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

Oct 12-15, 2016, Tokyo, Japan

A B S T R A C T B O O K

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

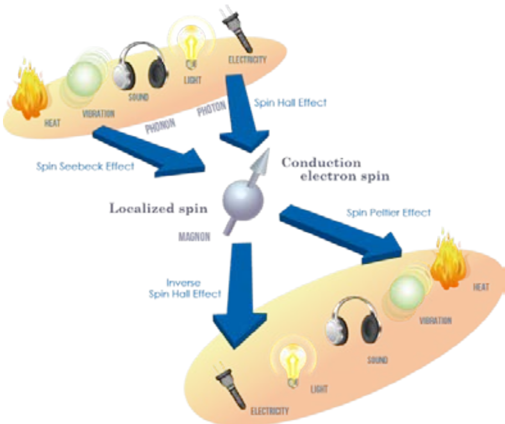
RIKEN Center for Emergent Matter Science

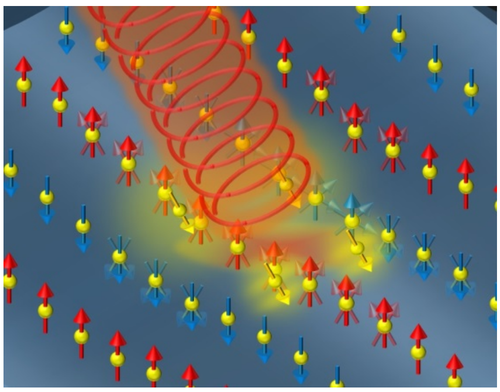
S. Tarucha, K. Ishibashi, K. Kono, G. Tatara

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

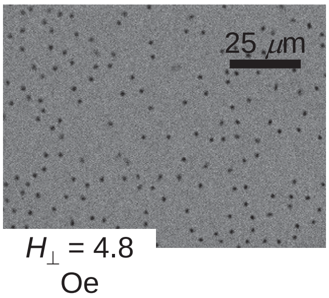
W1

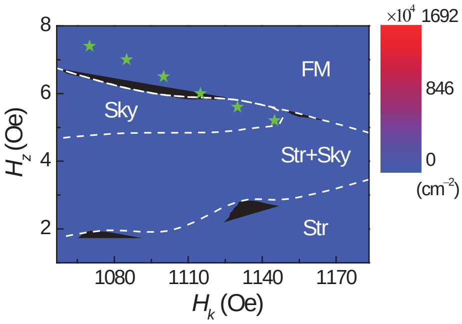
Spin Dynamics and Textures via Interfacial Spin-Orbit Coupling

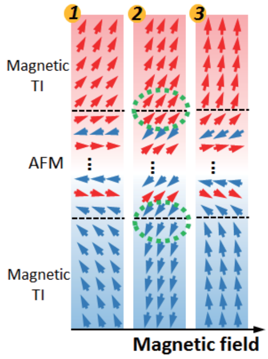
Kang L. Wang

Electrical and Computer Engineering, Materials Sciences and Engineering, and Physics, University of California Los Angeles, California 90095, United States, E: wang@ee.ucla.edu;

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

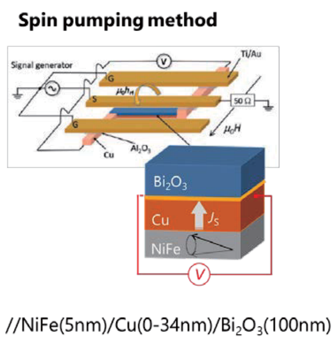
Spin to charge interconversion at the interfaces with strong SOI

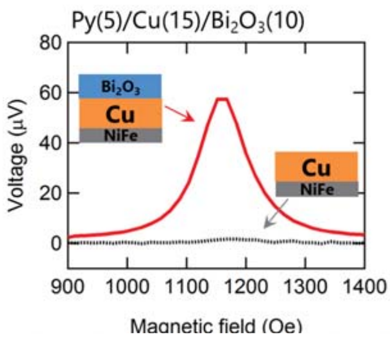
Y. Otani[1,2] S. Karube[1], J. Kim[2], K. Kondou[2]

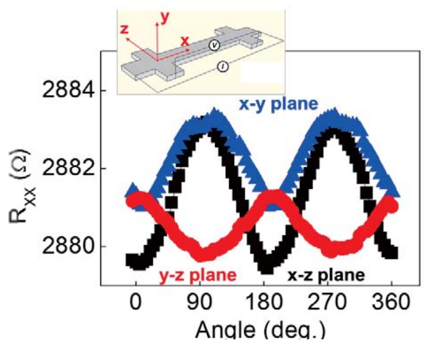
[1]*ISSP, University of Tokyo, Kashiwa 277-8681, Japan*

[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.







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]

[1]CNRS/Thales, F-91767 Palaiseau, France

[2] IJL-CNRS/U. Lorraine, F-54506 Vandoeuvre-Les-Nancy, France

[3]CEA, Grenoble, F-38000 France

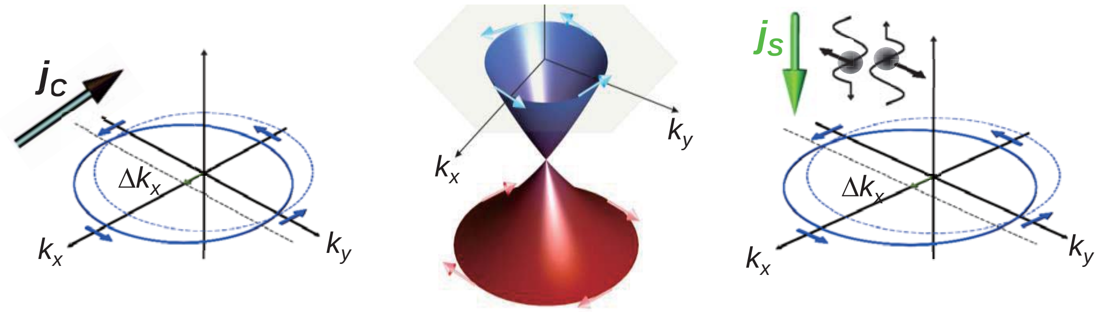
[4]Osaka Univ., Suita 565-0871,Japan

[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

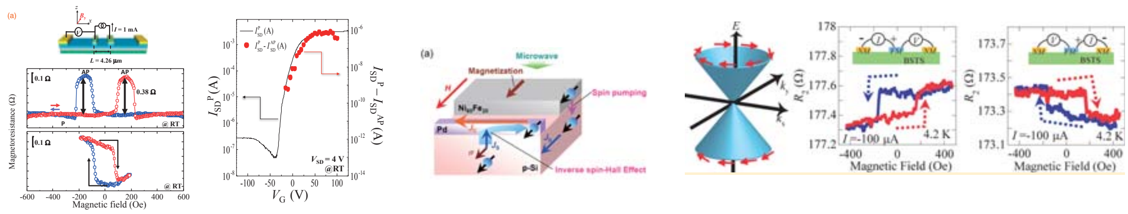
Masashi Shiraishi

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]

[1]*CIC nanoGUNE, 20018 San Sebastian, Basque Country, Spain*
[2]*IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Basque Country, Spain*

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.

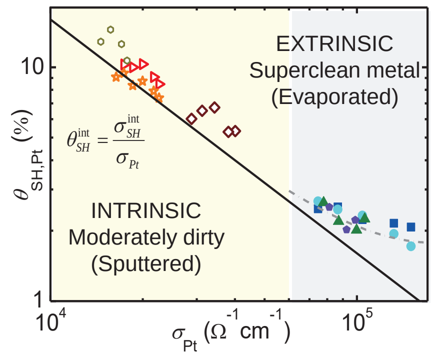


FIG.1. Conductivity dependence of the spin Hall angle of Pt.

[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*)

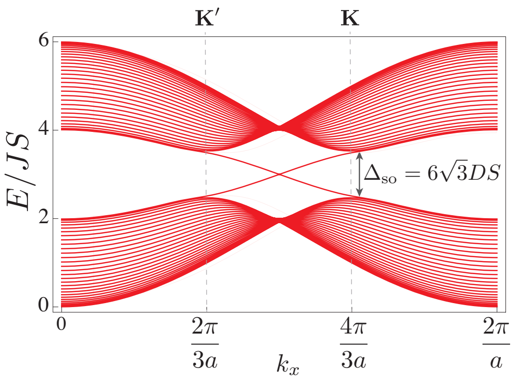
W6

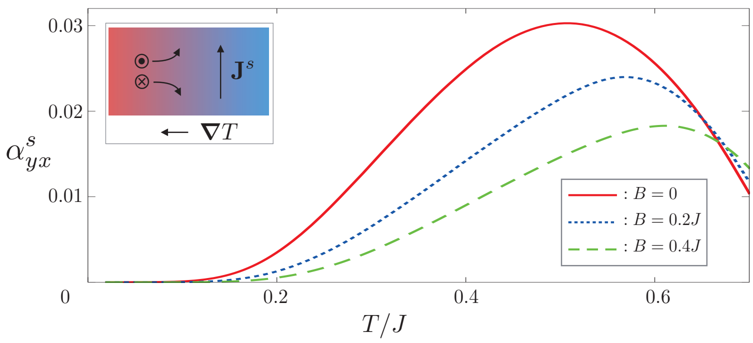
A Realization of the Haldane-Kane-Mele Model in a System of Localized Spins

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)

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.

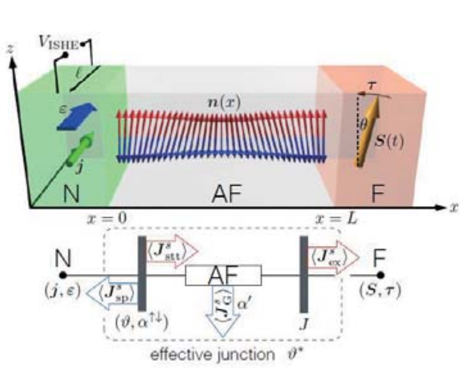


Figure 1 Spin current transmission in antiferromagnetic NiO.

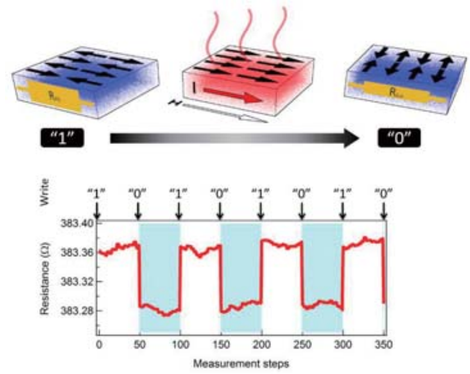


Figure 2 Sequential write-read in FeRh antiferromagnetic bit.

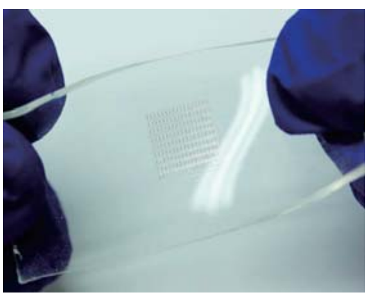
Flexible magnetic tunnel junctions and spin-orbit torque dynamics

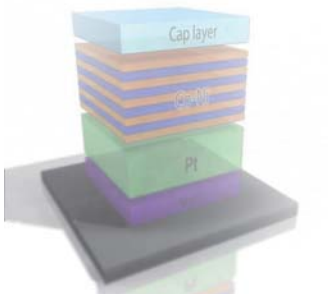
Hyunsoo Yang[1]

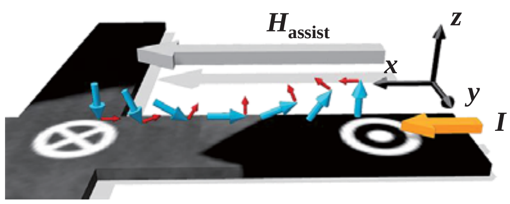
[1]*Department of Electrical and Computer Engineering, National University of Singapore, Singapore*

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.







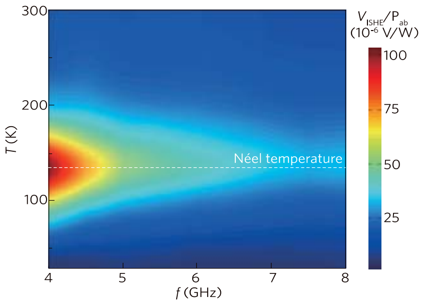
W9

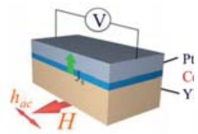
Spin Current Generators

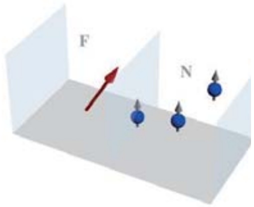
Eiji Saitoh[1,2,3,4]

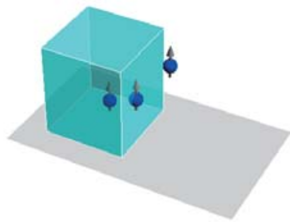
[1]ERATO-SQR, JST, Tokyo, 102-0076, Japan
[2]WPI-AIMR, Tohoku University, Sendai 980-8577, Japan
[3]Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan
[4]ASRC, Japan Atomic Energy Agency, Tokai 319-1195, Japan

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.









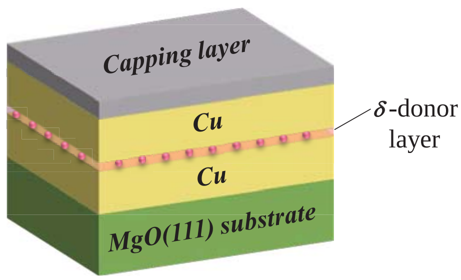
W10

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

Xiaofeng Jin

Department of Physics, Fudan University, Shanghai, 200433, China

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

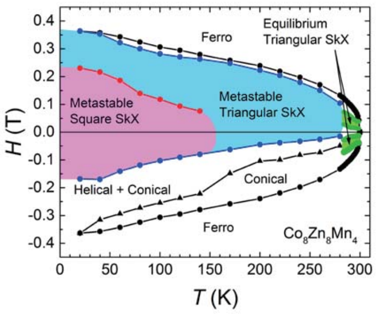
Y. Tokura[1,2]

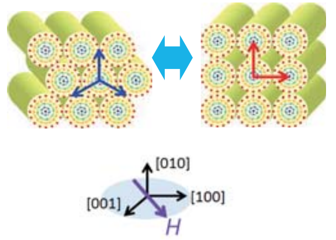
[1]RIKEN Center for Emergent Matter Science (CEMS), Wako351-0198, Japan
[2]Department of Applied Physics, University of Tokyo, Tokyo 11-8656, Japan

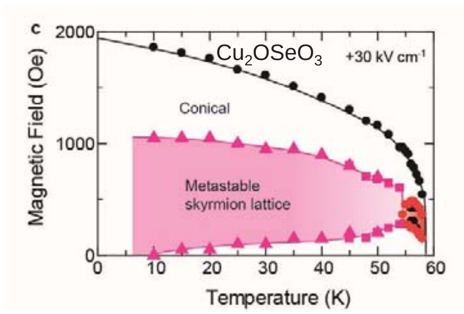
Magnetic skyrmions, as characterized and protected by topological charge, are generically observed in cubic chiral-lattice magnets, such as MnSi/FeGe type B20 compounds, Cu2OSeO3, and b-Mn type Co-Zn-Mn alloys. The thermodynamical skyrmion-lattices, mostly of hexagonal form, can be found in a narrow 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)

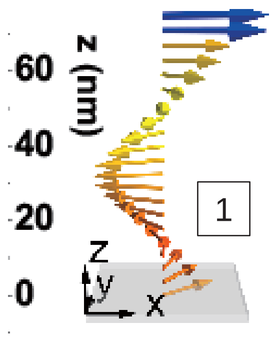
T2

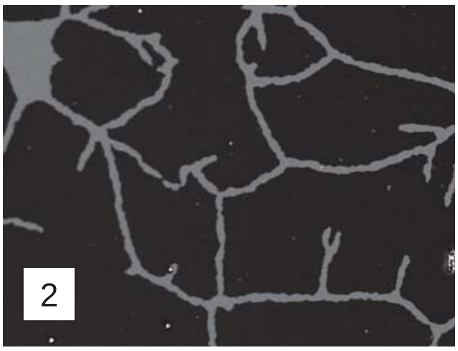
Chiral interactions in thin film magnets

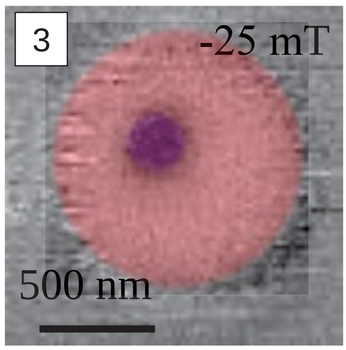
C. H. Marrows

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]).







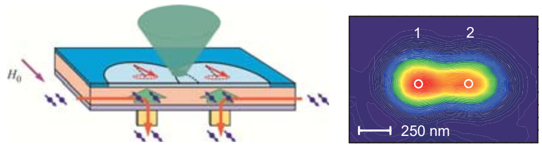
T3

Magnetization oscillations and waves driven by pure spin currents

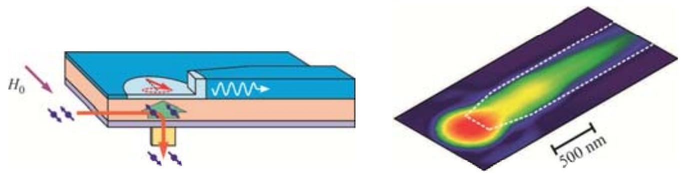
V. E. Demidov

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]
T. Koretsune[1], R. Arita[1], J. Shibata[4], H. Kohno[5]

[1]RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Japan
[2]Tokyo Metropolitan University , Hachioji 192-0397, Japan
[3]Toyo University,Kawagoe 350-8585, Japan
[4]Aoyama Gakuin University, Sagamihara 252-5258, Japan
[5]Nagoya University, Nagoya 464-8602, Japan

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*

Theo Rasing

Radboud University, Institute for Molecules and Materials, Heijendaalseweg 135, 6525AJ Nijmegen, the Netherlands
th.rasing@science.ru.nl

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.

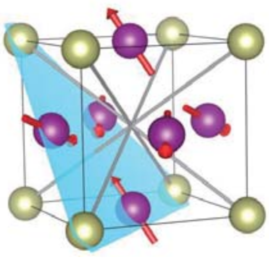
T6

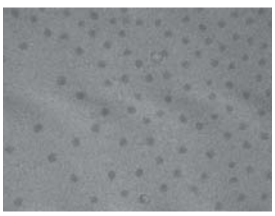
Spin-orbitronic materials and devices

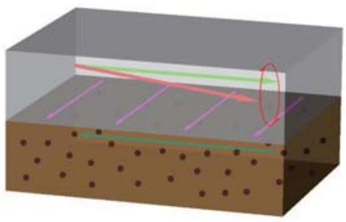
Timothy Phung[1]

[1]IBM Almaden Research Center, San Jose, California 95120, USA

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]

[1]Department of Physics, Tokyo Institute of Technology, Ookayama, Meguro-ku, Tokyo 152-8551, Japan
[2]TIES, Tokyo Institute of Technology, Ookayama, Meguro-ku, Tokyo 152-8551, Japan

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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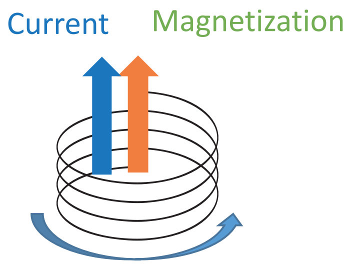


Fig. 1. Schematic picture of a solenoid

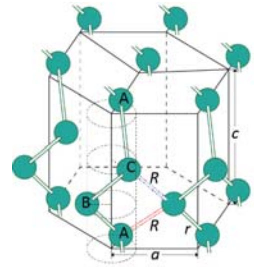


Fig. 2. Crystal structure of Te

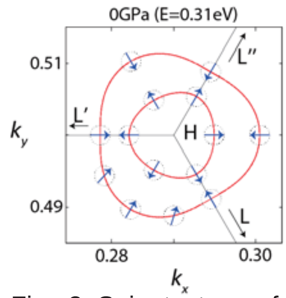


Fig. 3 Spin texture of the conduction bands in Te

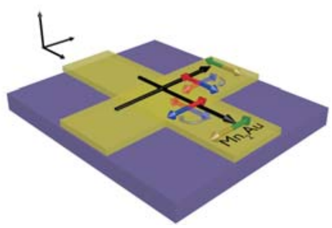
Antiferromagnetic Spin-Orbitronics

T8

Jairo Sinova[1]

[1]Johannes Gutenberg University Mainz, Staudingerweg 7, Mainz 55128

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

Dieter Weiss*)

Institut für Experimentelle und Angewandte Physik, Universität Regensburg, D-93040 Regensburg, Germany

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.*

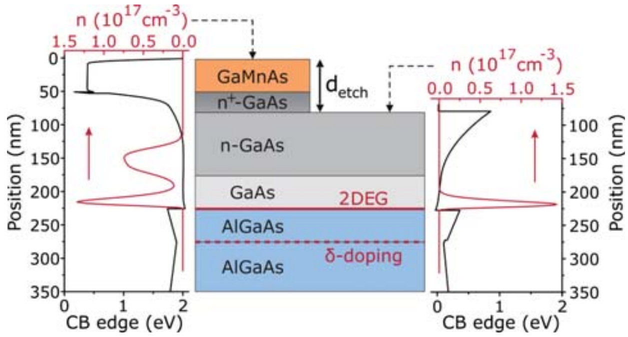


Fig. 1. Layout of the heterojunctions used for spin-injection/detection. The profile of the conduction band and of the electron density n is shown with (left) and without (right) Esaki junction. Etching of the highly doped (Ga,Mn)As and n^+-GaAs layers depletes the bulk of electrons, thus enabling exclusive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

[1]Naval Research Laboratory, Washington, DC 20375, USA
[2]NRC Research Associate at the Naval Research Laboratory, Washington, DC 20375, USA
[3]Sotera Defense Solutions, Inc., Annapolis Junction, MD 20701, USA
[4] US Naval Academy, Annapolis, MD 21402, USA
[5] Department of Physics, Virginia Tech, Blacksburg, Virginia 24061, USA

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].

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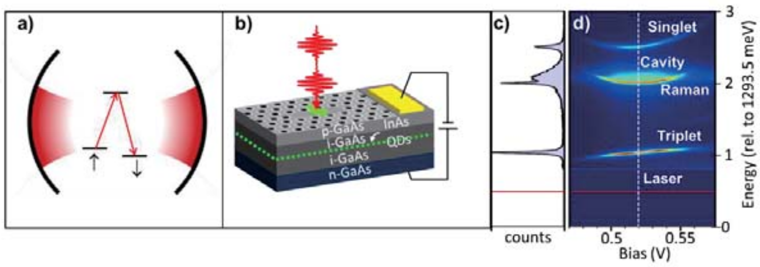


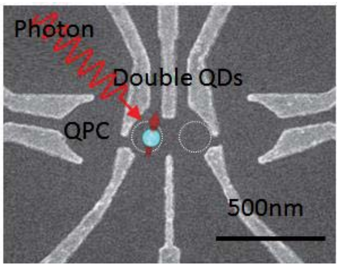
F2

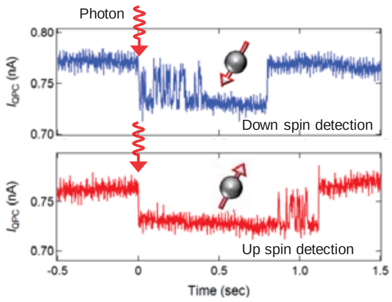
Photon-electron spin Poincaré interface using gate-defined quantum dots

A. Oiwa[1,2]

[1] The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan
[2] Center for Spintronics Research Network (CSRN), Graduate School of Engineering Science, Osaka University, Machikaneyama 1-3, Toyonaka, Osaka 560-8531, Japan

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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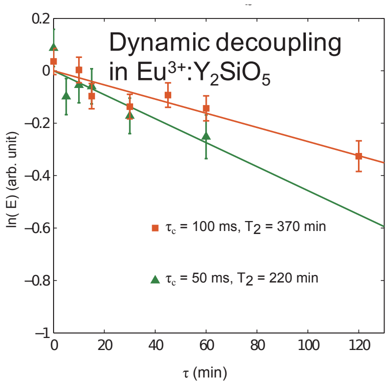
F3

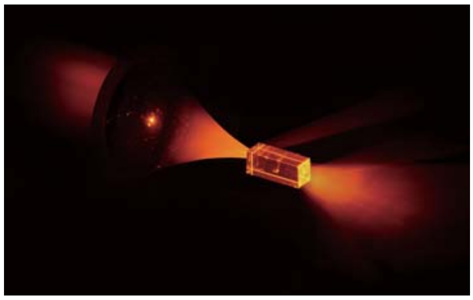
Spin wave storage of light using rare-earth doped crystals

M.J. Sellars[1]

[1]Centre for Quantum Computation and Communication Technology, Research School of Physics and Engineering, The Australian National University, Canberra 2600, Australia

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]

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

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]

[1] *CEMS, RIKEN, Saitama, Japan.* [2] *University of Michigan, Ann Arbor, USA*

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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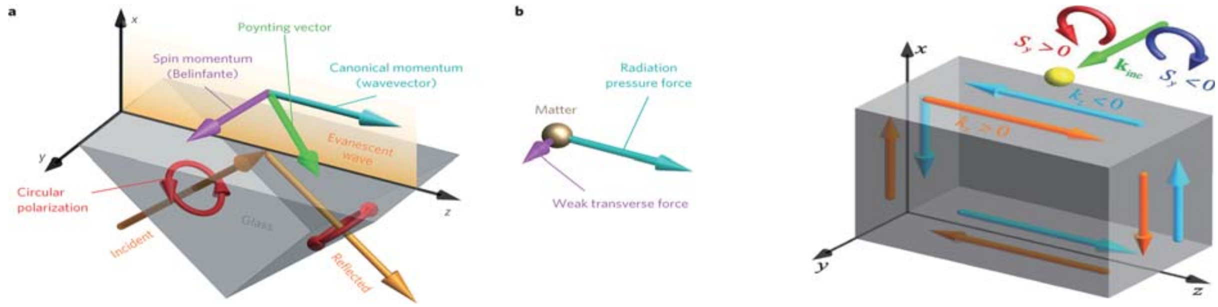

F6

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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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.

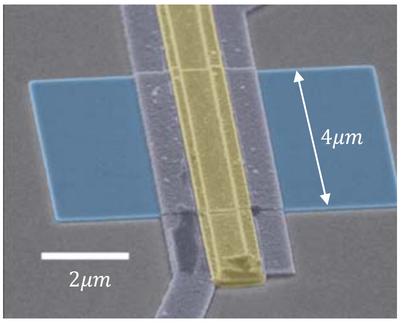
F8

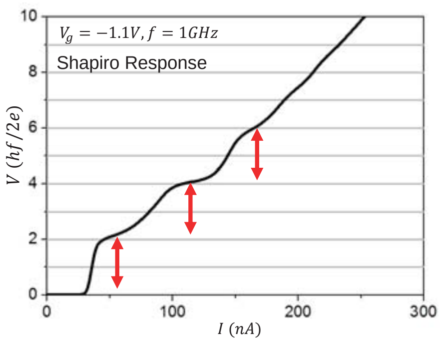
Signatures of 4π periodicity in the dynamics of HgTe Josephson junctions

R.S. Deacon[1], J. Wiedenmann[2], E. Bocquillon[2],
T. Klapwijk[3], S. Tarucha[1,4], K. Ishibashi[1], L.W. Molenkamp[2]

[1]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan.*
[2]*Physikalisches Institut (EP3), Universität Würzburg, Germany.*
[3]*Kavli Institute of Nanoscience, Faculty of Applied Sciences, Delft, The Netherlands.*
[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

[1]Department of Physics, University of Basel, Switzerland
[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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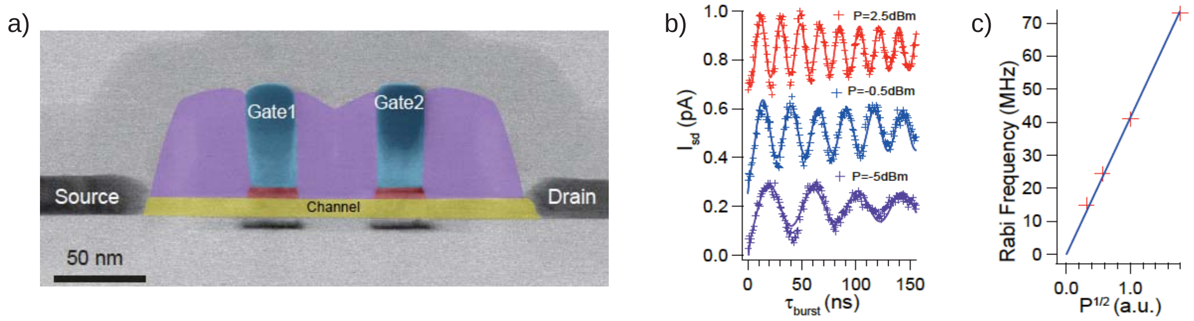
F10

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]

[1]CEA, INAC, F-38000 Grenoble, France
[2]CEA, LETI, Minatec Campus, F-38054 Grenoble, France
[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.



S1

Coherent long-distance displacement of individual electrons

Tristan Meunier[1, 2]

[1]*Univ. Grenoble Alpes, Inst NEEL, F-38042 Grenoble, France*
[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.

References

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S2

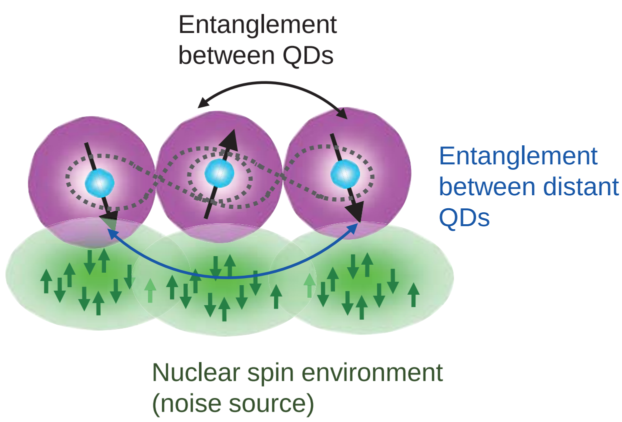
Distance-independent Dephasing of Phase-controlled Spin Entanglement

S. Tarucha[1,2]

[1]*RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan*
[2]*Schoolo of Engineering, The University of Tokyo, Hongo 113-8656, Japan*

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]

[1]*Department of Physics, McGill University, Montreal, Quebec, Canada*

[2]*Quantum Information Science Program, Canadian Institute for Advanced Research, Toronto, Ontario, Canada*

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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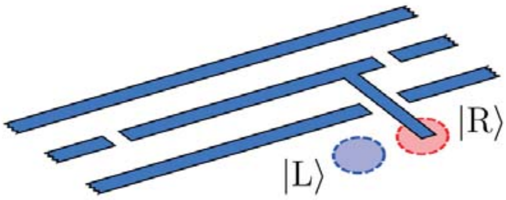
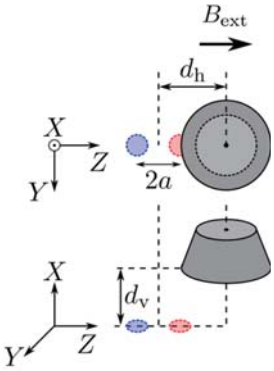




S4

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

Y. Hirayama[1,2,3]

[1]*Graduate School of Science, Tohoku University, Sendai, Miyagi 980-8578, Japan*

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

[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 ν=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.

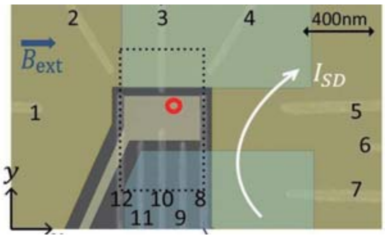
S5

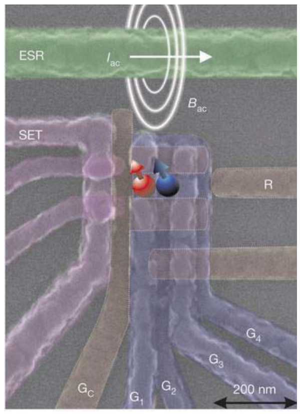
Quantum logic in silicon

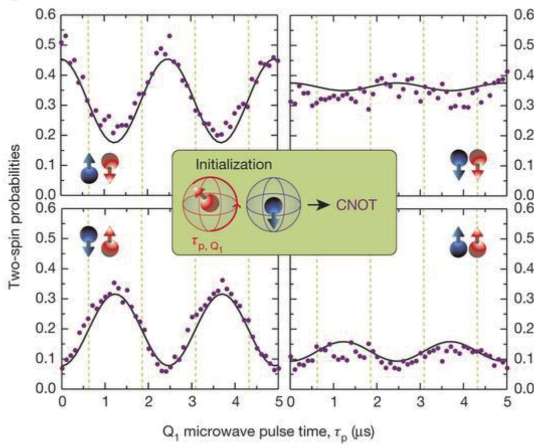
M. Veldhorst[1]

[1]QuTech, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands

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

National Institute of Information and Communications Technology (NICT),
4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan

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.

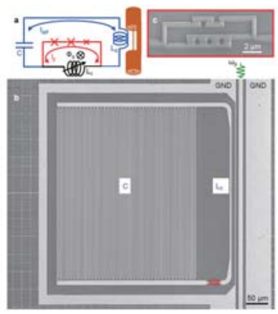


Figure 1 Superconducting qubit–oscillator circuit.

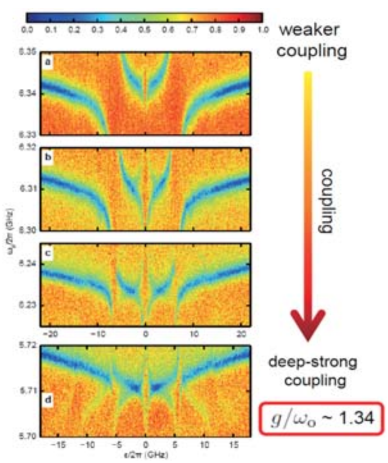


Figure 2 Transmission spectra of the circuit

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Acknowledgements

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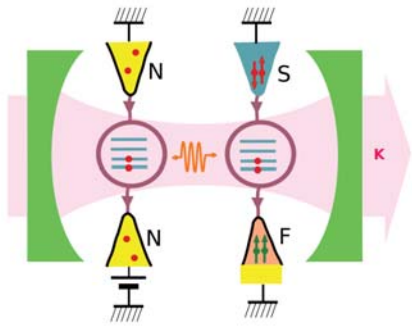
S7

Cavity quantum electrodynamics with carbon nanotubes

T. Kontos

Laboratoire Pierre Aigrain, Ecole Normale Supérieure-PSL Research University, 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]

[1]Key Laboratory for the Physics and Chemistry of Nanodevices and Department of Electronics, 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.

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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].

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