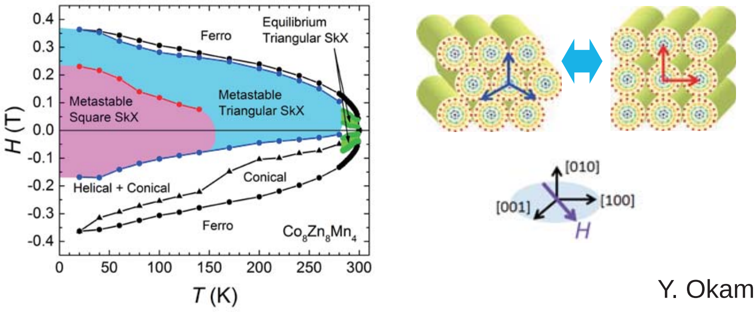
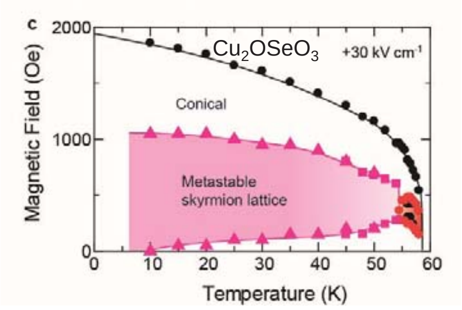
Magnetic skyrmions, as characterized and protected by topological charge, are generically observed in cubic chiral-lattice magnets, such as MnSi/FeGe type B20 compounds, Cu2OSeO3, and b-Mn type Co-Zn-Mn alloys. The thermodynamical skyrmion-lattices, mostly of hexagonal form, can be found in a narrow window of the temperature vs. magnetic-field space close to the paramagnetic phase bounday, as conventionally termed "A-phase". However, the rapid cooling and/or intentionally quenched-disorder-introducing procedures can greatly enhance the meta-stable skyrmion region down to much lower or zero temperature, as expected from the topological protection of the skyrmion forms.

The meta-stability of the skyrmion-lattice forms as generated by external stimuli (heat, stress, electric field and current) as well as the transition of the meta-stable skyrmion-lattice form is discussed together with versatile topological outcomes in electrodynamics, multiferroicity, and skyrmion dynamics in the above chiral-lattice magnets. These features may give important hints toward the realization of "skyrmionics".

K.Karube, J.S.White et al. Nat. Mater. (2016)





Y. Okamura, F. Kagawa et al. Nat. Commun. (2016)

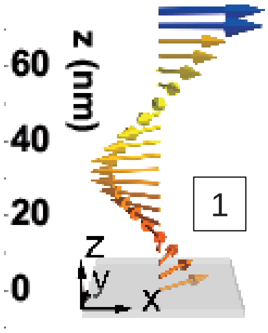
T2

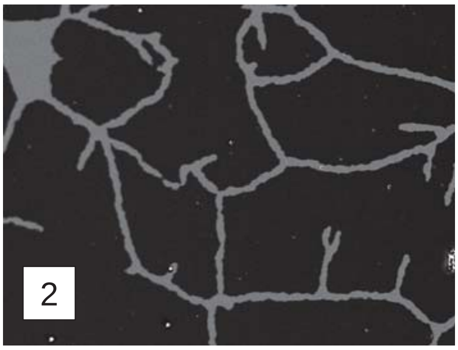
Chiral interactions in thin film magnets

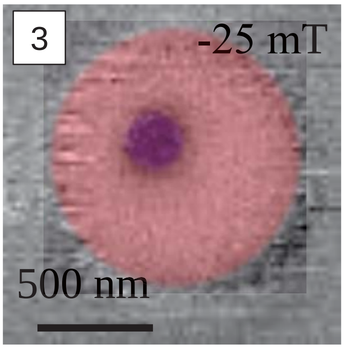
C. H. Marrows

School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, United Kingdom

The Dzyaloshinskii-Moriya interaction (DMI) arises where structural inversion symmetry is broken and favours chiral magnetic states. It has recently become a topic of intense interest due to its ability to stabilise spin textures with non-trivial topology, most notably skyrmions. We have grown epilayers of the helimagnetic metal FeGe that show interesting transport properties, can have their chiral states controlled by ferromagnetic capping layers [1], and show in inversion of the sign of the DMI on doping with Co. On the other hand, structural inversion asymmetry is also present at an interface, and ultrathin magnetic layers can also show DMI. This leads to homochiral domain walls that are topologically protected against mutual annihilation [2]. We have shown that the DMI of sputtered Pt/Co/Pt layers can be inverted by the insertion of an Ir overlayer, and that the DMI oscillates with electron count in the top layer in Pt/Co/$Pt_{1-x-y}Ir_xAu_y$ trilayers. Small skyrmion bubbles have been observed in {Pt/Co/Ir} × *N* multilayers by both Lorentz transmission electron microscopy (in sheet films) and scanning X-ray transmission microscopy (in patterned dots [3]).







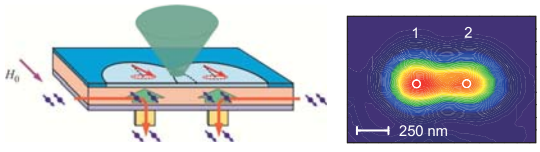
T3

Magnetization oscillations and waves driven by pure spin currents

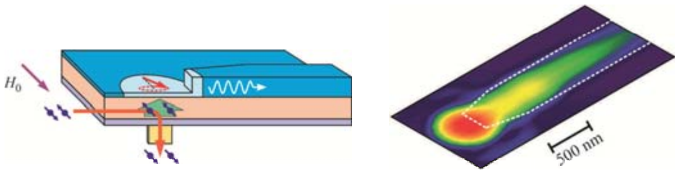
V. E. Demidov

Institute for Applied Physics and Center for Nanotechnology, University of Muenster,
Corrensstrasse 2-4, 48149 Muenster, Germany

Recent advances in the studies of pure spin currents have opened new horizons for the emerging technologies based on the electron's spin degree of freedom, such as spintronics and magnonics. The main advantage of pure spin current, as compared to the spin-polarized electric current, is the possibility to exert spin transfer torque on the magnetization in thin magnetic films without electrical current flow through the material. In addition to minimizing Joule heating and electromigration effects, this characteristic enables the implementation of spin torque devices based on the low-loss insulating magnetic materials, and offers an unprecedented geometric flexibility. Here I review our recent experimental achievements in investigations of magnetization oscillations excited by pure spin currents in different magnetic nanosystems. I discuss the spectral properties of spin-current nano-oscillators, and relate them to the spatial characteristics of the excited dynamic magnetic modes determined by the spatially-resolved measurements. I also show that these systems support locking of the oscillations to external microwave signals, as well as their mutual synchronization, and can be used as efficient nanoscale sources of propagating spin waves.



Mutually coupled spin-current nano-oscillators



Excitation of propagating spin waves by pure spin currents

T4

Transport, magnetic and optical properties induced by emergent spin electromagnetic fields in metallic ferromagnets

Gen Tatara[1], T. Kikuchi[1], H. Kawaguchi[1,2], A. Takeuchi[3]
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Recent topics related to electron transport in the presence of magnetization textures in ferromagnetic metals[1] are discussed focusing on the roles of an emergent effective electromagnetic field (spin gauge field) that couples to electron spin[2]. The concept of spin electromagnetic field was presented in the context of a voltage generated by a canting of a driven domain wall[3], and mathematically rigorous formulation in the adiabatic limit was given by Volovik[4]. The idea of effective gauge field can be extended to the cases with spin relaxation[5], Rashba interaction[6,7]. It was recently shown that an antisymmetric exchange interaction (Dzyaloshinskii--Moriya interaction) is caused by the spin gauge field in the presence of intrinsic spin current [8]. Moreover, optical properties of Rashba conductors such as directional dichroism when a magnetic field is applied turned out to be described by the effective gauge field generated by the Rashba interaction [9].

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T5

FEMTOSECOND OPTICAL CONTROL OF MAGNETISM: *TOWARDS THz SPINTRONICS*

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The 21st century digital economy and technology is presently facing fundamental scaling limits (heating and the superparamagnetic limit) as well as societal challenges: the move to mobile devices and the increasing demand of cloud storage leads to an enormous increase in energy consumption. These developments require new strategies and paradigm shifts, such as spin-based technologies. Also, the demonstration of all-optical control and even switching of magnetization by femtosecond laser pulses has lead to unprecedently fast, but also very energy efficient, writing and reading of magnetic information. A novel advancement would be to combine these two breakthroughs and develop ultrafast spintronics using femtosecond laser pulses.

Here we report about the anomalous Hall effect in 4f-3d ferrimagnetic alloys at THz frequencies. The strength of the observed THz spin-dependent transport phenomenon is in good agreement with expectations based on electronic transport measurements. Employing this effect we succeeded to reveal ultrafast dynamics of the anomalous Hall effect which accompanies the sub-100 ps magnetization reversal in a GdFeCo alloy. Employing terahertz (10^{12} Hz) emission spectroscopy and exploiting spin-orbit interaction, we also demonstrate optical generation of electric photocurrents in metallic ferromagnetic heterostructures at the femtosecond timescale. These experiments demonstrate the ability to control THz currents in spintronic devices magnetically and ultrafast and open up new opportunities for realizing spintronics in the unprecedented terahertz regime and provide new insights in all-optical control of magnetism.

T6

Spin-orbitronic materials and devices

Timothy Phung[1]

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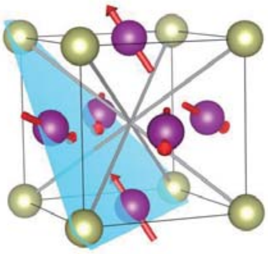
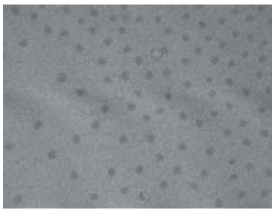
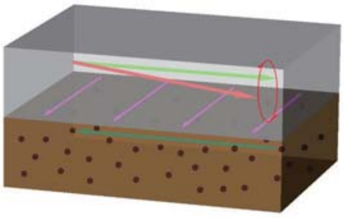
Spin orbit torques are generated by the conversion of charge to spin currents, and are of considerable interest for several proposed memory and logic devices. In this talk, I will discuss recent work done in our group on large spin orbit torques we have discovered in the triangular anti-ferromagnetic $IrMn_3$ system and the W(O) system. We find that remarkably that the spin orbit torque in $IrMn_3$ system is facet dependent, and furthermore stems from the chiral antiferromagnetic structure of $IrMn_3$. In the W(O) system, we find that whilst the incorporation of oxygen into the tungsten leads to significant changes in its microstructure and electrical resistivity, the large spin Hall angles measured are found to be remarkably insensitive to the oxygen doping level. This invariance of the spin Hall angle with the bulk W(O) properties for higher oxygen concentrations suggests that the spin orbit torques in this system may actually be partly interfacial in origin, and induced by scattering of the electrons at the W(O) | CoFeB interface rather than from the interior of the W(O) film. Lastly, the implications of these spin orbit torques found in these materials systems on technological applications will be discussed.







T7

Current-induced magnetizations in chiral systems

Shuichi Murakami[1,2]

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There are various mechanisms for conversions between charge current and spin, such as spin Hall effect and Rashba-Edelstein effect. The effects are driven by the spin-orbit coupling in the solids, and its magnitude is determined by the material itself and the nanostructure such as interfaces and quantum wells. In the present talk we give a totally different mechanism of conversion between charge current and magnetization. In analogy with the classical solenoid (Fig. 1), in a metallic crystal with chiral structure such as tellurium (Fig. 2) , a charge current along the chiral axis is shown to induce an orbital magnetization parallel to the current [1]. Such a chiral material also exhibits unconventional spin structure, such as hedgehog-type (Fig. 3) [2], which might be also useful for applications for spin-conversion phenomena.

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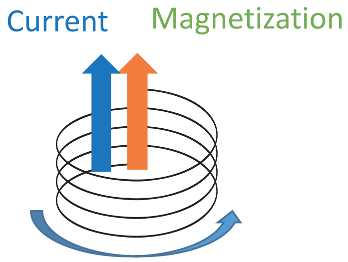

Fig. 1. Schematic picture of a solenoid

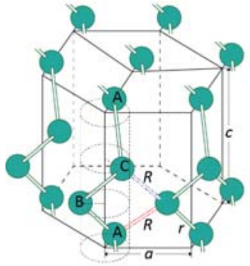

Fig. 2. Crystal structure of Te

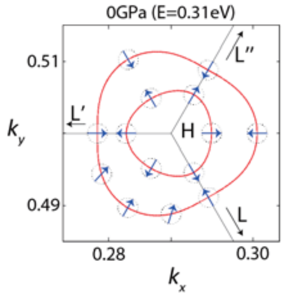

Fig. 3 Spin texture of the conduction bands in Te

Antiferromagnetic Spin-Orbitronics

T8

Jairo Sinova[1]

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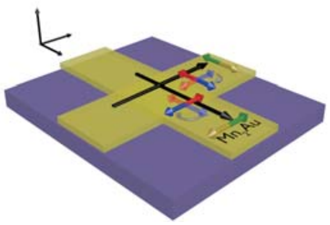
Understanding the origin and properties of the different phases of materials and how to control them is at the heart of condensed matter physics and physics in general. One of the grand challenges of the field is to control spin-dependent properties without using magnetic fields. To do so, one must resort to the relativistic nature of electrons, which arises directly from its particle-antiparticle description that gives its spin. In the relatively slow world of solids this leads to the spin-orbit coupling (SOC) that connects the spin and charge of the electron. We have learned how to exploit the relativistic SOC to create new paradigms of spin control in complex materials and discover new unexpected connections between seemingly disparate ideas as topology, materials science, high energy physics, ferromagnetism, thermoelectricity, and current-induced magnetization manipulation. I will broadly describe joint theoretical and experimental efforts on exploiting these ideas in antiferromagnets, whose properties have certain advantages over conventional ferromagnetic systems. I will also show in some detail how insights on the spin Hall effect have yielded novel ways to manipulate magnetization using relativistic torques, and how to extend these ideas to a new a phase of spintronics by exploiting anti-ferromagnetic materials in an active way to the point that we can even control their topological phases.



Spin injection into two-dimensional electron systems

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Spin injection, spin manipulation, and spin detection in two-dimensional electron systems (2DES) is at the heart of spin transistor concepts. Nonetheless, spin-injection/detection in 2DES remained so far largely unexamined. Here, I discuss our recent experiments on all electrical spin injection and detection in 2DES using (Ga,Mn)As/GaAs Esaki diode junctions (see Fig.1) as spin sensitive contacts. In my talk I will focus on the following experimental issues: (i) an observed enhancement of the spin injection efficiency far beyond 100% indicates the failure of the conventional drift-diffusion model and suggests that ballistic effects come into play. (ii) The strong bias dependence of the spin relaxation time, extracted from Hanle measurements, indicates a sizeable, spin current induced dynamic nuclear polarization (DNP) in the vicinity of the 2DES channel which causes a significant narrowing of the Hanle signal. (iii) Two-terminal measurement on an injector-2DEG-detector spin valve structure show an unexpectedly large DR/R value of several ten percent.

*) *Work done in collaboration with Mariusz Ciorga, Martin Oltscher, Thomas Kuczmik, Franz Eberle, Andreas Bayer, Martin Utz, Dieter Schuh, and Dominique Bougeard.*

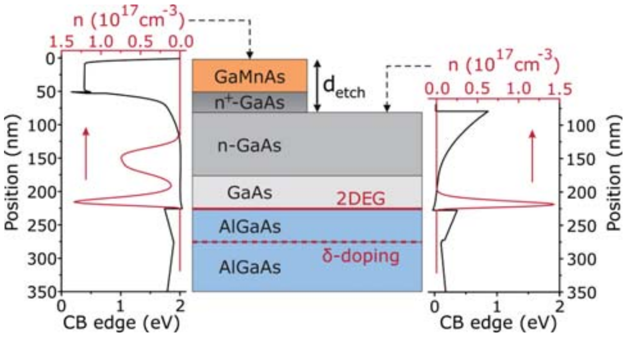

Fig. 1. Layout of the heterojunctions used for spin-injection/detection. The profile of the conduction band and of the electron density n is shown with (left) and without (right) Esaki junction. Etching of the highly doped (Ga,Mn)As and n^+-GaAs layers depletes the bulk of electrons, thus enabling exclusive charge transport in the 2DES.

F1

Cavity-enhanced Raman spin flip emission from single and coupled quantum dots

S. G. Carter[1], T. M. Sweeney[2], P. M. Vora[2], M. Kim[3], C. S. Kim[1], B. C. Pursley[2], L. Yang[2], P. G. Brereton[4], E. R. Cleveland[1], S. E. Economou[5], T. L. Reinecke[1], A. S. Bracker[1], and D. Gammon[1]

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[2]NRC Research Associate at the Naval Research Laboratory, Washington, DC 20375, USA
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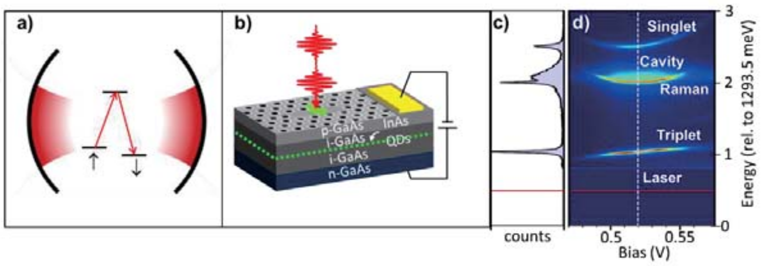
Quantum emitters coupled to nanophotonic cavities have been of great interest for enhancing the collection of photons, for nano-lasers, and as a quantum interface between photons and stationary qubits. The majority of this work has been with two-level systems coupled to a cavity. In this work we make use of three-level λ-type systems in which two lower energy spin states share a common excited state, with either or both transitions coupled to the cavity (see Fig. 1(a)). These systems are investigated using Raman spin flip emission, which provides a spin-photon interface as well as a source of indistinguishable photons. As illustrated in Fig. 1(b), we prepare this system by incorporating InAs quantum dots (QDs) within a suspended photonic crystal membrane, with the ability to electrically control the charge of the QDs using an n-i-p diode. For single QDs charged with a single electron, we have demonstrated that Raman emission is narrower than the optical transition linewidth, that it can be tuned over at least 125 GHz, and that the emission is correlated with the spin state [1]. Experiments with two coupled QDs in a photonic crystal cavity have taken this approach to a new limit in which the singlet-triplet spin splitting is much larger than the cavity linewidth, allowing the cavity to enhance only one leg of the Lambda system, as displayed in Fig. 1(c,d) [2].

[1] T. M. Sweeney et al., Nature Photon. **8**, 442-447 (2014).
[2] P. M. Vora et al., Nat. Commun. **6**, 1-9 (2015).



F2

Photon-electron spin Poincaré interface using gate-defined quantum dots

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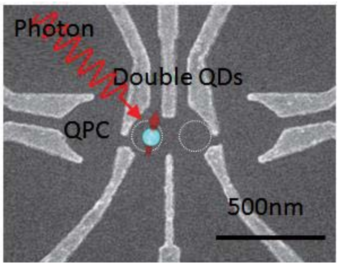
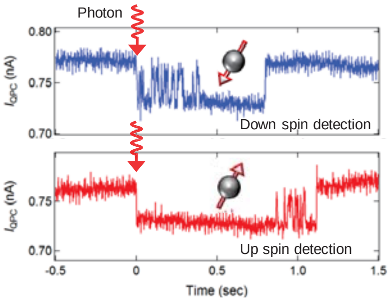
Quantum state conversion from a photon polarization state described by a Poincaré sphere to an electron spin state described by a Bloch sphere provides an elemental technology indispensable for long distance quantum communication. We propose a device which enables us to convert coherently between photon polarization states and electron spin states as Poincaré interface. The scheme for trapping and detecting the single electrons generated by a single photon has been developed using a gate-defined quantum dot (QD) [1,2,3]. Moreover, angular momentum conversion from single photons to single electron spins in gate-defined double QDs has been achieved [4]. At present, we aim to realize quantum state conversion and efficient coupling between photons and electron spins in QDs for applications to quantum communication. We discuss the detection of single photoelectron spins generated by single photons and angular momentum conversion using a gate-defined QD and recent progresses to enhance the coupling between photons and electron spins in QDs.





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[4] T. Fujita et al., arXiv1504.03696

F3

Spin wave storage of light using rare-earth doped crystals

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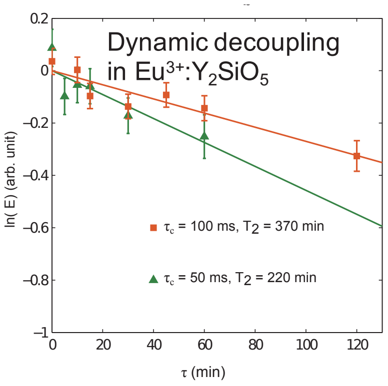
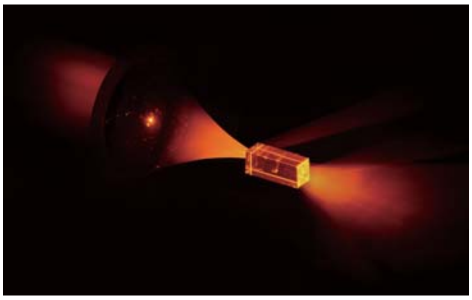
Quantum memories for light will be key elements in future quantum communication networks. Rare-earth optical centres in crystals, with their long optical and spin coherence times, are uniquely suited for this application. Quantum information stored on the rare-earth centres can be easily transferred between electronic states and nuclear spin states, enabling the long-term storage required for long range communications. Further, the high spatial density possible with these centres can be utilized to realise the large data storage densities required for high speed communications.

The talk will cover techniques to extend the spin storage time, demonstration of the generation and storage of quantum entanglement in a rare-earth based spin-wave memory and recent progress in developing a spin-wave quantum memory operating in the 1550 nm communication band.





F4

Quantum magnonics in a ferromagnetic sphere

Yasunobu Nakamura[1,2]

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A 1-mmϕ sphere of yttrium iron garnet, a well-known ferro(ferri)magnetic insulator, contains ~10^{19} net electron spins aligned in one direction. The spins, rigidly ordered by the exchange interaction and also interacting via the dipole forces, support collective excitations in the magnetostatic modes [1]. We control the quantum state of one of such modes coherently at the single magnon level by using a superconducting qubit. The qubit and the Kittel mode, the magnetostatic mode with spatially uniform spin precessions in the sphere, are strongly coupled via a microwave cavity mode, which results in the magnon-induced vacuum Rabi splitting of the qubit as well as Rabi oscillations between the qubit and the single-magnon excitation at resonance [2]. When the qubit and the Kittle mode are detuned, the dispersive interaction allows us to determine the magnon number distributions through the qubit spectroscopy [3]. These experiments demonstrate the potential of magnons as a quantum information carrier in the microwave domain. Coherent interaction of magnons with infrared light is also investigated [4,5].

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F5

Parity–Time (PT)-symmetry in optics and the quantum spin Hall effect of light.

Franco Nori [1,2]

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By analyzing fundamental spin properties of Maxwell waves, we show [1] that free-space light exhibits an intrinsic quantum spin Hall effect — surface modes with strong spin-momentum locking. These modes are evanescent waves that form, for example, surface plasmon-polaritons at vacuum-metal interfaces. Our findings illuminate the unusual transverse spin in evanescent waves [2] and explain recent experiments that have demonstrated the transverse spin-direction locking in the excitation of surface optical modes.

Optical systems combining balanced loss and gain provide a unique platform to implement classical analogues of quantum systems described by non-Hermitian parity–time (PT)-symmetric Hamiltonians. Such systems can be used to create synthetic materials with properties that cannot be attained in materials having only loss or only gain. We report PT-symmetry breaking in coupled optical resonators and observe non-reciprocity in the PT-symmetry-breaking phase due to strong field localization, which significantly enhances nonlinearity. Our results could lead to a new generation of synthetic optical systems enabling on-chip manipulation and control of light propagation.

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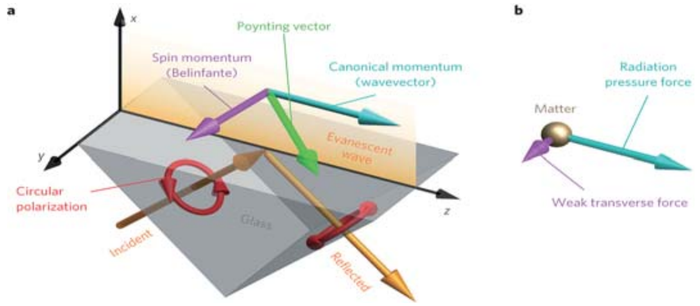

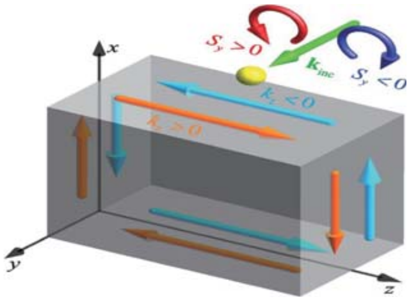

F6

Magnetoresistance of quantum dots with ferromagnetic split-gates

C. Schönenberger, A. Baumgartner, G. Fabian and J. Samm

Department of Physics, University of Basel, Basel, Switzerland
Swiss Nanoscience Institute at the University of Basel, Switzerland

We introduce a novel approach to control electron spins on single and multiple quantum dots (QDs). For this purpose we fabricate ferromagnetic split-gates near a semiconducting InAs nanowire (NW), consisting of two long ferromagnetic strips with characteristic external magnetic fields (switching fields), at which the magnetization is reversed. These ferromagnetic side-gates (FSGs) have a controlled and spatially confined magnetic field and can also be used as local electrical gates. The angle between the FSGs and the NW also allows one to tailor the stray field pattern along the NW.

We present proof-of-principle magneto-resistance (MR) experiments in which we find QD-state dependent MR and hysteretic MR switching. For most QD resonances, the conductance shows a sharp change at the FSG switching fields (here ~35 mT), consistent with a stray field of about 50 mT. Depending on the gate-tunable QD state, the MR switching can be positive or negative, with resistance changes of up to 50%.

More intriguingly, we also find more complex NW MR, similar to the tunneling magnetoresistance (TMR) between two ferromagnets, though the NW is *not in direct contact with a ferromagnet.* We explain all these experimental findings using intuitive single and double QD models and show, for example, that the TMR-like characteristics stems from a FSG-induced transition between singlet and triplet double QD states.

FSGs are not only relevant for prospective spin-transport, but can also be used for conceptually new experiments: a single FSG might create non-collinear spin projection axes on the two QDs of a Cooper pair splitter [1] to perform a test of Bell's inequality. Or a series of FSGs can induce a spatially periodic magnetic field that can be seen as a tunable synthetic spin-orbit interaction, possibly resulting in Fractional Fermions [2], i.e. quasi-particles related to Majorana Fermions.

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[2] Klinovaja *et al., Phys. Rev. Lett.* ***109, 236801 (2012)***

F7

Majorana zero modes in Coulomb islands

Charles M. Marcus
Villum Kahn Rasmussen Professor, Niels Bohr Institute, University of Copenhagen
Director of the Center for Quantum Devices, Niels Bohr Institute

Isolated hybrid super-conductor semiconductor nanowires are a novel platform for studying Majorana physics. This talk describes recent experiments in opened and isolated nanowires, revealing signatures of Majorana modes. Agreement as well as disagreement with theory is found and will be discussed. Research supported by Microsoft and the Danish National Research Foundation.

F8

Signatures of 4π periodicity in the dynamics of HgTe Josephson junctions

R.S. Deacon[1], J. Wiedenmann[2], E. Bocquillon[2],
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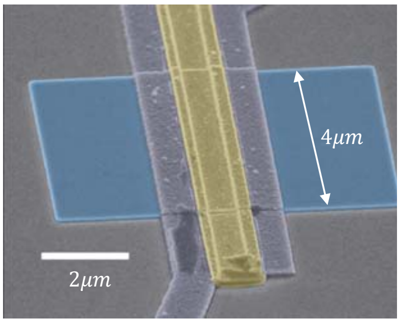
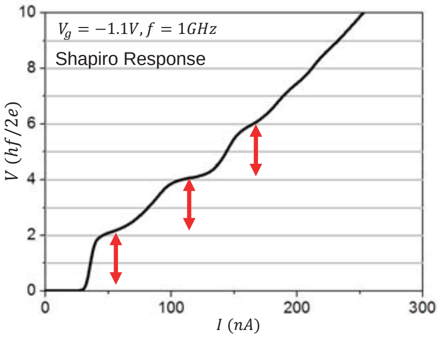
[4]Department of Applied Physics, University of Tokyo, Bunkyo, Tokyo, Japan.

We study Josephson junctions with weak links of the HgTe Quantum spin hall insulator. The signatures of a 4π-periodic current phase relation due to the topologically protected gapless Majorana modes of the junction are revealed in measurements of the ac-Josephson effect. We present two methods of detecting this mode [1-3]. First the Shapiro steps are measured in the presence of an rf-drive. We observe a doubling of the Shapiro step voltage indicating a fractional ac Josephson effect. In the second method we detect the Josephson emission from a voltage biased junction and detect a peak in the emission power at half the Josephson frequency of the junction again indicating the gapless mode.





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[3] R.S. Deacon, J. Wiedenmann, E. Bocquillon *et al.*, arXiv:1603.09611.

F9

From Majorana- to Para-Fermions in Nanowires and Helical Edge States

Daniel Loss

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

I will present recent results on exotic quantum bound states which can emerge in one and two dimensions in the presence of spin orbit interaction or spatially periodic magnetic fields [1], in RKKY systems forming intrinsic spin helices [2], with and without superconductivity. I will present candidate materials such as semiconducting Rashba nanowires, ^{13}C nanotubes [3], and atomic magnetic chains [2], and helical edge states of 2D topological insulators.
Examples of such bound states are fractionally charged fermions [4], Majorana fermions, and, in particular, parafermions [5] whose braid statistics enables entanglement and CNOT gates (in contrast to Majoranas) [6].

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F10

Electrically driven hole-spin resonance in silicon devices

S. De Franceschi[1,3],R. Maurand[1,3], D. Kotekar-Patil[1,3], L. Hutin[2,3],
L. Bourdet[1,3], H. Bohuslavskyi[1,2,3], A. Corna[1,3], S. Barraud[2,3], X. Jehl[1,3],
Y.-M. Niquet[1,3], M. Sanquer[1,3], and M. Vinet[2,3]

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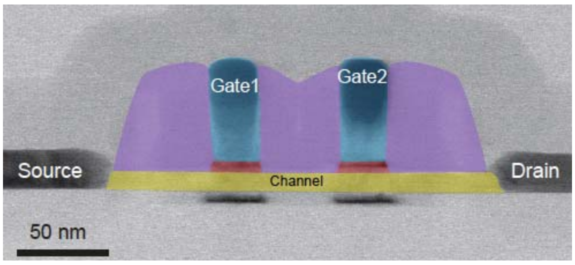
[3]University Grenoble Alpes, F-38000 Grenoble, France

We present recent experiments on hole-spin coherent manipulation in p-type silicon devices based on silicon-on-insulator field-effect transistor technology. The devices consist of a nominally undoped silicon nanowire channel connecting boron-implanted contact regions. Two parallel top gates are wrapped around three facets of the channel. A cross-sectional TEM view is shown in panel a). We show that a hole-spin confined under one of the gates can be efficiently manipulated by means of a microwave excitation applied to the gate itself. Rabi oscillations are shown in panel b). The hole spin state is read out and reinitialized through a Pauli blockade mechanism relying on hole current transport across the device. Coherent spin rotation frequencies reach 85 MHz at the highest microwave power applied (panel c)). We investigate the mechanism behind the observed electrically-driven spin resonance by studying its magnetic-field angular dependence.

a)



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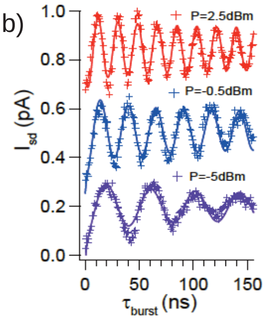
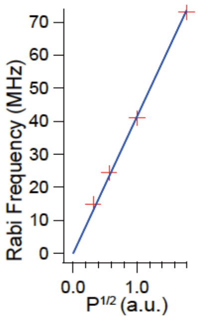


c)



S1

Coherent long-distance displacement of individual electrons

Tristan Meunier[1, 2]
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[2]*CNRS, Inst NEEL, F-38042 Grenoble, France*

Controlling semiconductor nanocircuits at the single electron spin level is a possible route for large-scale quantum information processing. In laterally-defined quantum dots, all the required quantum operations on individual electron spins such as single shot detection, one- and two-qubit gates have been demonstrated both in GaAs and in Si. To interconnect different nodes of a spin-based quantum processors, one of the options is to be able to displace individual electrons within semiconductor nanostructures in keeping the spin coherence.

We will discuss several strategies to displace individual electrons within AlGaAs heterostructures and their experimental implementations. We will demonstrate how the charge, the spin and the coherence of individual electrons can be preserved along the electron displacement. Finally, we will discuss the different mechanisms that are observed to limit the length over which classical and quantum information stored in individual electrons can be transferred.

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[2] Benoît Bertrand, Hanno Flentje, Shintaro Takada, Michihisa Yamamoto, Seigo Tarucha, Arne Ludwig, Andreas D. Wieck, Christopher Bäuerle and Tristan Meunier, *Phys Rev Lett* ***115****, 096801 (2015)*
[3] Benoit Bertrand, Sylvain Hermelin, Shintaro Takada, Michihisa Yamamoto, Seigo Tarucha, Arne Ludwig, Andreas D. Wieck, Christopher Bäuerle and Tristan Meunier *Nature Nanotechnology* ***11****, 672 (2016)*

S2

Distance-independent Dephasing of Phase-controlled Spin Entanglement

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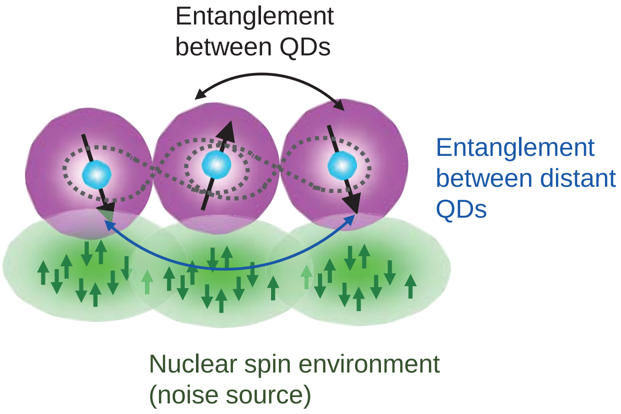
Entanglement is one of the most important features of quantum mechanics and can bring about exotic electronic properties of solid-state systems such as superconductivity and Kondo effect. To control the individual entangled electron pairs is a principal technology of quantum information. Quantum dots (QDs) can provide a useful tool to generate and detect the entangled spin pairs and in addition study the dephasing dynamics. The spin entanglement can be controlled using exchange interaction between two-spin states in two dots: |↑>|↓> and |↓>|↑> or Zeeman energy difference between two dots. The former is influenced by electrical noise because the inter-dot tunnel coupling is usually formed by an electrostatic potential. On the other hand the latter is influenced by magnetic noise, and therefore the dephasing can be independent of distance between spins. This is not the case for the exchange-controlled entangled state.

We use a tripled QD to prepare both types of spin entanglement between the adjacent and distant dots and demonstrate that the dephasing of the phase-controlled entangled state is independent of inter-dot distance. In addition we study environment noise to influence the spin dephasing in GaAs QDs and Si/SiGe QDs and discuss how to suppress the dephasing.



S3

Decoupling and decoherence for spin-resonator state transfer

W. A. Coish[1,2]

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Microwave-frequency superconducting resonators are ideally suited to perform dispersive qubit readout, to mediate two-qubit gates, and to shuttle states between distant quantum systems. A single electron spin in a double quantum dot exposed to a spatially inhomogeneous magnetic field can couple to such a resonator through an artificial spin-orbit coupling. I will discuss our theoretical analysis of a device geometry [1] that can be used to optimize this coupling and new strategies to suppress unwanted additional decoherence sources introduced by the magnetic-field gradient. In addition, I will present and characterize a novel dynamical decoupling protocol [2] that minimizes the influence of inhomogeneous broadening due to hyperfine coupling to nuclear spins or charge noise, while inhibiting "heating" of the resonator.

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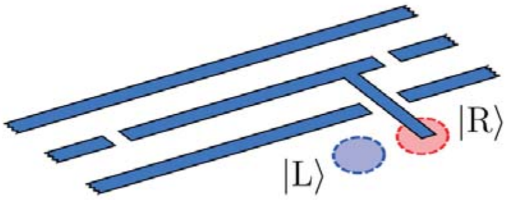
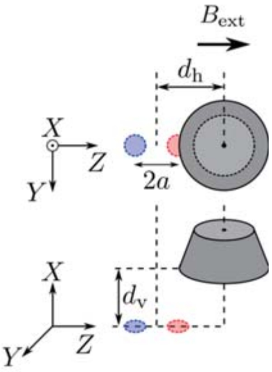
[2] F. Beaudoin, A. Blais, W. A. Coish, arXiv:1602.05090





S4

Interaction between electron and nuclear spins in GaAs and InSb quantum systems

Y. Hirayama[1,2,3]

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[2]*CSRN, Tohoku University, Sendai, Miyagi 980-8578, Japan*

Although nuclear spins become a source of decoherence in semiconductor quantum systems, they provide us a versatile tool to study electron spin physics in low-dimensional systems. They also provide a good stage for a study of many-body spin physics.

In this presentation, I will discuss two-dimensional physics clarified by nuclear-based measurements. They include spin physics of Landau-levels detected by Knight-shift measurements and magnetic-resonance-imaging (MRI) of quantum Hall breakdown. Most of these measurements are relied on dynamic nuclear polarization and highly-sensitive resistive-detection of nuclear polarization.

Such nuclear-based measurements can be applied to InSb quantum systems, where large effective g-factor enables us to use $\nu=2$ quantum Hall ferromagnet to induce and detect nuclear polarization. Fundamental phenomena of resistively-detected nuclear resonance in quantum Hall ferromagnet has been demonstrated by using InSb systems.

The nuclear-based characterization can be extended to a low-dimensional system, such as one-dimensional point contact.

S5

Quantum logic in silicon

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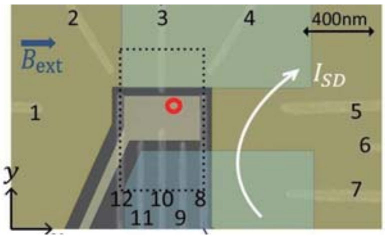
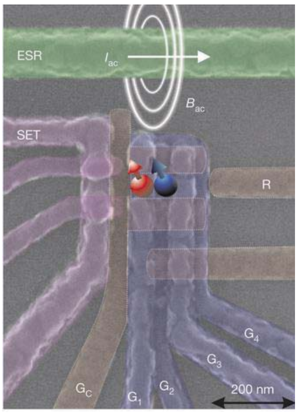
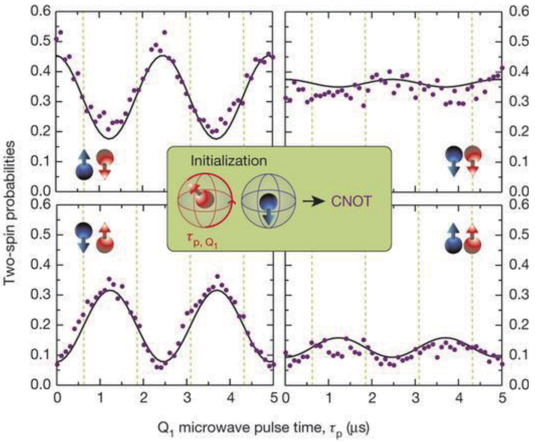
Electron spins in silicon quantum dots are one of the remaining few candidates for quantum information. We focus on single spin qubits, defined in Si/SiGe and Si-MOS quantum dots, controlled by on-chip microwave lines or nearby nanomagnets. Coherence times can be up to 28ms and single-qubit gate fidelities are already beyond 99%. Two-qubit gates based on the exchange-interaction have been achieved in both platforms. I will discuss and compare two-qubit CNOT operations implemented via controlled rotations or controlled phase. QuTech recently started an active collaboration with Intel, jointly developing an industrial road towards large-scale quantum computation. I will present our recent activities in the context of scaling up the number of qubits.







Left: SiGe qubit structure with nanomagnet for EDSR
Middle: Si-MOS qubit structure with stripline for ESR
Right: Two-qubit readout after CNOT operation

S6

Stable ‘Molecular’ State of Photons and Artificial Atom

K. Semba

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We have discovered qualitatively new states of a superconducting artificial atom dressed with virtual photons [1]. By carefully designing a superconducting persistent-current qubit interacting with an LC harmonic oscillator that has a large zero-point fluctuation via a large shared Josephson inductance (Fig. 1), we found the new ground state as predicted theoretically [2] (Fig. 2). Taking advantage of the macroscopic quantum system, we could realize circuits with coupling energy larger than both the photon energy and the qubit energy. This situation is sometimes called ‘deep strong coupling’. In addition, we have observed that the transitions between energy levels are governed by selection rules stemming from the symmetry of the entangled energy eigenstates, including the ground state. This result provides a new platform to investigate the interaction between light and matter at a fundamental level, helps understand quantum phase transitions and provides a route to applications of non-classical light such as Schrödinger cat states.

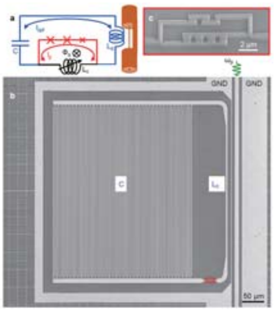

Figure 1 Superconducting qubit–oscillator circuit.

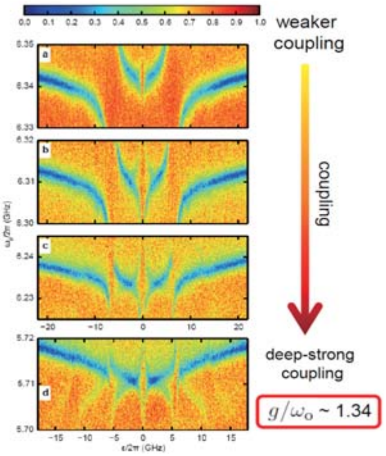

Figure 2 Transmission spectra of the circuit

References

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Acknowledgements

This work was supported in part by JSPS KAKENHI(S) Grant Number JP25220601.

S7

Cavity quantum electrodynamics with carbon nanotubes

T. Kontos

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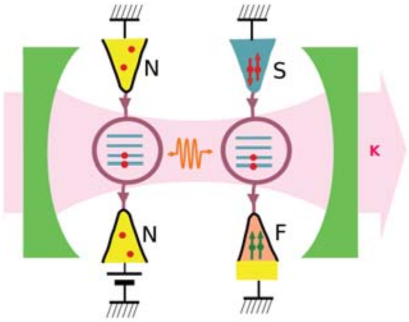
CNRS, Université Pierre et Marie Curie-Sorbonne Universités,
Université Paris Diderot-Sorbonne Paris Cité, 24 rue Lhomond, F-75231 Paris Cedex 05, France

Cavity quantum electrodynamics techniques have turned out to be instrumental to probe or manipulate the electronic states of nanoscale circuits. Recently, cavity QED architectures have been extended to quantum dot circuits. These circuits are appealing since other degrees of freedom than the traditional ones (e.g. those of superconducting circuits) can be investigated. I will show how one can use carbon nanotube based quantum dots in that context. In particular, I will focus on how to engineer a strong electron-photon interaction by dressing an electronic transition with coherent injection of Cooper pairs.

Quantum dots also exhibit a wide variety of many body phenomena. The cQED architecture could also be instrumental for understanding them. One of the most paradigmatic phenomenon is the Kondo effect which is at the heart of many electron correlation effects. I will show that a cQED architecture has allowed us to observe the decoupling of spin and charge excitations in a Kondo system.



S8

Topological superconducting devices made from semiconductor nanostructures

H. Q. Xu[1,2]

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Peking University, Beijing 100871, China
[2]Division of Solid State Physics, Lund University, Box 118, S-22100 Lund, Sweden

Topological superconducting systems are intriguing physical systems in which an elusive class of fermions—Majorana fermions, whose antiparticles are themselves, can be created and can be used to construct topological qubits for quantum computing. Here I report the realization and quantum transport measurements of topological superconducting quantum devices made from semiconductor nanostructures. The talk will be divided into two parts. In the first part, our study of topological superconducting quantum devices made from InSb nanowires and s-wave Sb superconductors will be reported and discussed. In each of the devices, a quantum dot is fabricated between two topological superconducting InSb nanowires. Both a zero conductance peak arising from Majorana fermions located at two outer ends of the two nanowires and two side conductance peaks arising from the interaction between the two inner Majorana fermions in the vicinity of the quantum dot are observed. In the second part of my talk, our very recent work on topological quantum devices made from InSb nanoplates and s-wave Al superconductors will be reported and discussed. Here, I will show that it is possible to turn the semiconductor InSb nanoplates into two-dimensional topological insulators. As a consequence, in a Josephson junction made from an InSb nanoplate in the topological phase, the measured supercurrent as a function of magnetic field shows an interference pattern which is in accordance with the transport through the edges of the nanoplate. Finally, future directions of the field and perspective applications of topological superconducting quantum devices in the quantum information technology will be discussed.

S9

Control of odd-frequency s-wave Cooper pairs in double quantum dots

Y. Tanaka, Department of Applied Physics Nagoya University

Odd-frequency pairing is a Cooper pair, where pair amplitude (pair function) has a sign change after exchanging two times of electrons forming Cooper pair. Odd-frequency pairing ubiquitously exists in inhomogeneous superconducting systems[1]. Odd-frequency spin-triplet s-wave pairing produces long range proximity effect in ferromagnet junctions [2] and anomalous proximity effect in diffusive normal metal / spin-triplet p-wave superconductor junctions [3]. Odd-frequency pairing also becomes an important concept topological superconductivity [4] since Majorana fermion must accompany odd-frequency pairing [5]. In most cases, odd-frequency pairing has been discussed in spin-triplet superconductors.   Here, we propose an all-electrical experimental setup to detect and manipulate the amplitude of odd-frequency pairing in a double quantum dot [6]. The odd-frequency pair amplitude is induced from the breakdown of orbital symmetry when Cooper pairs are injected in the double dot with electrons in different dots. When the dot levels are aligned with the Fermi energy, i.e., on resonance, nonlocal Andreev processes are directly connected to the presence of odd-frequency pairing. Therefore, their amplitude can be manipulated by tuning the level positions. The detection of nonlocal Andreev processes by conductance measurements contributes a direct proof of the existence of the odd-frequency pair amplitude [6].

This work has been done by collaboration with P. Burset, Bo Lu, H. Ebisu and Y. Asano.

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[5]Y. Asano and Y. Tanaka, Phys. Rev. B 87, 104513 (2013).

[6]P. Burset, Bo Lu, H. Ebisu, Y. Asano, and Y.Tanaka, Phys. Rev. B 93, 201402 (2016).

Abstracts of Poster Session

①

Oct 13, 17:45-19:45

N-1

Spin-related phenomena detected by spin current

Yasuhiro Niimi[1]

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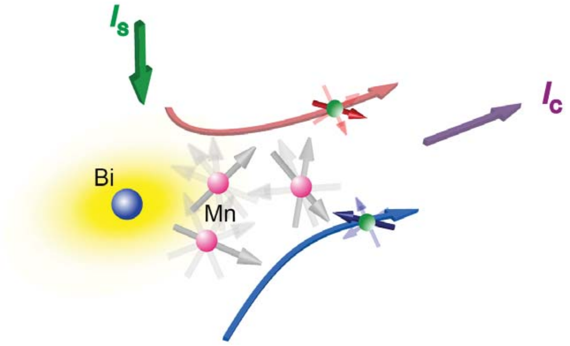
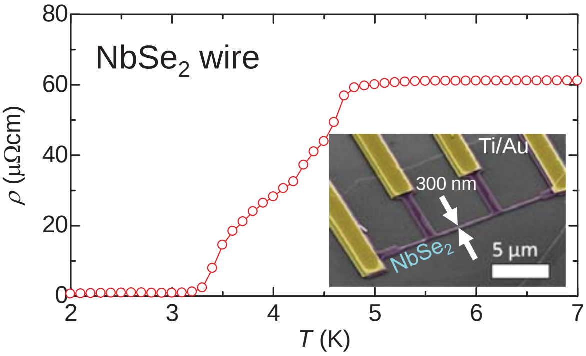
The generation and manipulation of spin current, flow of spin angular momentum, are at the heart of modern spintronics. The spin Hall effect (SHE) and its inverse (ISHE) are the most promising methods to enable the interconversion between charge and spin currents. In the research group, we aim to utilize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





N-2

detection of antiferromagnetic phase transition by spin current

Z. Qiu[1,2], D. Hou[1,2], K. Uchida[3,4], E. Saitoh[1,2,3,5]

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[2]Spin Quantum Rectification Project, ERATO, Japan Science and Technology Agency, Sendai 980-8577, Japan
[3]Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan
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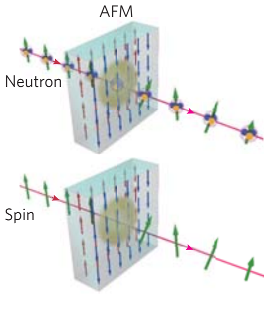
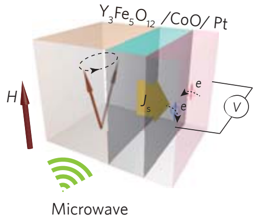
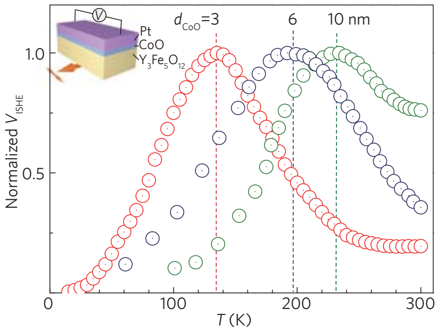
Spin fluctuation and transition have always been one of central topics of magnetism and condensed matter science. To probe them, the spin fluctuation is found transcribed onto scattering intensity in the neutron scattering process, which is represented by dynamical magnetic susceptibility and maximized at phase transitions. Importantly, a neutron carries spin without electric charge, and it can bring spin into a sample without being disturbed by electric energy, although large facilities such as a nuclear reactor is necessary. Here we show that spin pumping, frequently used in nanoscale spintronic devices, provides a desktop micro probe for spin transition; spin current is a flux of spin without an electric charge and its transport reflects spin excitation. We demonstrate detection of antiferromagnetic transition in ultra-thin CoO films via frequency dependent spin-current transmission measurements, which provides a versatile probe for phase transition in an electric manner in minute devices.







N-3

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

E. Sagasta[1,*] W. Yan[1,*] M. A. O. Ribeiro[1] Y. Niimi[2] L. E. Hueso[1,3] F. Casanova[1,3]

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[2]Department of Physics, Graduate School of Science, Osaka University, 1-1 Machikaneyama Toyonaka, Osaka 560-0043, Japan
[3]IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, Basque Country, Spain
[*] This authors contributed equally to this work

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

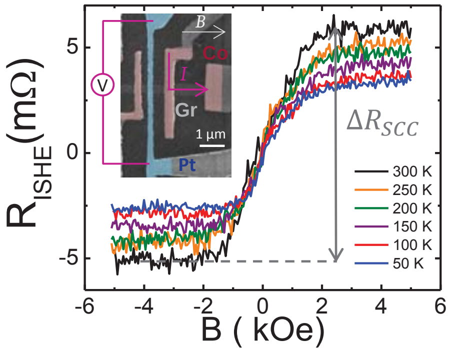


Fig. 1: ISHE resistance (V/I) as a function of the magnetic field *B* at different temperatures. Inset: SEM image of the Pt/graphene lateral nanodevice with the ISHE measurement configuration.

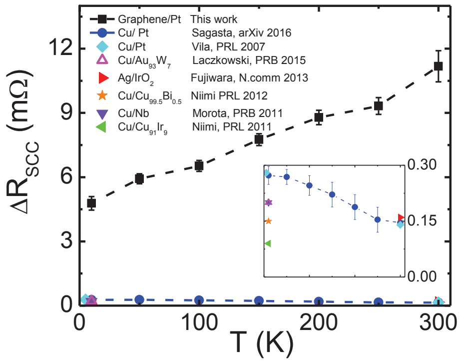


Fig. 2: Experimentally measured ΔR_{SCC} as a function of temperature for different spin Hall metals employing different spin channels. Inset: Zoom of the previous plot showing the data of the devices with metallic spin channels.

N-4

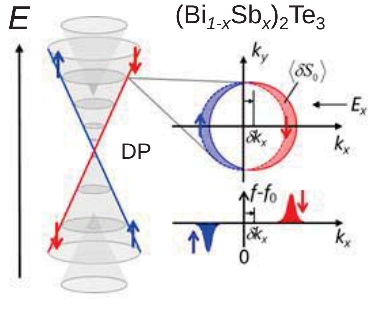
Observation of charge-to-spin current conversion by Dirac surface state of topological insulators

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

[1] RIKEN (CEMS), [2] University of Tokyo, [3] IMR, Tohoku University, [4] Kyushu Institute of Technology, [5] ISSP, University of Tokyo

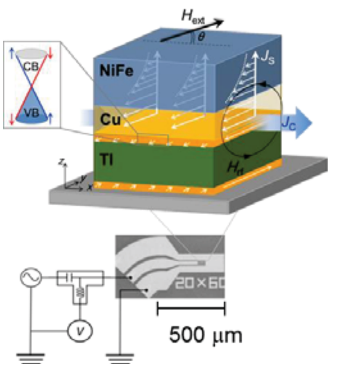
The spin-momentum locking in the surface state offers a possibility of a highly efficient charge-to-spin current (C-S) conversion compared with ordinary spin Hall effect in paramagnetic metals. By applying spectral analysis based on spin-torque FMR to topological insulator (TI) /non-magnetic metal/ferromagnetic-metal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

C-to-S conversion in surface state of TI



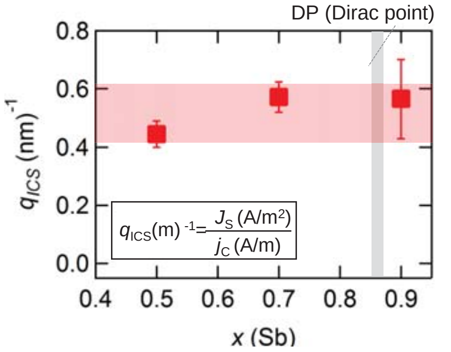
- Spin accumulation $<\delta S_0>$ due to Fermi circle shift at surface state

Spin torque FMR



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

C-to-S conversion coefficient



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

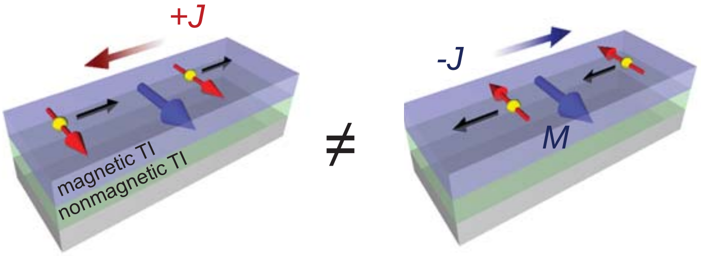
N-5

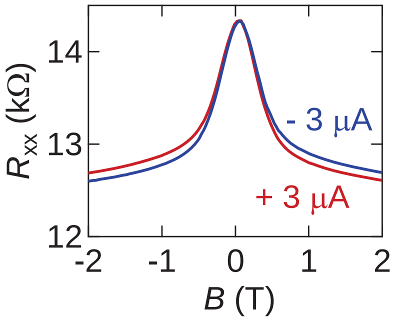
Large unidirectional magnetoresistance in magnetic topological insulator

K. Yasuda[1], A. Tsukazaki[2], R. Yoshimi[3],
K. S. Takahashi[3], M. Kawasaki[1,3] and Y. Tokura[1,3]

[1] *Department of Applied Physics, University of Tokyo*
[2] *IMR, Tohoku University*
[3] *CEMS, RIKEN*

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





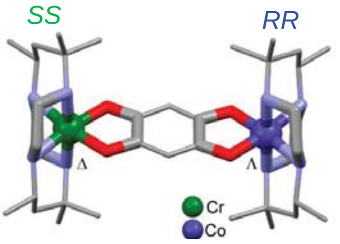
N-6

Magnetization Switching via Charge Transfer in a [CrCo] Complex

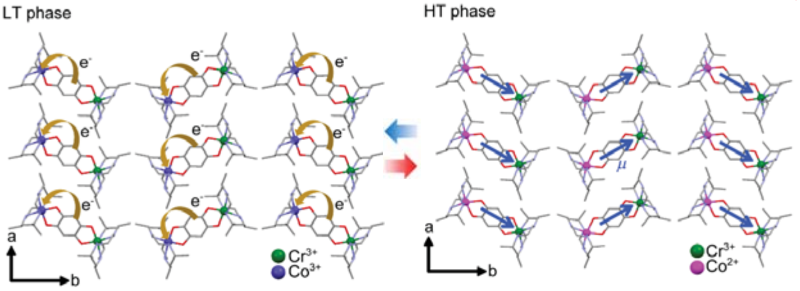
O. Sato, S. Kanegawa, S. Kang

Institute for Materials Chemistry and Engineering, Kyushu University, Fukuoka, 819-0395, Japan

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



[CrCo] Complex



Thermally- and photo-induced directional electron transfer

N-7

Direct observation of spin accumulation at Rashba-like interface

J. Puebla[1], F. Auvray[2], Y. Otani[1,2]

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

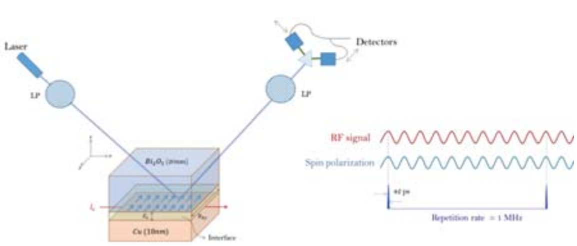

Fig. 1. Longitudinal magneto-optical Kerr effect setup for optical detection of spin accumulation.

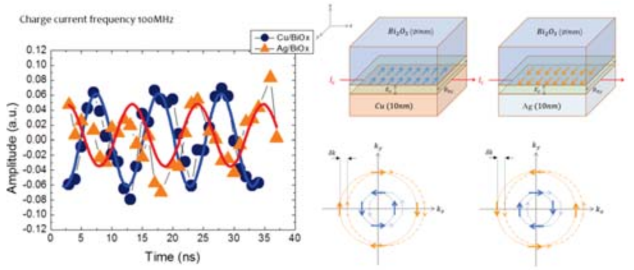

Fig. 2. Optical detection of spin accumulation at Cu/Bi_2O_3 (blue) and Ag/Bi_2O_3 (orange) interface. Right hand side, shows schematics of the expected spin accumulation for Cu/Bi_2O_3 and Ag/Bi_2O_3 interfaces, and their corresponding Fermi contour representations.

N-8

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

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

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

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

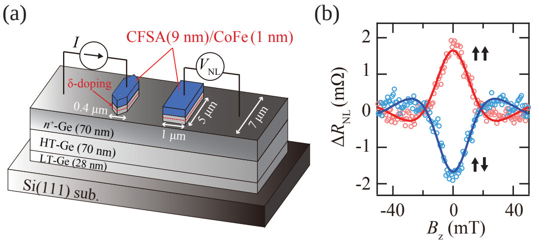

Fig. 1 (a) Schematic of a $Co_2FeSi_{0.5}Al_{0.5}/CoFe/n^+$-Ge LSV.
(b) Nonlocal Hanle effect curves at 8 K.

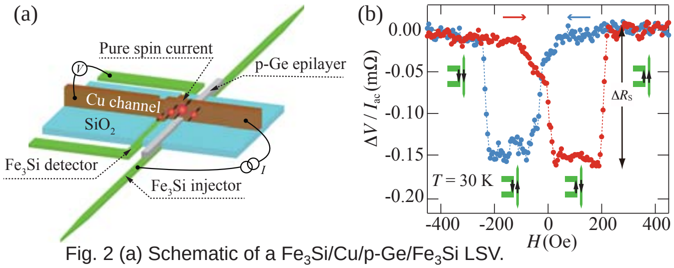

Fig. 2 (a) Schematic of a $Fe_3Si/Cu/p$-Ge/Fe_3Si LSV.
(b) A nonlocal magnetoresistance curve at 30 K.

N-9

Laser–induced spin-wave in metals under microscope

A. Kamimaki[1,2], Y. Sasaki[1,2] S. Iihama[2], Y. Ando[2], and S. Mizukami[1]

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

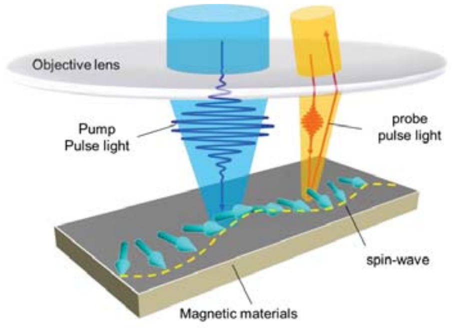

Fig. 1 The cartoon of the experiment.

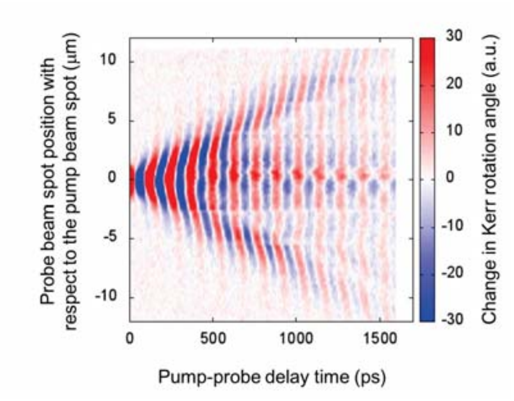

Fig. 2 Laser-induced spin-wave in CoFeB.

N-10

Spin Conversion from Spin Waves into NV Centers in Diamond

T. An

School of Materials Science, Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, Ishikawa, 923-1292, Japan

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

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

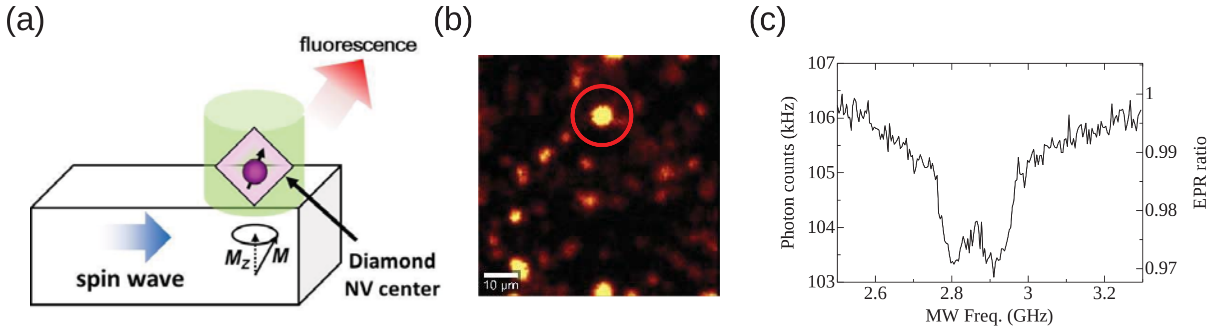

Fig. 1

Spin conversion at interface of metal and dielectric

N-11

S. Miwa[1,2]

[1]*Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan*
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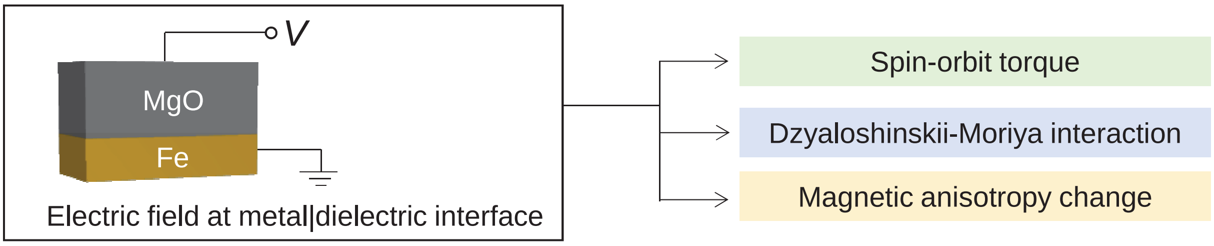
Coauthors: P. Risius, K. Nawaoka, K. Matsuda, K. Tanaka, M. Goto, F. Bonell, E. Tamura, Y. Suzuki (Osaka U) M. Suzuki, T. Nakamura, Y. Kotani (JASRI), M. Tsujikawa, M. Shirai (Tohoku U), T. Ohkubo, K. Hono (NIMS), T. Nozaki, S. Yuasa (AIST)

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

At Fe|MgO interface, a large interfacial spin-orbit torque can be generated. An Fe|MgO|V system shows large spin-torque about 4x10^9 (1/Vs) which is comparable to the spin-transfer torque in magnetic tunnel junctions with low resistance area product. We also show electric-field induces electric-dipole and generates interfacial Dzyaloshinskii-Moriya interaction. In addition, at metal|dielectric interface, electric field is atomically inhomogeneous due to the strong electrostatic screening effect in metals. Such field enables us to access electric-quadrupole. We found that the electric-quadrupole induction is correlated to the magnetic anisotropy energy change at metal|dielectric interface.



Electric field at metal|dielectric interface

- Spin-orbit torque
- Dzyaloshinskii-Moriya interaction
- Magnetic anisotropy change

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

N-12

Graphene spin-charge converter controlled by gate voltage

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

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

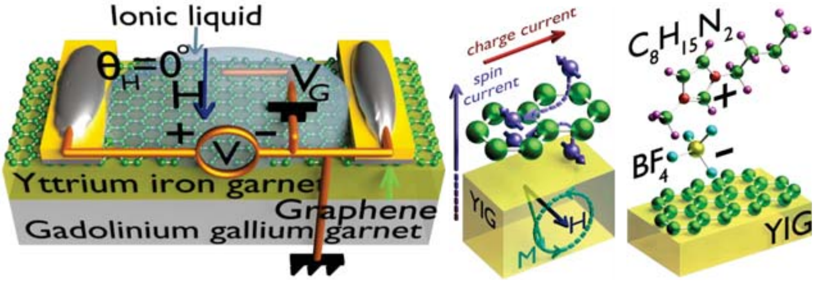

Fig. 1. (Left) Layout of the spin-charge conversion experiment. (Center) Under the ferromagnetic resonance pure spin current was transferred through the ferrimagnetic insulator / graphene interface and converted into an in-plane charge current. (Right) Schematic view of an electric gate using ionic gel.

N-13

Majorana Bound States in Magnetic Skyrmions

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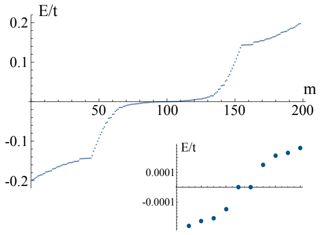
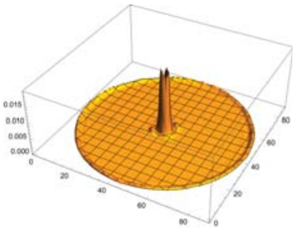
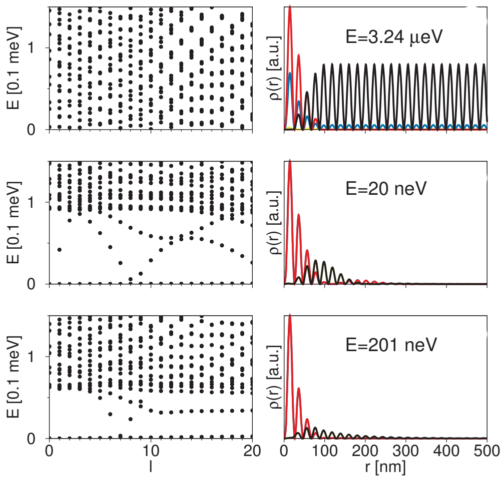
Magnetic skyrmions are highly mobile nanoscale topological spin textures. We show, both analytically and numerically, that a magnetic skyrmion of an even azimuthal winding number placed in proximity to an s-wave superconductor hosts a zero-energy Majorana bound state in its core, when the exchange coupling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







N-14

Magnon instability driven by heat current

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

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

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

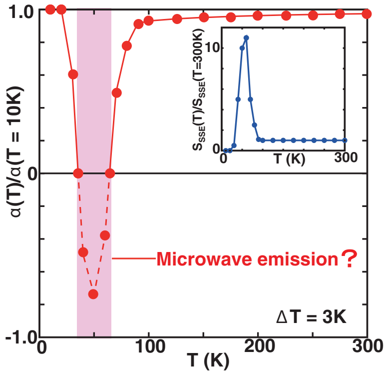

Fig. 1. The temperature dependence of the Gilbert damping constant calculated for a YIG/Pt under a temperature bias ΔT=3K [1]

[1] L. Lu *et al*., Phys. Rev. Lett. **108**, 257202 (2012)
[2] Y. Ohnuma *et al*., Phys. Rev. B **92**, 224404 (2015)

N-15

Non-reciprocal responses in Rashba system

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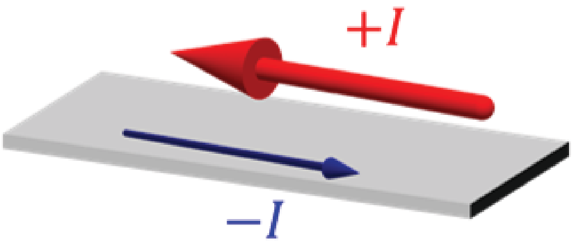
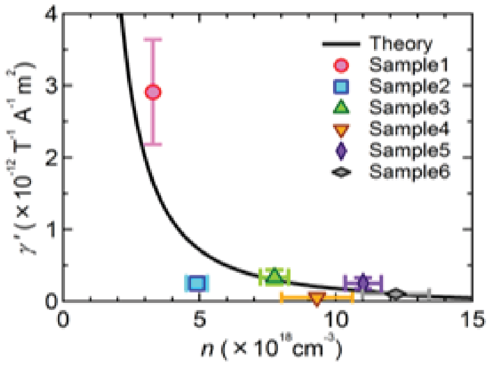
Non-reciprocal responses are consequences of the inversion symmetry breaking where lots of physical responses have directivity. The electrical resistivity, which is the most fundamental physical property of materials, also shows the non-reciprocity**: the resistivity depends on the direction of the current**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





N-16

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

S. Lepadatu,[1,2] H. Saarikoski,[3] R. Beacham,[4] M. J. Benitez,[4,5] T. A. Moore,[1] G. Burnell,[1]
S. Sugimoto,[1] D. Yesudas,[1] M. C. Wheeler,[1] J. Miguel,[6] S. S. Dhesi,[6] D. McGrouther,[4]
S. McVitie,[4] C. Mitsumata,[7] C. H. Marrows[1], and G. Tatara[3]
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[3] RIKEN Center for Emergent Matter Science, RIKEN, Wako, Saitama, Japan, [4] University of Glasgow, Glasgow, UK,
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Domain walls in ferromagnetic nanowires are potential building-blocks of future technologies such as racetrack memories, in which data encoded in the domain walls are transported using spin-polarised currents. However, the development of energy-efficient devices has been hampered by the high current densities needed to initiate domain wall motion. We show that an order of magnitude reduction in the critical current density to 1.0×10^{11} Am^2 can be achieved for in-plane magnetised coupled domain walls in CoFe/Ru/CoFe synthetic ferrimagnet tracks [1]. Theoretical modelling indicates that this is due to nonadiabatic driving of anisotropically coupled walls. Moreover, for memory applications, techniques to *stop* a moving wall at intended positions precisely and without delay is essential. We propose that an array of locally-embedded Rashba interaction can be used as pinning centers for current-driven domain walls (see Fig. 2 and Ref. [2]).

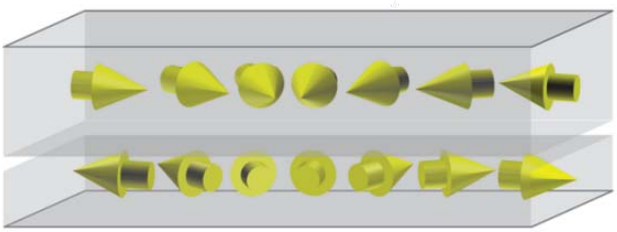

Fig. 1 Domain wall in a synthetic ferrimagnet.

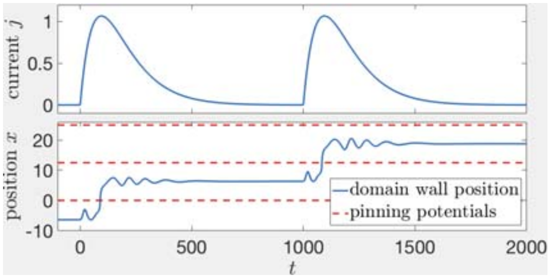

Fig. 2 Simulation of current pulses driving a domain wall.

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

N-17

Detection of voltage excited spin wave by ps-TRMOKE

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

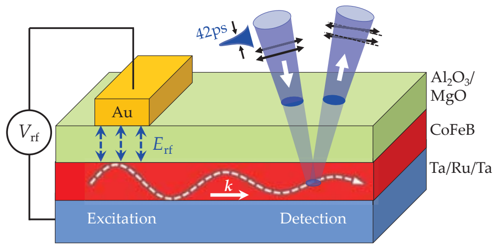

Fig. 1: Schematic of device and experiment

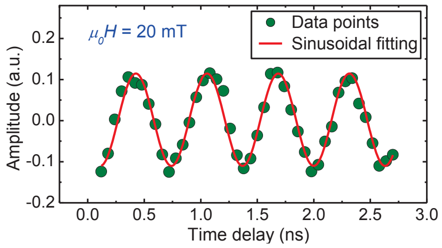

Fig. 2: Spin wave signal as a function of time

N-18

Doppler shift picture of the Dzyaloshinskii-Moriya interaction

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

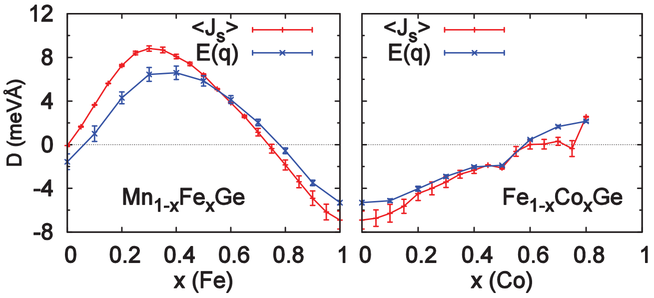

Fig: The numerical results of the Dzyaloshinskii-Moriya coefficient D. One is calculated as the intrinsic spin current D=<Js>, and the other is by the total energy of electrons E(q)=Dq+Jq^2.

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

N-19

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

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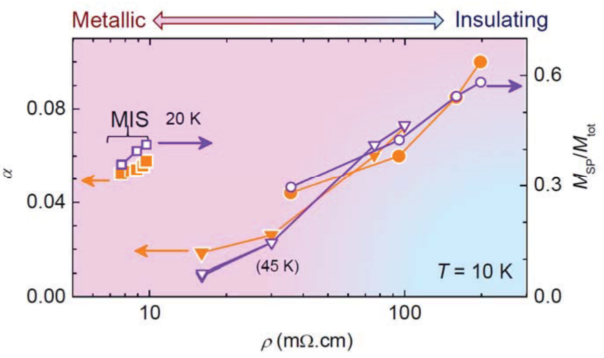
The damping constant α is a fundamental parameter, which governs the magnetization dynamics, and determines the performance of spintronics devices. In this work, we investigate a possible control of α of (Ga,Mn)As by applying an electric field E.

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

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



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

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

N-20

Spin Hall effect in ferromagnetic FePt alloy

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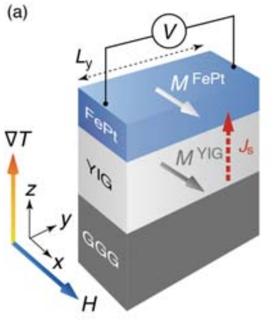
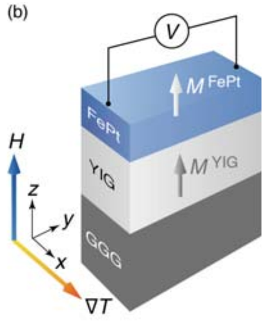
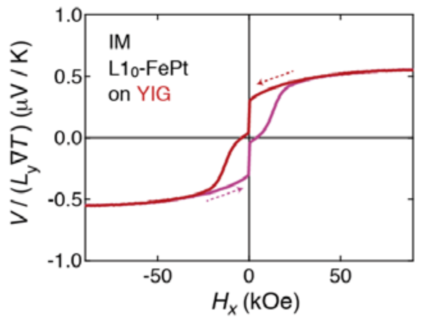
Spin Hall effect (SHE), which converts charge current (J_q) to spin current (J_s), has recently been examined not only in nonmagnetic metals and semiconductors but also in ferromagnetic metals, and the unified understanding for the above phenomena is of importance to design spintronic devices.

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







N-21

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

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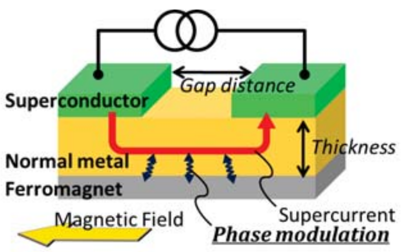
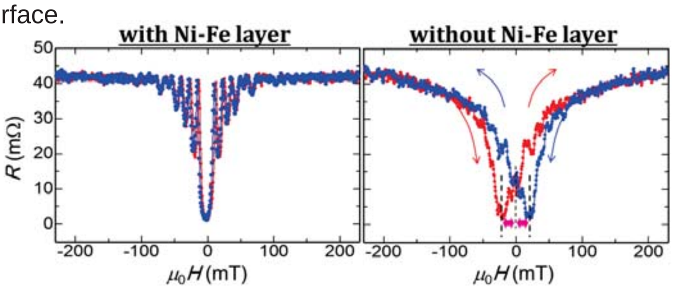
Exchange interaction between Cooper-pair and spin-polarized electrons is expected to provide intriguing phenomena in ferromagnet/superconductor hybrid structures. One of these phenomena is a spin-triplet Cooper pair, which is recently reported to be realized through the phase modulation from the singlet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

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





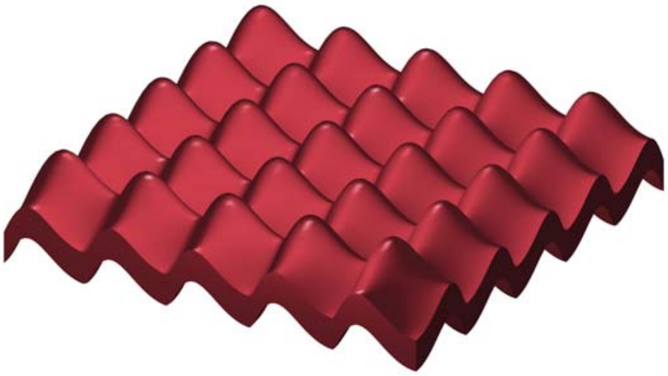
N-22

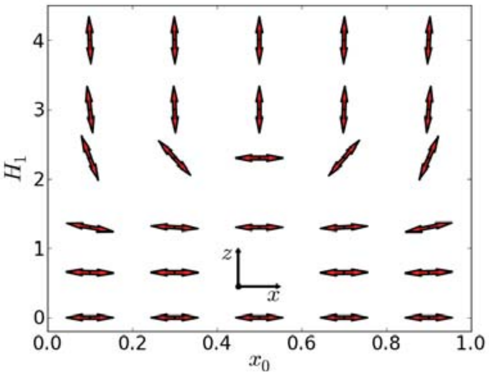
Magnetic Anisotropy due to Interplay of Curvature and Dipolar Interaction

O.A. Tretiakov[1]

[1]*Institute for Materials Research (IMR), Tohoku University, Sendai 980-8577, Japan*

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





N-23

A Holographic Dual of Ferromagnets

Naoto Yokoi[1], Masafumi Ishihara[2], Koji Sato[2], and Eiji Saitoh[1,2,3,4]

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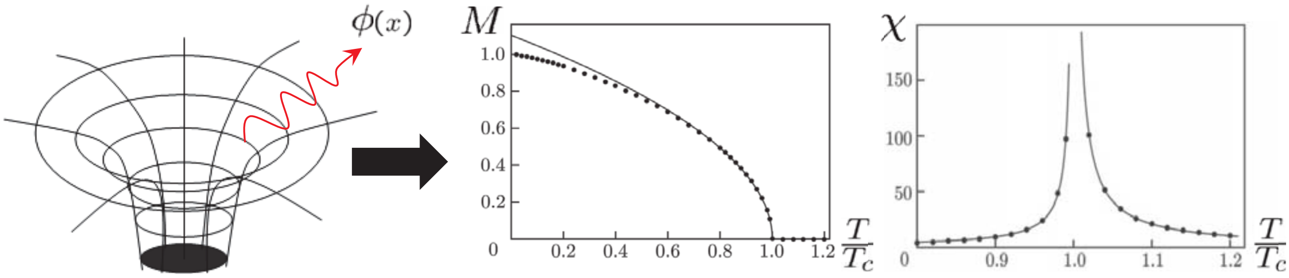
We propose a dual description for ferromagnetic systems based on the holographic duality, which relates *D*-dimensional quantum many body systems to (*D+1*)-dimensional gravitational theories.

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



Magnetization and susceptibility obtained from the holographic duality

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N-24

Spin Wave Transmission in FeRh Thin Films

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[1]Laboratory for Materials and Structures, Tokyo Institute of Technology, Yokohama 226-8503, Japan

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

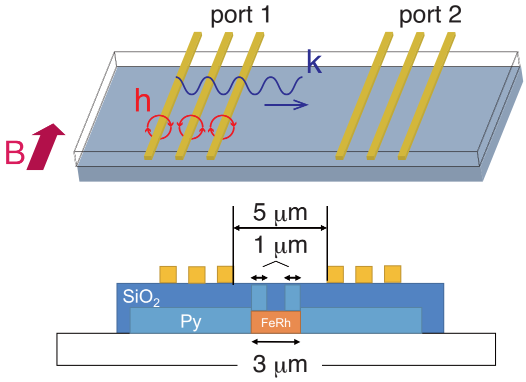

Fig. 1 NiFe/FeRh/NiFe junction structure.

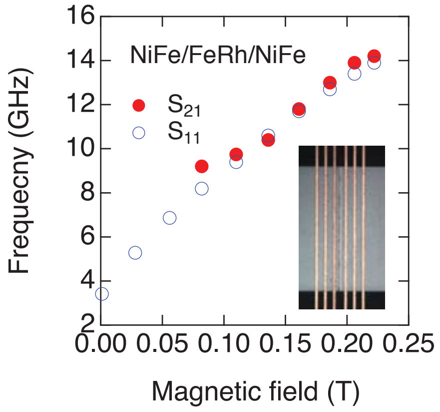

Fig. 1 Dispersion relationships for S_{11} and S_{21}.

N-25

Time-resolved imaging of spin wave transmission

T. Satoh

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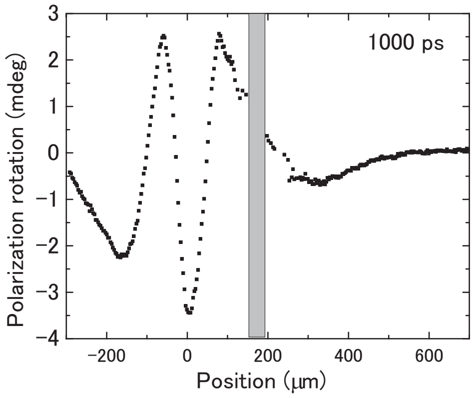
Magnetization control using ultrashort optical pulses has been extensively studied in recent years. One of the nonthermal control of magnetization is based on the inverse Faraday effect, where circularly polarized pulses generate the effective magnetic field along the propagation vector in a transparent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

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



N-26

Effective Hamiltonian theory for nonreciprocal light propagation in magnetic Rashba conductor

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

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

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[3] J. Shibata, A. Taleuchi, H. Kohno, and G. Tatara, J.Phys. Soc. Jpn. **85**, 033701 (2016).

N-27

Spin injection into the topological crystalline insulator SnTe using spin pumping

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

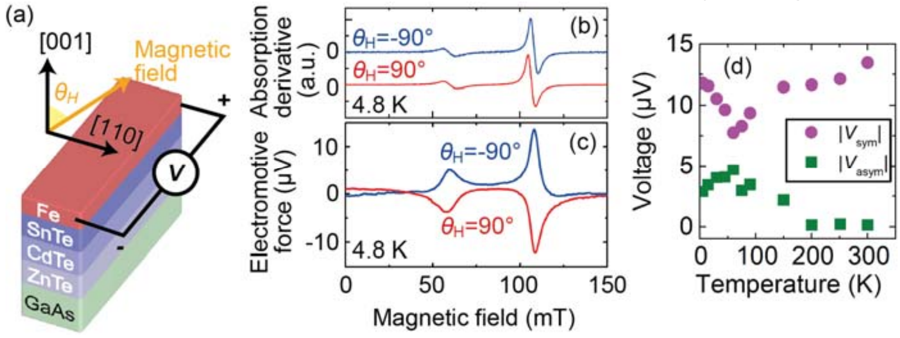

FIG. 1 (a) Schematic illustration of the device structure and the measurement alignment used in this study. (b)(c) Absorption derivative (b) and the EMF (c) as a function of a magnetic field at 4.8 K. (d) Temperature dependence of $|V_{sym}|$ and $|V_{asym}|$ with the magnetic field direction θ_H = 90º.

N-28

Size effect of electrical transport properties in NiS_2

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

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

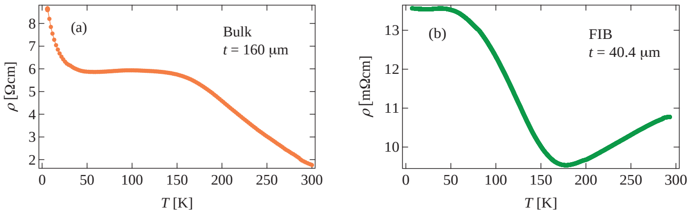

Fig. 1. Temperature dependence of resistivity (a) t = 160 μm, (b) t = 40.4 μm.

Reference

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N-29

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

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

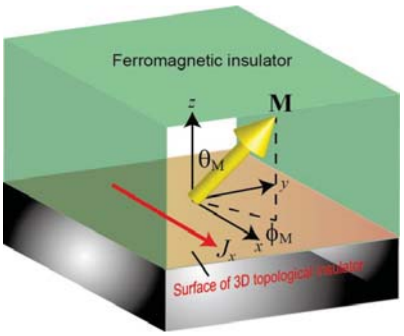

FIG. 1. Schematic picture of the system consisting of a three-dimensional topological insulator with a ferromagnetic insulator. Electric currents only flow at the interface between both insulators

Reference
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N-30

Electric-field-induced magnetic resonance in topological antiferromagnetic insulators

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

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

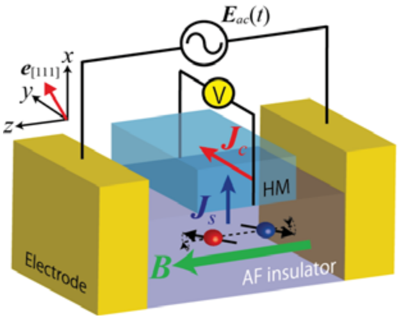

FIG. 1. Schematic figure of a possible experimental setup to observe the electric-field-induced AF resonance in this study.

Reference
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[3] S. W. Kim *et al.*, Appl. Phys. Lett. **106**, 252401 (2015).
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N-31

First-principles Approach for Skyrmion-driven Thermoelectric Conversion

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

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

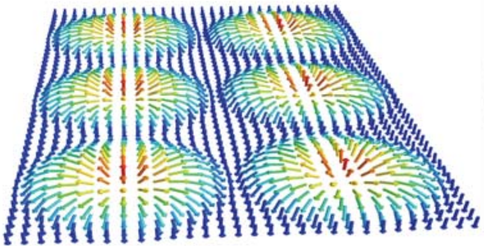

Fig.1 square SkX (15×15 size)

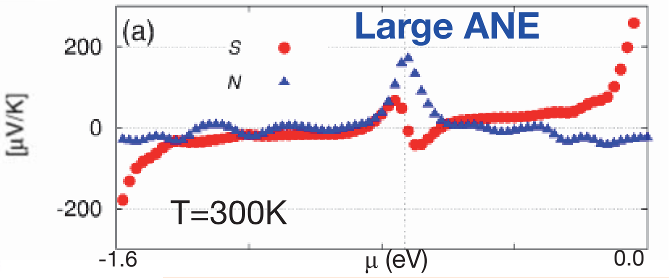

Fig.2 Large ANE coefficient (blue) at specific μ in a SkX (6×6 size)
(from Figure 3 in Ref.★)

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

N-32

Edelstein magnetoresistance in CoFe/Cu/Bi_2O_3

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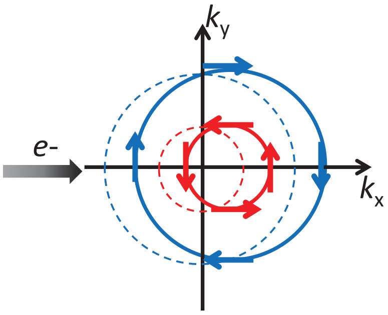
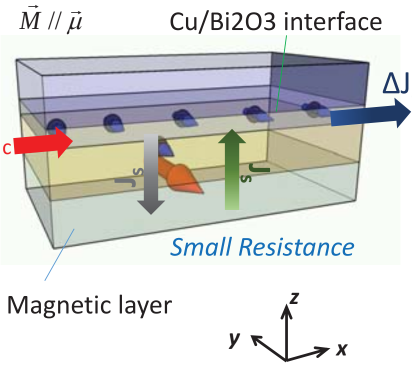
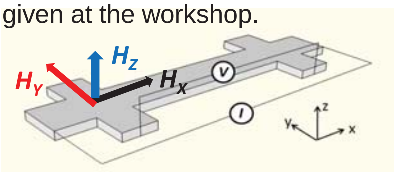
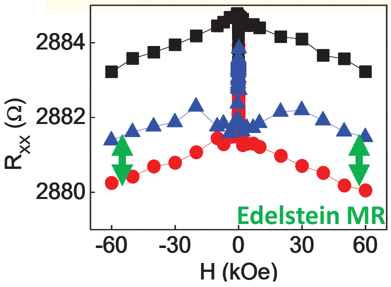
It can be expected that interconversion between spin and charge current originated by Edelstein effect can modulate the resistance similar mechanism with spin Hall magnetoresistance (SMR). Here we studied modulation of the resistance originated from the Edelstein effect at Cu/Bi_2O_3 interface. Hall-bar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









N-33

Thermal generation of spin current in antiferromagnets

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M. Nakamura[1], Y. Kaneko[1], M. Kawasaki[1,2], and Y. Tokura[1,2]

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

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

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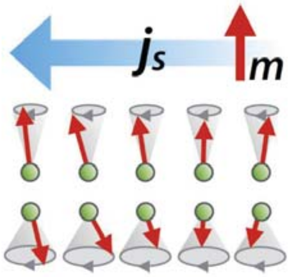

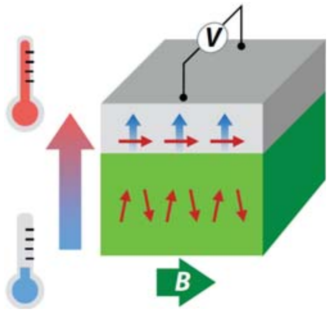

N-34

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

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

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

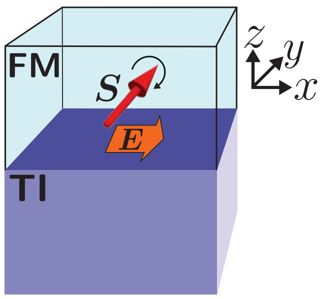

Fig.1. A ferromagnet deposited on the surface of a topological insulator.

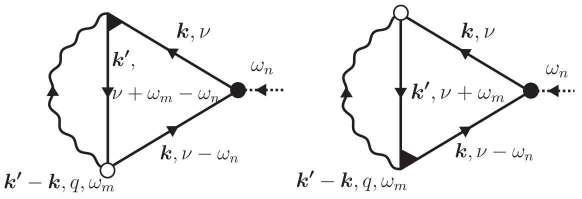

Fig.2. The lowest-order Diagrams contributing to the spin current.

N-35

Conservation of angular momentum in DMI spin textures

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

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

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

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N-36

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

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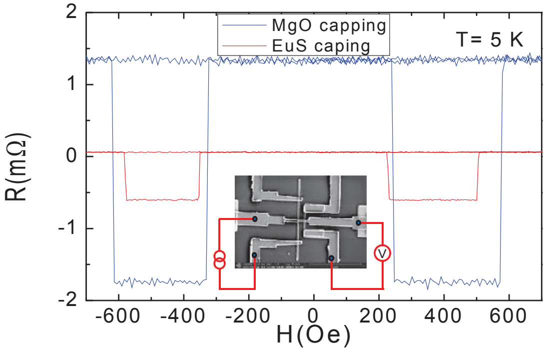
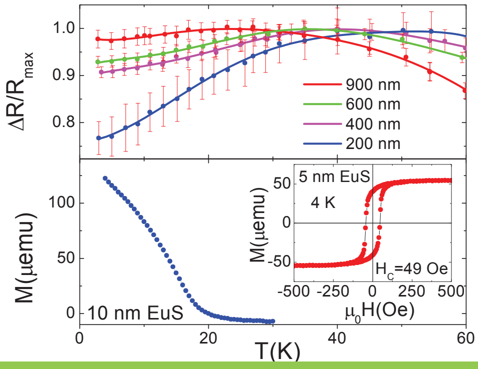
Recent experiments have shown that the spin-current flowing through a nonmagnetic metal (NM) in intimate contact with a ferromagnetic insulator (FI) can be manipulated with the magnetization direction of the FI even though no current flows through the FI. We study the effect of interfacial exchange field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



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



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

N-37

Spin-hydrodynamic Conversion Effect

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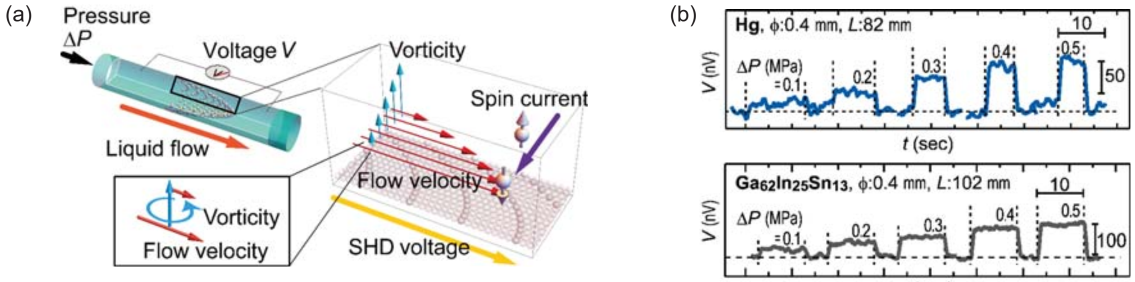
Generation and utilization of spin currents are essential for the field of spintronics, dealing with spin-based transport in condensed matter systems. The key is angular-momentum conversion from/to spin degrees of freedom. Several forms of the angular momentum are utilized but there existed an angular-momentum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

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



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

N-38

Transition behavior in Pd-doped FeRh wire

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

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

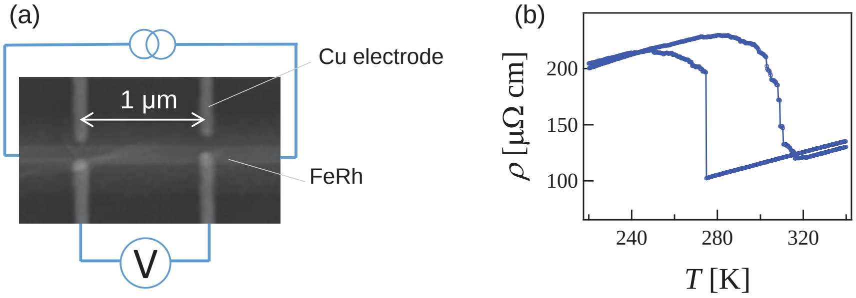

Figure 1. (a) SEM picture and (b) temperature dependence of resistivity of a Pd-doped FeRh wire.

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

N-39

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

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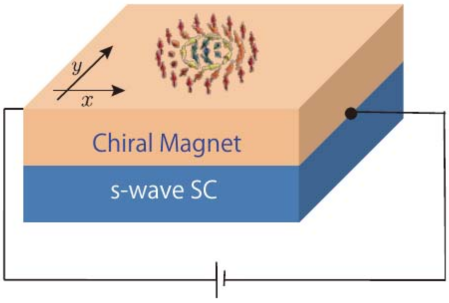
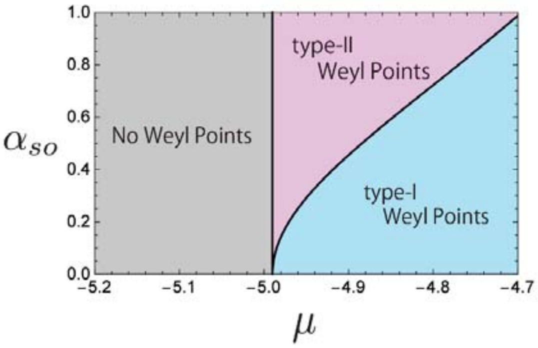
[2]*Dept. of Materials Engineering Science, Osaka Univ., Toyonaka, Osaka* 560-8531*, Japan*

Recent studies show superconductivity provides new perspectives on spintronics. We study a heterostructure composed of an s-wave superconductor and a cubic chiral-magnet that can stabilize a topological spin texture, a skyrmion. We propose a supercurrent-induced spin torque that originates from the spin-orbit coupling, and we show that the spin torque can drive a skyrmion in an efficient way that reduces Joule heating.

We also study the band structure of Bogoliubov quasiparticles and show the existence of Weyl points, whose positions can be controlled by the direction of the magnetization. This results in an effective magnetic field acting on the quasiparticles in the presence spin textures. Furthermore, the tilt of the Weyl cones can also be tuned by the strength of the spin-orbit coupling, and we propose a possible realization of type-II Weyl points.

arXiv: 1607.02336





N-40

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

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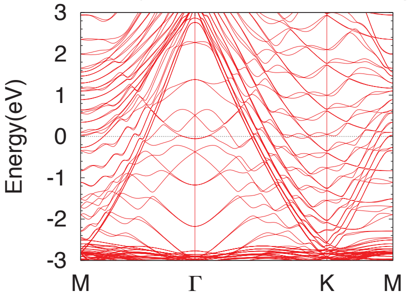
Bismuth is a material with a strong spin-orbit coupling. Rashba effect is due to spin-orbit splitting, and Rashba parameters are key parameters for spintronics [1]. Recently, the interfaces of the heterostructures consisting of bismuth and metal have been extensively studied [2]. Those interfacial systems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

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



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

N-41

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

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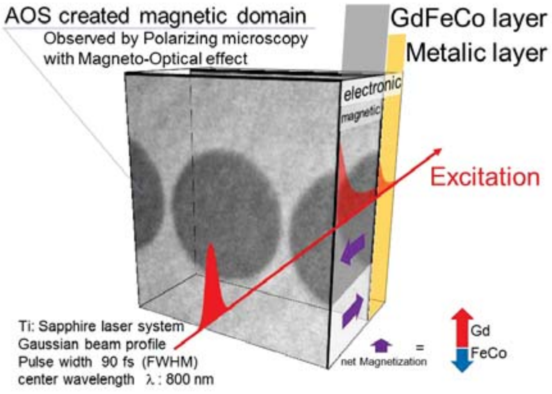
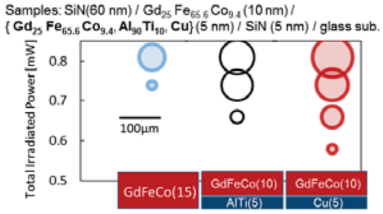
Only tens fs of laser pulse are sufficient to induce the non-adiabatic and non-equilibrium energy dissipation process of electron in metalic thin films. All – Optical magnetization Switching (AOS) is originated from the non-adiabatic and non-equilibrium energy dissipation process of electron, spin and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





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

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

N-42

The fluctuation of charge, heat and spin currents

H. Okada, Y. Utsumi

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

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

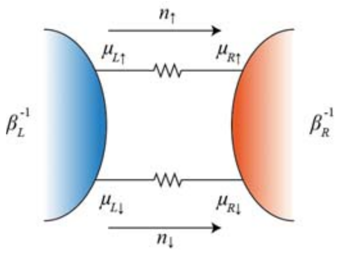


Fig. 1. Schematic picture of thermo-magneto-electric device

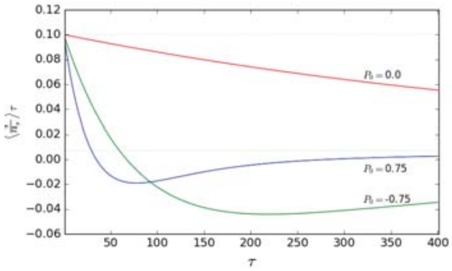


Fig. 2. Time dependence of the COP

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

N-43

Bidirectional conversion between microwave and light via ferromagnetic magnons

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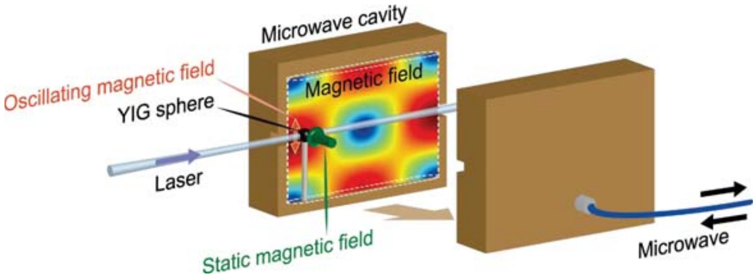
[2]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan*

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



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

N-44

Anomalous Nernst effect in Co / Ni multilayers

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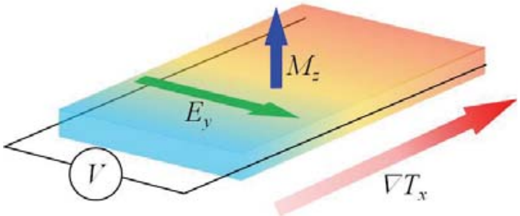
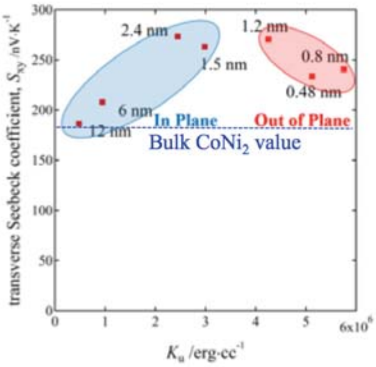
The Nernst effect is a common thermomagnetic effect, that has been known for a long time. When a temperature gradient is applied on a material with spontaneous magnetization, an electric field is induced in the perpendicular direction to both the temperature gradient and the magnetization, which is called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





N-45

Barnett effect in rare-earth metals

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M. Matsuo[1,2], S. Maekawa[1,2], and E. Saitoh [1,2,3,4]

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[2]ERATO, Japan Science and Technology Agency, Sendai 980-8577, Japan
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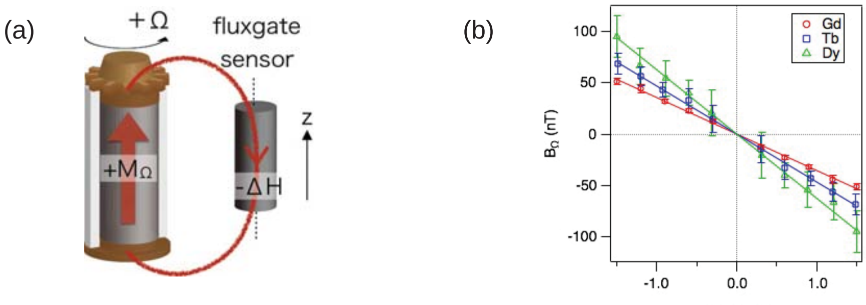
The magnetomechanical factor *g'* of Gd, Tb, and Dy metals were determined by measurements of the Barnett effect using homemade apparatus, which consists of fluxgatesensor, magnetic shield, and high speed rotar. We performed mechanical rotation experiments up to 1.5 kHz at room temperature. The emergent magnetic field (Barnett field) in sample caused by mechanical rotation linearly depends on the rotational frequency as shown in Fig. (b). The *g'* factor of Gd, Tb, and Dy samples were estimated to be 2.00±0.08, 1.53±0.17, and 1.15±0.32, respectively, from the slopes of the rotation dependence of the Barnett field. This study provides a new technique for determination of the g factor even under zero magnetic field.



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

N-46

Rashba-Edelstein magnetoresistance in metallic heterostructures

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

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

References

[1] H. Nakayama *et al.*, Phys. Rev. Lett. **110,** 206601 (2013).

[2] H. Nakayama *et al.*, Phys. Rev. Lett. **117,** 116602 (2016).

[3] S. Vélez *et al.*, Phys. Rev. Lett. **116,** 016603 (2016)

Abstracts of Poster Session

②

Oct 14, 17:15-18:45

Q-1

Bistable Photon Emission in Hybrid-QED

Neill Lambert[1], Franco Nori[1,2] and Christian Flindt[3]

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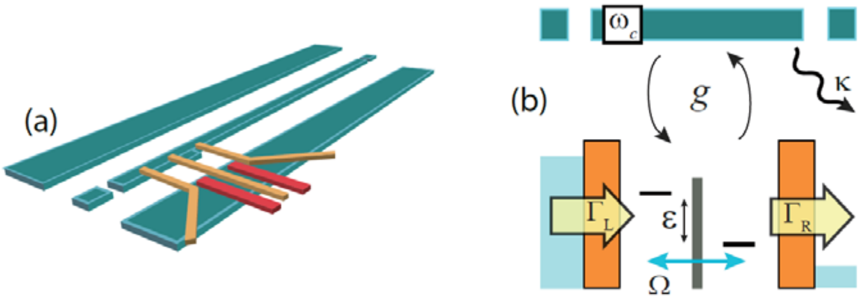
We study the photon emission from a double quantum dot coupled to a microwave cavity [1,2]. We predict that the resulting photonic statistics exhibit a dynamic bistability, which we validate by showing that the distribution describing these statistics has the shape of a tilted ellipse. The switching rates which describe the bistability can be extracted from the electrical current and the shot noise in the quantum dots, and used to predict this elliptic form of the photonic distribution. Our results may be useful for more deeply characterizing the single-atom lasers based on gate-defined quantum dots as the gain medium.

[1] N. Lambert, F. Nori, and C. Flindt, Phys. Rev. Lett. 115, 216803 (2015),

[2] N. Lambert, C. Flindt, and F. Nori, Europhysics Letters 103, 17005 (2013).



(a) Schematic layout of a double quantum dot coupled to a microwave transmission line cavity.

(b) Within the dot, electrons flow from left to right, and pass through a double-well potential which couples to the cavity.

Q-2

Non-perturbative and non-Markovian environments: exact solvers and applications

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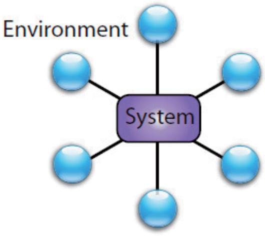
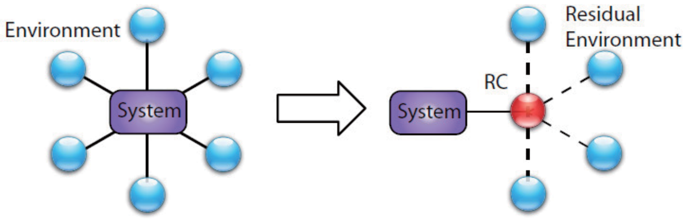
[2]DTU Fotonik, Denmark [3]Photon Science Institute, The University of Manchester, [4]Berlin Technical University
[5]Department of Materials, The University of Oxford, [6]SUPA, Heriot-Watt University,
[7]Department of Physics, University of Michigan, Ann Arbor, MI, USA

To theoretically model and understand quantum devices we must understand their interaction with the environment. Many perturbative approaches have been developed, but is becoming apparent that these fail in many physical situations, and that a non-perturbative and dynamic environment can have a profound effect on applications. We have extended an existing approach (the HEOM method of Tanimura and Kubo), and also developed a new approach (the reaction-coordinate method), and applied both of them to a range of physical examples and applications.



The environment is typically composed of infinite degrees of freedom. Methods based on perturbation theory are typically pursued, but break down when the coupling to the environment is of the same order as the internal system frequencies.



One approach to deal with this difficult problem is to identify the dominant degrees of freedom in the environment, and model those explicitly, while treating the rest perturbatively

Q-3

Quantum optics with giant artificial atoms

A. F. Kockum[1], L. Guo[2], M. Pletyukhov[3], A. L. Grimsmo[4], S. R. Sathyamoorthy[2], A. Blais[4], P. Delsing[2], F. Nori[1], and G. Johansson[2]

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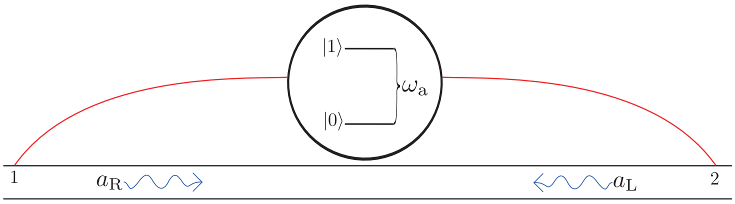
In quantum optics experiments with both natural and artificial atoms, the atoms are usually small enough that they can be approximated as point-like compared to the wave- length of the electromagnetic radiation they interact with. However, a recent experiment coupling a superconducting qubit to surface acoustic waves shows that a single artificial atom can be coupled to a bosonic field at several points which are wavelengths apart [1]. This situation could also be engineered with an xmon qubit coupled to a microwave transmission line [2].

Here, we present results of theoretical studies of such “giant artificial atoms” [2,3,4]. In the Markovian regime, where the travel time between coupling points is negligible, we find that interference effects due to the positions of the coupling points give rise to a frequency dependence for the strength of the coupling between the giant artificial atom and its surroundings [2]. The Lamb shift of the atom is also affected by the positions of the coupling points. We discuss possible applications for these frequency dependencies (which can be designed). In the non-Markovian regime, where the distance between coupling points is large, an excited giant atom exhibits revivals and non-exponential decay [3]. In this regime, we have also studied novel features that occur in the correlation function $g^2(t)$. Finally, we also explore setups with several giant atoms coupled to a transmission line in various configurations [4].

A sketch of a giant artificial atom, coupled to right- and left-moving modes in a one-dimensional transmission line at two points which are wavelengths apart.



[1] M. V. Gustafsson *et al.*, Science **346**, 207 (2014)
[2] A. F. Kockum *et al.*, Phys. Rev. A **90**, 013837 (2014)
[3] L. Guo *et al.*, in preparation (2016)
[4] A. F. Kockum *et al.*, in preparation (2016)

Q-4

Second Harmonic Generation in Topological insulators

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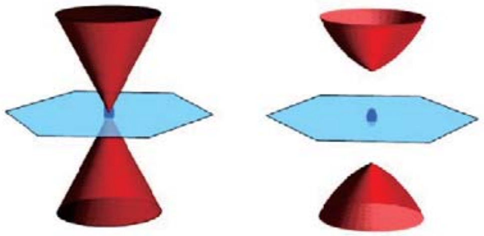
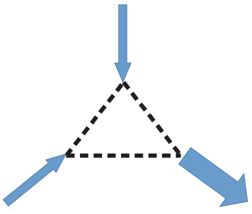
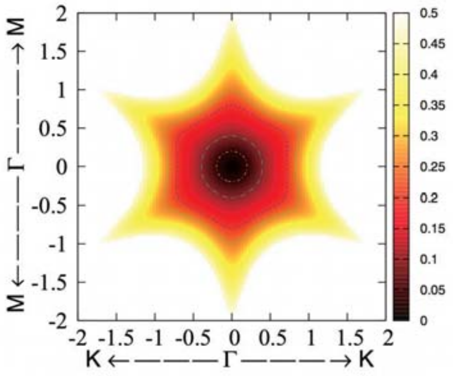
[2] *University of Michigan, Ann Arbor, United States*

The metallic surface states of a topological insulator support helical Dirac fermions protected by topology with their spin locked perpendicular to their momentum. They can acquire mass through magnetic doping or through hybridization of states on opposite faces of a thin sample and thus an out of plane spin component (Sz) was introduced. The Fermi cross section changes from circular to a snowflake shape as the chemical potential is increased above the Dirac point because of a hexagonal warping which also changes the spin texture, the orbital magnetic moment, the matrix element for optical absorption, and the circular dichroism. We find that the second harmonic generation described by a nonlinear response function will not vanish in the long wave length limit (q→0) only when the hexagonal warping and the gap coexist.







Q-5

Nonreciprocal Transport in Noncentrosymmetric Superconductors

R. Wakatsuki[1], Y. Saito[1], S. Hoshino[2], T. Ideue[1], M. Ezawa[1], Y. Iwasa[1,2], and N. Nagaosa[1,2]

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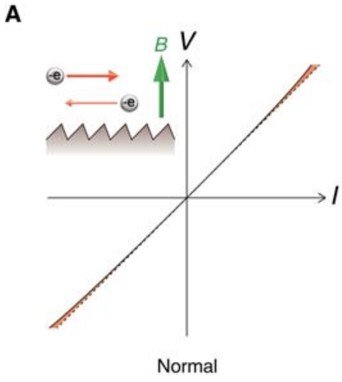
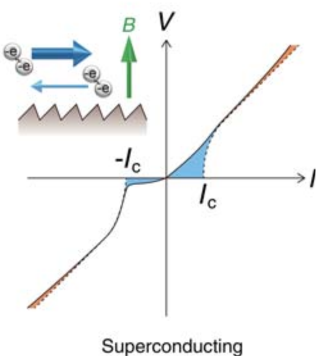
In noncentrosymmetric systems, magnetochiral anisotropy (or nonreciprocal transport) such as direction dependent resistivity appears under a magnetic field. In practice, however, the magnetochiral anisotropy in a bulk material is very small (Fig. A). Here, we report that once a noncentrosymmetric material enters into its superconducting fluctuation regime, the magnetochiral anisotropy is strongly enhanced (Fig. B) by a factor of $(\epsilon_F/\Delta)^3$, with the Fermi energy ϵ_F and the superconducting gap Δ.

As a representative material of noncentrosymmetric superconductors, we have studied 2H-MoS_2 under the electric-double-layer transistor configuration. We have observed the large enhancement of the magnetochiral anisotropy in the superconducting fluctuation regime, and the results are consistent with the theoretical predictions (Fig. C).

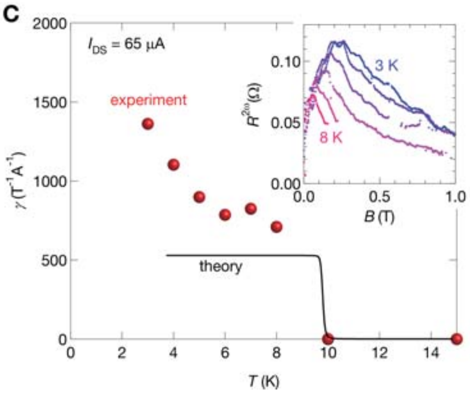
A



B



C



Q-6

Anomalous Thermal Hall Effect in a disordered Weyl ferromagnet

Atsuo Shitade

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

Thermal Hall effect is a heat analog of the Hall effect, namely, the heat current flows perpendicular to a temperature gradient. According to the Wiedemann-Franz law, the Lorenz ratio $L^{ij} \equiv \kappa^{ij}/T\sigma^{ij}$ goes to the universal value $L_0 \equiv \pi^2 k_B^2/3e^2$ in electronic systems at low temperature, in which κ^{ij} and σ^{ij} are the thermal and electric (Hall) conductivities, and T is temperature. At finite temperature, we can investigate effects of inelastic scattering by the breakdown of the Wiedemann-Franz law.

In spite of its usefulness, it is theoretically difficult to calculate κ^{xy}. This is because $T\kappa^{xy}$ is not expressed by the Kubo formula $T\tilde{\kappa}^{xy}$ alone but is corrected by the heat magnetization $2M_{Qz}$. Recently, I found a “vector potential” coupled to the energy current and established the Keldysh formalism for calculating $T\tilde{\kappa}^{xy}$ and $2M_{Qz}$ even in disordered or interacting systems [1].

Here I apply this formalism to a disordered Weyl ferromagnet which exhibits the anomalous (thermal) Hall effect. I first quantum-mechanically calculate κ^{ij} and σ^{ij} on an equal footing and reproduce the Wiedeman-Franz law. This is the first step towards a unified theory of the anomalous Hall effect at finite temperature, where inelastic scattering by magnons is relevant.

[1] A. Shitade, Prog. Theor. Exp. Phys. **2014**, 123I01 (2014).

Q-7

Antiferromagnetic nuclear spin helix and topological superconductivity in ^{13}C nanotubes

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We investigate the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction arising from the hyperfine coupling between localized nuclear spins and conduction electrons in interacting carbon nanotubes made of ^{13}C. Using the Luttinger liquid formalism, we show that the RKKY interaction is sublattice dependent, resolving the inconsistency between the earlier work and the spin susceptibility calculation in noninteracting nanotubes. The RKKY interaction forms $q=\pm 2k_F$ peaks with the Fermi wave number k_F, and induces a novel antiferromagnetic nuclear spin helix with a spatial period π/k_F (Fig. 1). The transition temperature reaches up to several tens of mK, due to the feedback effect through the Overhauser field from the ordered nuclear spins. The nuclear spin helix, combining spin and charge degrees of freedom, results in a synthetic spin-orbit interaction, which is crucial for nontrivial topology. In the presence of the proximity-induced superconductivity, this system has a potential to realize Majorana fermions without the need of fine tuning the external parameters, such as chemical potential and magnetic field (Fig. 2).

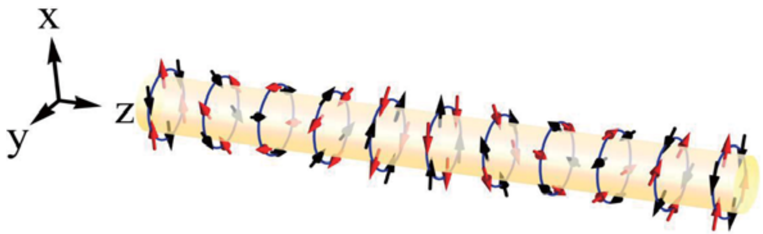

Fig. 1 Illustration of the antiferromagnetic nuclear spin helix in ^{13}C nanotubes.

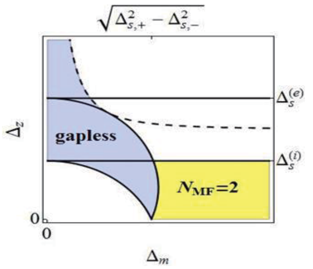

Fig. 2 phase diagram

Q-8

Equal-spin Andreev Reflection between Spin-resolved Quantum Hall Bulk State and Superconductor

S. Matsuo[1], K. Ueda[1], S. Baba[1], H. Kamata[2], M. Tateno[1],
J. Shabani[3], C. J. Palmstrom[3], and S. Tarucha[1, 2]

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[2]Center for Emergent Materials Science, RIKEN, Wako, Saitama, Japan
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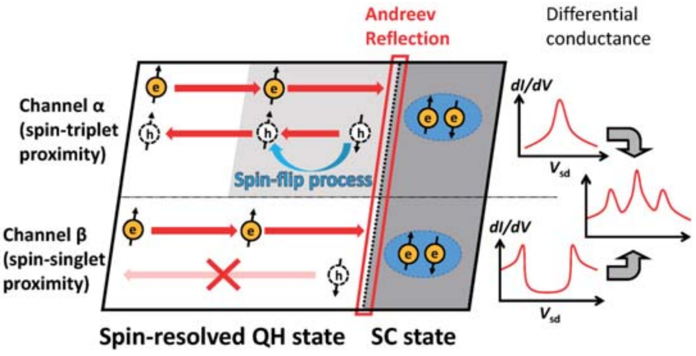
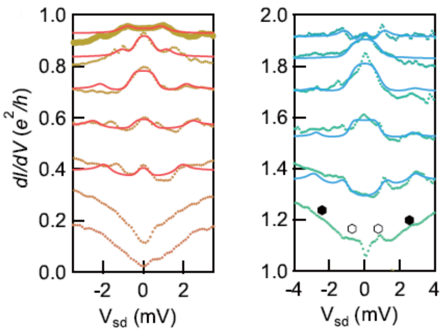
A junction between superconductor and normal conductor is a platform to study the Andreev reflection, in which the incident electron is reflected as a hole having the opposite spin direction. Recently the supercurrent through the ferromagnet or halfmetal has been reported. This contradicted results were explained by the "equal-spin" Andreev reflection intermediated by the spin-flip process. We will report on observation of this "equal-spin" Andreev reflection between superconducting NbTi and spin-resolved quantum Hall bulk state of InAs quantum well having strong spin-orbit interaction. The obtained differential conductance has sub-gap feature on the zero-bias region and additional side peaks out of the sub-gap feature. The peculiar structures are explained by the model with assumption that there are two channels, one of which contributes to the "equal-spin" Andreev reflection and the other contributes the conventional Andreev reflection. Our results will pave the way for superconducting spintronics on semiconductor.





Q-9

Fractional charge in 1D quantum dots array

Peter Stano[1], Jin-Hong Park[1], Guang Yang[1], Jelena Klinovaja[2], Daniel Loss[1,2]

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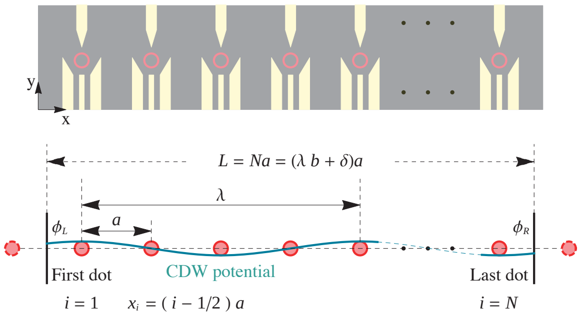
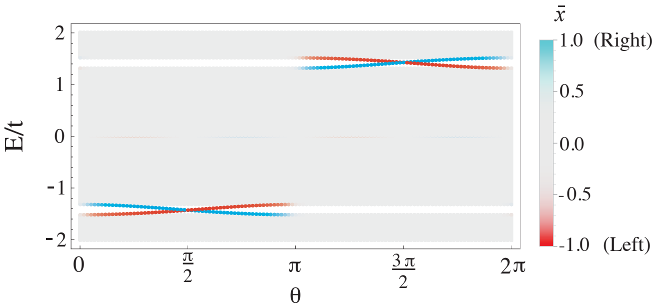
[2]Department of Physics, University of Basel, Switzerland

We show that fractional charges can be realized at the boundaries of a linear array of tunnel-coupled quantum dots in the presence of a periodically modulated onsite potential. While the charge fractionalization mechanism is similar to the one in polyacetylene, here the values of fractional charges can be tuned to arbitrary values by varying the phase of the onsite potential or the total number of dots in the array. We also find that the fractional boundary charges, unlike the in-gap bound states, are stable against static random disorder. We discuss the minimum array size where fractional boundary charges can be observed.





Q-10

Atomistic spin dynamics with a semi-quantum thermostat

J. Barker[1] and G.E.W. Bauer[1,2,3]

[1]Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan
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The use of classical Heisenberg models to understand the dynamical and thermodynamical properties of magnetic materials is now common place. Hamiltonians can be parameterised in exquisite detail from first principles or neutron scattering measurements. However there are issues with even a qualitative comparison with experiments and theory because of the disregard for the quantum nature of spin. The differences can be especially large in the low temperature regime which are sometimes required for experiments. In this talk I will present a modified approach which obeys quantum statistics but retains the classical spin vectors which make this approach easy to use and useful for dynamics. The results show an excellent agreement with theory and experiments allowing truly quantitative calculations to be performed.

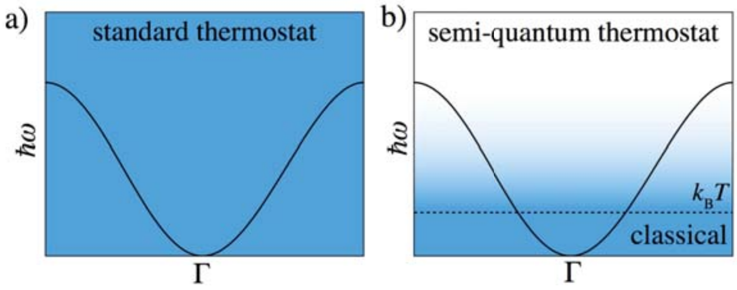

Fig. 1 - Classical vs. semi-classical approach

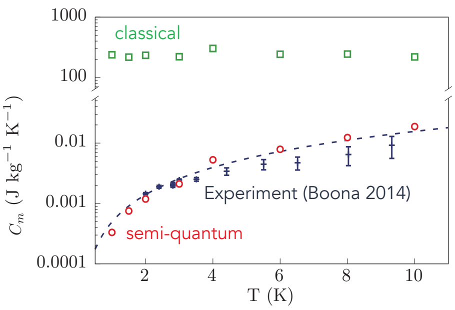

Fig. 2 - Magnon specific heat of YIG

Q-11

Development of (110) GaAs quantum wells for emission layers of spin-controlled lasers

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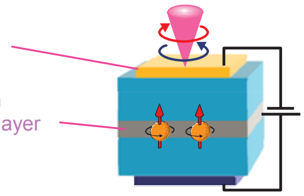
[2]Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan

Spin-controlled lasers, which enable electron spin imformation to convert light polarization, have become a focus of interest as next-generation light sources [1]. Semiconductor quantum wells (QWs) are crucial building blocks of the spin lasers. We conducted systematic measurements of the surface morphology, photoluminescence (PL) intensity, carrier lifetime τ_c, and spin relaxation time τ_s of the GaAs/AlGaAs(110) QWs grown with different growth conditions to examine the possibility of using them as the emission layer of spin lasers. Excellent surface flatness and high PL intensity (I_{PL}) were obtained from the samples with growth temperature ≥ 450 °C and As/Ga flux ratio ≥ 40. We also found that the high-quality (110) QWs exhibit high spin-detection sensitivities $\eta = [\tau_s/(\tau_s+2\tau_c)] \geq 0.3$; these values have never been reached so far in the (100) QWs. The results suggest that the (110) QWs obtained are certainly superior to the existing (100) QWs in the emission layer of the spin lasers [2-4].

[1] J. Sinova *et al.*, *Nat. Mater*. **11**, 368 (2012). [2] Y. Ohno *et al.*, *Phys. Rev. Lett.* **83**, 4196 (1999). [3] S. Iba *et al., J. Appl. Phys.* **118**, 083901 (2015). [4] S. Iba *et al., Jpn. J. Appl. Phys.* in press.

Spin-controlled laser (spin laser)



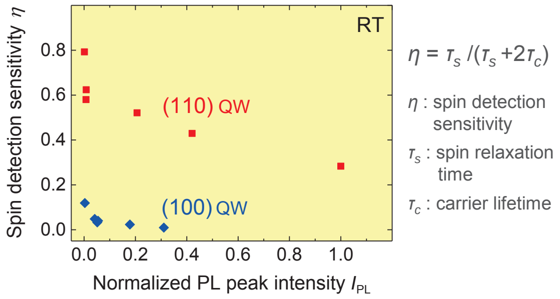
Spin injection by using ferromagnetic electrode

Circular dichroism gain in semiconductor emission layer

Features

- Circularly polarized coherent output
- Threshold current reduction
- High speed modulation
- Spin amplification & transmitter

High spin detection sensitivity and PL intensity of (110) QWs



$\eta = \tau_s/(\tau_s+2\tau_c)$

η : spin detection sensitivity

τ_s : spin relaxation time

τ_c : carrier lifetime

Q-12

Ground State Electroluminescence

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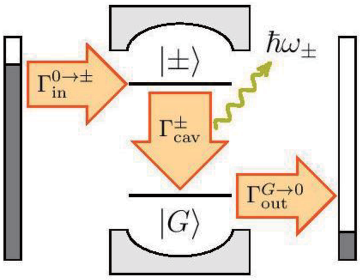
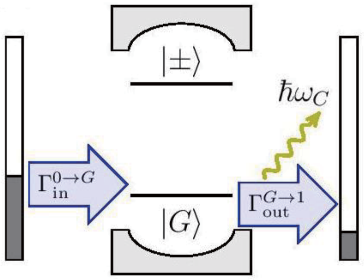
Electroluminescence, the emission of light in the presence of an electric current, provides information on the allowed electronic transitions of a given system. It is commonly used to investigate the physics of strongly coupled light-matter systems, whose eigenfrequencies are split by the strong coupling with the photonic field of a cavity. In this work, we showed that, together with the usual electroluminescence, systems in the ultrastrong light-matter coupling regime emit a uniquely quantum radiation when a flow of current is driven through them. While standard electroluminescence relies on the population of excited states followed by spontaneous emission, the process we describe herein extracts bound photons from the dressed ground state and it has peculiar features that unequivocally distinguish it from usual electroluminescence.



Schematics for standard electroluminescence. Electrons enter the system in an excited state, which decays emitting a photon at the polaritonic frequency.



Schematics for ground state electroluminescence. Electrons enter the system in the ground state which cannot decay. However, in the ultra-strong coupling regime, electrons can get out the system leaving one photon (at the bare cavity) frequency inside the cavity.

Q-13

Single photon-electron pairs generation from polarization entangled photon pairs

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[2] Lehrstuhl fur Angewandte Festkörperphysik Ruhr-Univ. Bochum
[3] The Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka, Japan
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Quantum entanglement has been studied in solid physics to realize distributed photonic quantum communication based on a quantum repeater. Nevertheless it is still challenging to experimentally demonstrate the entanglement between stationary solid qubits and photonic qubits [1, 2]. Here we try to generate the entanglement between an electron spin and a photon polarization by combining generation of polarization entangled photon pairs and coherent quantum state transfer from single polarized photons to single electron spins in a GaAs laterally defined quantum dots [3, 4]. In this work, we generated single entangled photon pairs using spontaneous parametric down conversion in a Type-II BBO crystal, and demonstrated coincidence measurement on the electron transferred from one of the entangled paired photons and the remaining photon.

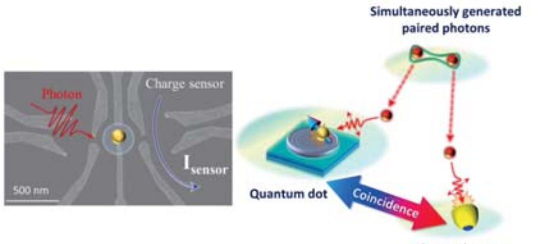

Fig.1 SEM image of the quantum dot device (left) and a schematic of the experiment setup (right)

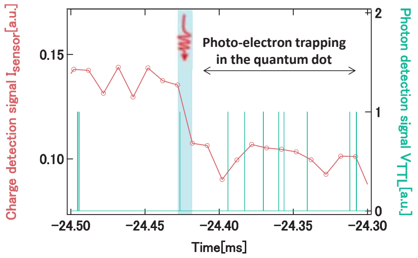

Fig.2 Time trace of the coincidence signals

1] K.De.Greve, *et al.*, Nature **491**, 421 (2012). [2] W.B.Gao, *et al.*, Nature **491**, 426 (2012) . [3] R.Vrijen and E.Yablonovitch, Physica E **10**, 569 (2001). [4] T.Fujita, *et al.*, arXiv 1504.03696(2015).

Q-14

Charge and spin dynamics in a quantum dot-lead coupled system

T. Otsuka[1,2], T. Nakajima[1,2], M. R. Delbecq[1], S. Amaha[1],
J. Yoneda[1,2], K. Takeda[1], G. Allison[1], P. Stano[1,3], A. Noiri[1,2], T. Ito[1,2],
D. Loss[1,4], A. Ludwig[5], A. D. Wieck[5], and S. Tarucha[1,2]

[1]RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan
[2]Department of Applied Physics, University of Tokyo, Bunkyo, Tokyo 113-8656, Japan
[3]Institute of Physics, Slovak Academy of Sciences, 845 11 Bratislava, Slovakia
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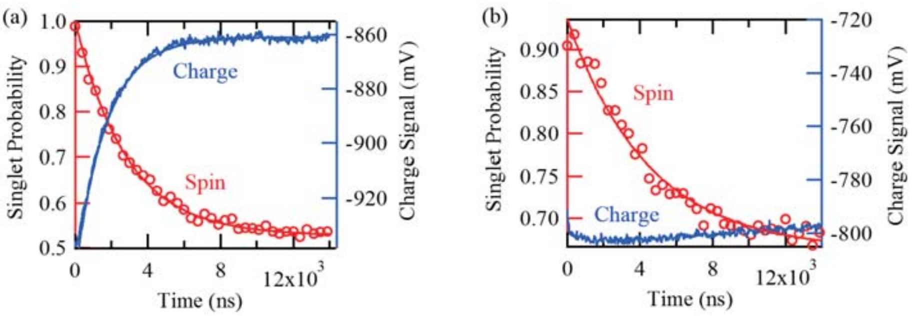
Electron spins in semiconductor quantum dots (QDs) are considered good candidates for quantum bits in quantum information processing. In this research field, control and readout of the spin states have been developed and established. We apply these techniques to explore spin dynamics in a hybrid system which consists of a QD and an open electronic reservoir. We observe spin relaxations in a QD under the effect of the coupling to a lead. By comparing the spin signals with the charge relaxation signals, we examine the mechanism of the spin state evolutions [Fig.(a) first- , (b) second-order tunneling process]. These results will be important in the exploration of further spin dynamics in QD-lead hybrid systems and utilized for spin manipulation.



Q-15

Measuring the time dependence of a Rabi oscillation of an electron spin in a semiconductor quantum dot

A. Noiri[1], T. Nakajima[2], J. Yoneda[2], T. Otsuka[2], K. Takeda[2], M. R. Delbecq[2],
G. Allison[2], K. Kawasaki[1], A. Ludwig[3], A. D. Wieck[3], S. Tarucha[1,2]

[1]Department of Applied Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
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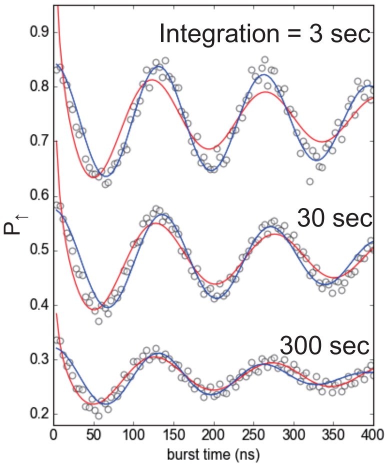
A Rabi oscillation of an electron spin in a semiconductor quantum dot (QD) has been demonstrated using electron spin resonance. Especially in III-V semiconductor QDs, the spin dynamics is influenced by nuclear spin fluctuation (σ) through the hyperfine interaction. Previous work on a GaAs QD [1] demonstrates the Rabi oscillations of two different regimes ($f_{\mathrm{Rabi}}/\sigma \gg 1$ and $f_{\mathrm{Rabi}}/\sigma \lesssim 1$) by changing the Rabi frequency f_{Rabi}. The Rabi oscillations of these two regimes are approximated by the following equation: $P_{\uparrow}(t_{\mathrm{MW}}) = A\exp(-(t_{MW}/T_2^{\mathrm{Rabi}})^2)\cos(2\pi f_{\mathrm{Rabi}} t_{\mathrm{MW}}) + B$(in $f_{\mathrm{Rabi}}/\sigma \gg 1$) [i], and $P_{\uparrow}(t_{\mathrm{MW}}) = At_{\mathrm{MW}}^{-0.5}\cos(2\pi f_{\mathrm{Rabi}} t_{\mathrm{MW}} + \pi/4) + B$ (in $f_{\mathrm{Rabi}}/\sigma \lesssim 1$) [ii], respectively.

We observe Rabi oscillations of these two regimes by fixing the f_{Rabi}, but changing σ by decreasing the data acquisition time to study the impact of the measurement time. The figure shows the Rabi oscillations measured with different integration times fitted by equation [i] (blue) and [ii] (red). With 3 sec integration time, the data is well fitted by the blue curve ($\sigma \ll f_{\mathrm{Rabi}}$). On the other hand, the data is well fitted by the red curve ($f_{\mathrm{Rabi}}/\sigma \lesssim 1$) for larger integration times. This indicates that σ increases by increasing the integration time in agreement with the recent work [2].



Reference
[1] J. Yoneda et al., PRL (2014).
[2] M. R. Delbecq et a., PRL (2016).

Q-16

Transport properties of InAs nanowires on hexagonal boronnitride

H. Kamata[1,2], R. S. Deacon[1,3], S. Matsuo[2], S. Baba[2], K. Li[4],
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[2]Department of Applied Physics, University of Tokyo, Bunkyo, Tokyo, Japan
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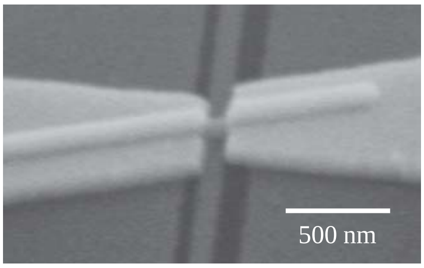
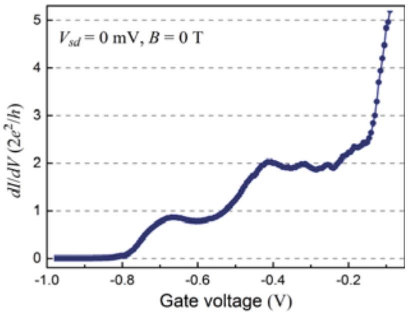
[6]The Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka, Japan

InAs nanowires, which have a surface charge accumulation layer and exhibit a strong spin-orbit interaction, are predicted to be good candidates for the observation of helical states and furthermore Majorana bound states in a hybrid superconductor device. Although ballistic transport in nanowires plays an important role in creating a topological phase transition in proximitized nanowires, conductive electrons in the accumulation layer experience strong surface roughness scattering and ionized impurity scattering such that the transport is entirely diffusive. Here, to suppress such scatterings we employ hexagonal boronnitride as a gate dielectric, and demonstrate conductance quantization in InAs nanowires at zero magnetic field.





Q-17

Proximity induced triplet supercurrent in Nb/(In, Fe)As/Nb junctions

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The Institute for Solid State Physics, The University of Tokyo, Chiba 277-8581, Japan

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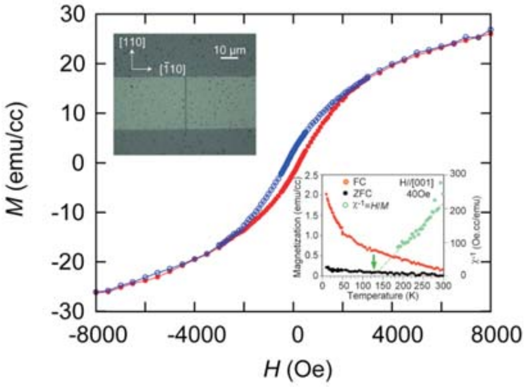
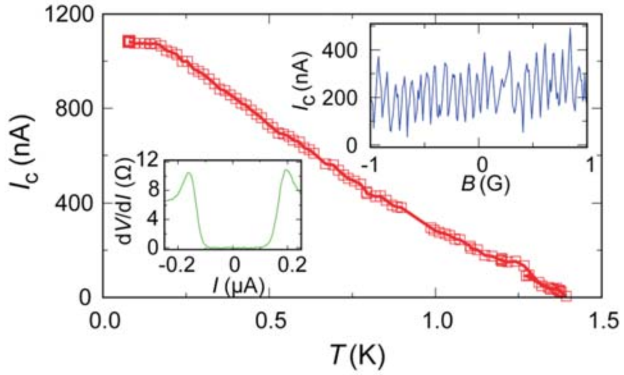
Superconductor/ferromagnet/superconductor (SFS) junctions exhibit attractive phenomena such as π junction states or triplet Cooper pairs. In order to explore such spin-related superconducting phenomena, we fabricated Nb based SFS junctions on an n-type ferromagnetic semiconductor (In,Fe)As.

Figure 1 represents the *M*-*H* curve of the (In,Fe)As in the sample and the insets show a optical micrograph and the temperature dependence of the magnetization. The (In,Fe)As exhibits clear hysteresis and its Curie temperature is about 120 K. We observed clear zero resistance states, namely finite triplet supercurrent, as shown in the lower left inset of Fig.2. The critical currents exhibit oscillation as a function of the magnetic fields, suggesting the existence of superconducting coherence in the (In,Fe)As due to the Josephson effect. The temperature dependence also indicates the superconducting proximity effect in the (In,Fe)As.





Q-18

Construction of van der Waals magnetic tunnel junction using ferromagnetic layered dichalcogenide

R. Moriya[1], Y. Yamsasaki[1], M. Arai[1], S. Masubuchi[1], K. Ueno[2], and T. Machida[1,3]

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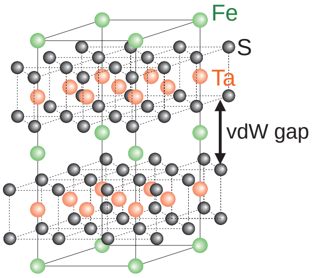
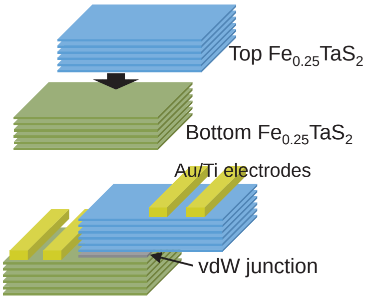
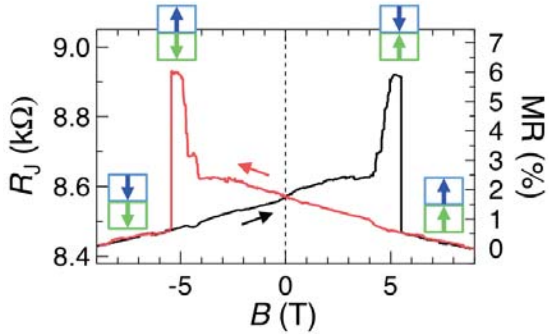
[3] *CREST-JST*

We investigate the micromechanical exfoliation and van der Waals (vdW) assembly of ferromagnetic layered dichalcogenide $Fe_{0.25}TaS_2$. The vdW interlayer coupling at the Fe-intercalated plane of $Fe_{0.25}TaS_2$ allows exfoliation of flakes. A vdW junction between the cleaved crystal surfaces is constructed by dry transfer method. We observe tunnel magnetoresistance in the resulting junction under an external magnetic field applied perpendicular to the plane, demonstrating spin-polarized tunneling between the ferromagnetic layered material through the vdW junction.







Q-19

Cluster-multipole-driven Anomalous Hall Effect in antiferromagnets

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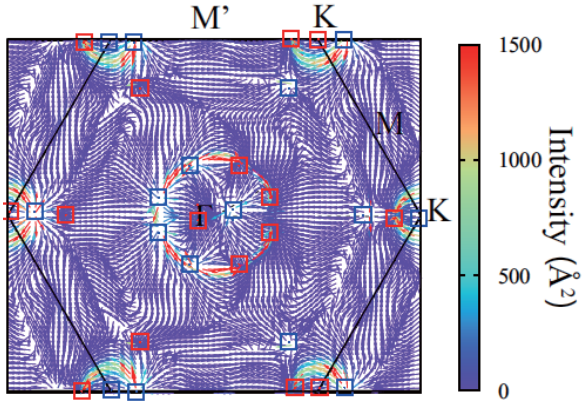
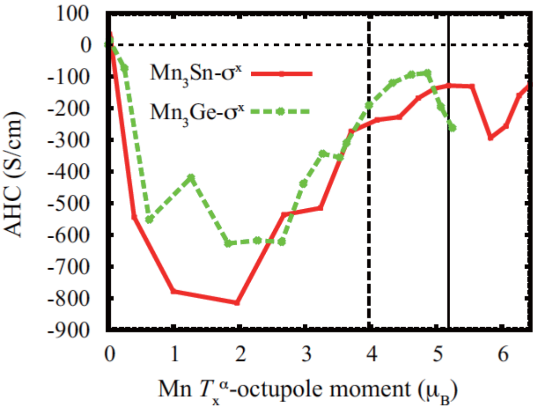
[1]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan*
[2]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*

Modern formalism of intrinsic anomalous Hall conductivity (AHC), which expresses AHC as non-vanishing effect of Berry curvatures, has provided profound insight of anomalous Hall effect (AHE). We have investigated the electronic structure, Berry curvature (left figure), Weyl node's chirality (blue (+1) and red (-1) squares in left figure), and AHC (right panel) in the antiferromagnetic (AFM) states of Mn$_3$***Z*** (***Z*** =Sn, Ge) by first-principles calculations. We show that the AFM states of Mn$_3$***Z*** produce a number of Weyl nodes and generate complex flows of Berry curvature around the Fermi level (Left figure). We provide a comprehensive theoretical framework of AHC for general magnetic systems by introducing order parameters using multipole formalism for magnetic clusters and show that the AFM states of Mn$_3$***Z*** are characterized by an octupolar moment. We show that the new order parameters, generalized from the ordinary magnetization, make it possible to discuss AHE for AFM systems in the same framework of AHE for ordinary ferromagnetic systems.





Q-20

Spin resonance effects in parallel-coupled quantum dots

G. Giavaras[1] and F. Nori[1,2]

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[2]*Department of Physics, University of Michigan, Michigan, USA*

Electrical detection of spin resonance is examined theoretically for a system of two parallel-coupled quantum dots. The energy levels of the two dots are adjusted so that the first dot is occupied by a single spin during the dynamics [1]. The second dot is a tunnel-coupled to metallic leads allowing current to flow through the system (Figure 1). We shown that in the presence of an oscillating magnetic field and for a specific gate voltage regime current flows only when the applied microwave frequency equals the Zeeman splitting of the single spin. This results in a current peak indicative of the single-spin resonance. From the general current plot the lowest two-electron levels can be mapped-out (Figure 2). Thus, for example, in the presence of spin-orbit interaction the size of the anticrossing gap can be estimated [2]. The system studied here is relevant to silicon devices where spin impurities are often coupled to quantum dots as well as to coupled donor-dot systems.

[1] Giavaras and Nori, Phys. Rev. B in press

[2] Giavaras and Nori, in preparation.

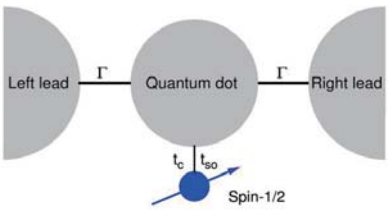

Figure 1: Physical system.

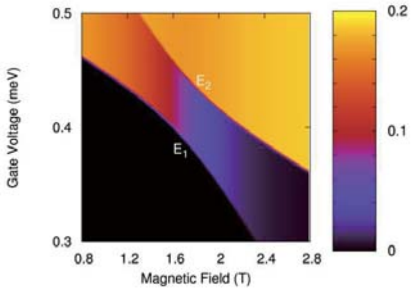

Figure 2: Electrical current through the quantum dot due to electron-spin-resonance, in the presence of spin-orbit-interaction.

Q-21

Effects of skew scattering on non-dissipative transport properties

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For non-dissipative transport phenomena, such as the anomalous Hall effect (AHE) and the spin Hall effect (SHE), the skew scattering plays an important role [1-3]. Its contributions to AHE and SHE are proportional to the inverse of the impurity concentration, and thus dominant in clean systems, but they are known to vanish for the two-dimensional Rashba model with the point-like (non-magnetic) impurity potential [4]. It is of interest to find any conditions for the skew scattering to contribute, and the way to enhance the effects.

In order to reveal these points, we calculate the skew scattering terms (Fig.1) for AHE and SHE for the following two systems; (1) a general single-band model, and (2) three-dimensional Dirac electrons as a simple multi-band model. In both models, point-like nonmagnetic impurities are assumed as electron scatterers. For model (1), we found that the skew-scattering term vanishes if the damping of electrons is independent of spin.

In contrast, for model (2), in which the damping of electrons is spin-independent, the skew scattering does contribute to SHE. This is because the damping is band-dependent, and this works to simulate the spin-dependent scattering (in the case of single-band model).

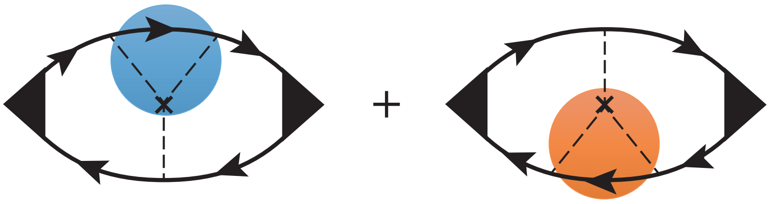

Fig. 1

[1] J. Smit, Physica **21**, 877 (1955); **24**, 39 (1958).
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Q-22

Large Chern number in films of transition metal oxides

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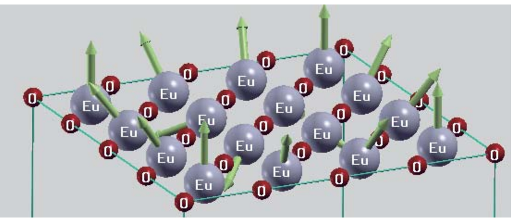
Skyrmion crystals could show large anomalous Hall conductivity(AHC) which changes drastically as a function of Fermi level[1], and thus we expect large anomalous Nernst effect as well[2].

Such AHC is attributed to spin chirality[3] generated by non-trivial spin structure, and its realization in realistic materials is searched for both theoretically[4] and experimentally[5][6].

However, the origin of such energy dependence of AHC is not clear yet, and therefore the purpose of this study is to understand it from first principles calculations by varying spin structures.

We calculated energetics of magnetic structures and Chern numbers of each band[7], which is the contribution of the band to AHC, in films of transition metal oxides by first principles code OpenMX[8]. In this presentation, we report the results and discuss the origin of large Chern number.



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Q-23

Lowering electron temperature for measurement of spin relaxation in quantum dots

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and S. Tarucha[1,2]

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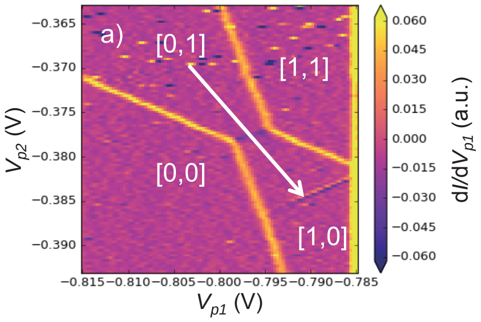
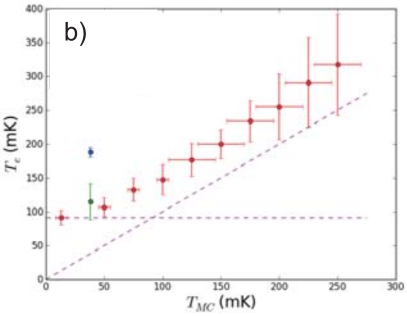
Quantum dots (QDs) coupled to electron reservoirs (i.e. electric leads) are good platforms to study open and/or non-equilibrium systems. Furthermore a new coupling regime showing non-trivial dynamics may be reachable if measurements are performed over very short time scales and at low temperatures. In this work we present our efforts to reduce the electron temperature (T_e) of a double QD system. T_e is determined from analysis of the charge transition as a function of gate voltages as an electron moves from the left to the right QD (indicated by the arrow in the stability diagram shown in Fig. a) and compared with the temperature of the dilution refrigerator (Fig. b).





Q-24

Quantum Monte-Carlo study of quantum spin ice under a [111] magnetic field

T. A. Bojesen[1] and S. Onoda[1,2]

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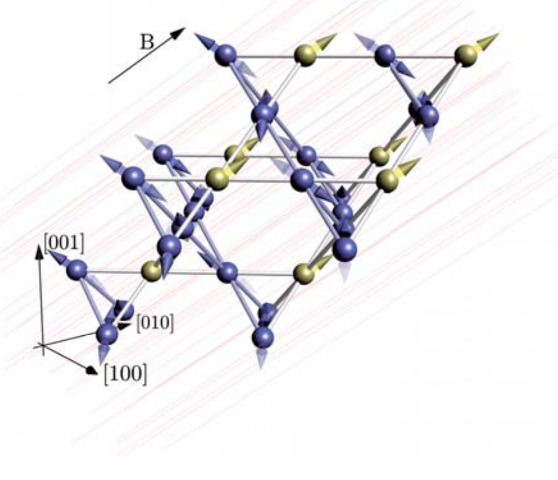
The quest for novel quantum spin liquids (QSL) has been an intriguing issue in condensed matter physics. Recent quantum Monte-carlo (QMC) simulations have demonstrated a crossover from a pyrochlore spin ice to a U(1) QSL ground state when nearest neighbor spin flip exchange interactions are turned on. [Y. Kato and S. Onoda, Phys. Rev. Lett. 115, 077202 (2015)]

In this work we have investigated the fate of the U(1) QSL under a [111] magnetic field using extensive unbiased QMC simulations. It is found that the classical-to-quantum crossover on cooling - confirmed at zero magnetic field in the previous study - continues to moderately high magnetic field. Kagomé ice entropy and magnetization plateaux appears in an intermediate temperature and field region, which is followed by a release of the entropy at lower temperatures. Predictions for the spin-polarized neutron scattering profile and transport coefficients are made on a basis of the simulations.



Q-25

High-Fidelity Readout of Two-Spin Correlations Using a Metastable Charge State in Triple Quantum Dots

T. Nakajima[1], M. R. Delbecq[1], T. Otsuka[1], P. Stano[1], S. Amaha[1], J. Yoneda[1], A. Noiri[2], K. Kawasaki[2], K. Takeda[1], G. Allison[1], A. Ludwig[3], A. D. Wieck[3], and S. Tarucha[1,2]

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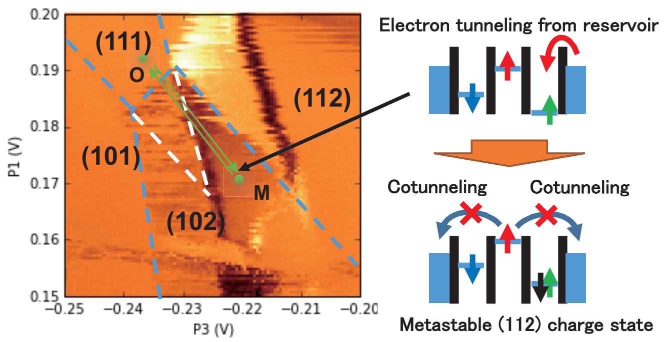
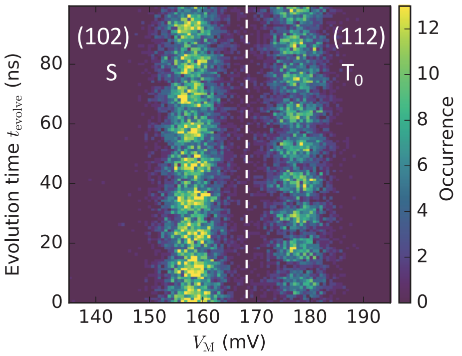
Probing electron spin correlations is an essential ingredient for spin-based quantum information processing and for studying mesoscopic quantum spin dynamics. In semiconductor quantum dots, the Pauli spin blockade is an established spin-to-charge conversion technique used to distinguish a spin singlet and triplets.

In this work, we demonstrate a new spin-to-charge conversion technique using a metastable charge state in triple quantum dots, which significantly improves the signal-to-noise ratio and the reliability. As shown in the left figure, spin-blocked states are transferred to a stable charge state by loading an extra electron from a reservoir. This allows for high-fidelity single-shot readout of spin correlations in a quantum dot array as demonstrated in the histogram plot in the right figure.





Q-26

Centre resonance frequency shift of a strongly driven silicon quantum dot spin qubit

K. Takeda[1], J. Kamioka[2], J. Yoneda[1], T. Otsuka[1], M.R. Delbecq[1], G. Allison[1], T. Nakajima[1], T. Kodera[2], S. Oda[2], and S. Tarucha[1]

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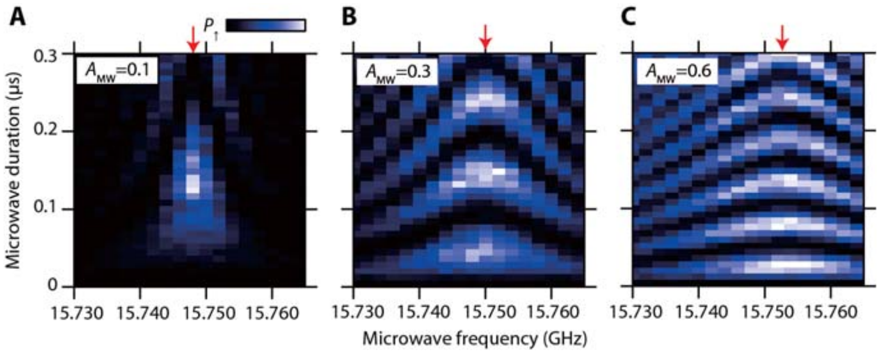
Electron spins in silicon quantum dots are one of the most promising candidates for implementing high-fidelity qubits in solid-state quantum computing. Here we report the effect of strong microwave excitation of a Si/SiGe spin qubit with a micro-magnet field gradient. To increase the qubit fidelity, it is straightforward to apply large microwave power to increase the Rabi oscillation frequency (f_{Rabi}) and therefore increase the number of possible operations within the coherence time. However, as the microwave power is increased, in addition to the increasing f_{Rabi}, we observe a shift of the centre resonance frequency of several MHz. To implement a high-fidelity qubit, the frequency shift has to be taken into account since it causes an unwanted phase accumulation for the qubit. We finally show that the qubit phase accumulation can be reduced by the quadrature microwave control.



Q-27

High-fidelity spin control in an enriched Si/SiGe quantum dot with a micromagnet

J. Yoneda[1], K. Takeda[1], T. Otsuka[1], T. Nakajima[1], M.R. Delbecq[1], G. Allison[1], T. Honda[2], T. Kodera[2], S. Oda[2], Y. Hoshi[3], N. Usami[4], K.M. Itoh[5], and S. Tarucha[1]

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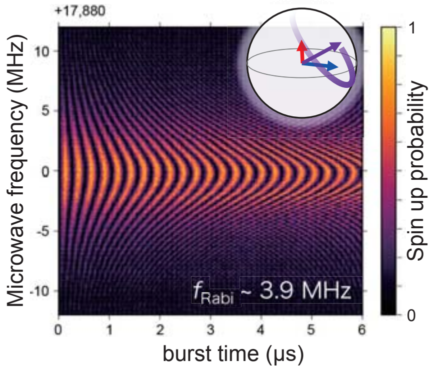
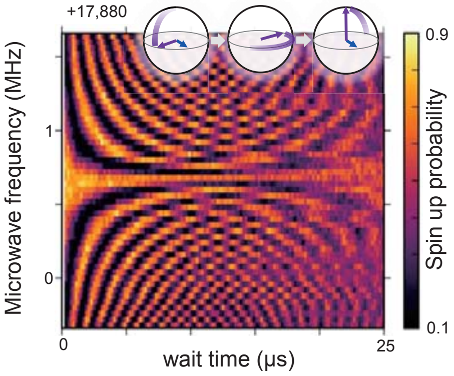
Improving control fidelities well beyond the fault-tolerant threshold is imperative to alleviate stringent requirements on quantum processing architectures. In a scalable quantum-dot-qubit platform, fidelities just above the surface-code threshold have been achieved either by use of isotopically purified materials or local magnetic fields of a proximal micromagnet. Here we demonstrate that by unifying these approaches, one can obtain high compatibility of long phase coherence (T_2^*~20 μs) and fast controllability (T_π ~ 40 ns), to realize < 0.1 % error rate per qubit gate. These results provide a promising route to large-scale, fault-tolerant quantum computing systems based on quantum-dot spins.





Q-28

Magnetic Analogue of Superconductivity in Quantum Spin Ice

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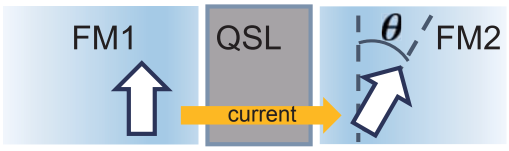
RIKEN, Wako, Saitama 351-0198, Japan

We discuss unconventional magnetic interference phenomena of spinons coupled with emergent U(1) gauge field which is considered to be a relevant description of quantum spin ice systems.

Quantum spin ice monopoles are deconfined bosonic quasiparticles which carry a fractionalized spin-1/2 charge. When they show a Bose-Einstein condensation, a magnetic order appears as in the Higgs ferromagnetic phase of Yb2Ti2O7 [1]. In an analogue of superconducting systems, the condensation behaves like that of Cooper pairs. Naively, magnetic analogue of Josephson effects are expected to occur at a junction systems of quantum spin liquid, which corresponds to insulating barrier in usual Josephson junctions, terminated by two domains having different ferromagnetic moment directions. This might show a remarkable contrast to the conventional ferromagnets where spin waves have dissipation and damping.

For the calculation of a proximity effect of ferromagnetic phases to a quantum spin liquid phase, we perform the gauge mean field theory proposed in Ref.[2] dealing with spatially dependent gauge fields in the junction system. The transport of monopole charges is investigated by imposing a boundary condition specific to ferromagnetic domains and/or introducing domains in basic parameters to produce such a junction systems. A possible relevance of the results to ultraslow spin relaxation observed in some Yb2Ti2O7 samples is discussed.



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Q-29

Hybrid cQED architecture as a model system for non-equilibrium physics in condensed matter

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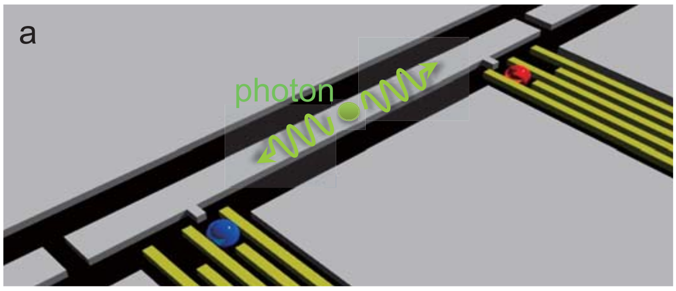
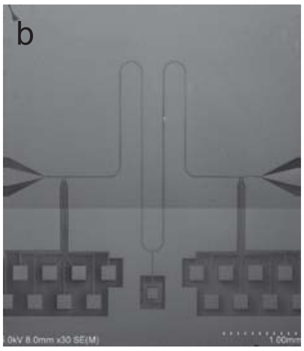
As the number of Quantum Dots used in arrays for semiconductor based quantum computing increases one needs to think of a way to transfer information coherently from one block of quantum dots to another. We show a scheme (figure a) to implement this using SiGe quantum dots and a superconducting cavity (figure b). When the superconducting cavity is tuned to be occupied by no more than one photon this photon may be used to coherently transfer information between the two quantum dots. This is an important step towards an enlarged quantum dot architecture. It has been shown by other groups that a charge state in one dot can be transferred to and read out using the resonator. Due to the weak magnetic coupling we need to engineer an electric coupling to couple to the spin.

This system is further interesting as it is an ideal platform to simulate various condensed matter systems which cannot be solved classically.





Q-30

Detection and control of the charge states of a quintuple quantum dot in a scalable multiple quantum dot architecture

Takumi Ito[1, 2], Tomohiro Otsuka[1, 2], Shinichi Amaha[1], Matthieu R. Delbecq[1, 2], Takashi Nakajima[1, 2], Jun Yoneda[1, 2], Kenta Takeda[1, 2], Giles Allison[1], Akito Noiri[1, 2], Kento Kawasaki[1, 2] and Seigo Tarucha[1, 2, 3]

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Multiple Quantum dots (QDs) can offer intriguing fermionic Hubbard models and are also proposed to implement spin-based quantum computing. However, further scale up of the QD system beyond quadruple QDs requires technical advances. In this work, we realize a semiconductor quintuple quantum dot (5QD) or series coupled five quantum dots with a new sample architecture relevant for further scaling up the QD system. Figures show the stability diagram measured for the left three dots QD_1 to QD_3 (a), and the right three dots QD_3 to QD_5 (b) using the left, and right charge sensors, respectively. Multiple QDs have complicated charge configurations, which need to be defined in multiple voltage planes. Therefore, we divide the 5QD into two triple QDs each having two reservoirs and one charge sensor to predominantly address the nearest three dots. This technique will be applicable to multiple QDs in a scalable manner.