Content

Arrival

Workshop Dates: October 1 – October 19, 2018

Workshop Venue:
UCAS Zhong-Guan-Cun Teaching Building, University of Chinese Academy of Sciences (UCAS), Zhongguancun campus site.
Oct. 1 – Oct. 11: **Rm. S101** (Teaching Building)
Oct.12: **Rm. S201** (Teaching Building)
Oct. 13 – Oct. 14: **Rm. S106** (Teaching Building)
Oct. 15 – Oct. 19: **Rm. S101** (Teaching Building)

Address: No. 3, Nan-Yi-Tiao Road, Zhongguancun, Haidian District, 100190, Beijing China.
Address (Chinese): 北京市海淀区中关村南一条 3 号，中国科学院大学中关村教学楼

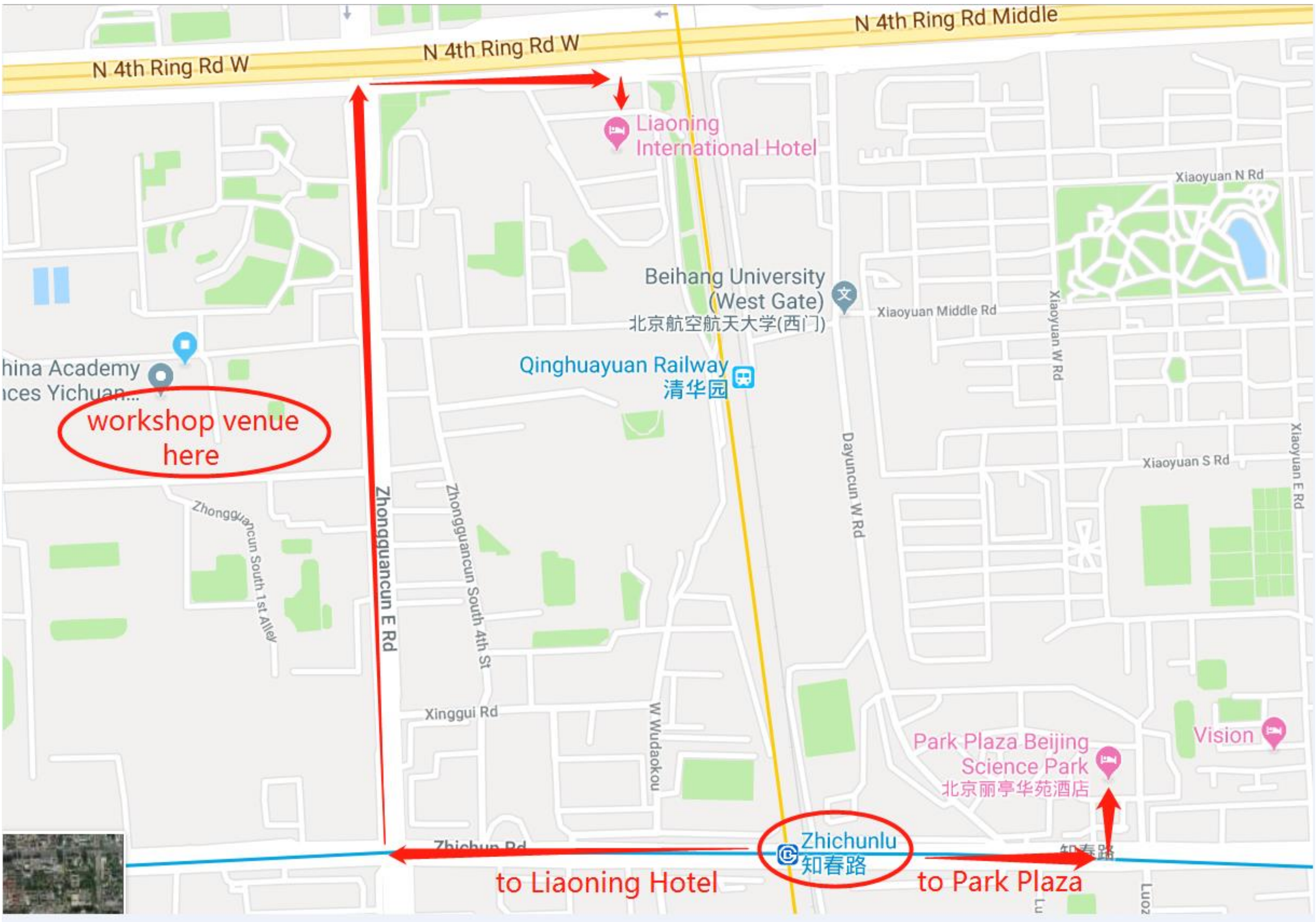
Map

Transportation

From Airport to Hotels:

By Subway:

1. Take the Airport Line at the airport to Sanyuanqiao Station (2 stops),
2. Transfer to Line 10 at Sanyuanqiao Station, to Zhichunlu Station (9 stops),
3. Leave the station at Exit B and walk to your hotels (see the map below)



By Taxi:
Please go to the taxi area at the airport to take taxis. Do not trust anybody who approach and offer a ride, even when they claim themselves as taxi drivers/companies.

The notes below may help you to communicate with the drivers:

请送我去辽宁大厦（地址：北京市海淀区北四环西路甲2号），谢谢！ 请给我一张发票，谢谢！ Please take me to Liao-Ning International Hotel, Thank you! Please also give me an invoice, thanks.

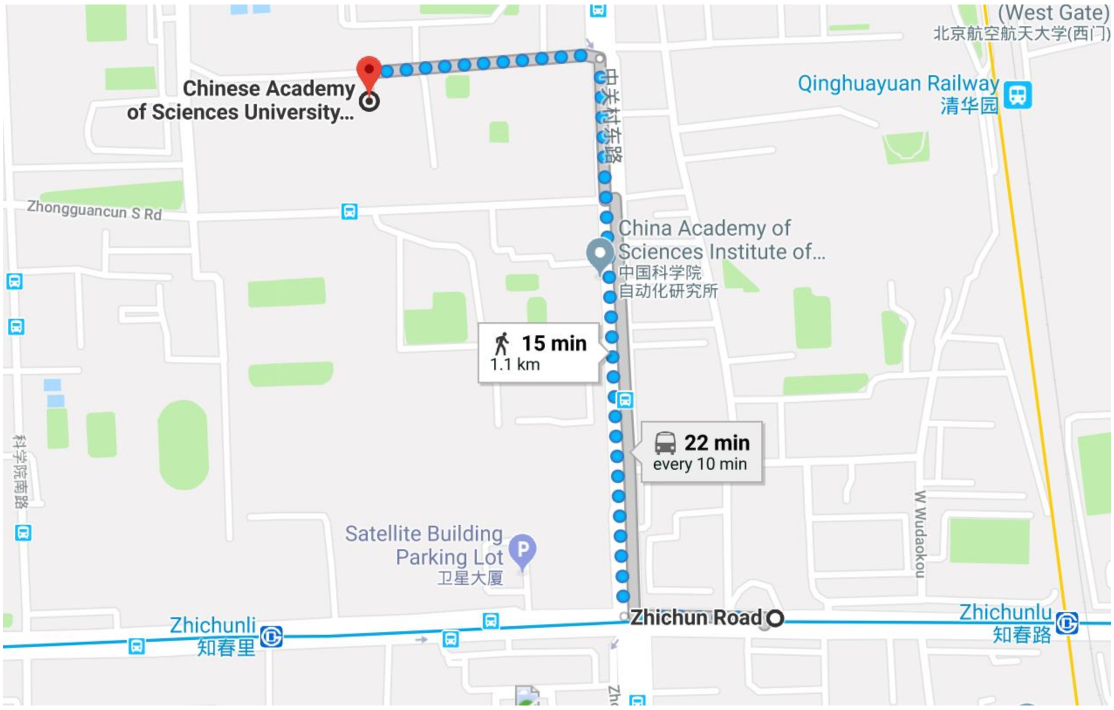
Please take me to Park Plaza Hotel, Thank you! Please also give me an invoice, thanks. 请送我去丽亭华苑酒店，谢谢！ （地址：北京市海淀区知春路25号） 请给我一张发票，谢谢!

Please check our website (http://kits.ucas.ac.cn) for more accommodation & traffic information: kits.ucas.ac.cn → About → For Visitors → Accommodation and Transportation

From Airport to workshop venue:

By Subway:

1. Take the Airport Line at the airport to Sanyuanqiao Station (2 stops),
2. Transfer to Line 10 at Sanyuanqiao Station, then to Zhichunlu Station (9 stops),
3. Leave the station at Exit B and walk to Teaching Building (about 1.2km)



By taxi:

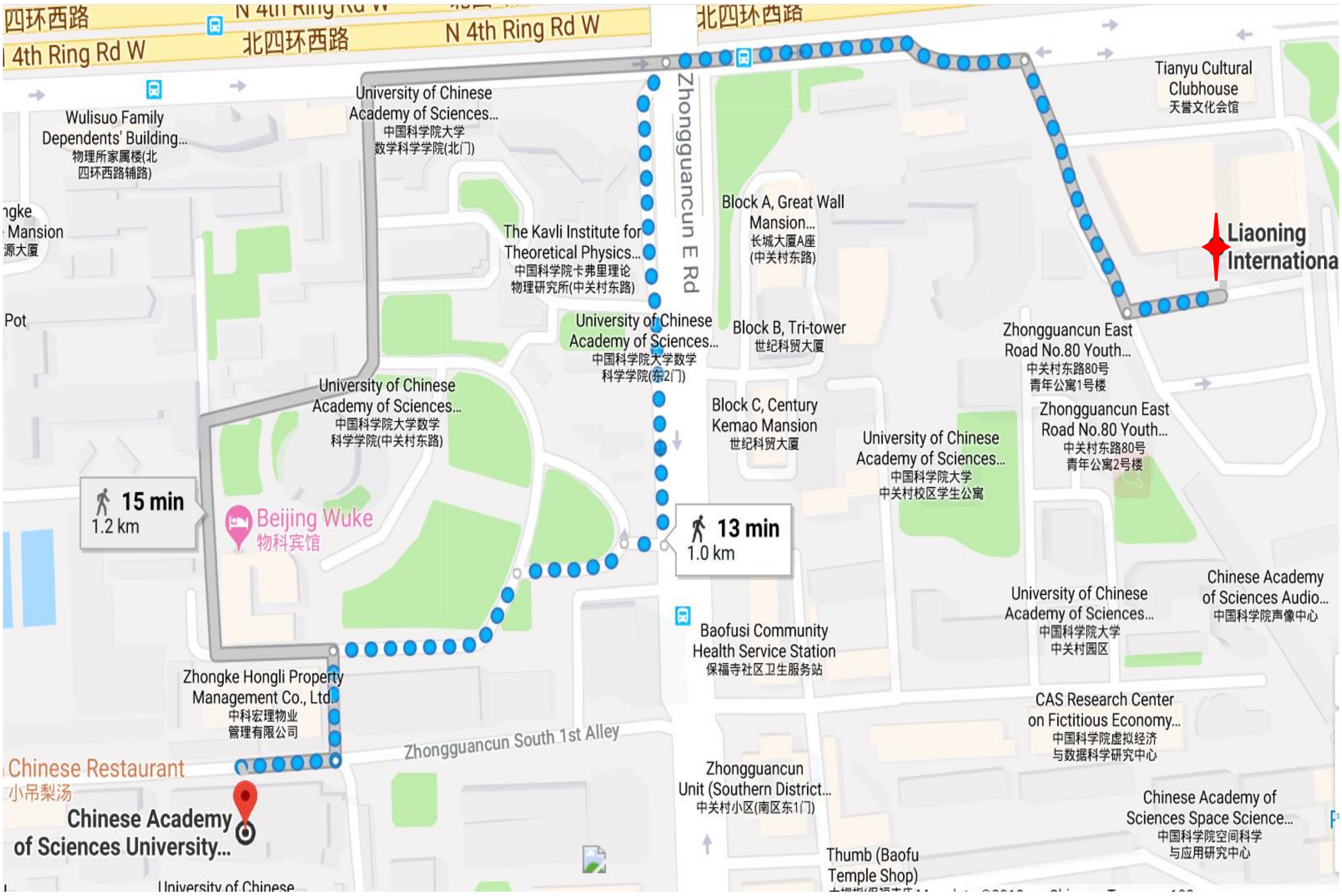
Please go to the taxi area at the airport to take taxis. Do not trust anybody who approach and offer a ride, even when they claim themselves as taxi drivers or companies.

The notes below may help you to communicate with the drivers:

Please take me to Teaching Building, CAS Please give me an invoice, thank you! 请带我去中国科学院中关村校区教学楼 (北京市海淀区中关村南一条 3 号 中关村校区) 请给我一张发票，谢谢

Other Maps

Hotels to workshop venue (UCAS Teaching Building)



Locations of Teaching Building & lunch place

Workshop lunch will be at **Beijing Wuke Restaurant** (between Kavli ITS & A building as shown on the map above)

Registration

All participants may register at the workshop venue. Please sign your attendance and collect your name card.

For overseas speakers:

Please provide the following documents:

- Bank Info. Form
- Original boarding pass
- Signed Contract for bank remit (done at the workshop)
- Invoice/receipt of the flight ticket(done at the workshop)

For domestic non-Beijing speakers:

Please provide the following information (yanpeiming@ucas.ac.cn)

- Domestic Bank information, include:
- Bank name & branch name (XX 银行 XX 支行)
- Bank account holder's name and the ID number. If the account is not under your own name please provide both yours and the holder's information.

Offices

Please find the workshop secretaries (Pei-Ming Yan or Na-Fang Chu) to get keys for temporary offices, thank you.

Wi-Fi Connection:

- Eduroam is recommended.
- If you do not have an eduroam account please contact the workshop secretaries to get your campus wireless account.

Meals

Workshop lunch will be at Wuke Restaurant (map on page 7).

Workshop Timetable

The First Week:

	Workshop				
	Monday 1/10	Tuesday 2/10	Wednesday 3/10	Thursday 4/10	Friday 5/10
10:00-10:30	Joseph Heremans	Geoffrey S. Beach	Teruo Ono	Olivier Klein	Jonathan Sun
10:30-11:00	Hiroshi Kohno	Jiang Xiao	James Haigh	Kai Chang	Yusuke Hashimoto
11:00-11:10	Coffee Break				
11:10-11:40	Can-Ming Hu	Tobias Kampfrath	Di Wu	Silvia Viola Kusminskiy	Peng Yan
11:40-12:10	TRIF MIRCEA TEOD	Gen Tatara	Antonio Costa		
	Lunch				

The Second Week:

	Workshop				
	Monday 8/10	Tuesday 9/10	Wednesday 10/10	Thursday 11/10	Friday 12/10
10:00-10:30	Chaoliang Zhang	Bob Buhrman	Maxim Mostovoy	Atsufumi Hirohata	Christian Back
10:30-11:00	Olena Gomonay	Pietro Gambardella	Masamitsu Hayashi	Felix Casanova	Bert Koopmans
11:00-11:10	Coffee Break				
11:10-11:40	Ulrich Nowak	Kentaro Nomura	Alejandro Leon	Hyunsoo Yang	Wolfgang Belzig
11:40-12:10	Kyung-Jin Lee	Shufeng Zhang	Inanc Adagideli	Haifeng Ding	Carlos Egues
12:10-12:40	Bo Gu				Mamoru Matsuo
	Lunch				
14:30-15:30		Tao Yu		Xiang Zhang	
		Vahram Grigoryan		Jianjian Miao	
		Yuichi Ohnuma		Yunyan Yao	
		Chuanpu Liu		Qi Zheng	

The Third Week:

	Workshop				
	Monday 15/10	Tuesday 16/10	Wednesday 17/10	Thursday 18/10	Friday 19/10
10:00-10:30	Paul J. Kelly	Hubert Ebert	Michael Flatté	YoshiChika OTANI	Sadamichi Maekawa
10:30-11:00	Joseph Barker	Ingrid Mertig	Frank Freimuth	Mathias Klaeui,	Yan Zhou
11:00-11:10	Coffee Break				
11:10-11:40	Jakub Zelezny	Rembert Duine	Martin Gradhand	Oleg Tretiakov	
11:40-12:10	Jingsheng Chen	Alexey Kovalev	Anjan Soumyanarayanan	Yaroslav Blanter	
	Lunch				

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Paramagnon drag in Li-doped MnTe

Y. Zheng[1], M. Rasoulianboroujeni[2], T. Lu[3], M. H. Polash[2], N. Liu[3], R. P. Hermann[4], M. E. Manley[4], H. Zhao[2], D. Vashaee[2,5], Joseph P. Heremans[1,6,7]

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4. Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge TN-37831-6064
5. Department of Materials Science and Engineering, North Carolina State University, Raleigh, NC 27606, USA
6. Department of Physics, The Ohio State University, Columbus, OH 43210, USA.
7. Department of Materials Science and Engineering, The Ohio State University, Columbus, OH 43210, USA.

Magnon-drag is an advective transport process whereby a temperature gradient generates a magnon flux that in turn impels momentum to conduction electrons, resulting in the appearance of an additional contribution to the Seebeck coefficient. We show here that in Li-doped MnTe this contribution persists well into the paramagnetic regime. MnTe is an antiferromagnetic (AFM) semiconductor with a Neel temperature T_N~307 K. At $T < T_N$, magnon drag adds a contribution α_{md} to the thermopower that scales roughly as T^2. Surprisingly, the drag persists up to $T > 3\times T_N$. Short-range AFM ordering (paramagnons) is shown by neutron diffraction to persist in the PM state. The paramagnon lifetime is much longer than the electron-magnon interaction time, and the spin-spin spatial correlation length in the PM state is much longer than the free electron effective Bohr radius. Thus, to electrons, paramagnons look like magnons and give a paramagnon-drag thermopower. This contribution of the local thermal fluctuations of the magnetization to the thermopower results in optimally-doped material having a thermoelectric figure of merit ZT>1 at T>~800 K. This is the first material with a technologically significant thermoelectric energy conversion efficiency attributable to a spin-caloritronic effect.

Level Attraction: Cavity Spintronics Finds a New Path

Can-Ming Hu
University of Manitoba, Winnipeg, Canada

Cavity Spintronics [1] (also known as Spin Cavitronics) is a newly developing interdisciplinary field that brings together cavity community with researchers from spintronics. So far, at the center stage of this new field is the coherent magnon-photon coupling, which leads to level repulsion by producing a quasi-particle called cavity magnon polariton. In this talk, I will report our latest experiment that reveals magnon-photon level attraction [2]. Based on dissipative magnon-photon coupling, this effect is distinct from traditional level repulsion, resulting in the coalescence of hybridized modes [3]. The experimental features of these new hybridized states can be accounted for by the magnetization back action which exists inside the cavity, and are revealed by our experiments due to the ability to control such a cavity Lenz effect. Exploiting this capability, we observe a sharp transition between the two hybridization effects. As observation of coherent magnon-photon coupling has spawned the field of cavity spintronics, this new form of magnon-photon coupling may open up new avenues for exploiting the light-matter interactions using cavity spintronic approach.

[1] C.-M. Hu, Physics in Canada, 72, No. 2, 76 (2016); arXiv: 1508.01966.
[2] M. Harder, et al., Phys. Rev. Lett., (2018), in print.
[3] Vahram L. Grigoryan, Ka Shen, and Ke Xia, Phys. Rev. B 98, 024406 (2018).

Spin Wave Computing

Jiang Xiao

Abstract: In the conventional von-Neumann computing architecture, the data storage and data processing are separately realized in the memory and the central processing unit, communicating via the data bus. This separated architecture limits the computing speed and the energy efficiency. Here we introduce a computing concept of purely magnetic nature, which seamlessly integrates the memory and processing by employing the static magnetic texture for the data storage, and its collective excitation – the spin wave for processing. Based on this processing-in-memory spin wave computing architecture, we propose an instruction- based universal logic gate, which realizes all unary and binary logic gates in one single structure. We further construct a full functional 4-bit Arithmetic Logic Unit using only sixteen spin wave universal logic gates, operating in a weaving fashion as a Jacquard loom machine. The spin wave-based architecture proposed here also sets a model for the future energy efficient non-volatile computing, the distributed processing-in-memory computing, and the evolvable neuromorphic computing.

Probing and controlling ultrafast spin dynamics with terahertz radiation

Tobias Kampfrath

Abstract: In magnetic materials, many resonances and relaxation processes coincide with the terahertz (THz) range. Examples are the frequencies of magnons and phonons, and the spin-dependent rates of electron scattering. Therefore, THz electromagnetic radiation is a powerful tool for probing and even controlling spin dynamics in spintronic structures. Here, we conduct THz spectroscopy of YIG|Pt and CoFeB|Pt bilayers to gain insight into the ultrafast elementary steps that lead to the formation of the spin and spin-dependent Seebeck effect. Promising applications such as contact-free interface probing, THz spin pumping, high-throughput material characterization and efficient generation of broadband THz pulses emerge.

Spintronics without spin current

Gen Tatara

Theory of spin-charge conversion effects in spintronics are presented in terms of correlation functions of physical observables, spin and electric current. Direct and inverse spin Hall effects and spin pumping effect are studied considering metallic systems with random spin-orbit interaction and spatially nonuniform Rashba interaction. The theory is free from ambiguity associated with spin current, and provides clear physical picture of the spin-charge conversion effects. In the present approach, so-called the spin current transmission efficiency is essentially the nonuniform component of magnetic susceptibility.

[1] G. Tatara, cond-mat arXiv:1808.04066

Ferrimagnetic spin-orbitronics

Teruo Ono
[1] *Institute for Chemical Research, Kyoto University, Uji, Kyoto, 611-0011, Japan*
[2] *Center for Spintronics Research Network, Osaka University, Osaka, 560-8531, Japan*

Antiferromagnetic spintronics is an emerging research field which aims to utilize antiferromagnets as core elements in spintronic devices. Antiferromagnets are expected to show much faster spin dynamics than ferromagnets because they have higher resonance frequencies than ferromagnets. However, experimental investigations of antiferromagnetic spin dynamics have remained unexplored mainly because of the immunity of antiferromagnets to magnetic fields.

We show that fast field-driven antiferromagnetic spin dynamics is realized in ferrimagnets at the angular momentum compensation temperature T_A. Using rare-earth–3d-transition metal ferrimagnetic compounds where net angular moment is nonzero at T_A, the field-driven DW mobility remarkably enhances up to 20 km $s^{-1}T^{-1}$. The collective coordinate approach generalized for ferrimagnets and atomistic spin model simulations show that this remarkable enhancement is a consequence of antiferromagnetic spin dynamics at T_A. Correlation between T_A, the magnetization compensation temperature, and the Curie temperature has been investigated [2]. Vanishing the skyrmion Hall effect at T_A has been also demonstrated [3]. Our finding allows us to investigate the physics of antiferromagnetic spin dynamics and highlights the importance of tuning of the angular momentum compensation point of ferrimagnets.

This work was partly supported by JSPS KAKENHI Grant Numbers 15H05702, 26870300, 26870304, 26103002, 25220604, 2604316, Collaborative Research Program of the Institute for Chemical Research, Kyoto University, Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University, and R & D project for ICT Key Technology of MEXT from the Japan Society for the Promotion of Science (JSPS).

[1] K.-B. Kim *et al., Nature Materials* **16**, 1187 (2017).
[2] Y. Hirata *et al., Phys. Rev.* B **97**, 220403(R) (2018).
[3] Y. Hirata *et al.,* arXiv:1809.00415.

Selection rules for cavity-enhanced Brillouin light scattering from magnetostatic modes

We show that optical resonators can be used to enhanced the strength of magnon Brillouin light scattering. The optical resonances we exploit are the whispering gallery modes confined at the surface of an yttrium iron garnet sphere by total internal reflection. These are coupled to the ferromagnetic resonance modes via the Faraday effect. Our experiments on optical coupling in this manner have demonstrated an enhancement in magnon Brillouin light scattering when the system is tuned to a triple-resonance point [1]. This occurs when both the input and output optical modes are resonant with those of the whispering gallery resonator, with a separation given by the ferromagnetic resonance frequency. Extending the measurements to higher order magneto-static modes, we have confirmed recent theoretical predictions [2] of the selection rules for scattering, dependent on the mode indices of the optical and magnetic modes. We give experimental evidence that the opto-magnonic coupling to nonuniform magnons can be higher than that of the uniform Kittel mode, due to the better spatial overlap with the optical modes.

[1] J. A. Haigh, A. Nunnenkamp, A. J. Ramsay, and A. J. Ferguson, "Triple-Resonant Brillouin Light Scattering in Magneto-Optical Cavities," PRL 117 133602 (2016).

[2] J. A. Haigh, N. J. Lambert, S. Sharma, Y. M. Blanter, G. E. W. Bauer, and A. J. Ramsay, "Selection rules for cavity-enhanced Brillouin light scattering from magnetostatic modes", PRB 97 214423 (2018).

[3] S. Sharma, Y. M. Blanter, and G. E. W. Bauer, "Light scattering by magnons in whispering gallery mode cavities," PRB 96 094412 (2017).

Reduced interfacial magnetic moment and Rashba interaction induced magnetoresistance in Pt/YIG

Di Wu
Department of physics, Nanjing University, China

The heterostructure of Pt/YIG is one of the most studied systems in magnon transport. The Pt/YIG interface plays an important role in the interconversion between magnon and charge-based pure spin current. We found that the magnetic moment of the YIG surface is significantly reduced after capping the Pt films. In contrast, the magnetic properties remain essentially unchanged for YIG capping with the Cu films. The X-ray magnetic circular dichroism measurements show that a selective charge transfer occurs from Pt to the tetrahedral site Fe of YIG. In addition, we found a new type of magnetoresistance effect in Cu/Pt/YIG where the Pt layer forms discontinue islands. The systematically study shows that the Pt/YIG interface is response to the magnetoresistance. The numerical Boltzmann simulation suggests that the magnetoresistance effect originates from the interfacial Rashba spin-orbit interaction at the Pt/YIG interface. These findings could lead to important consequences on the magnon-spin current interconversion in Pt/YIG.

Spin excitations of magnetic adatoms on 2D topological insulators

Antonio Costa
Universidade Federal Fluminense

We study the spin excitation spectra and the dynamical exchange coupling between iron adatoms on a Bi bilayer nanoribbon. We show that the topological character of the edge states is preserved in the presence of the magnetic adatoms. Nevertheless, they couple significantly to the edge spin currents, as witnessed by the large and long-ranged dynamical coupling we obtain in our calculations. The adatoms display large effective magnetocrystalline anisotropies and their excitation spectra indicate strong damping of the spin motion.

Non-linear dynamics and magnetic textures in cavity optomagnonics

Silvia Viola Kusminskiy
Max Planck Research Group Leader
Max Planck Institute for the Science of Light
Staudtstr. 2
91058 Erlangen

In optomagnonics, light couples coherently to collective magnetic excitations in solid state systems. Recent experiments have demonstrated this coupling for the first time. This topic is of high interest for quantum information processing platforms at the nanoscale. In this talk, I show how to obtain the microscopic optomagnonic Hamiltonian starting from the Faraday effect and discuss the optically-induced classical nonlinear dynamics for a homogeneous magnetic mode. A unique feature of optomagnonic systems is moreover the possibility of coupling light to spin excitations on top of magnetic textures. For the case of a microdisk geometry, I discuss the coupling between magnon modes in the presence of a magnetic vortex, and light confined to whispering gallery modes.

Spin torque and magnetic memory materials, devices and systems
Opportunities and challenges

J. Z. Sun
IBM T. J. Watson Research Center
Yorktown Heights, NY 10598, USA

Spin-tranfer-Torque (STT) based devices are being actively pursued by many semiconductor manufacturers today as a memory technology for applications beyond CMOS scaling limit. The chief advantages of the so-called spin-torque magnetic random access memory (STTMRAM) include simple integration topology, non-volatility in data retention, and potentials for processor-embedded applications. Integration of advanced metal-oxide-metal tunnel junctions into the backend of silicon technologies presents a set of materials and processing challenges that are being aggressively addressed industry-wide. In this talk I review the basic device physics of STT-based nanomagnetic switching, using the characteristics of the twoterminal STT-based tunnel junction as an example. As an example of real-world device and materials complexity, I'll discuss the dependence of tunnel device STT switching characterstics on junction resistance-area product, and the likely role hot-electron spin-flip scattering plays in these processes. The demand for high area-density circuit for costcompetitiveness, the need for highly reliable switching characteristics for computation, and the nature of finite temperature nanomagnet dynamics combine to generate needs for significantly more spin-current density. For fast, nonvolatile and deterministic manipulation of nanomagnets, and based on present-day device physics understanding, this requires new sources of spin-current to be considered, such as thermal magnonic or spin-orbit-derived spin-currents. I will briefly review recent advances with these new sources of spin currents, and the likely common challenges they will give rise to, in terms of materials and device design and development.

Phase-resolved spin-wave tomography

Yusuke Hashimoto
AIMR, Tohoku University

I will discuss the excitation and the propagation dynamics of optically-excited spin waves in an iron-based garnet film by phase-resolved spin-wave tomography, which is the reconstruction of the dispersion relation of spin waves with their phase information.

Bound-state spin-wave spectroscopy exploiting nonlinear three-magnon processes

Peng Yan

School of Electronic Science and Engineering and State Key Laboratory of Electronic Thin Film and Integrated Devices, University of Electronic Science and Technology of China, Chengdu 610054, China

One recent breakthrough in the field of magnonics is the experimental realization of reconfigurable spin-wave nanochannels formed by a magnetic domain wall with a width of 10–100 nm. This remarkable progress enables an energy-efficient spin-wave propagation with a well-defined wave vector along its propagating path inside the wall. In the mentioned experiment, a microfocus Brillouin light scattering spectroscopy was taken in a line-scans manner to measure the frequency of the bounded spin wave. Due to their localization nature, the confined spin waves can hardly be detected from outside the wall channel, which guarantees the information security to some extent. In this work, we theoretically propose a scheme to detect/eavesdrop on the spin waves inside the domain-wall nanochannel via nonlinear three-magnon processes. The approach can be parallelly applied for probing the Dzyaloshinskii-Moriya interaction in narrow magnetic stripes. The idea is analytically formulated with micromagnetic simulations performed to verify the theoretical predictions.

Spin-orbit torque switching in nanoscale devices – physics and material engineering

C. Zhang[1,2,3,4], Y. Takeuchi[2], S. Fukami[2,3,4,5,6,7], and H. Ohno[2,3,4,5,6,7]
[1]*Frontier Research Institute for Interdisciplinary Science, Tohoku University, Sendai 980-8578, Japan.*
[2]*Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, Sendai 980-8577, Japan.*
[3]*Center for Spintronics Integrated Systems, Tohoku University, Sendai 980-8577, Japan.*
[4]*Center for Innovative Integrated Electronic Systems, Tohoku University, Sendai 980-0845, Japan.*
[5]*Center for Spintronics Research Network, Tohoku University, Sendai 980-8577, Japan.*
[6]*Center for Science and Innovation in Spintronics (Core Research Cluster), Tohoku University, Sendai 980-8577, Japan.*
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In these years, an increasing number of studies have been carried out on generation of spin-orbit torque (SOT) and magnetization switching induced by the SOT in various material systems such as Ta/CoFeB/MgO, Pt/Co/AlO_x, and W/CoFeB/MgO [1-3]. In spite of intensive researches, however, there have remained several issues towards device applications. The focus of this talk is mainly on two of them, which are particularly important for the applications. The first one is the understanding of the factors which determine the threshold current density (J_{th}) of SOT switching. We here present a systematic evaluation of device size dependence of SOT-induced magnetization switching in Ta/CoFeB/MgO and W/CoFeB/MgO down to 30 nm. Based on the obtained results, we discuss the factors determining J_{th}, including the effects of spatial incoherence of magnetization during switching, finite temperature, and the field-like component of SOT [4-5]. We show that J_{th} for devices with nanometer-sized dots is much larger than the values observed in frequently-used micrometer-sized devices and becomes of the order of 10^{12} A/m^2, which needs to be reduced for applications. Following it, we go on to the second issue; reduction of J_{th} by material engineering. Here we focus on W/CoFeB/MgO and control two parameters for the deposition of W layer during dc magnetron sputtering: the sputtering power (P_W) and Ar gas pressure (p_{Ar}). We investigate the P_W and p_{Ar} dependence of crystal structure and resistivity of W and switching efficiency in nanoscale W/CoFeB/MgO devices. The results indicate that the switching current of nanoscale devices becomes smaller while effective anisotropy field becomes larger for the devices with more resistive W channel deposited at lower P_W and higher p_{Ar}. The effective spin Hall angle evaluated from the switching-probability measurement

varies by a factor ~3 depending on the sputtering condition [6]. Recently, we achieve the highest effective spin Hall angle of -0.62 in high-resistivity-W/CoFeB/MgO [6-7].
A portion of this work was supported by the ImPACT Program of CSTI and JST-OPERA, and JSPS KAKENHI Grant Number 18K13796.

[1] I. M. Miron, *et al.*, Nature Mater. **9**, 231 (2010).
[2] L. Liu *et al.*, Science **336**, 555 (2012).
[3] S. Fukami *et al.*, Nature Nanotech. **11**, 611 (2016).
[4] C. Zhang *et al*., Appl. Phys. Lett. **107**, 012401 (2015).
[5] C. Zhang *et al*., Jpn. J. Appl. Phys. **57**, 04FN02 (2018).
[6] C. Zhang *et al*., Appl. Phys. Lett. **109**, 192405 (2016).
[7] Y. Takeuchi *et al*., Appl. Phys. Lett. **112**, 192408 (2018).

Ultrafast dynamics and switching in antiferromagnets induced by spin-polarised currents

Gomonay, Dr. Olena V.

In my presentation I consider different mechanisms which can be responsible for switching between the states of an antiferromagnet. Spin current can induce magnetic dynamics via coherent rotation of the N\'eel vector or through the motion of the domain walls. Depending on the geometry, spin current can also modify equilibrium orientation of the N\'eel vector and remove degeneracy of otherwise equivalent domains. I compare threshold currents and effective forces for each of the possible mechanisms and analyse experimental situations in which these mechanisms can be implemented.

Spin dynamics, spin currents, and switching: ferro- versus antiferromagnets

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Antiferromagnetic materials are in the focus of current research in magnetism because of their potential for applications in spintronics. Possible advantages of spintronics devices based on antiferromagnetic materials include their lack of stray fields, the low susceptibility to external fields, and the rich choice of new materials, including a variety of antiferromagnetic insulators.
This talk focuses on a comparison between spin dynamics in ferromagnets and antiferromagnets, respectively, based on spin model simulations. We present a new concept for a magnonic spin valve based on a trilayer of ferromagnetic and antiferromagnetic materials and we investigate the superparamagnetic limit of antiferromagnetic nanoparticles, focusing on a comparison to the known properties of ferromagnetic nanoparticles. Furthermore, we compare spin torque switching in ferro- and antiferromagnets regarding their switching times, finding drastically enhanced switching dynamics in antiferromagnets.

Spin currents and spin-orbit torques in ferromagnetic trilayers

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Magnetic torques generated through spin-orbit coupling promise energy-efficient spintronic devices. It is important for applications to control these torques so that they switch films with perpendicular magnetizations without an external magnetic field. In this talk, we demonstrate field-free switching in ferromagnetic trilayers consisting of in-plane magnetized bottom ferromagnet, non-magnet, and perpendicularly magnetized top ferromagnet[1] and show that this structure potentially reduces the switching current. This work has been done in collaboration with Byong-Guk Park, Seung-heon C. Baek, Young-Wan Oh, Geun-Hee Lee, Kab-Jin Kim from KAIST, Korea, Vivek P. Amin , M. D. Stiles from NIST, USA, and Gyungchoon Go, Seung-Jae Lee from Korea University, Korea.

References

1. S.-h. C. Baek *et al*. *Nat. Mater*. **17**, 509 (2018).

Enhanced magneto-optical Kerr effect, Faraday effect, and orbital moment at Fe/insulator interfaces

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The magneto-optical Kerr effect is the phenomenon in which the light reflected from a magnetized material has a rotated plane of polarization, and the Faraday effect is the similar phenomenon for the light transmitted through a magnetized material. The magneto-optical Kerr effect and Faraday effect, which originate from spin-orbit coupling in materials, have been extensively studied. For applications of magneto-optical devices, large Kerr effect and Faraday effect are hihgly required.

By density functional theory calculations, we have found large magneto-optical Kerr effect and Faraday effect at Fe/insulator interfaces [1, 2]. Our study indicates that interfacial Fe atoms in the Fe films have a low-dimensional nature, which causes the following two effects: (i) The diagonal component σ_{xx} of the optical conductivity decreases dramatically because the hopping integral for electrons between Fe atoms is suppressed by the low dimensionality. (ii) The off-diagonal component σ_{xy} of the optical conductivity does not change at low photon energies, but it is enhanced at photon energies around 2 eV, where we obtain enhanced orbital magnetic moments [3] and spin-orbit correlations for the interfacial Fe atoms. Large Kerr angle and Faraday angle develop in proportion to the ratio σ_{xy}/σ_{xx}. Our findings indicate an efficient way to obtain large effect of spin-orbit coupling at metal/insulator interfaces without using heavy elements.

[1] B. Gu, S. Takahashi, and S. Maekawa, Phys. Rev. B 96, 214423 (2017).
[2] N. Kobayashi, K. Ikeda, B. Gu, S. Takahashi, H. Masumoto, and S. Maekawa, Scientific Reports 8, 4978 (2018).
[3] Y. Ogata, H. Chudo, B. Gu, N. Kobayashi, M. Ono, K. Harii, M. Matsuo, E. Saitoh, and S. Maekawa, J. Magn. Magn. Mater. 442, 329 (2017).

Spin Currents and Spin-Orbit Coupling: Friends, Foes and Puzzles

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The determination a few years ago that strong spin currents can be generated by the spin Hall effect in certain heavy metal based thin film systems opened up new opportunities and new urgency for further theoretical and experimental research to better understand and characterize the effects of strong spin-orbit coupling in conducting systems, both in the "bulk" and at heavy metal/ferromagnet interfaces. Measurements of the spin torques such currents exert on an adjacent ferromagnetic layer allows the quantification of a lower bound for the spin Hall conductivity of the heavy metal, with the lower bound being due to the less than fully determined, but likely significant, spin current losses at the interface. This losses are generally attributed to spin back-flow and spin memory loss (interfacial spin scattering). Recent experiments where the resistivity of Pt has been controllably changed by surface scattering and alloying have consistently found that the spin Hall conductivity σ_{SH} of Pt is dominated by the intrinsic effect, now generally interpreted as due to Berry curvature in the Pt band structure. Surprisingly the lower bound for $\sigma_{SH} \approx 5\times10^5$ ($\hbar$/2e) Ω^{-1} m^{-1} that is obtained from these experiments is equal or greater than that obtained for σ_{SH} for Pt from first principles calculations. In recent experiments we have also found that interfacial spin current attenuation scales directly with the strength of the spin orbit coupling at the interface, so σ_{SH} is almost certainly considerably larger than this lower bound, perhaps as high as ~ 1×10^6 ($\hbar$/2e) Ω^{-1} m^{-1}. I will review recent measurements of the spin currents, and hence the effective σ_{SH}, in Pt based systems, and also measurements of the interfacial spin current attenuation with variable spin orbit coupling at the Pt/FM interface. I will also briefly discuss a recent study of the spin Hall conductivity of a different, complex oxide material where the lower bound for the spin Hall conductivity is found to be comparable to that of Pt even through the carrier density in this complex oxide is considerably lower than that of typical metals. Such high spin Hall conductivities seem to be a puzzle for current theoretical understanding, but provide positive news for applications.

Nonreciprocal electric transport and charge-spin conversion in ferromagnetic/heavy metal layers

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Recent studies evidenced the emergence of asymmetric electron transport in layered conductors owing to charge-spin conversion phenomena such as the spin Hall effect and Rashba-Edelstein effect. In this talk, I will describe the emergence of a unidirectional magnetoresistance in ferromagnetic/heavy metal layers and ferromagnetic helices, and discuss the different origins of such an effect.

Spintronics functionalities of topological magnetic semimetals

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In these few years the application of the topological materials has drawn much interest to achieve high-efficient manipulation of the magnetization as spintronics devices. In this presentation we discuss a theoretically study of spin torques and the dynamics of magnetic textures in magnetic Weyl semimetals [1,2]. We propose that magnetic textures in the Weyl semimetal retain a localized electric charge when the curl of the texture is finite. This suggests that more efficient electrical manipulation of the magnetic texture might be possible in the Weyl semimetal than in the conventional ferromagnetic metal due to the strong correlation between the magnetic texture and the charge degrees of freedom [3,4,5]. We discuss an electrically-induced spin torque exerted on magnetization in the Weyl semimetals, and derive the analytical expressions of the spin torques. We analyze the dynamics of domain walls driven by the obtained spin-transfer torque. By solving the Thiele equation, we find that a domain wall velocity can be one order of magnitude faster than that of a conventional ferromagnetic nanowire. Moreover, the domain wall motion is not affected by an intrinsic pinning effect, namely a threshold field to drive domain walls is expected be small. Consequently, a fast control of domain walls can be achieved with less dissipation from the Joule heating in the Weyl semimetal. [6]

[1] K. Nomura and D. Kurebayashi, Phys. Rev. Lett. **115**, 127201(2015) .
[2] D. Kurebayashi and K. Nomura, Phys. Rev. Applied. **6**, 044013 (2016).
[3] Y. Araki, A. Yoshida, and K. Nomura, Phys. Rev. B **94**, 115312 (2016).
[4] Y. Araki and K. Nomura, Phys. Rev. Applied. **10**, 014007 (2018).
[5] Y. Araki, A. Yoshida, and K. Nomura, Phys. Rev. B **98**, 045302 (2018).
[6] D. Kurebayashi and K. Nomura, unpublished

Effect of spin current on spin-momentum locking systems

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Surface states of a topological insulator or Rashba interface states are special magnetic materials in which the spin-direction of electrons is correlated with the momentum. We theoretically explore effects of spin current injection to such states, beyond what known as the spin-to-charge current conversion. We introduce three macroscopic variables that characterize the spin-momentum coupled states and establish the equations of motion of these variables in the presence of the external magnetic field and spin current injection. We predict a number of possible experimentally accessible novel magnetic dynamic phenomena in these systems.

Electric excitation of topological magnetic defects in frustrated magnets

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Mott insulators with competing Heisenberg exchange interactions form a new class of materials where topological magnetic defects, such as skyrmions, can exist in absence of inversion symmetry breaking [1—4]. Skyrmions in centrosymmetric materials have more degrees of freedom and show more complex dynamics than skyrmions in chiral magnets. In addition, the electric polarization induced by non-collinear spin textures couples topological magnetic defects to an applied electric field [5]. This magnetoelectric coupling allows for an electric control of skyrmions in Mott insulators accompanied by low energy losses. In my talk I will discuss stability, dynamics and ferroelectric properties of skyrmions and merons in frustrated magnets. I will also discuss materials that can host these topological defects.

References:
[1] T. Okubo, S. Chung and H. Kawamura, Phys. Rev. Lett. **108**, 017206 (2012) .
[2] A. O. Leonov and M. Mostovoy, Nature Commun. **6**, 8275 (2015); **8**, 14394 (2017).
[3] S. Hayami, S.-Z. Lin, and C. D. Batista, Phys. Rev. B **93**, 184413 (2016).
[4] Y. A. Kharkov, O. P. Sushkov and M. Mostovoy, Phys. Rev. Lett. **119**, 207201 (2017).
[5] S-W. Cheong and M. Mostovoy, Nature Materials **6**, 13 (2007).

Spin conversion effects in spin orbit materials

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Generation of spin current is critical to develop technologies based on the current induced control of magnetization via spin orbit torques. The spin Hall effect and the Rashba-Edelstien effect convert charge current to spin current: the size of spin current in some systems is sufficiently large to enable magnetization control of nearby magnetic layers. We have studied various spin conversion processes in heterostructures with large spin orbit coupling. To characterize the magnitude of spin current, transport and voltage measurements are used. The layer material and thickness dependence of the current-spin, heat-spin and light-spin conversion processes will be discussed.

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Spintronics with interfacial rare-earth atoms

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The magnetism of solids arises from the partially filled 3d and 4f subshells. While spintronic effects involving 3d-transition metals are widely explored, the possible advantages of 4f-rare-earth materials are much less investigated. In this presentation, we focus on *Magnetic insulator| light metal* interfaces with rare-earth adatoms. Rare earths have a large atomic spin-orbit coupling, as well as an exchange between their angular momentum and the spin and orbital momentums of conduction electrons. As a result of those interactions, applied voltages can act as effective crystal-fields that modulate the magnetic energy of the system. Moreover, dynamic rare-earth moments pump both spin and transverse charge currents into the metal.

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Work Extraction and Landauer's Principle in a Quantum Spin Hall Device

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Landauer's principle states that erasure of each bit of information in a system requires at least a unit of energy $k_B T$ ln2 to be dissipated. In return, the blank bit may possibly be utilized to extract usable work of the amount $k_B T$ ln2, in keeping with the second law of thermodynamics. While in principle any collection of spins can be utilized as information storage, work extraction by utilizing this resource in principle requires specialized engines that are capable of using this resource. In this work, we focus on heat and charge transport in a quantum spin Hall device in the presence of a spin bath. We show how a properly initialized nuclear spin subsystem can be used as a memory resource for a Maxwell's Demon to harvest available heat energy from the reservoirs to induce charge current that can power an external electrical load. We also show how to initialize the nuclear spin subsystem using applied bias currents which necessarily dissipate energy, hence demonstrating Landauer's principle. This provides an alternative method of "energy storage" in an all-electrical device. We finally propose a realistic setup to experimentally observe a Landauer erasure/work extraction cycle.

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Spin Current Generation by Mechanical Rotation

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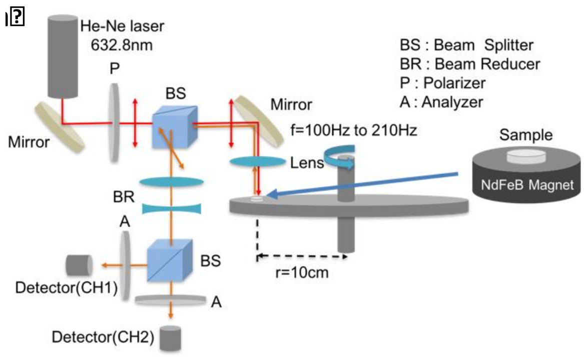
Spin current can be defined as a steady flow of spin angular momentum in the absence of any net charge flow. To date, spin currents have been generated predominantly by spin injection from a ferromagnet, the application of an electro-magnetic field, Zeeman splitting and thermal gradients [1, 2]. In 2011, Matsuo *et al.* [3] proposed a method for the generation of a pure spin current by mechanical rotation. By solving the Pauli-Schrödinger equation, they predicted that a spin current could be generated via the angular momentum carried by a conductor rotating mechanically at high speed. For materials with a large spin-orbit coupling parameter such as tungsten and platinum, there is a detectable spin imbalance that accumulates at the edges of the sample as electrons with opposite spins migrate in opposite directions.

In this study, we develop a highly sensitive magneto-optical set-up to measure a mechanically-induced spin current in a paramagnetic foil. The schematic of the set-up can be seen in Figure 1. The foils of 2 mm diameter were polished to a < 0.3 μm surface roughness. The samples were mounted on NdFeB permanent magnets painted in matte black with surface stray fields ranging from 1 kOe to 5 kOe. The magnets were fixed at a radial distance of 0.10 m on a balanced carbon fibre plate and rotated at frequencies up to 210 Hz. Induced moments on the surface of the rotating foils were measured using a magneto-optical Kerr effect (MOKE) setup.



The signal decreases with the increasing rotation frequency. The decrease in the signal with the frequency is thought to be predominantly due to the reduced time the foil stays under the fixed probe beam at higher frequencies. However, additional moments induced on the surface of the foils, by Barnett effect and the mechanically-generated spin current are also expected to contribute to the signal. For magnets with stray fields less than 4 kOe, the gradient of the signal decrease is found to be linearly proportional to the field strength, which is induced by Barnett effect. For fields larger than 4 kOe, higher order field dependencies seem to appear. This suggests the emergence of the mechanical spin current and the resulting magnetic moment [4]. The larger second-order coefficient of the W data, as compared to the Pt, agrees with the prediction as seen in Matsuo *et al.* [3]. The second-order field dependence of the induced moment is interpreted as the first experimental observation of mechanically induced spin currents. The induced moment is estimated to be 3.3 $\times$ 10^{-6} Wb in the plane of the foil, which is above the standard detection limit of conventional MOKE measurements (~10^{-10} Wb).

References

[1] S. Maekawa *et al.* (Eds.), Spin Current (Oxford University Press, Oxford, 2012).

[2] A. Hirohata, A. and K. Takanashi, *J. Phys. D: Appl. Phys.* **47**, 193001 (2014).

[3] M. Matsuo *et al.*, *Phys. Rev. Lett.* **106**, 076601 (2011).

[4] A. Hirohata *et al.*, *Sci. Rep.* **8**, 1974 (2018).

Unveling the mechanisms of the spin Hall effect in heavy metals

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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. Our results explain the dispersion of values in the literature and find a route to maximize this important effect [3]. I will also present a systematic study in Ta, a material with a claimed giant SHE. We experimentally demonstrate the dominance of the intrinsic mechanism in Ta and the observation of a record value of the spin Hall angle (-35 %) [4]. Next, I will show recent results of SHE in ultra thin Au using the same spin absorption technique. Unexpectedly, a large and negative spin Hall angle (-10%) is obtained, as opposed to results observed earlier in thicker films using the same technique (smaller and positive) [5]. We experimentally confirm the interfacial origin of this enhanced SHE, in good agreement with recent first-principle calculations [6]. Finally, I will show how to optimize the spin-to-charge current conversion at room temperature by combining Pt with a graphene channel [7], opening up exciting opportunities towards the implementation of spin-orbit-based logic circuits.

[1] C. K. Safeer et al., Nat. Nanotech. **11**, 143 (2016)
[2] S. Manipatruni et al., arXiv:1512.05428v2 (2017)
[3] E. Sagasta, F. Casanova et al., Phys. Rev. B **94**, 060412(R) (2016)
[4] E. Sagasta, F. Casanova et al., Phys. Rev. B **98**, 060410 (R) (2018)
[5] M. Isasa, F. Casanova et al., Phys. Rev. B **91**, 024402 (2015).
[6] S. Li et al., arXiv:1807.03433v1 (2018)
[7] W. Yan, F. Casanova et al., Nature Comms. **8**, 661 (2017)

Spin-orbit technologies: memory switching to THz generation

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Current induced spin-orbit torques (SOTs) provide a new way to manipulate the magnetization. We first try to understand various spin textures. In order to probe spin textures, we utilize the bilinear magnetoelectric resistance [1], photovoltage microscopy [2] for topological insulators, and Lorentz transmission electron microscopy [3] for imaging of chiral spin textures, skyrmions in an exchange-coupled Co/Pd multilayer.

We then utilize those spin textures for magnetization switching. We find that a full sign reversal of SOTs occurs as the oxygen bonding increases in Pt/CoFeB/MgO, which evidences an interfacial SOT mechanism [4]. We show much enhanced current induced SOTs from Co/Pd multilayers [5], ferrimagnetic CoGd systems [6], a topological insulator Bi_2Se_3 [7,8] as well as an oxide heterostructure $SrTiO_3/LaAlO_3$ [9,10], which generate strong spin currents to switch the magnetization. In order to understand detailed switching SOT switching mechanism, time resolved SOT spin dynamics is probed [11], and oscillatory SOT switching induced by field-like torques is measured [12]. We propose a field-free SOT switching scheme using one domain wall motion in an anti-notch structure [13]. Finally, we discuss the generation of THz for heavy metal/ferromagnet structures using SOTs [14,15].

1. P. He et al., Nat. Phys. 14, 495 (2018)
2. Y. Liu et al., Nat. Commun. 9, 2492 (2018)
3. S. Pollard et al., Nat. Commun. 8, 14761 (2017)
4. X. Qiu et al., Nat. Nanotechnol. **10**, 333 (2015)
5. M. Jamali et al., Phys. Rev. Lett. **111**, 246602 (2013)
6. R. Mishra et al., Phys. Rev. Lett. **118**, 167201 (2017)
7. Y. Wang et al., Phys. Rev. Lett. **114**, 257202 (2015)
8. Y. Wang et al., Nat. Commun. **8**, 1364 (2017)
9. K. Narayanapillai et al., Appl. Phys. Lett. **105**, 162405 (2014)
10. Y. Wang et al., Nano Lett. **17**, 7659 (2017)
11. J. Yoon et al., Sci. Adv. **3**, e1603099 (2017)
12. J. Lee et al., Commun. Phys. **1**, 2 (2018)
13. J. Lee et al., Nano Lett. **18**, 4669 (2018)
14. Y. Wu et al., Adv. Mat. **29**, 1603031 (2017)
15. M. Chen et al., Adv. Opt. Mat. **6**, 1800430 (2018)

Self-consistent determination of spin Hall angle and spin diffusion length in Pt and Pd

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Spin Hall angle (θ_{SH}) and spin diffusion length (λ_{sd}) are the key parameters in describing the spin-charge conversion which is the essential ingredient of spintronics. Despite their importance and many efforts devoted to quantify them, significant inconsistencies exist in the reported values for the same given material. We report a self-consistent method to quantify both θ_{SH} and λ_{sd} of nonmagnetic materials (NM) by spin pumping with various ferromagnetic (FM) pumping sources [1]. We characterize the spin-charge conversion for Pt and Pd with various FM combinations by means of (i) effective spin-mixing conductance, (ii) microwave photo-resistance, and (iii) inverse spin Hall effect measurements, and find that the pumped spin current suffers an interfacial spin loss (ISL) whose magnitude varies for different interfaces. With proper treating of the ISL effect, consistent values of θ_{SH} and λ_{sd} are obtained for both Pt and Pd regardless of the ferromagnet used.

In collaboration with X. D. Tao, Q. Liu, B. F. Miao, R. Yu, Z. Feng, L. Sun, B. You, J. Du, D. Wu (Nanjing University), K. Chen, S. Zhang (University of Arizona), L. Zhang, Z. Yuan (Beijing Normal University).

[1] Tao et al., Sci. Adv. 4, eaat1670 (2018)

Spin orbit fields at the Fe/GaAs(001) interface

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Interfacial spin-orbit fields (SOFs) enable the manipulation of the magnetization through an in-plane charge current. Besides technological interest, the intricate processes involved in spin to charge conversion at interfaces have provoked theoretical and experimental efforts to disentangle the underlying mechanisms. Here we study a particularly simple single crystalline interface, Fe/GaAs(001). The structural and magnetic properties of this particular interface are well understood [1] and we have used it to demonstrate various effects related to interfacial spin orbit fields.

Recently, we have demonstrate crystalline anisotropic magneto-resistance showing C_{2v} symmetry [2] as well as anisotropic magneto-optic response [3]. Here, we use ferromagnetic resonance based methods to investigate interfacial SOFs [4] and anisotropic damping [5]. We report the observation of robust SOFs occuring at a single crystalline Fe/ GaAs (001) interface at room temperature. We find that the magnitude of the interfacial SOFs, caused by the reduced symmetry at the interface, is of the same order of magnitude as for ferromagnetic metal/non-magnetic metal systems. The spin-orbit fields at the interface also enable spin-to-charge current conversion at the interface, known as spin-galvanic effect [4]. Our results also demonstrate that single crystalline Fe/GaAs interfaces may enable efficient electrical magnetization manipulation [6].

Unconventional Magnons and their Impact on Spin Pumping Transport

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Exotic quasiparticles have been observed in complex spin systems exhibiting spin ice rules, skyrmions and so on. Here, we discuss the emergence of novel quasiparticles, mediated by magnetic dipolar interactions, that have been hiding in simpler spin systems with uniformly ordered ground states. Amongst other properties, these quasiparticles exhibit a spin ranging from zero to above $1\hbar$ [1]. Of particular interest is our finding that the eigenmodes in an easy-axis antiferromagnet are spin-zero quasiparticles instead of the widely believed spin-1 magnons [2]. These unusual properties originate from a competition between quantum mechanical squeezing (increasing the spin) and hybridization (decreasing the spin).
We then present a theoretical study of spin transport across a ferrimagnet/non-magnetic conductor interface, when a magnetic eigenmode is driven into a coherent state. In the simple case of ferromagnets with non-integer "effective spin" above $1\hbar$, we show that spincurrent noise measurement can reveal this fundamental quantum phenomenon [1]. This is in full analogy to the effective charge known e.g. in the fractional quantum Hall regime, which has been experimentally determined via shot noise measurements.
Furthermore, we extend our model to continuously encompasses systems from ferromagnets to antiferromagnets [3], thereby allowing analytical results for the full range of materials within a unified description. We also allow arbitrary interfaces (disordered and asymmetric). The obtained spin current expression includes intra- as well as cross-sublattice terms. We find that the cross-sublattice terms, disregarded in previous studies, play an important role and result in qualitative changes to our understanding of spin pumping in antiferromagnets. The dc current is found to be sensitive to the asymmetry in interfacial coupling between the two sublattice magnetizations and the mobile electrons, especially for antiferromagnets.

References:
[1] A. Kamra and W. Belzig, Super-Poissonian shot noise of squeezed-magnon mediated
spin transport, Phys. Rev. Lett. 116, 146601 (2016).
[2] A. Kamra, U. Agrawal, and W. Belzig, Noninteger-spin magnonic excitations in untextured magnets, Phys. Rev. B 96, 020411(R) (2017).
[3] A. Kamra and W. Belzig, Spin pumping and shot noise in ferrimagnets: bridging ferro- and antiferromagnets, Phys. Rev. Lett. 119, 197201 (2017).

Topological and non-topological edge states in quantum dots and Chern Insulators

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Common wisdom has it that edge states appear only in topological systems, e.g., topological insulators and topological superconductors. In this talk I will discuss edge states in topological and non-topological InAsBi quantum dots described by a confined Bernevig-Hughes-Zhang model. Interestingly we find that quantum dots exhibit protected helical edges states both in the topological and non-topological regimes [1]. We also investigate edge states in Chern insulators and find that they display trivial edge states not arising from band topology (Chern number) [2]. We identify the approximate chiral symmetry of the Chern insulator (exact only in the nodal semimetal) as the relevant ingredient behind the appearance of these trivial edge states. This work was supported by CNPq, CAPES, UFRN/MEC, FAPESP, PRP-USP/Q-NANO, German Science Foundation (DFG) via Grant No. SFB 1170 "ToCoTronics" and the ENB Graduate School on Topological Insulators. and the Center for Emergent Materials, an NSF MRSEC under Award No. DMR-1420451.

[1] M. E. Flatté and J. C. Egues, arXiv:1803.02936 (submitted).

[2] D. R. Candido, M. Kharitonov, J. C. Egues, and E. Hankiewicz, Phys. Rev. B, Rapid Commun. (to appear).

Fluctuation of spin current at magnetic interfaces

Mamoru Matsuo
Kavli Institute for Theoretical Sciences at University of Chinese Academy of Sciences

In mesoscopic physics, it is well known that measurement of electrical current noise through a device provides useful information about electron transport [1]. As expected from fruitful physics of the current noise, fluctuation of the pure spin current has a potential to provide important information on spin transport in a spintronics device.

In this talk, we investigate the fluctuation of a pure spin current induced by the spin Seebeck effect and spin pumping at magnetic interfaces based on Keldysh Green's function [2,3]. We show that the spin-current noise provides important information on effective magnon spin and heating effect under spin pumping. We hope that the present formulation serves as a bridge between two well-established research areas, mesoscopic physics and spintronic physics.

[1] Ya. M. Blanter and M. Bu¨ttiker, Phys. Rep. 336, 1 (2000).
[2] M. Matsuo, Y. Ohnuma, T. Kato, and S. Maekawa, Phys. Rev. Lett. 120, 037201 (2018).
[3] K. Nakata, Y. Ohnuma, and M. Matsuo, Phys. Rev. B in press.

Atomistic spin dynamics calculations with a quantum thermostat

Joseph Barker

I will present our work on including quantum thermal statistics into the atomistic spin dynamics formalism. This has enabled us to make quantitative calculations of magnon thermodynamics and conductivities in complex materials such as yttrium iron garnet—a magnetic insulator commonly used in experiments. Our results highlight that approximations routinely used in analytic approaches fall short at room temperature.

SPIN CURRENTS IN ANTIFERROMAGNETS

J. Železný [1]

[1]*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*

Antiferromagnets have recently attracted considerable attention in the spintronics community because they have some unique advantages over ferromagnetic materials and spintronics provides means of accessing and utilizing the antiferromagnetic order. Compared to ferromagnetic materials, however, the range of spintronic functionalities available in the most studied simple collinear antiferromagnets, is limited. In contrast, in more complex antiferromagnets, such as non-collinear antiferromagnets, symmetry is lower and more spintronics effects can be present. The non-collinear antiferromagnets could thus combine the advantages of collinear antiferromagnets such as fast magnetic dynamics with the useful functionalities of ferromagnets.

Here, we discuss spin currents primarily in non-collinear antiferromagnets of the Mn_3X type (see Fig. 1). Our work [1] shows that a spin current flowing in the same direction as the charge current occurs in these antiferromagnets. In other words, this means that, like in ferromagnets, the charge current in the Mn_3X is spin-polarized. In addition, we also show that a transverse spin currents occur in these antiferromagnets. This includes the conventional spin Hall effect, but also a new type of spin Hall effect, originating from the magnetic structure. These spin currents could be utilized in a variety of devices. For example, the spin-polarized current will result in a spin-transfer torque in an antiferromagnetic junction (see Fig. 2), whereas the transverse spin current will result in a spin-orbit torque in an antiferromagnet/ferromagnet bilayer system.

[1] J. Železný et al., Spin-polarized current in non-collinear antiferromagnets, Phys. Rev. Lett. **119,** 187204 (2017)

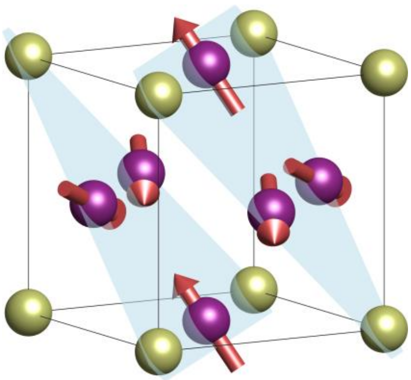

Fig. 1: Crystal structure of Mn_3Ir

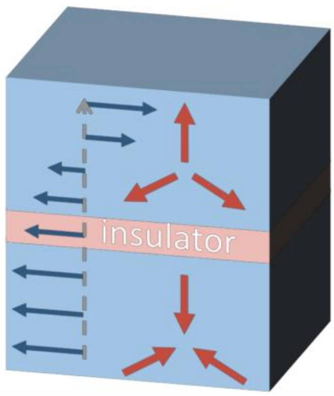

Fig. 2: Antiferromagnetic junction. Gray arrow shows direction of current flow and blue its spin-polarization.

Electrical switching of perpendicular magnetization in a single ferromagnetic layer

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Department of Materials Science and Engineering, National University of Singapore, Singapore 117575

Abstract: Electrical manipulation of magnetization is essential for integration of magnetic functionalities such as magnetic memories and magnetic logic devices into electronic circuits. The current induced spin-orbit torque (SOT) in heavy metal/ferromagnet (HM/FM) bilayers via the spin Hall effect1,2 and/or the Rashba effect3 provides an efficient way to switch the magnetization4,5. In the meantime, current induced SOT has been used to switch a single magnetic layer such as ferromagnetic semiconductor (Ga,Mn)As6 and antiferromagnetic metal CuMnAs7 with broken inversion symmetry. Here we demonstrate the electrical switching of perpendicular magnetization in a single ferromagnetic layer, L10-ordered FePt.8 The current induced spin-orbit effective fields increase with the thickness and chemical ordering parameter (S) of L10 FePt films. In 20 nm FePt films with high S (>0.9), we observe a surprisingly large charge-to-spin conversion efficiency (3.46), which is one order of magnitude larger than that in HM/FM bilayers. Possible inversion asymmetries including surface Pt-aggregation are considered to discuss the origin of the SOT. We anticipate our findings may stimulate the exploration of the spin-orbit torques in magnetic materials with perpendicular magnetocrystalline anisotropy and the application of high-efficient perpendicular magnetization switching in single FM layer.

References:

1. Dyakonov, M. I. & Perel, V. I. Current-induced spin orientation of electrons in semiconductors. Physics Letters A 35, 459-460 (1971).
2. Sinova, J., Valenzuela, S. O., Wunderlich, J., Back, C. H. & Jungwirth, T. Spin Hall effects. Reviews of Modern Physics 87, 1213-1260 (2015).
3. Yu, A. B. & Rashba, E. I. Oscillatory effects and the magnetic susceptibility of carriers in inversion layers. Journal of Physics C: Solid State Physics 17, 6039 (1984).
4. Miron, I. M. et al. Perpendicular switching of a single ferromagnetic layer induced by in-plane current injection. Nature 476, 189-193 (2011).
5. Liu, L., Lee, O. J., Gudmundsen, T. J., Ralph, D. C. & Buhrman, R. A. Current-induced switching of perpendicularly magnetized magnetic layers using spin torque from the spin Hall effect. Phys Rev Lett 109, 096602 (2012).
6. Chernyshov, A. et al. Evidence for reversible control of magnetization in a ferromagnetic material by means of spin-orbit magnetic field. Nat Phys 5, 656-659 (2009).
7. Wadley, P. et al. Electrical switching of an antiferromagnet. Science 351, 587 (2016).
8. Liu L. et.al. Electrical switching of perpendicular magnetization in a single ferromagnetic layerarXiv:1807.08244

Event horizons for spin waves and what we can do with them

Duine, Rembert

In this talk I will briefly explain our proposal to engineer black-hole-like event horizons for spin waves, and show how these can be used to amplify spin waves and even make a spin-wave laser. Most of the talk is devoted to open problems that we are working on in this context.

References:

Phys. Rev. Lett. 118, 061301 (2017) and arXiv:1807.07312 [cond-mat.mes-hall]

Boundary twists, instabilities and creation of skyrmions and antiskyrmions

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We formulate and study the general boundary conditions dictating the magnetization profile in the vicinity of an interface between magnets with different properties. Boundary twists in the vicinity of an edge due to Dzyaloshinskii-Moriya interactions have been first discussed in [Wilson et al., Phys. Rev. B 88, 214420 (2013)] and in [Rohart and Thiaville, Phys. Rev. B 88, 184422 (2013)]. A recent work [K. M. D. Hals and K. Everschor-Sitte, Phys. Rev. Lett. 119, 127203 (2017)] has shown that boundary conditions at the edge of a chiral magnets require the consideration of the full rank-3 Dzyaloshinskii-Moriya tensor. Here we show that the rank-3 Dzyaloshinskii-Moriya tensor is necessary to describe the behavior of magnetization in the vicinity of interface separating materials with different properties. We show that in general case the boundary conditions lead to the magnetization profile interpolating between the N\'eel- and Bloch-type twists. We further explore how such twists can be utilized for creation of skyrmions and antiskyrmions, e.g., in a view of magnetic memory applications. To this end, we study various scenarios how skyrmions and antiskyrmions can be created from interface magnetization twists due to local instabilities created by currents and changes in magnetic fields. We also show that a judicious choice of Dzyaloshinskii-Moriya tensor (hence a carefully designed material) can lead to local instabilities generating certain types of skyrmions or antiskyrmions. The local instabilities are shown to appear in solutions of the Bogoliubov-de-Gennes equations describing ellipticity of magnon modes bound to interfaces. In one considered scenario, a skyrmion-antiskyrmion pair can be created due to instabilities at an interface between materials with properly engineered Dzyaloshinskii-Moriya interactions. We use micromagnetics simulations to confirm our analytical predictions.

Theoretical Advances in Quantum Sensing Using Coherent and Collective Spin Dynamics

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The existence of highly coherent spin centers and spin currents, and the potential to measure correlated spin dynamics and precessional response, provides opportunities for improved sensing of magnetization response, of fluctuating magnetization, and even of spin center/defect presence itself. I will describe some promising new directions in coherent quantum sensing, including the sensitivity of spin coherent systems to nearby fluctuating magnetization (e.g. magnons), the potential to use highly spin coherent defect spins to measure the diamagnetic response of nearby materials, and the use of low-field magnetoresistive effects to identify the nuclear structure of a defect in a tunnel junction, and thus diagnose the effects of damage on semiconductor devices. This work has been supported by NSF, AFOSR, DTRA, and DARPA/DETECT.

Current-induced Dzyaloshinskii-Moriya interaction and spin-orbit torques in noncollinear magnets

Frank Freimuth[1]

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Tuning the Dzyaloshinskii-Moriya interaction (DMI) enables controlling the size of domain walls and skyrmions, which holds much promise for novel memory device concepts. So far electric gating and laser pulses have been explored as tools to tune DMI. Currently, the variation of DMI under applied electric current is attracting attention [1]. In equilibrium, DMI is determined by the ground-state spin current. This suggests that nonequilibrium spin currents driven by applied electric currents modify DMI [2]. In order to derive a rigorous expression for current-induced Dzyaloshinskii-Moriya interaction (CIDMI) we first identify its inverse effect: When magnetic textures vary as a function of time, electric currents are driven by various mechanisms, which can be distinguished according to their different dependence on the time-derivative of magnetization and on the spatial derivative. We show that the response of the electric current to the time-dependent magnetization gradient contains the inverse of CIDMI, which allows us to obtain an expression for CIDMI [3]. We find that CIDMI is related to the modification of orbital magnetism induced by magnetization dynamics, which we call dynamical orbital magnetism (DOM). We show that not only currents but also torques are generated by time-dependent gradients of magnetization. For this latter effect the inverse consists in the modification of DMI by magnetization dynamics, which we call dynamical DMI (DDMI). We find that CIDMI contributes substantially to the current-induced torques in noncollinear magnets and that the Onsager reciprocity relations are violated when this contribution is not taken into account [3]. Thus, CIDMI and spin-orbit torques (SOTs) are strongly intertwined in noncollinear magnets and therefore need to be considered together. Similarly, we find that DDMI needs to be taken into account in the theory of damping in noncollinear magnets in order to satisfy the Onsager reciprocity relations.

We will discuss CIDMI, SOT and chiral damping in textured Rashba ferromagnets [3,4] and in Co/Pt and Mn/W magnetic bilayers [5]. Additionally, we will discuss Co/Cu/Co trilayers, where spin currents generated by in-plane current at one FM/NM interface can be used to switch the other FM [6]. Despite the absence of heavy metals with strong spin-orbit coupling the SOTs in Co/Cu/Co trilayers are sizable. The SOT and the DMI in the top FM can be tuned by the magnetization direction of the bottom FM.

The temperature dependence of SOTs found in experiments is often not yet well understood. We will discuss our formalism development for the calculation of the magnonic contribution to the SOT, which is still work in progress, and we will discuss how this formalism needs to be modified for the calculation of the magnonic unidirectional magnetoresistance.

[1] G. V. Karnad et al., arXiv:1806.02439 e-print (2018)

[2] F. Freimuth et al., PRB 96, 054403 (2017)

[3] F. Freimuth et al., arXiv:1806.04782 e-print (2018)

[4] F. Freimuth et al., PRB 96, 104418 (2017)

[5] F. Freimuth et al., PRB 92, 064415 (2015)

[6] F. Freimuth et al., PRB 98, 024419 (2018)

Novel functions observed in a topological antiferromagnet Mn3Sn

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CREST, JST, Japan)
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Recently a chiral antiferromagnet Mn3Sn has been demonstrated to exhibit a large anomalous Hall effect (AHE) at room temperature, the magnitude of which reaches almost the same order of magnitude as in ferromagnetic metals irrespective of a tiny spontaneous magnetization of about 1 mT [1]. The first principle calculation revealed that this large AHE originates from a significantly enhanced Berry curvature associated with the formation of Weyl points near Fermi energy [2,3]. Even more recently detailed comparison between angle-resolved photoemission spectroscopy (ARPES) measurements and density functional theory (DFT) calculations revealed significant bandwidth renormalization and damping effects due to the strong correlation among Mn 3d electrons. Magnetotransport measurements provide strong evidence for the chiral anomaly of Weyl fermions, i.e. the emergence of positive magnetoconductance only in the presence of parallel electric and magnetic fields. In this way all the characteristic electronic properties of Mn3Sn implies that spin Hall effect (SHE) could also take place in the Mn3Sn.

In this study we set up our device that consists of ferromagnetic NiFe (blue squares) and non-magnetic Cu electrodes formed on the top surface of a micro-fabricated single crystal of Mn3Sn. We found that antiferromagnets have richer spin Hall properties than non-magnetic materials, that is, in the non-collinear antiferromagnet Mn3Sn, the SHE has an anomalous sign change when its triangularly ordered moments switch orientation. Our observations demonstrate that a novel type of contribution to the SHE (magnetic SHE, MSHE) and the inverse SHE (MISHE) that is absent in nonmagnetic materials can be dominant in some magnetic materials, including antiferromagnets. We attribute the dominance of this magnetic mechanism in Mn3Sn to the momentum-dependent spin splitting produced by the non-collinear magnetic order. This discovery further expands the horizons of antiferromagnet spintronics, and motivates a more universal outlook on spin-charge coupling mechanisms in spintronics.

In this talk we show experimental results of two complementary experiments such as detection of spin accumulation induced by the direct SHE and spin pumping induced inverse SHE in Mn3Sn. Our experimental results demonstrate that we could observe the spin accumulation associated with the direct DHE and also the signals due to the inverse SHE.

[1] S. Nakatsuji, N. Kiyohara, and T. Higo, Nature **527**, 212–215 (2015).
[2] J. Kuebler, and C. Felser, EPL **108**, 67001 (2014).
[3] Yang, H. et al. http://arxiv.org/abs/ 1608.03404 (2016).
[4] K. Kuroda et al. Nat Mater. **16**, 1090 (2017)

Long Distance Spin Transport in Magnetic Insulators

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Current devices made of *ferromagnetic* materials with charge-based spin currents used in spintronic devices have a number of drawbacks due to their *parasitic magnetic stray fields*, their large magnetic damping and ohmic losses and due to their intrinsically low characteristic frequencies that respectively limit their density integration, their power consumption and operation speed. The two key challenges are thus to design devices that remove stray fields and charge transport. Theoretically it was predicted that pure spin current could be generated, transported and employed in antiferromagnetic insulators to enable such new devices[1–3]. However experimentally, only a few systems have been investigated, most relying on coupled ferromagnet(FM)/antiferromagnet (AFM) layers[4–7]. A key limiting factor for the transport of a spin-current in insulating antiferromagnets has been the reported spin-diffusion length of only a few nanometers.[5–8]

We have recently studied spin transport across ferromagnetic and antiferromagnetic insulators in a magnon spin valved device.[9] Here combining two ferromagnets, decoupled by an CoO antiferromagnetic spacer, we measure a different spin transport signal of > 100% depending on whether the ferromagnetic layers are aligned parallel or anti-parallel, which is reminiscent of the behaviour of a charge-based spin valve.[9]

Using single crystalline Fe_2O_3, we probe spin transport in insulating antiferromagnets over long distances. We first probe the direction of the Néel order parameter by spin Hall magnetoresistance[10] to identify the antiferromagnetic spin configuration. We then use appropriately engineered non-local geometries to study high frequency magnon propagation in an antiferromagnetic insulator: Our devices consist of platinum (Pt) strips, deposited on different 3d insulating antiferromagnetic compounds along easy or hard axes. When we apply a current in a platinum stripe, we inject magnons by both thermal effect (second harmonic signal) and by spin Hall effect (first harmonic signal) and detect their propagation in a second platinum stripe by Inverse spin Hall effect. Based on the geometry of our system, we unambiguously distinguish long-distance transport based on equilibrium (Bose-Einstein condensate) or non-equilibrium magnons. The underlying physical mechanisms in our experiments allows us to observe the persistence of the two signals for distances of tens of micrometers, i.e more than two orders of magnitude larger than previous reports in antiferromagnetic thin films.[11] Those results demonstrate the possibility of propagating long distance magnons in antiferromagnetic insulators, opening the way to spin-electronics devices with antiferromagnets.[11] While many of the features observed can be understood at least qualitatively, we find surprising dependences of the transport on the crystallographic directions and applied fields and we are looking forward to fruitful discussions about these unpublished and not understood results.

1. Gomonay, E. V. & Loktev, V. M., *Low Temp. Phys.* **40,** 17–35 (2014).
2. Jungwirth, T., Marti, X., Wadley, P. & Wunderlich, J., *Nat. Nanotechnol.* **11,** 231–241 (2016).
3. MacDonald, A. H. & Tsoi, M., *Philos. Trans. R. Soc. Math. Phys. Eng. Sci.* **369,** 3098–3114 (2011).
4. Zhang, W. *et al.*, *Phys. Rev. Lett.* **113,** 196602 (2014).
5. Wang, H., Du, C., Hammel, P. C. & Yang, F., *Phys. Rev. Lett.* **113,** 097202 (2014).
6. Hahn, C. *et al.*, *EPL Europhys. Lett.* **108,** 57005 (2014).
7. Frangou, L. *et al., Phys. Rev. Lett.* **116,** 077203 (2016).
8. Prakash, A., Brangham, J., Yang, F. & Heremans, J. P., *Phys. Rev. B* **94,** 014427 (2016).
9. Cramer, J. *et al.*, *Nature Commun.* **9**, 1089 (2018).
10. Baldrati, L. *et al.*, *Phys. Rev. B* 98 024422 (2018).
11. Lebrun, R. *et al. Nature* 561, 222 (2018).

Stability and Spin-transfer/Spin-orbit Torque Driven Dynamics of Antiskyrmions

Oleg Tretiakov

I will discuss antiskyrmions in ferromagnetic and antiferromagnetic ultrathin films with anisotropic Dzyaloshinskii-Moriya interaction. Using a spin-space symmetry transformation from a skyrmion to antiskyrmion and numerical simulations based on truncated minimum energy path method, we calculate the lifetimes of antiskyrmions. We demonstrate that in recent experiment the lifetime of antiskyrmions is very long, accounting for their observed high stability. Furthermore, the mapping between skyrmion to antiskyrmion allows us to describe analytically the antiskyrmion dynamics due to both spin-transfer and spin-orbit torques. I will also discuss the effect of impurities on antiskyrmion stability.

Light scattering and magnon cooling in cavity optomagnonics

Yaroslav M. Blanter, Antoni van Leeuwenhoek Professor
Kavli Institute of Nanoscience, Delft University of Technology

I will first briefly discuss the theory of interaction of magnons in a ferromagnetic (YIG) sphere with photons - cavity whispering gallery modes. We will see that the theory explains the main feature of the recent experimental results - asymmetry between Stokes and anti-Stokes peaks in transmission of light, and that it also predicts the existence of only one peak (Stokes or anti-Stokes) in reflection. I will furthermore discuss our theoretical proposal on how magnons can be cooled by cavity photons.

Spin-Rotation Coupling

Sadamichi Maekawa[1,2]

1. *Riken Center for Emergent Matter Science (CEMS), Wako, 351-0198, Japan,*
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The study on coupling between magnetism and mechanical rotation has a long history [1,2]. The phenomena due to the coupling are caused by the angular momentum conservation between electron spin and mechanical rotation, which has been proved in the general relativistic quantum mechanics [3].

We introduce mechanical effects in spintronics and propose a variety of novel spintronic phenomena [4]. Special attention is paid on the difference between spin angular momentum and magnetic moment [5 - 7].

The spin-rotation coupling opens a door from "Spintronics" to "Spin-Mechatronics".

[1] A.Einstein and W.J.de Haas, Verhandl.Deut.Physik.Ges, **17**,154 (1915).
[2] S.J.Barnett, Phys. Rev. **6**, 239 (1915).
[3] See, for example, M.Matsuo, J.Ieda and S.Maekawa, Phys. Rev. Lett. **106**, 076601 (2011).
[4] ***Spin Current*** *(Second Edition)*, eds. S. Maekawa *et al.* (Oxford University Press, 2017).
[5] D.Kobayashi,T.Yoshikawa,M.Matsuo,R.Iguchi,S.Maekawa,E.Saitoh and Y.Nozaki, Phys. Rev. Lett. **119,** 077202 (2017).
[6] M.Imai et al.: Appl. Phys. Lett. **113**, 052402 (2018).
[7] Y. Ogata et al.: J. Magn. Magn. Mat. **442**, 329 (2017).

Magnetic skyrmions in nanostructures

Yan Zhou

In this talk, I will present some of our recent work on micromagnetics simulations of magnetic skyrmions in constricted geometries. We propose some new mechanisms for skyrmion creation and manipulation in nanostructures such as nanowires and nanodisk. We believe our study is fundamentally important for a better understanding of how to inject and control skyrmions as information carriers in nanoscale hybrid spintronic and magnonic devices.

Surface damping and chiral magnetoelastic coupling of surface spin waves from surface roughness

Tao Yu, Sanchar Sharma, Yaroslav M. Blanter, and Gerrit E.W. Bauer
Kavli Institute of NanoScience, Delft University of Technology, 2628 CJ Delft, The Netherlands

Surface roughness including the static and dynamical ones are found to significantly influence the dynamics of the surface spin waves or magnons (Damon-Eshbach mode) in the magnetic films with inplane magnetic field. The static surface roughness can strongly enhance the damping of the surface spin waves, which terms with the surface spin damping, showing the non-Gilbert damping behavior. In the excitation of the uniform spin waves, i.e., the Kittel mode, even an uniform microwave field can pump considerable amount of the surface magnons in the assistant of the surface roughness. Moreover, the asymmetry of the surface roughness on the two surfaces of the film induces an unbalanced distributions for the surface magnons propagating with opposite momenta. The dynamical surface roughness that can come from the out-of-plane component of the elastic waves induces an additional surface magnetoelastic coupling, which can significantly influence the coupling strength in the magnetic films with large saturated magnetizations. This surface magnetoelastic coupling can dominantly couple the surface spin waves propagating on one rather than both surfaces, which terms with the chiral magnetoelastic coupling.

Synchronization in coupled magnon-photon system

Vahram L. Grigoryan, Ka Shen, and Ke Xia
The Center for Advanced Quantum Studies and Department of Physics, Beijing Normal University, Beijing 100875, China

We study spin-photon coupling in a cavity in the presence of field-induced and damping like torque. We show that new hybridized modes can be achieved in coupled magnon-photon system. For field-induced torque the anticrossing gap can be manipulated. Narrowing the anticrossing gap between two hybridized modes and phase locked coupling can be realized. The ferromagnetic resonance and cavity modes become synchronized and oscillate at the same frequency near the resonance frequency. In normal metal-ferromagnetic insulator bilayer system spin transfer torque induced "negative damping" compensates the energy loss from intrinsic and coupling induced damping. Due to strong coupling between magnon and photon, the negative damping leads to new hybridized polariton modes and coherent amplification of microwave at resonant frequency.

Probe of spin dynamics in superconducting NbN thin films and topological insulator $(Bi_xSb_{1-x})_2Te_3$ via spin pumping

Yunyan Yao

The emerging field of superconductor (SC) spintronics has attracted intensive attentions recently. Many fantastic spin-dependent properties in SCs have been discovered, including large magnetoresistance, long spin lifetimes, and the giant spin Hall effect, etc. Regarding the spin dynamics in superconducting thin films, few studies have been reported yet. Firstly, I will mainly report the investigation of the spin dynamics in an *s*-wave superconducting NbN film via spin pumping from an adjacent insulating ferromagnet GdN film. A profound coherence peak of the Gilbert damping of GdN is observed slightly below the superconducting critical temperature of the NbN, which agrees well with recent theoretical prediction for *s*-wave SCs in the presence of impurity spin-orbit scattering. This observation is also a manifestation of the dynamic spin injection into superconducting NbN thin film. Secondly I will give a short report about the various temperature spin pumping into the topological insulator (TI) $(Bi_xSb_{1-x})_2Te_3$ from the adjacent magnetic insulator (MI) YIG. As the Bi concentration x is systematically tuned in 5-nm-thick $(Bi_xSb_{1-x})_2Te_3$ TI films, the weight of the surface relative to bulk

states peaks at x = 0.32 when the chemical potential approaches the Dirac point. At this concentration, the Gilbert damping constant of the 10-nm-thick YIG films in the MI/TI heterostructures is enhanced by an order of magnitude. As temperature decreasing, the Gilbert damping increase for all concentration TI, and corresponding explanations are not clear yet.

Spintronic recurrent neural network for brain-inspired computing

Qi Zheng

Great progress has been achieved in the software implementation of artificial intelligence recently, where "deep learning" is a representative example. The hardware devices for the brain-inspired computing, on the other hand, is just an emergent field of research. The magnetic nanostructures that have been extensively studied in spintronics, such as magnetic tunnel junctions, magnetic domain walls, etc. possess the required physical properties of the elements for brain-inspired computing and are therefore naturally suitable to be used for the hardware implementation of artificial neural networks.

We focus on the physical implementation and examination of the brain-inspired computing based upon spintronic devices using micromagnetic simulation. We design a spintronic recurrent neural network consisting of magnetic tunnel junctions, which can be used to generate a desired periodic rhythmic patterns. It demonstrates that the artificial neural networks made of spintronic devices can process dynamical information, beyond the focus of the present researches of machine learning-the recognition and classification of static objects.

Non-Hermitian dynamics of magnon

Xiang Zhang

The cavity magnon system we recently studying presents a non-Hermitian Hamiltonian under the consideration of photon injecting and magnon decaying. Although such non-Hermitian quantum mechanics seems bizarre at first sight, under the PT symmetric range it has real eigenvalues and showing several interesting physical consequences. In this presentation I will firstly give a detailed talk on the non-Hermitian quantum mechanics and then describe the photon-magnon-phonon coupling system we are studying. We will focus on the physical implications and the related questions for discussion.

Theory of spin Peltier effect

Yuichi Ohnuma[1,2], Sadamichi Maekawa[2,1,3] and Mamoru Matsuo[1,2]

1. Kavli-ITS, University of Chinese Science Academy, 2. RIKEN, CEMS, 3. Advanced Science Research Center, Japan Atomic Energy Agency,

In the field of spintronics, interconversion between heat and spin currents has been investigated actively since the discovery of the spin Seebeck effect (SSE) in 2008 [1]. SSE refers to the spin-current generation from heat in magnetic materials, ranging from magnetic metals [1] and semiconductors [2] to insulators [3]. Recently, the spin Peltier effect (SPE) which is the heat generation from the spin current was reported experimentally [4,5]. While SPE has been studied using a phenomenological model [6], its microscopic theory is missing.

In this study, we formulate a microscopic theory of SPE in paramagnetic metal (PM)/ferromagnetic insulator (FI) junction systems using the method of non-equilibrium Green's function [7]. Spin and heat currents generations driven by temperature gradient and spin accumulation are formulated as functions of spin susceptibilities in the PM and the FI. We show that SSE and SPE are summarized by Onsager's reciprocity relation.

References

[1] K. Uchida et al., Nature **455**, 778 (2008).
[2] C. M. Jaworski et al., Nat. Mater. **9**, 898 (2010).
[3] K. Uchida et al., Nat. Mater. **9**, 894 (2010).
[4] J. Flipse et al., Phys. Rev. Lett., 113, 027601 (2014).
[5] S. Daimon et al., Nat. Commun. 7, 13754 (2016).
[6] V. Basso et al., Phys. Rev. B, **93**, 184421 (2016).
[7] Y. Ohnuma, M. Matsuo, and S. Maekawa, Phys. Rev. B, **96**, 134412 (2017).

Algebraic Quantum Spin Liquid from an Exactly Solvable Spin-1/2 Kitaev Model

Jianjian Miao

We propose an exactly solvable quantum spin-1=2 model with time reversal invariance on a two dimensional brick-wall lattice, where each unit cell consists of three sites. We found that the ground states are algebraic quantum spin liquid states. The spinon excitations are gapless and the energy dispersion is linear around two Dirac points. The ground states are of three-fold topological degeneracy on a torus. Breaking the time reversal symmetry opens a bulk energy gap and the Z2 vortices obey non-Abelian statistics.

Note Pads

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