2013 NSFC-JSPS seminar on magnetic surface and films
with novel characterization techniques

21-25 October, 2013

Fudan University, Shanghai, China

Index

Sponsors Acknowledgement

2013 NSFC-JSPS seminar on magnetic surface and films with novel characterization techniques sponsors are an invaluable part of our success. The support and funding they provide allow us to create this seminar and exposition experience possible for our attendees and invited speakers. We thank the host institution, Surface Physics Laboratory (National Key Laboratory) at Fudan University to provide us venue for this seminar. We are grateful to funding agents, institutes sponsoring this seminar.

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Committee:

Professor Takanori Koshikawa
Fundamental Electronics Research Institute
Osaka Electro-Communication University, Neyagawa, Japan
Professor Yizheng Wu
Physics department
Fudan University, Shanghai, China,
Professor Wen-Xin Tang
College Material Science and Engineering & Physics department, Chongqing University, China
School of Physics, Monash University, Clayton, Australia

Local emergency contact:
Yizheng Wu: 13482851658

Schedule

Oct. 21, Monday	Oct. 22, Tuesday	Oct. 23, Wednesday	Oct. 24, Thursday	Oct. 25,
9:00-9:15 openning	Chair: W.S. Wan	Chair: Tsuneo Yasue	Chair: Kazue Kudo	lab tour
Chair: X.F. Jin	9:00-9:45 Takanori Koshikawa	9:00-9:45 Claus M. Schneider	9:00-9:45 Gen Tatara	
9:15-10:00 Jürgen Kirschner	9:45-10:20 Hideaki Kasai	9:45-10:20 Xiaohong Xu	9:45-10:20 Ke Xia	
10:00-10:35 Teruo Kohashi	10:20-10:40 Coffee Break	10:20-10:40 Coffee Break	10:20-10:40 Coffee Break	
10:35-10:55 Coffee Break	Chair: H. Kasai	Chair: HongWu Zhao	Chair: Ke Xia	
Chair: S. Hasegawa	10:40-11:15 Shuji Hasegawa	10:40-11:25 Yoshichika Otani	10:40-11:15 Kazue Kudo	
10:55-11:40 Stuart Parkin	11:15-11:50 Xiaofeng Jin	11:25-12:00 Haifeng Ding	11:15-11:50 Toyohiko Kinoshita	
11:40-12:15 Toyokazu Yamada	11:50-12:25 Ken Harada	12:00 Group photo	11:50-12:25 Di Wu	
Lunch	Lunch	Lunch	Lunch	Lunch
Chair: T. Kinoshita	Chair: T. Kohashi	Discussion	Chair: Ken Harada	Discussion
14:00-14:45 Jian Shen	14:00-14:45 Andreas Schmid		14:00-14:35 Jianhua Zhao	
14:45-15:20 Jiafeng Feng	14:45-15:20 Tsuneo Yasue		14:35-15:10 Chunlei Gao	
15:20-15:50 Coffee Break	15:20-15:50 Coffee Break		15:10-15:40 Coffee Break	
chair: Jian Shen	Chair: H.F. Ding		Chair: Jianhua Zhao	
15:50-16:35 Teruo Ono	15:50-16:35 Xiuzhen Yu		15:40-16:15 Yi Ji	
16:35-17:10 Yizheng Wu	17:35-17:10 Canhua Liu		16:15-16:50 Weishi Wan	
17:10-17:45 Hongwu Zhao			16:50-17:25 Wenxin Tang	
		18:30-21:00 Banquet	17:25-17:40 Closing	

October 20 Sunday

Registration:
Starting from 4:00 pm at Baolong Hotel

Reception:
6:30 PM

Address:
Grand Mercure Baolong Hotel
180 Yixian Road
Shanghai 200434
Tel +86 21 3505 9666
www.grandmercurebaolong.com

October 21 Monday

On-site registration starts at 8:00am.

The shuttle bus leaves from the hotel at 8:30am:

9:00-9:15	**Opening Yizheng Wu**	
Session Mon-1	Chair: **Xiaofeng Jin**, Fudan university, China	
9:15-10:00	Advances in electron spin polarimetry	**Jürgen Kirschner** Max Planck Institute of Microstructure Physics, Halle
10:00-10:35	Spin polarized scanning electron microscopy (Spin SEM)	**Teruo Kohashi** Central Research Laboratory, Hitachi, Ltd.
Session Mon-2	Chair: **Shuji Hasegawa**, University of Tokyo, Japan	
10:55-11:40	The Spin on domain walls	**Stuart Parkin** IBM Almaden Research Center, USA.
11:40-12:15	Single molecular spintronics: giant magnetoresistance through a single molecule	**T. K. Yamada** 1 Graduate School of Advanced Integration Science, Chiba University, Japan 2 Physikalisches Institut, Karlsruhe Institute of Technology, Germany
Session Mon-3	Chair: **T. Kinoshita** Japan Synchrotron Radiation Research Institute, Japan	
14:00-14:45	Magnetic Nanodots induced Novel Magnetic Phenomena	**J. Shen** Fudan University, China
14:45-15:20	High magnetoresistance in MgO magnetic tunnel junctions	**J. F. Feng** 1 Beijing National Laboratory for Condensed Matter Physics, China 2 Trinity College, Ireland
Session Mon-4	Chair: **J. Shen**, Fudan University, China	
15:50-16:35	Current-induced Domain Wall Motion and Its Application	**Teruo Ono** Institute for Chemical Research, Kyoto University, Japan
16:35-17:10	Tuning Antiferromagnetic spin orientation in epitaxial thin films	**Y. Z. Wu** Fudan University, China,
17:10-17:45	Spin Seebeck Effect in Ferromagnetic films	**H. W. Zhao** Chinese Academy of Sciences, China

October 22 Tuesday

The shuttle bus leaves from the hotel at 8:30am:

Session Tues-1	Chair: **W.S. Wan**, 1 Chongqing University, China 2 Lawrence Berkeley National Laboratory, USA	
09:00-09:45	Spin polarized low energy electron microscopy	**T. Koshikawa** Osaka Electro-Communication University, Japan
09:45-10:20	The Yoshimori-Kasai Model	**Hideaki Kasai** Osaka University, Japan
Session Tues-2	Chair: **H. Kasai,** Osaka University, Japan	
10:40-11:15	Splitting and Spin Transport at Surface States of Non-Magnetic Materials with Strong Spin-Orbit Coupling	**Shuji Hasegawa** University of Tokyo, Japan
11:15-11:50	Quantum transport in epitaxial Bi(111) thin films	**Xiaofeng Jin** Fudan University, China
11:50-12:25	Lens-Less Foucault Imaging (LLFI) Method	**Ken Harada** Central Research Laboratory, Hitachi Ltd., Japan
Session Tues-3	Chair: **T. Kohashi,** Central Research Laboratory, Hitachi, Ltd.	
14:00-14:45	Tailoring the chirality of magnetic domain walls by interface engineering	**A.K. Schmid** Lawrence Berkeley National Laboratory, USA
14:45-15:20	Dynamic observation of magnetic domain structure of Co/Ni multilayer with spin-polarized low energy electron microscopy	**T. Yasue** Osaka Electro-Communication University, Japan
Session Tues-4	Chair: **H. F. Ding,** Nanjing University, China	
15:50-16:35	Lorentz TEM study on dynamical skyrmions	**Xiuzhen Yu** Riken Center for Emergent Matter Science, Japan
16:35-17:10	Majorana Fermions Excited by Interplay of Magnetic Field and Superconductivity	**Canhua Liu** Shanghai Jiao Tong University, China

October 23 Wednesday

The shuttle bus leaves from the hotel at 8:30am:

Session Wed-1	Chair: **T. Yasue,** Osaka Electro-Communication University, Japan	
09:00-09:45	Probing Ultrafast Magnetization Dynamics with Element Selectivity	**Claus M. Schneider** 1 Peter Grünberg Institute, Germany 2 University Duisburg-Essen, Germany
09:45-10:20	Long-range ferromagnetic ordering in diluted magnetic oxides	**Xiaohong Xu** Shanxi Normal University, China
Session Wed-2	Chair: **H. W. Zhao,** Chinese Academy of Sciences, China	
10:40-11:25	Long Distance Diffusive Spin Transport and Precession Dynamics	**Yoshichika Otani** 1 University. of Tokyo, Japan. 2 CEMS, RIKEN, Japan
11:25-12:00	Spin Hall Angle Quantification from Spin Pumping and Microwave Photoresistance	**H. F. Ding** Nanjing University, China
12:00	**Group Photo**	
14:00	**Discussion**	
18:30-21:00	**Banquet**	

October 24 Thursday

The shuttle bus leaves from the hotel at 8:30am:

Session Thur-1	Chair: **K. Kudo,** Ochanomizu University, Japan	
09:00-09:45	Emergent spin electromagnetism induced by magnetization textures in the presence of spin-orbit interaction	**Gen Tatara** Center for Emergent Matter Science (CEMS), Japan
09:45-10:20	Thermal spin-transfer torque in MgO based tunnel junction	**K. Xia** Beijing Normal University, China
Session Thur-2	Chair: **K. Xia**, Beijing Normal University, China	
10:40-11:15	LLG simulations of magnetic domain pattern on Co/Ni multilayers	**Kazue Kudo** Ochanomizu University, Japan
11:15-11:50	Direct observation of magnetic behavior by time-resolved photoemission electron microscope	**T. Kinoshita** Japan Synchrotron Radiation Research Institute, Japan
11:50-12:25	Understanding the bias dependence of magnetoresistance in organic spin valves: role of ferromagnetic/organic interfaces	**D. Wu** Nanjing University, China
Session Thur-3	Chair: **K. Harada**, Central Research Laboratory, Hitachi Ltd., Japan	
14:00-14:35	Ferromagnetic Proximity Effect in a Co2FeAl/(Ga,Mn)As Bilayer	**Jianhua Zhao** Chinese Academy of Sciences, China
14:35-15:10	Identifying Surface Magnetic Anisotropy with Spin-polarized STM on the atomic scale	**Chunlei Gao** Shanghai Jiao Tong University, China
Session Thur-4	Chair: **J. H.Zhao**, Chinese Academy of Sciences, China	
15:40-16:15	Spin-transport, spin-transfer, and spin-charge coupling in nanoscale metallic lateral spin valves	**Y. Ji** University of Delaware, USA
16:15-16:50	The New Aberration-Corrected LEEM/PEEM at Chongqing University	**Weishi Wan** 1 Chongqing University, China 2 Lawrence Berkeley National Laboratory, USA
16:50-17:25	Design of spin polarized electron gun	**Wen-Xin Tang** Chongqing University, China
17:25-17:40	**Closing remark** **Takanori Koshikawa**	

Advances in electron spin polarimetry

J. Kirschner*
Max Planck Institute of Microstructure Physics
Weinberg 2, 06120 Halle, Germany

Email: sekrki@mpi-halle.mpg.de

Low energy electron scattering or diffraction has been shown to provide much higher detection efficiency than the conventional “Mott detector”. Based on SPLEED we developed a “spin-polarizing mirror” which consists of a pseudomorphic monolayer of Au on non-reconstructed Ir(100). It has a very good long-term stability in UHV: more than 3 weeks have been observed without noticeable degradation. The (single-channel) figure of merit is about one order of magnitude higher than the well-known W(100) LEED detector. Its mirror property with conservation of angular momentum and energy allows for multi-channel detection with up to 10000 independent simultaneous detection channels in conjunction with a momentum microscope. Examples will be given.

* This work was done in collaboration with R. Feder, F. Giebels, H.Gollisch, D. Vasilyev

Spin-Polarized Scanning Electron Microscopy (Spin SEM)

Teruo Kohashi
Central Research Laboratory, Hitachi, Ltd., 1-280, Higashi-koigakubo Kokubunji
Tokyo, 185-8601, Japan
Email: teruo.kohashi.fc@hitachi.com

Spin-polarized scanning electron microscopy (spin SEM) [1] is a method to observe magnetic domain structures at a sample surface. It is based on the phenomenon where the spin-polarization of the secondary electrons from a ferromagnetic sample is anti-parallel to the magnetization vector at the originating point of the secondary electrons [2]. The spin-polarizations are analyzed while scanning the sample surface with a probe electron beam, which produces an image of the magnetic domain structure. This principle has brought us several excellent capabilities. The spatial resolution reaches better than 10 nm, and it can produce magnetic domain images not affected by topography. Moreover, it can analyze not only magnetic domain shapes but also magnetization directions in three dimensions (3D). Spin SEM has mainly been used in metal ferromagnetics or for magnetic devices such as recording media [3], taking advantage of these characteristics. In addition to those applications, we have reported on our study of the spintronic material LaSrMnO, where layered antiferromagnetism was clearly visualized [4].

In this talk, after explanation of the principle and the basic components of the instrument, I will show various spin SEM results. One of them is a high-temperature measurement. Recently we have succeeded in implementing a new observation techniques in order to study structural changes in magnetic domains at high temperatures (up to 500 ℃). The Co single crystal was measured using this system [5]. The images were taken from room temperature up to 500 °C in increments of 100 °C (Fig. 1). At room temperature, small domains of 2–3 μm were produced from the hcp structure of a six-folded-symmetry crystal. As the temperature increased, the features of the domains did not change up to 200 °C. The small domains disappeared and domains larger than 10 μm appeared at 300 °C, and small (2–3 μm) domains appeared inside the large domains at 500 °C. In other words, the domain structure changed conspicuously at two temperatures. These changes are considered to be related to the phase transition.

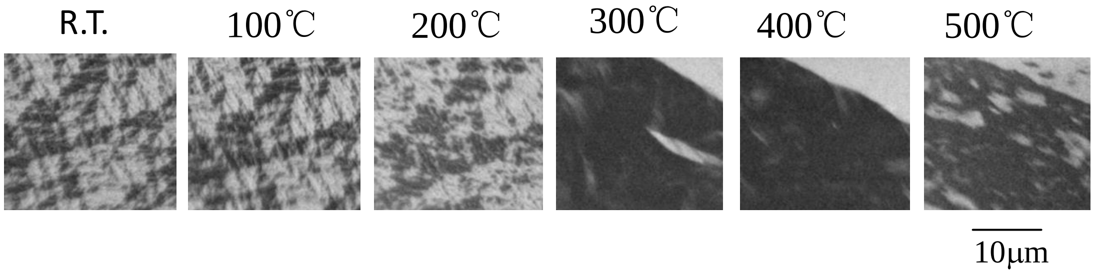

Figure 1. The magnetic domain images of Co(0001) as functions of temperatures. Small (2-5 μm) domains disappeared and domains larger than 10 μm appeared at 300 °C, and small (2-3 μm) domains appeared inside the large domains at 500 °C [5].

Acknowledgement

These works were done with Prof. K. Koike and Prof. H. Matsuyama of Hokkaido Univ, Dr. M. Konoto of National Institute for Advanced Industrial Science and Technology and Dr. K. Motai of Hitachi, Ltd.

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The Spin on domain walls

Stuart Parkin
IBM Almaden Research Center, 650 Harry Road, San Jose,CA 95120, USA.

Email: parkin@almaden.ibm.com

Single molecular spintronics: giant magnetoresistance through a single molecule

T. K. Yamada,[1,2] S. Schmaus,[2,3] A. Bagrets,[3,4] Y. Yamagishi,[1] F. Evers,[3,4] W. Wulfhekel[2,3]

[1] *Graduate School of Advanced Integration Science, Chiba University, Japan*
[2] *Physikalisches Institut, Karlsruhe Institute of Technology, Germany*
[3] *DFG-Centre for Functional Nanostructures, Karlsruhe Institute of Technology, Germany*
[4] *Institut für Nanaotechnologie, Karlsruhe Institute of Technology, Germany*
Email: toyoyamada@faculty.chiba-u.jp

Exploring spin-polarized transport characteristics of single molecules is a promising direction of research with an outlook for potential application in future nano-scale electronic devices the functionality of which will employ not only charge but also the electron's spin.

As the first step towards this goal, we present giant magneto-resistance (GMR) measurements of single hydrogen phthalocyanine (H_2Pc) molecules contacted by two ferromagnetic electrodes. Using a spin-polarized scanning tunnelling microscopy (SP-STM) at 4K, single molecules were addressed and their conductance in dependence of the magnetization of the electrodes was measured. Magnetic Co nano-islands on Cu(111) and Co coated W tips were used as ferromagnetic electrodes to make a Co/H_2Pc/Co single molecular junction. The different magnetization directions were naturally achieved as the Co nano-islands can either be magnetized into or out of the Cu substrate plane. A GMR of +60% was observed which is significantly larger than the tunnelling magneto resistance of +5% obtained from direct tunnelling measurements between the tip and the nano-islands without the involvement of H_2Pc molecules [1].

From the experiments of the Co/H_2Pc/Co single molecular junction, the hybridization of LUMO states of H_2Pc with Co 3d minority spin states was found to be the key to generate large positive GMR, which indicates different GMR for H_2Pc and antiferromagnet Mn as majority spin states dominate around the Fermi energy of Mn. With the spin-polarized STM at 4K we measured magneto-resistance through the Fe/H_2Pc/Mn single molecular junction.

H_2Pc single molecules were deposited on Mn(001) ultrathin films grown on an Fe(001)-whisker. The bct Mn(001) ultrathin films are known to have layer-wise antiferromagnetic coupling between atomic layers, which was directly observed by SP-STM magnetic images [2]. An Fe-coated W tip was gently approached to the molecule and the conductance in contact was measured. Since the coercive field of Mn/Fe(001) is much smaller than that of the Fe/W tip, it is possible to switch only the magnetization of the Mn/Fe(001), which was directly confirmed by a reverse of magnetic contrast in STM images. In this way, we succeeded to measure GMR through the same single molecule, and obtained, surprisingly, a negative magneto resistance of -54 % [3], i.e. anti-parallel coupling between Fe and the top most Mn layer has lower resistance, which is comparable to the case of the Co/H_2Pc/Co junction. Possible reason of the polarity switch of GMR is that the spin transport through the H_2Pc single molecule is dominated by minority and majority spins for Co/H_2Pc/Co and Fe/H_2Pc/Mn junctions, respectively.

Our experimental results show that the single phthalocyanine molecules can be used for near-future spintronics devices. Hybridization of molecular orbital with spin states of 3d nano metals is the key to obtain large magneto resistance [4,5].

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Magnetic Nanodots induced Novel Magnetic Phenomena

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

Email: shenj5494@fudan.edu.cn

Study of Magnetic nanodots is at central in the field of nanomagnetism. Besides the interesting properties caused by dimensionality effect, magnetic nanodots can induce many novel phenomena when forming heterostructures with other electronic materials. In this work, I will use several examples to demonstrate their effect. These examples include 1) Collective ferromagnetic behavior of magnetic nanodot arrays on 2-dimensional electron gas, 2) Colossal magnetoresistance of organic thin films induced by inserting a layer of magnetic nanodots, and 3) Dramatic enhancement of metal-insulator transition temperature in manganites capped by a layer of magnetic nanodots. All these fascinating phenomena originate directly from the interaction between magnetic nanodots with the electronic structures of the host materials. Their underlying mechanism will also be discussed based model calculations.

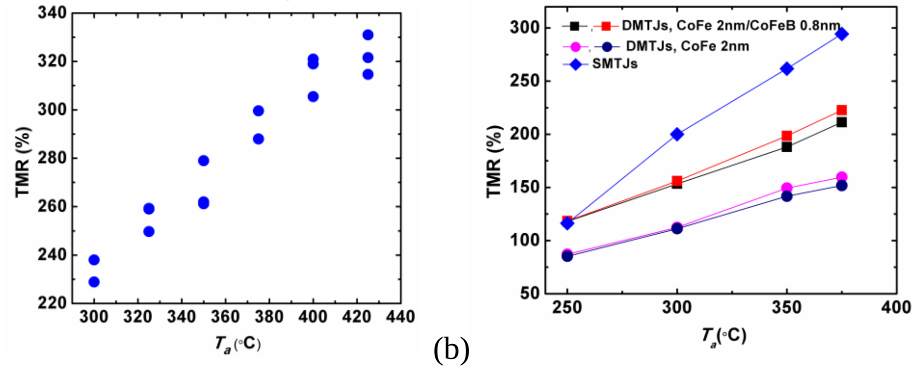
High magnetoresistance in MgO magnetic tunnel junctions

J. F. Feng,[1,2] G. Q. Yu,[1,2] G. Feng,[2] X. F. Han,[1] and J. M. D. Coey[2]
1 *Beijing National Laboratory for Condensed Matter Physics, Institute of Physics,*
2 *CRANN and School of Physics, Trinity College, Dublin 2, Ireland*

Email: jiafeng98@gmail.com

Magnetic tunnel junctions (MTJs) have attracted a great deal of attention since the demonstration of the tunneling magnetoresistance (TMR) effect at room temperature. Following theoretical predictions, a large TMR ratio of up to 200% at room temperature in MTJs with CoFeB electrodes and MgO tunnel barriers was achieved. A record room temperature TMR of 604% has since been reported in a pseudo spin valve stack [1], which is close to the theoretical maximum. Major advances in MTJs have led to important applications in hard-disk read heads, sensors, and magnetic random access memory.

Here we give a review of our work on TMR in MgO barrier magnetic tunnel junctions. We investigated the TMR effect in single barrier MTJs (SMTJs) and double barrier MTJs (DMTJs). Using a Shamrock cluster deposition tool, DMTJ and SMTJ stacks were grown on thermally oxidized silicon wafers with layer sequences Ta 5/Ru 30/Ta 5/$Ni_{81}Fe_{19}$ 5/$Ir_{22}Mn_{78}$ 10/$Co_{90}Fe_{10}$ 2.5/Ru 0.9/$Co_{40}Fe_{40}B_{20}$ (CoFeB) 3/MgO 2.5/$Co_{50}Fe_{50}$(CoFe) 2/CoFeB 0.5-1/MgO 2.5/CoFeB 3/Ru 0.9/ $Co_{90}Fe_{10}$ 2.5/ $Ir_{22}Mn_{78}$ 10/ $Ni_{81}Fe_{19}$ 5/Ta 5/Ru 5 and Ta 5/Ru 30/Ta 5/ $Ni_{81}Fe_{19}$ 5/ $Ir_{22}Mn_{78}$ 10/ $Co_{90}Fe_{10}$ 2.5/Ru 0.9/CoFeB 3/MgO 2.5/CoFeB 3/Ta 5/Ru 5 (in nm). As shown in Fig. 1 (a) and (b), the highest TMR reaches 330% and 222% at room temperature in our SMTJs and DMTJs [2, 3], this is comparable to TMR data in the same kinds of MTJs recorded by others.



(a) (b)

Fig.1 The annealing temperature dependence of TMR in SMTJs (a) and DMTJs (b).

Acknowledgement

This work was supported by the joint project between China and Ireland.

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Current-induced Domain Wall Motion and Its Application

Teruo Ono
[1]*Institute for Chemical Research, Kyoto University, Japan*

Email: ono@scl.kyoto-u.ac.jp

Electrical displacement of a domain wall (DW) is a prospective method for information processing in new type of magnetic non-volatile memories and logic devices [1-4]. Such novel spintronic devices require a low DW drive current and a high DW de-pinning field for stable information retention.
When a magnetic DW is driven by electric current via adiabatic spin torque, the theory predicts a threshold current even for a perfect wire without any extrinsic pinning [4]. We have shown that this intrinsic pinning determines the threshold current, and thus that the adiabatic spin torque dominates the DW motion resulting in DW motion along electron flow, in a perpendicularly magnetized Co/Ni system sandwiched by a symmetric capping and seed layers [5-9]. We have also shown that the threshold current density for the DW motion and the DW velocity are almost independent of the external magnetic field in the range of 50 Oe, leading to the reliable device operation against an external magnetic field disturbance [6, 10]. Furthermore, by quantifying domain-wall depinning energy barriers by magnetic field and current, we found that there exist two different pinning barriers, extrinsic and intrinsic energy barriers, which govern the thermal stability and threshold current, respectively. This unique two-barrier system allows low-power operation with high thermal stability, which is impossible in conventional single-barrier systems [11].
On the other hand, DW motion to the current direction has been observed in the Pt/Co/AlOX structure in which the structural inversion symmetry of a film was broken [12]. Recently, the effect of structural inversion asymmetry (SIA) on current-induced DW dynamics has been studied by many other groups. We also observed DW motion to the current direction even in Co/Ni system by introducing SIA [13]. I will also show results of systematic investigation by changing thickness of Co/Ni layer and discuss the contribution of adiabatic spin transfer torque, Rashba field, and spin Hall torque in the current-induced DW motion.

Acknowledgement

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Tuning Antiferromagnetic spin orientation in epitaxial thin films

J. Zhu[1], Q. Li[1], J. X. Li[1], Z. Ding[1], C. Y. Hua[2], M. J. Huang[2], H.-J. Lin[2], Z. Hu[3], Y. Z. Wu[1,*]
[1]*Fudan University, Shanghai, China,*
[2]*NSRRC, Hsinchuc Taiwan, China ,*
[3] *Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany,*

Email: wuyizheng@fudan.edu.cn

The exchange coupling in in ferromagnetic (FM) / antiferromagnetic (AFM) system is one of the most intensively studied subjects in nanomagnetism research in the past decades due to its application in spintronics devices. AFM system is one of fundamental magnetic systems in condensed matter physics; however, if comparing with the ferromagnetic (FM) system, it is difficult to experimentally determine the AFM spin structure and to tune the AFM spin orientation. Therefore, in order to get a profound understanding on the mechanism of exchange coupling, it is important to tune the spin orientation in AFM thin film.

In this talk, I will report our efforts on tuning the AFM spin orientation in single crystalline CoO and NiO film. The AFM spin orientation was determined by the x-ray linear dichroism effect (XMLD). We found the CoO spin orientation can be controlled by the film strain, and an AFM spin reorientation transition can be observed when the CoO film changes from compressive strain to tensile strain. The surface atomic steps can also induce strong in-plane AFM anisotropy for CoO film grown on miscut MgO(001) substrate. The exchange coupling between CoO and NiO spins can induce NiO AFM spin reorientation in NiO/CoO/MgO(001). Moreover, the exchange coupling in Fe/CoO was systematically studied. The crystalline anisotropy of CoO film has significant effect on the exchange-coupling induced anisotropy in Fe film. An abnormal volume anisotropy in Fe film was discovered in Fe/CoO/MgO(001) system due to the strain in CoO film. The in-plane CoO AFM spins can induce a uniaxial anisotropy in Fe Film one order larger than the perpendicular aligned CoO AFM spin. The dynamics of the in-plane AFM spin reorientation in Fe/CoO/MgO(001) system was investigated by Magneto-Optic Kerr effect. The CoO AFM domain can be switched by the external film. For the first time, the energy barrier of CoO AFM domain nucleation and domain wall propagation were quantitatively determined through the temperature dependent measurement, which linearly increases with the CoO thickness.

Spin Seebeck Effect in Ferromagnetic films

H. W. Zhao
Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190

Email: hwzhao@iphy.ac.cn

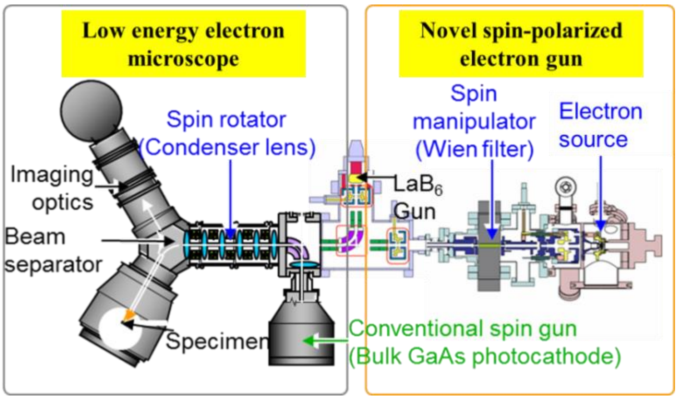
To generate pure spin currents without movement of charge is of crucial importance in spintronics that could allow computer speed and power consumption to move past limitations of current technologies. The spin Seebeck effect (SSE) provides a feasible way to drive a nonequilibrium spin current, as a result of a temperature gradient in magnetic materials. This talk reviews current status and our research in the area of spin dependent thermal transport of ferromagnetic films, which help to summarize the emerging broad range of applications and to expand the understanding of their properties. In particular, the magnetothermoelectric characteristics of permalloy film have been investigated by exquisite manipulation of heat flow. Through the angle and field dependence of thermal voltages, the hybrid of the anomalous and the planar Nernst effect can be observed in the combined longitudinal and transverse temperature field. The interplay between the magnetization of Py and the temperature gradient gives rise to the complex field dependent behaviors of anomalous and the planar Nernst effect during magnetization reversal. Further, the SSE in the Au/YIG system has been investigated systematically with 2D vector field technique.

Spin polarized low energy electron microscopy

T. Koshikawa [1], T. Yasue[1], M. Suzuki[1], K. Tsuno[1], S. Goto[2],
T.Nakanishi[3], G. Jin4 and Y. Takeda[5]
[1]*Osaka Electro-Communication University, Neyagawa, Osaka 572-8530, Japan*
[2] *San-yu Electronic Corp. Hyakunin-cho, Shinjuku, Tokyo 167-0073, Japan*
[3] *School of Science, Nagoya Univ. Furo-cho, Chigusa, Nagoya 468-8602, Japan*
[4] *School of Engineering, Nagoya Univ. Furo-cho, Chigusa, Nagoya 468-8602, Japan*
[5] *Aichi Synchrotron Radiation Center, Yamaguchi-cho, Seto 489-0965, Japan*

Email: kosikawa@isc.osakac.ac.jp

Magnetic property of thin film materials is very important for magnetic devices. In order to clarify the detailed magnetic thin film property, we need more sophisticated magnetic microscopy which gives us high spatial resolution, dynamic observation and so on. Here we present the results of developed novel high spin-polarized and very high brightness low energy electron microscope (SPLEEM) with new idea; strained super lattice cathodes for high spin-polarization (90%), the back side illumination of laser beam to the cathode for very high brightness (1.3×10^7 A/cm^2 sr) and XHV (extreme high vacuum) at the electron source chamber for long life time (over 2 months) shown in Fig. 1 [1-3]. The compact spin-polarized electron gun has been developed with a new idea. We have proposed a multi-pole Wien filter which enables 3-dimensional spin operation with one device instead of two devices. In the present development 8 poles Wien filter has been adopted. The results of magnetic images and asymmetries of Co(4ML)/W(110) vs. polar and azimuthal angles are shown in Fig.2, which shows that spin direction can be operated three dimensionally with one device. Such novel instrument has applied to the magnetic images of [Co/Ni$_2$]yW(110) [4]. The dynamic simulation has also been carried out on the basis of Landau Lifshitz Glbert equation [5]



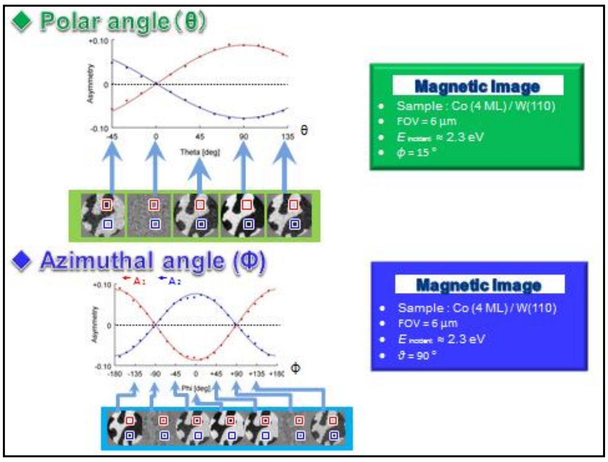


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Figure 1. High brightness and highly spin-polarized SPLEEM.
Figure 2. The magnetic images and the asymmetries vs. the polar and azimuthal angles for Co(4ML)/W(110)

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The Yoshimori-Kasai Model

Hideaki Kasai[1,2], Elvis F. Arguelles[1]
[1]*Department of Applied Physics, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[2]*Center for Atomic and Molecular Technologies, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*

Email: kasai@dyn.ap.eng.osaka-u.ac.jp

In 1983, Yoshimori and Kasai proposed a model (YK Model) for the Kondo lattice where they slightly modified the periodic Anderson model by introducing a small dispersion in the f-band to describe the temperature dependence of resistivity in HFS (heavy fermion systems).[1,2] In this theory, electron-hole symmetry is assumed and the Coulomb interaction is taken into account in the onsite self-energy. The latter assumption allows the self-energy of the present system to have the same skeleton diagram of that in the Kondo problem and eventually derive an expression of the temperature-dependent resistivity, which qualitatively agrees with experimental results. Through the years since its formulation,[3] YK model has been serving as a platform for numerous research studies in HFS with modifications such as slave boson mean field approximation and dynamical mean field theory (DMFT) included to accommodate more complicated systems. Furthermore, YK model can provide a starting point for studies of many interesting phenomena in strongly correlated systems such as exotic superconductivity,[4-7] crossover from local Femi liquid (FL) to heavy Fermi liquids, Kondo effect, RKKY interaction, and frustration in magnetic atoms on metal surfaces ,[8-13] which have important implications to Spintronics and other applications.[14-17] Thanking all people who are involved in the research in these fields experimental as well as theoretical, we present the phase diagram of the YK model in this conference.

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Spin Splitting and Spin Transport at Surface States of Non-Magnetic Materials with Strong Spin-Orbit Coupling

Shuji Hasegawa[1]
[1]*Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*

Email: shuji@phys.s.u-tokyo.ac.jp

Transports of charge as well as spin at crystal surfaces are now intensively studied for aiming at possible application to spintronics devices. Surface (electronic) states are generally decoupled from the bulk states, and therefore they are intrinsically low-dimensional and in a situation of broken space-inversion symmetry. These provide rich physics of transport, especially on surfaces of strong spin-orbit-coupling (SOC) materials.

The surface-state bands are known to be spin-split of strong SOC crystals such as Bi and Bi alloys, which is called by *Rashba effect* [1-4]. Similar effect is observed on a special kind of materials called *topological insulators* such as BiSb, BiSe, and BiTe alloys. Some of them have spin-split Dirac-cone type surface-state bands. This implies that spin-polarized current will flow at the surfaces of such materials. In my presentation, by using thin films of pure Bi [1-4], BiSb [5], BiSe [6,7], and BiTe grown on Si(111) substrate, I will show our recent results on the spin-split surface-state bands revealed by spin- and angle-resolved photoemission spectroscopy and also on the spin flow phenomena detected by four-tip scanning tunneling microscopy (STM) with a magnetic tip. By doping holes in a topological insulator, we could measure the conductivity of the single Dirac-cone surface-state band [8]. Spin-polarized current was detected on Bi(111) surface when the current-injector tip and voltage-pick up tip was as close as less than 1micron [9]. These results show that non-magnetic materials of SOC can be useful for spin physics and devices.

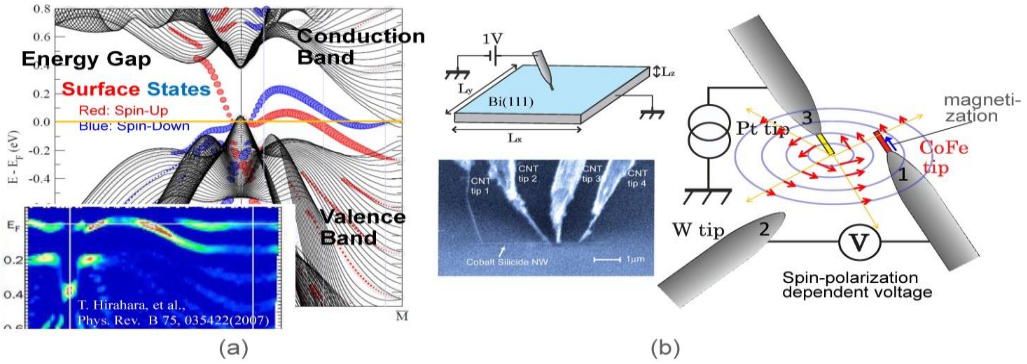

Figure (a) Calculated band dispersion of 20 atomic-layer-thick Bi(111) thin film, and photoemission result [2]. (b) Schematic illustration of an experiment to detect spin-polarized current on Bi(111) surface using four-tip STM with a CoFe coated carbon nanotube tip. [9].

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Quantum transport in epitaxial Bi(111) thin films

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

Email: xfjin@funda.edu.cn

Transport measurements have been made on epitaxial Bi thin films on Si(111) as a function of temperature and magnetic field. The results show that not only the top and bottom surfaces but also the side surfaces of a Bi(111) thin film are all metallic, yet the film interior is a well-defined insulator; meanwhile, the surface of Bi thin film on Si(111) can be oxidized but the interface underneath remains robustly metallic. It is further realized that all these nontrivial physical properties usually connected with a topological insulator are in fact caused by the topologically trivial but strong spin-orbit interaction in Bi.

Lens-Less Foucault Imaging (LLFI) Method

Ken Harada
Central Research Laboratory, Hitachi Ltd., Hatoyama, Saitama 350-0395, Japan
Email: ken.harada.fz@hitachi.com

The conventional Foucault imaging method, as one kind of optical mode of Lorentz microscopy, can visualize magnetic domains in infocus condition. The Foucault mode, however, requires a magnetic-field shielding lens and an off-centered objective aperture simultaneously for imaging. As the microscopes have to be customized for observing magnetic domain structures, the Foucault mode has not been utilized practically.

Recently two novel Foucault imaging methods were developed; one method was named as twin Foucault imaging (TFI) [1], which uses an electron biprism instead of the objective aperture. The TFI method made it possible to observe two Foucault images simultaneously, which are deflected oppositely by the 180 °domains. Another method was named as lens-less Foucault imaging (LLFI) [2], which was developed for utilization of conventional transmission electron microscope without any special equipment for Lorentz microscopy.

Figure 1 shows an optical system of LLFI method. The objective lens was switched off and an electron beam was converged by a condenser lens to the crossover on the selected area aperture plane. The selected area aperture was used as an objective aperture to select the deflected beam for Foucault mode, and the successive magnifying lens was controlled for observation of the specimen images. The irradiation area on the specimen was controlled by selecting the appropriate diameter of the condenser aperture.

Figure 2 shows an example of Foucault images of the 90 °ferromagnetic domains of $La_{0.75}Sr_{0.25}MnO_3$ (LSMO). The magnetization distribution among the 90 °domains is directly visualized. The observation was done using the commercial high-resolution electron microscope HF-3300 (300-kV acceleration voltage and field emission gun) by Hitachi High-Technologies Corp. without any modification to the optical system. Each inset in Fig. 2 shows a single dispersed deflection spot with the selected area aperture of 5 m in diameter. Inset of right-downward in Fig. 2(a) shows the small angle diffraction observed with a camera length of 150 m. The LLFI method also has an advantage to observe the small angle diffraction.

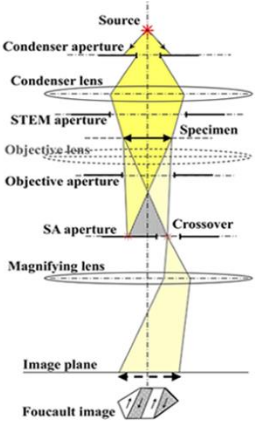

Figure 1. Optical system of LLFI.

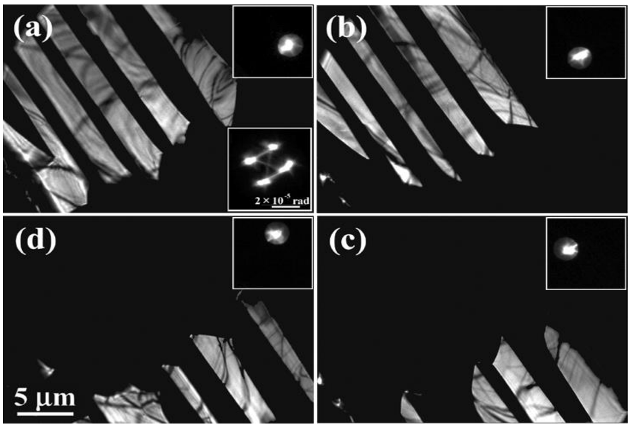

Figure 2. Foucault images of 90 ° domains of LSMO from single deflection spot which is shown in each inset. The inset of right downward in (a) is small angle diffraction pattern.

Acknowledgement

This work was done by collaboration with Dr. Y. Taniguchi and Mr. H. Matsumoto of Hitachi High-Technologies Corp., and LSMO specimen was supplied by Prof. S. Mori of Osaka Prefecture University.

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Tailoring the chirality of magnetic domain walls by interface engineering

G. Chen[1], T.P. Ma[2], A.T. N'Diaye[1], H.Y. Kwon[3], C. Won[3], Y.Z. Wu[2], and A.K. Schmid[1]
[1]*NCEM, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[2]*Department of Physics, Fudan University, Shanghai 200433, People's Republic of China*
[3]*Department of Physics, Kyung Hee University, Seoul 130-701, Korea*

Email: akschmid@lbl.gov

The rich physics of chiral spin textures includes strongly asymmetric response of left-handed versus right-handed spin structures under applied current, and extremely high domain wall mobility in response to very low critical current density [1,2]. These properties make chiral magnetic materials promising candidates for the development of new spintronics applications. How one might control the magnetic chirality of domain walls and change it between right-handed, left-handed, or achiral, has remained a key question in this field.

Using spin-polarized low energy electron microscopy, we found a new type of chiral domain wall structure in perpendicularly magnetized systems [3]. Moreover, we discovered that subtle adjustment of a non-magnetic spacer layer allows us to tailor the chirality of a magnetic $[Co/Ni]_n$ multilayer, as shown in Figure 1. By introducing magnetic chirality as a new degree of freedom, this finding raises rich possibilities to influence the dynamic properties of magnetic domain walls.

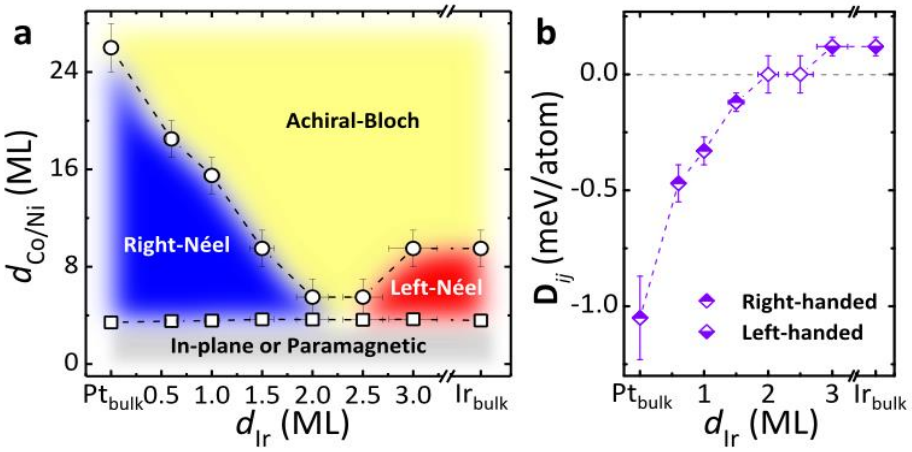

Figure 1: (a) Domain wall spin texture as a function of the thickness of $[Co/Ni]_n$ multilayer films (vertical axis) and as a function of the thickness of an Ir spacer layer inserted between the magnetic multilayers and the Pt(111) substrate (horizontal axis). Blue, yellow, and red color-coding highlights regions where the domain walls are right-handed Néel walls, a-chiral Bloch walls, and left handed Néel walls, respectively. (In the region shaded gray, films are either paramagnetic or magnetized within the film plane). **(b)** The experimental measurements summarized in panel (a) allow us to estimate the strength of the Dzyaloshinskii–Moriya interaction vector $\mathbf{D}_{ij}$, which is the driving force of the chirality.

Acknowledgement

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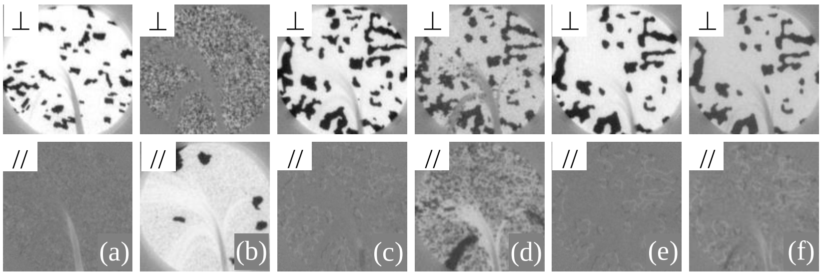
Dynamic observation of magnetic domain structure of Co/Ni multilayer with spin-polarized low energy electron microscopy

M. Suzuki [1], K. Kudo[2], K. Kojima[3], T. Yasue[1], N. Akutsu[1], W. A. Diño[3],
H. Kasai[3], E. Bauer[4] and T. Koshikawa[1]
[1]*Osaka Electro-Communication University, Neyagawa, Osaka 572-8530, Japan*
[2]*Ochanomizu University, Tokyo 112-8610, Japan*
[3]*Graduate School of Engineering, Osaka University, Suita, Osaka 565-0871, Japan*
[4]*Arizona State University, Tempe, Arizona 85287-1504, USA*
Email: yasue@isc.osakac.ac.jp

Perpendicular magnetic anisotropy (PMA) of the magnetic thin films and multilayers has attracted much attention not merely from the aspect of the basic understanding of the surface magnetism but also by the application to spintronic devices. It is well known that Co-based multilayers exhibit PMA, and many theoretical and experimental works have been carried out [1]. Co/Ni is frequently examined system, and Co/Ni_2 multilayer is predicted to exhibit PMA [2]. However, the details of mechanism which stabilizes PMA in Co/Ni multilayers have not yet been understood. The easiest way to understand the mechanism would be to observe growth processes and relevant domain structures directly. In the present work, the evolution of the magnetic domain structure of Co/Ni multilayers was investigated dynamically during growth with high brightness and highly spin-polarized low energy electron microscopy (SPLEEM) [3-5].

Figure 1 shows a series of SPLEEM snap shots taken during the growth of 1 ML Co/2 ML Ni ($CoNi_2$) multilayer at room temperature on W(110) substrate. After the completion of the first $CoNi_2$, the in-plane magnetization was observed. 2 ML of Ni layer on it strongly modifies the magnetic anisotropy from in-plane to out-of-plane as seen in fig. 1(a). The following deposition of 1 ML of Co induces the in-plane magnetization with faint out-of-plane component (fig. 1(b)). The strong PMA reveals by the deposition of Ni layer again in fig. 1(c). The next Co deposition diminishes PMA, but the clear out-of-plane domains are still observed with some in-plane component in fig. 1(d). The same story is repeated in the growth of 4th pair of $CoNi_2$ (figs. 1(e) and (f)). The in-plane component after Co deposition, however, is becoming weaker and weaker with the increasing the number of $CoNi_2$ pairs. From this observation, it is concluded that Ni layer enhances PMA and Co layer tends to discourage it. And the PMA becomes more stable with increasing the repetition of CoNi pair, where the Co/Ni interface plays an important role to establish PMA [6]. The change of the domain structure has been well reproduced by the simulation based on LLG equation which will be shown by Dr. Kudo in the seminar[7].



$Ni_2/CoNi_2$ $[CoNi_2]_2$ $Ni_2/[CoNi_2]_2$ $[CoNi_2]_3$ $Ni_2/[CoNi_2]_3$ $[CoNi_2]_4$

Figure 1. SPLEEM images of Co/Ni_2 multilayer on W(110). Upper column: out-of-plane images, and lower column: in-plane images. Field-of-view is 6 μm.

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Lorentz TEM study on dynamical skyrmions

Xiuzhen Yu[1] and Yoshinori Tokura[1, 2]
[1]*Riken Center for Emergent Matter Science*
[2]*Department of Applied Physics and QPEC, University of Tokyo*

Email: yu_x@riken.jp

The cryo-Lorentz transmission electron microscope (TEM) is a powerful tool to directly observe magnetic domain structures with controllable temperatures (6 ~ 300 K) and a high spatial resolution (< 2 nm). Recently, we used an improved Lorentz TEM with the application of controllable magnetic field (0-1 T) to observe the nanometric skyrmions - magnetic vortices in helimagnets [1-4] with non-centrosymmetric crystal structure or magnetic bubbles [5] in uniaxial ferromagnets with centrosymmetric crystal structure. Figure 1A-1C shows the nanometric hexagonal skyrmion lattice in a helimagnets FeGe. Combining electrical control with in-situ dynamical Lorentz TEM observations, we have found that the ultralow current density (less than 10^8 A/m^2) can create and drive magnetic skyrmions in a microdevice [6]. (The time-scale snapshots shown in Fig. 1E show the changes of magnetic structure with a pulse current (shown in Fig. 1D)) Such low current density is several orders of magnitude lower than that for driving magnetic domain walls in ferromagnets.

Collaborators of the this work include Prof. Naoto Nagaosa, Dr. Yoshio Matsui, Prof. Yoshinori Onose, Dr. Yusuke Tokunaga, Prof. Mixum Mostovoy, Dr. Yasujiro Taguchi, Dr. Yoshio Kaneko, Mr. Naoya Kanazawa, Dr. S. Seki, Dr. Koji Kimoto, Dr. Toru Hara, Dr. Takuro Nagai, and Ms. Weizhu Zhang.

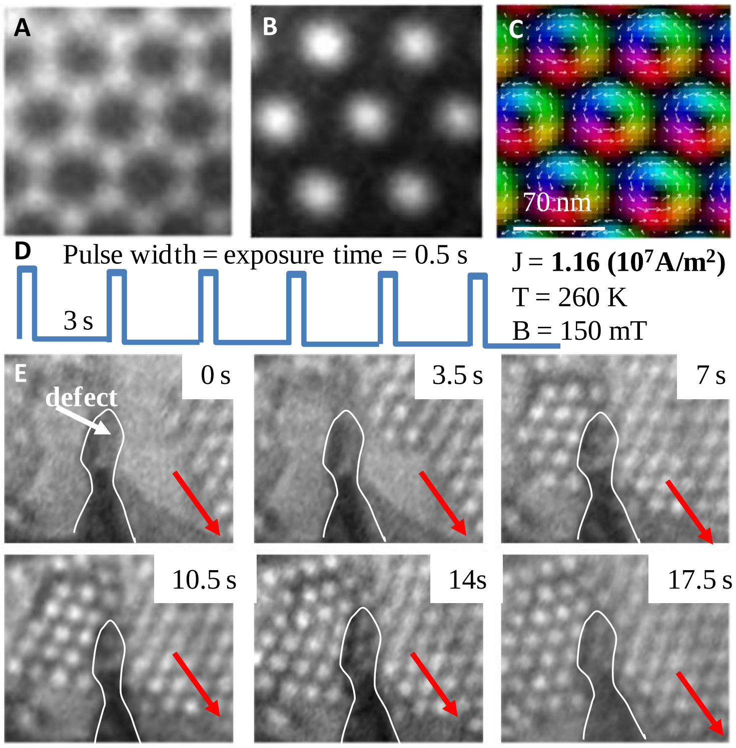

Figure 1 Lorentz TEM images of skyrmion lattice in a helimagnet FeGe. **A-B** Over-focus (**A**) and underfocus (**B**) Lorentz TEM images of skyrmion lattice. **C** The corresponding magnetic component map in the skyrmion lattice. Color and white arrows indicate the magnitude and direction of in-plane magnetizations. Dark color in the map show the out-plane magnetizations. **D** A schematic of pulse current. **E** Time-scale Lorentz TEM images obtained after pulse current traverses the TEM sample.

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Majorana Fermions Excited by Interplay of Magnetic Field and Superconductivity

Canhua Liu and Jin Feng Jia
Department of Physics and Astronomy, Shanghai Jiao Tong University
800 Dongchuan Road, Shanghai, 200240, China

Email: canhualiu@sjtu.edu.cn

Majorana fermions (MFs) have attracted a great deal of research interests in the field of condensed matter physics, mainly because of their non-Abelian exchange statistics that can be used for low-decoherence topological quantum computation [1,2]. It is theoretically predicted that MFs may exist at Abrikosov vortex cores of a topological superconductors (TSCs) aroused by an external magnetic field. However, TSCs are very rare in nature. Fortunately, a massive theoretically studies recently showed that TSCs can be obtained by the combination of a simple s-wave superconductor (sSC) and a metal or semiconductor with a peculiar band structure that requires an odd number of spin non-degenerate electronic bands crossing Fermi level[1,2]. Following this idea [3], we succeeded in fabricating the TSCs by growing thin films of topological insulators (TI) on an sSC, NbSe2 [4]. With scanning tunneling microscope that can be performed at 0.4 K and in a magnetic field up to 11 T, we visualized the Abrikosov vortices and measured the Andreev bound states therein on the TI/sSC surface. Several unconventional results have been obtained in the experiment, and are attributed to be the signature of existence of Majorana fermions.

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Probing Ultrafast Magnetization Dynamics with Element Selectivity

Claus M．Schneider[1,2]
1 peter Grünberg Institute, Research Center Jülich, D-52425 Jülich, Germany
2Faculty of Physics, University Duisburg-Essen, D-47057 Duisburg, Germany
E-mail: c.m.schneider@fz-juelich.de

Understanding the physical limits of magnetization dynamics is of central importance for the development of magnetic data storage and spintronics. Of particular interest is the phenomenon of ultrafast demagnetization on the femtosecond regime. It is expected to give insight into the energy and angular momentum transfer processes between the electronic and spin systems.

We present several results of a novel element-selective pump-probe approach involving table-top pulsed laser systems, which allows us to investigate the demagnetization behavior for the individual constituents in an alloy or a thin film stack. This is achieved by probing the magnetic system with fs VUV light pulses from a HHG up-conversion process reaching harmonics with photon energies of up to 70 eV. The resonant magnetic reflectivity at the transition metal M-edges in a T-MOKE geometry provides large magnetic signals[1], which enable us to study spin dynamic processes with true element selectivity and a time resolution of better than 20 fs, i.e. approaching the time scale equivalent of the exchange interaction [2,3].

Experiments on pure Fe and Ni films yield demagnetization times of 100 fs(Fe) and 150(fs). In Permalloy (Ni80Fe20) films the mean demag time constant increases to 240 fs, however, With a distinct time delay between the response of Fe and Ni [4]. Initially the Ni response is lagging behind the Fe response for about 20 fs, until both demagnetize with the same time constant. This time ag is found to increase to about 80 fs When alloying Cu into Permalloy, thereby weakening the exchange between Fe and Ni and reducing the Curie temperature . These findings demonstrate that although in the static case Fe and Ni are strongly exchange coupled. this coupling may be overcome by strong optical excitations on very short time scales.

Our Studies on magnetic layer stacks revealed a new and very efficient demagnetization mechanism, namely spin superdiffusion. The optically excited “hot spins” quickly leave the excitation volume leading to a strong spin current into neighboring areas. In a thin film system this may even cause a transient increase of the magnetization in an adjacent ferromagnetic layer, if the spin current adds to the majority spin density[5]. The spin current yields also information about the demagnetization processes in the individual layers in its time dependence and can be suppressed by an insulating interlayer[6].

Acknowledgement

This work is a result of a close collaboration with the groups of M．Murnane and H. Kapteyn(JILA Boulder), T. Silva(NIST Boulder). M. Aeschlimann (U Kaiserslautern)and P. Oppeneer(U Uppsala)

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Long-range ferromagnetic ordering in diluted magnetic oxides

Fengxian Jiang, Shifei Qi, Zhiyong Quan, Jiuping Fan, Xiaohong Xu,
School of Chemistry and Materials Science, Shanxi Normal University,
Linfen 041004, China

Email: *xuxh@dns.sxnu.edu.cn*

The emerging field of spintronics aims at utilizing the spin and charge aspects of electrons. Both semiconducting and magnetic properties can be achieved within a single material by doping various transition metals (TMs). Despite the progress in developing diluted magnetic oxides, there has been much controversy concerning the origin and mechanism that causes the magnetism. The complete understanding of the ferromagnetic behavior in dilute magnetic oxides depends on a deeper insight into the complex defect and transport physics in these systems. We choose two prototype examples, ZnO doped with Co and codoped with Co/Al, and In_2O_3 doped with Fe or codoped with Fe/Sn, to explore the effect of intrinsic defects and additional doping on magnetism theoretically and experimentally. It is confirmed that the defects are indispensable for producing the ferromagnetism. More importantly, we find that electrons from the additional donor can not only enhance local ferromagnetic ordering of Fe-Fe or Co-Co dimer, but also are essential for producing the long-range ferromagnetic coupling between transition-mental dimers. These findings provide a good basis to understand the contributions of both BMPs and free carriers for the ferromagnetism in diluted magnetic oxide semiconductors.

Long Distance Diffusive Spin Transport and Precession Dynamics

Yoshichika Otani[1,2]*, Hiroshi Idzuchi[1,2], Yasuhiro Fukuma[2,3]
[1]*ISSP, Univ. of Tokyo, Kashiwa 277-8581, Japan.*
[2]*CEMS, RIKEN, Wako 351-0198, Japan,*
[3]*Kyushu Institute of Technology, Iizuka 820-8502, Japan,*

Email: yotani@issp.u-tokyo.ac.jp

Rapid development in spintronics is underpinned by solid understanding of fundamental properties of spin transport. Although a velocity is one of the most fundamental quantities characterizing transport phenomena, that of diffusive spin current has been interpreted by a response of spin precession within an empirical model over twenty-five years. Here, we demonstrate a velocimetry of spin current using Larmor precession, which enables us to go beyond a limitation of the empirical model. This velocimetry was applied for the metallic lateral spin valves with Py/MgO/Ag junctions, resulting in considerable agreement between experimentally obtained transit-time distribution and widely-used empirical model as in Fig. 1, of which transit-times are as high as tens of pico-seconds per a few micro-meters.
Importantly we found the velocity of spin current for Py/Ag junctions was much faster than that given by the empirical model. We identified its origin as the spin absorption effect, and have developed the theoretical description of dynamic transport property for diffusive spin current in lateral spin valves with various interface resistances. These provide a powerful scheme to access genuine dynamic transport properties of spin currents.

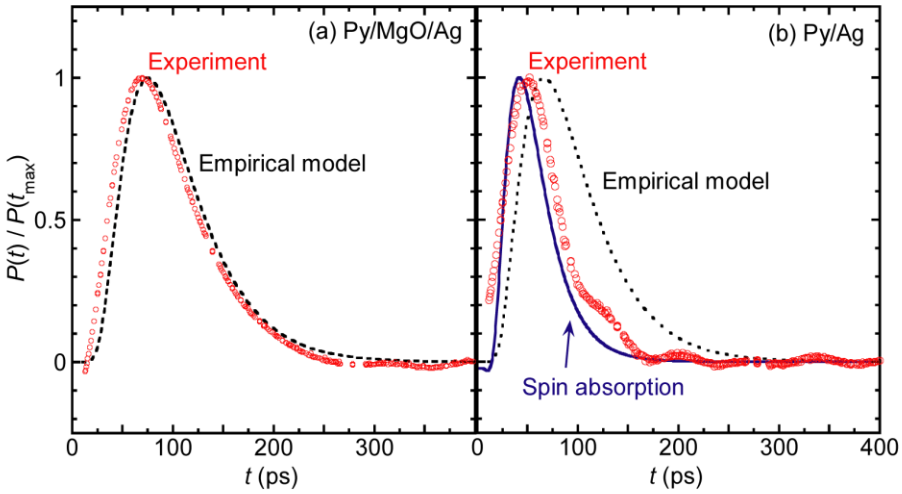

Figure 1. Open circles show transit time distribution determined by performing Fourier transform on Hanle signals for both Py/MgO/Ag and Py/Ag lateral spin valves. Dashed curves are derived by the empirical model, i.e., conventional diffusion distribution with spin-flip. Solid curve shows the distribution including the effect of spin absorption.

Spin Hall Angle Quantification from Spin Pumping and Microwave Photoresistance

H. F. Ding
National Laboratory of Solid State Microstructures and Department of Physics,
Nanjing University, 22 Hankou Road, Nanjing 210093, P. R. China

Email: hfding@nju.edu.cn

The spin Hall effects (SHE) refers to the generation of a spin current transverse to an applied charge current in a paramagnetic metal or a doped semiconductor [1]. Concurrently, a spin current can also give rise to a transverse charge current, which is called the inverse spin Hall effect (ISHE). The efficiency of the spin-charge conversion can be quantified by a single material-specific parameter, *i.e.*, the spin Hall angle (SHA). Recently, a method based on spin pumping effect and ISHE is developed to determine the SHA [2,3]. But reported values from different groups are quite different for nominally identical materials (Pt) with this method. [2-5] The discrepancy may be related to the fact that the ISHE signal is typically mixed with the unwanted effects related to the anisotropic magnetoresistance (AMR) effect [6], as well as the difficulty to estimate the exact amplitude of the injected pure spin current.

In this work, we present a method to separate the ISHE from other effects and determine the injected pure spin current for the SHA quantification. The nonmagnetic/ferromagnetic bilayer stripes are integrated into the slots between the signal and ground lines of a coplanar waveguide (CPW), then the magnetic dynamics are excited with an out-of-plane microwave magnetic field. In this configuration, the ISHE voltage induced by spin pumping can be distinguished from unwanted voltage due to anisotropic magnetoresistance (AMR) effect according to their different dependence with respect to magnetic field direction. The successful separation is demonstrated with an almost perfect Lorentz line shape for the obtained signal and the frequency independent SHA value. The effective spin mixing conductance can be determined by the enhanced Gilbert damping factor due to the losing spin momentum during spin pumping. In combination with the microwave photoresistance measurements for the in- and out-of-plane precessing angles of the magnetization, we determine the amplitude of the injected pure spin current for individual samples. With varying the nonmagnetic layer thickness, the SHA and spin-diffusion length of Pt and Pd are quantified.

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Emergent spin electromagnetism induced by magnetization textures in the presence of spin-orbit interaction

Gen Tatara[1], Noriyuki Nakabayashi[2]
[1]*RIKEN Center for Emergent Matter Science (CEMS), 2-1 Hirosawa, Wako, Saitama, 351-0198 Japan*
[2]*Graduate School of Science and Engineering, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397 Japan*

Email: gen.tatara@riken.jp

Magnetic textures in metallic systems induces emergent electromagnetic fields which couples to electrons' spin [1]. These fields in the absence of spin-orbit interaction have been experimentally observed by use of the anomalous Hall effect and motion of domain wall and vortices [2]. Spin motive force was recently applied to detect velocity of magnetic skyrmion lattice [3].

In the absence of spin relaxation, the spin electromagnetic fields satisfy the Maxwell's equation [1]. The structure when spin-orbit interaction is introduced was explored recently [4-7]. It turned out that Rashba interaction introduces a novel spin gauge field resulting in Rashba-induced spin Berry's phase, but the structure of the Maxwell's equation is unchanged [7]. When spin relaxation is present, the emergent fields satisfy the Maxwell's equation but with an emergent monopole term [4]. The monopole, spin damping monopole, is non-topological, and thus local control of its current is possible. The Ampere's law indicates that monopole current induces a novel monopole-driven spin motive force whose origin is different from the conventional one induced by the time-dependent spin Berry's phase.

The discovery of spin electromagnetic fields satisfying the Maxwell's equation even when the spin-orbit interaction is introduced will provide a theoretical ground for designing novel spintronics functions. In particular, the newly found monopole is expected to play crucial roles in converting a spin signal into electric one, i.e., in the integration of spintronics into conventional electronics.

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Thermal spin-transfer torque in MgO based tunnel junction

Ke Xia
Department of Physics, Beijing Normal University, China

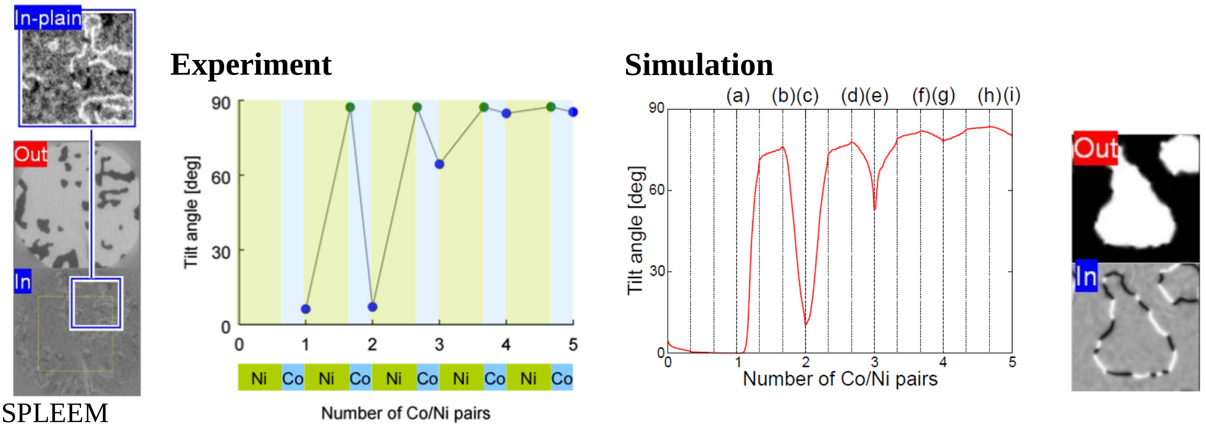
Email: kexia@bnu.edu.cn

Recently experimental and theoretical studies focusing on thermal (spin caloritronics) effects on MgO based tunnel junctions have attracted considerable interesting. Evidence for thermally induced spin transfer torque has been observed in spin valves. In this talk, we will report calculations of the thermoelectric transport properties for a Fe/MgO/Fe tunnel junctions based on realistic electronic structures. We demonstrate that the thermal spin-transfer torque (TST) in a junction with ultrathin MgO barrier amounts to 10^{-7}J/m^2/K at room temperature, which is estimated to cause magnetization reversal for temperature differences over the barrier of the order of 10 K. The large TST for ultrathin barriers can be explained by multiple scattering between interface states. Under ambient temperatures the angular dependence of the in-plane spin transfer torque is very asymmetric, which can lead to thermally induced high-frequency generation. Possibility of tuning the thermoelectric effects with bias is also discussed.

LLG simulations of magnetic domain pattern on Co/Ni multilayers

Kazue Kudo[1], Masahiko Suzuki[2], Kazuki Kojima[3], Tsuneo Yasue[2], Noriko Akutsu[4], Wilson Agerico Diño[3], Hideaki Kasai[3], Ernst Bauer[5], Takanori Koshikawa[2]
[1]*Department of Information Sciences, Ochanomizu University, Tokyo 112-8610, Japan*
[2]*Fundamental Electronics Research Institute, Osaka Electro-Communication University, Neyagawa, Osaka 572-8530, Japan*
[3]*Department of Applied Physics, Graduate School of Engineering, Osaka University, Suita, Osaka 565-0871, Japan*
[4]*Faculty of Engineering, Osaka Electro-Communication University, Neyagawa, Osaka 572-8530, Japan*
[5]*Department of Physics and Astronomy, Arizona State University, Tempe, AZ85287-1504, USA*
Email: kudo@is.ocha.ac.jp

Magnetic domains in a thin film can provide a wide variety of pattern formation. They reflect its properties such as the magnetic anisotropy. Spin polarized low energy electron microscopy (SPLEEM) is an excellent magnetic imaging technique for the study of the magnetic structure of surfaces and thin films, and it enables real time observation of magnetic domain patterns. Recent SPLEEM experiments have shown that the magnetic anisotropy, and hence magnetic domain patterns, in a Co/Ni multilayer change depending on the number of layers [1]. In the experiment, pairs of 2-ML-thick Ni and 1-ML-thick Co layers were deposited on W(110). For the first and second Co/Ni pairs, perpendicular magnetization appears after Ni deposition, and in-plane magnetization appears after Co deposition. However, after the deposition of the third Co/Ni pair, magnetization remains perpendicular to the film even after Co deposition. When domain patterns appear in the perpendicular magnetization images, the in-plane magnetization images show clear domain-wall structures. We simulate the magnetic domain patterns which were observed in the SPLEEM experiments. The model employed in the simulations is the Landau-Lifshitz-Gilbert (LLG) equation, which describes the dynamics of local magnetization. We choose the anisotropy parameters in the LLG equation so as to simulate the change of the average tilt angle of magnetization with respect to the film plane that was observed in the experiment. The numerical simulations well reproduce magnetic domain patterns with clear domain walls [2].



SPLEEM images Average tilt angle Average tilt angle Snapshots

Figure 1. Left half is SPLEEM images and the time dependence of average tilt angle obtained from experiments. Right half is the time dependence of average tilt angle and snapshots obtained from simulations [1,2].

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Direct observation of magnetic behavior by time-resolved photoemission electron microscope

T. Kinoshita
Japan Synchrotron Radiation Research Institute/SPring-8, Sayo, Hyogo 679-5198, Japan

Email: toyohiko@spring8.or.jp

The present status and the recent progress of pump-probe time-resolved photoemission electron microscopy at SPring-8 are introduced [1, 2]. The storage ring of SPring-8 is operated with many different bunch modes in order to satisfy the demands of time-resolved measurements on a variety of time-scales. We combine these bunch modes with laser pulses and/or high-frequency pulse generators to achieve a variety of pump-probe PEEM measurements and investigate phenomena such as magnetic domain motions and photo-induced phase- transitions. These ultra-short excitation sources provide pulsed magnetic fields, electric fields and photon-pulses. The element-specific time evolution of materials in response to the excitation can be observed with spatial and temporal resolutions of (50 - 300) nm and (40 - 100) ps, respectively, with repetition frequencies of up to 42 MHz. By using the magnetic circular dichroism effect, the domain motion of sub-micron sized magnetic areas can be observed. The time evolution of electronic structures in local areas can also be studied. In this talk, the experimental setups and representative activities will be presented. For example, we show the results of dynamical observation of the vortex core motion in mesoscopic size magnetic dots in response to a magnetic field pulse as well as an rf-field. We compare the displacements of the cores by the single magnetic field pulse and that by the rf-field in the resonance condition. We also introduce the dynamical measurement of light-induced magnetization reversal by utilizing femto-second pulsed lasers [3].

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Understanding the bias dependence of magnetoresistance in organic spin valves: role of ferromagnetic/organic interfaces

S. W. Jiang,[1] D. J. Shu,[1] L. Lin,[1] Y. J. Shi,[1] J. Shi,[2] H. F. Ding,[1] J. Du,[1] M. Wang,[1] and D. Wu[1]

[1]*National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China*

[2]*Department of Physics and Astronomy, University of California, Riverside, California 92521, USA*

Email: dwu@nju.edu.cn

We use an indirect deposition method to fabricate organic spin valves (OSVs) and investigate the origin of the inverse magnetoresistance (MR) in prototypical $La_{0.7}Sr_{0.3}MnO_3$ (LSMO)/Alq_3/Co OSVs. The inverse MR has been found in many OSV devices but has not been well understood. By inserting a tunnel barrier between LSMO and Alq_3, we effectively broaden the energy range of the accessible electronic states in Co electrode involved in transport. As a result, we observe a highly asymmetric MR bias dependence, with the inverse MR peaking at a negative bias and a sign reversal occurring at a positive bias. In contrast, in OSVs without any tunnel barrier, only the electronic states at the Fermi level are involved, which gives rise to the inverse MR at all bias voltages. Our experimental results in conjunction with the first-principles calculations demonstrate that the strongly hybridized Co *d*-states with Alq_3 molecules at the interface are responsible for the Co *d*-like energy-dependent spin polarization and therefore the observed MR bias dependence. These findings can open up new possibilities to engineer interfacial bonding between ferromagnetic materials and a wide variety of molecules for desired spin transport properties.

Ferromagnetic Proximity Effect in a Co_2FeAl/(Ga,Mn)As Bilayer

Jianhua Zhao
State Key Laboratory of Superlattices and Microstructures, Institute of Semiconductors,
Chinese Academy of Sciences, Beijing 100083, China

Email: jhzhao@red.semi.ac.cn

(Ga, Mn) as is widely accepted as one kind of diluted magnetic semiconductor with intrinsic ferromagnetism [1]. However, the low Curie temperature (T_c) has limited its application in spintronic devices. The highest T_C of 200 K was obtained by combining heavy Mn doping, post-growth nano-patterning and annealing, but still well below room temperature for practical application [2]. Another promising way to increase T_c is using the magnetic proximity existing in ferromagnet/(Ga,Mn)As bilayers. For examples, in Fe/(Ga,Mn)As bilayers antiferromagnetic exchange interaction and the substantial increase of T_c were observed [3,4]. In this work, we investigated magnetic proximity in the bilayers consisted of (Ga,Mn)As and a half metal, Heusler alloy Co_2FeAl, one kind of desirable spintronic material due to its high spin polarization, low Gilbert damping constant and high T_c. Unlike the common antiferromagnetic exchange existing in most Fe/(Ga,Mn)As bilayers, we found that Co_2FeAl and (Ga,Mn)As are ferromagnetically exchange coupled, with a 1.36 nm thick (Ga,Mn)As layer remaining spin-polarized up to 400 K due to magnetic proximity effect [5]. The minor loops of the Co_2FeAl/(Ga,Mn)As bilayer shift with small ferromagnetic interaction field of +24 Oe and -23 Oe at 15 K. The observed ferromagnetic interfacial coupling is supported by *ab initio* density functional calculations. These findings may provide a viable pathway for designing room-temperature semiconductor spintronic devices through magnetic proximity effect.

This work was collaborated with S. H. Nie, J. Lu, K. K. Meng, L. Chen, L. J. Zhu, D. Pan at Institute of Semiconductors, CAS, J. C. Tung at National Chengchi University, Y. Guo at National Taiwan University, Y. Y. Chin, H. J. Lin, C. T. Chen at National Synchrotron Radiation Research Center, Taiwan, W. Q. Liu, Y. B. Xu at University of York, and W. S. Yan at National Synchrotron Radiation Laboratory, Hefei.

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Identifying Surface Magnetic Anisotropy with Spin-polarized STM on the atomic scale

Chunlei Gao
Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), Department of Physics, Shanghai Jiao Tong University, Shanghai, China

Email: clgao@sjtu.edu.cn

Spin-polarized scanning tunneling microscopy (Sp-STM) has demonstrated its ability in resolving magnetic structure on the atomic scale. Here, taking the advantage of Sp-STM operating in the vector field, the surface magnetic anisotropy is identified in various magnetic surfaces. Three systems will be discussed including antiferromagnetic Néel structure, antiferromagnetic semiconductor and magnetic doped topological insulator. The spatial, angle and energy resolved surface spin density shows the complexity of surface magnetism.

Spin-transport, spin-transfer, and spin-charge coupling in nanoscale metallic lateral spin valves

Yi Ji
Department of Physics and Astronomy, University of Delaware

Email: yji@physics.udel.edu

In a metallic lateral spin valve a nonmagnetic channel of various geometries is connected to magnetic spin injectors and detectors. Both spin-polarized charge currents and pure spin currents can be generated by electrical spin injections. The interactions between the spin currents and the magnetic elements yield spin-dependent voltage signals as well as spin-transfer switching and dynamics. The flexibilities of lateral structures and the non-invasive nature of the pure spin currents offer potentials for complex spin transport structures.

The spin diffusion lengths and interfacial spin polarizations are crucial for a high quality lateral spin valve. We will show that the spin relaxation process in the nonmagnetic channel is dominated by surface slip scattering from magnetic impurities. The spin-flip rate can be reduced by oxidizing the surface impurities in air. An aluminum oxide interface between the ferromagnet and the nonmagnetic channel provides a substantial interfacial polarization. The absorption of a pure spin current into the ferromagnet is asymmetric across the finite-size junctions. This asymmetry leads to an unconventional approach for detecting nonlocal spin accumulation. Spin-transfer effects have been achieved in lateral spin valves in a broad range of temperatures from 4.5 K to 200 K. Both full magnetization reversals and evidence for magnetization dynamics have been observed with sustained injection currents.

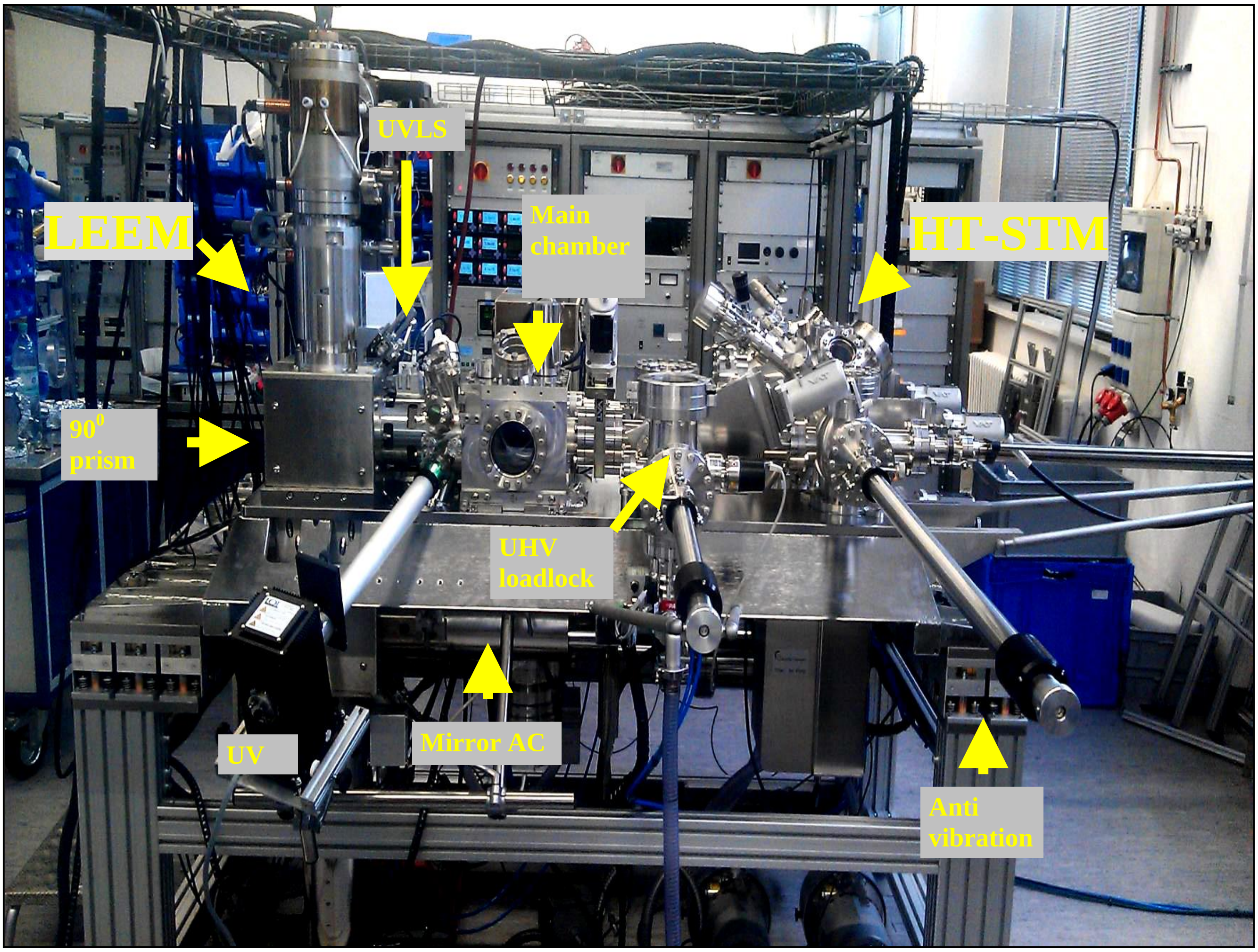
A nanometer-sized break-junction gap can be formed between the spin detector and the nonmagnetic channel by electromigration. Large spin signals with both signs (non-inverted or inverted) have been detected. The spin signals are truly nonlocal and are consistent with the delicate nature of a break junction. Theoretically a spin-charge coupling effect across the resistive break-junction leads to a large chemical potential split, which provides conduction channels for pure spin currents across the interface. Therefore an interface resistive to a charge current can be actually conductive to a spin current. The signs and magnitudes of the spin signals can be understood by the profiles of the electrochemical potentials across the interface on the scale of the charge screening length.

The New Aberration-Corrected LEEM/PEEM at Chongqing University

Weishi Wan[a,b] and Wen-Xin Tang[a,c]
College of Material Science and engineering & Physics department, Chongqing University, P. R. China[a]
Lawrence Berkeley National Laboratory, Berkeley, USA[b]
School of Physics, Monash University, Clayton, VIC 3800, Australia[c]

Email: wwan@lbl.gov ; wenxintang@cqu.edu.cn

With the support of Chongqing University, we have procured a state-of-the-art aberration-corrected LEEM/PEEM from SPECS, which has reached the spatial resolution of 1.7 nm during on-site commissioning in Germany. The main feature of this microscope is that it contains 3 prism arrays, as oppose to 2 in their standard configuration, allowing the possibility of adding a second electron gun to the system. To that end, we are currently developing an ultrafast spin-polarized electron gun with the support of the Chinese National Science Foundation. Together with the necessary lenses, the future electron gun will realize ultrafast spin-polarized LEEM in our lab.



Design of spin polarized electron gun

Weishi Wan[a,b], Lei, Yu[a], Xiaodong Yang[a], Sujuan Wu[a], Jun Feng[b] and Wen-Xin Tang[a,c]
College of Material Science and Engineering & Physics department, Chongqing University, P. R. China[a]
Lawrence Berkeley National Laboratory, Berkeley, USA[b]
School of Physics, Monash University, Clayton, VIC 3800, Australia[c]

Email: wwan@lbl.gov ; wenxintang@cqu.edu.cn

In this talk, we will report the optical design of the spin-polarized electron gun and the column leading to the SPECS AC-LEEM for future time resolved spin polarized low energy electron microscopy.

SPECS FE-LEEM/PEEM 90

FE-LEEM/PEEM P90

COMPACT LOW ENERGY ELECTRON &
PHOTOELECTRON EMISSION MICROSCOPES

KEY FEATURES

- High Lateral Resolution
- Integrated Imaging Energy Filter
- Robust Sample Stage with Five Computer-Controllable Axes
- Sample Holder with Integrated Sample Heater
- LEEM: Cold Field Emission Source with Low Energy Spread

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T +49 30 46 78 24-0
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Baolong Hotel is about 2km away from Fudan university, and about 20mins driving away from the downtown without traffic.

Conference site information

The workshop will be held in a conference room in Yifu Technology Building inside the Fudan main campus. The following shows the campus map. The lunch place locates at the east Canteen as marked by the yellow region.

There are two good places including many good restaurants to have lunch or dinner outside the campus. All kind of Chinese foods together with Korean food, Japanese food, Thailand food and Italian food can be found in Wanda Plaza and Basin 3 Plaza.