一般セッション(口頭講演) | 10 スピントロニクス・マグネティクス：10.2 スピン基盤技術・萌芽的デバイス技術

2025年3月14日(金) 9:00 ~ 11:30 K303 (講義棟)

[14a-K303-1~9] 10.2 スピン基盤技術・萌芽的デバイス技術

野崎 友大(産総研)

英語発表

9:00 ~ 9:15

[14a-K303-1]

Chirality-induced magnetoresistance driven by molecular vibration

〇Shinji Miwa[1], Tastuya Yamamoto[2], Takashi Nagata[1], Shoya Sakamoto[1], Kenta Kimura[3], Masanobu Shiga[1], Weiguang Gao[1], Hiroshi Yamamoto[4], Keiichi Inoue[1], Taishi Takenobu[5], Takayuki Nozaki[2], Tatsuhiko Ohto[5] (1.UTokyo, 2.AIST, 3.OMU, 4.IMS, 5.Nagoya Univ.)

英語発表

9:15 ~ 9:30

[14a-K303-2]

Short-term memory property in non-substituted lattice mismatched iron garnet-based room temperature spin-glass

〇(PC)shamim sarker[1], E M K Ikball Ahamed[1], Haining Li[1], Zhiqiang Liao[1], Yang Dongxun[1], Siyi Tang[1], Hiroyasu Yamahara[1], Munetoshi Seki[1], Hitoshi Tabata[1] (1.Tokyo Univ)

9:30 ~ 9:45

[14a-K303-3]

磁気カイラルメタ分子による巨大非相反透過

〇三田 健太郎[1]、児玉 俊之[1]、上田 哲也[2]、中西 俊博[3]、澤田 桂[4]、千葉 貴裕[1]、冨田 知志[1] (1.東北大、2.京都工繊大電気電子、3.京大工、4.理研Spring-8)

奨励賞エントリー 英語発表

9:45 ~ 10:00

[14a-K303-4]

Nonlocal Electrical Detection of Reciprocal Orbital Edelstein Effect

〇(D)Weiguang Gao[1], Liyang Liao[1], Yoshichika Otani[1,2,3] (1.Institute for Solid State Physics, 2.Center for Emergent Matter Science, 3.Trans-scale Quantum Science Institute)

奨励賞エントリー 英語発表

10:00 ~ 10:15

[14a-K303-5]

Nonlinear Hall Effects in the Presence of the Chiral Spin Textures

〇(M1)Takeshi Tasaki[1,2], Takaaki Dohi[1], K. Vihanga De Zoysa[1], Koya Saijo[1,2], Hideo Ohno[1,3,4,5], Shunsuke Fukami[1,2,3,4,5,6] (1.RIEC, Tohoku Univ., 2.Tohoku Univ., 3.WPI-AIMR, 4.CSIS, Tohoku Univ., 5.CIES, Tohoku Univ., 6.InaRIS)

奨励賞エントリー 英語発表

10:30 ~ 10:45

[14a-K303-6]

Probing the spin texture of topological surface states using current-induced magneto-optical Kerr effect

〇(D)Shunzhen Wang[1], Ryota Miyazaki[1], Yuta Kobayashi[1], Masashi Kawaguchi[1], Kohji Nakamura[2], Masamitsu Hayashi[1] (1.The Univ. of Tokyo, 2.Mie Univ.)

奨励賞エントリー 英語発表

10:45 ~ 11:00

[14a-K303-7]

Observation of the orbital Hall effect in Si using spin-torque ferromagnetic resonance (II)

〇Ryoga Matsumoto[1], Ryo Ohshima[1,2], Yuichiro Ando[3], Masashi Shiraishi[1,2] (1.Kyoto Univ., 2.Kyoto Univ. CSRN, 3.Osaka Metro. Univ.)

英語発表

11:00 ~ 11:15

[14a-K303-8]

Enhancement of the anomalous Nernst effect by nano-porous structures

〇(D)Takuya Tsujimoto[1], Toshio Miyamachi[1], Masaki Mizuguchi[1] (1.Nagoya Univ.)

奨励賞エントリー 英語発表

11:15 ~ 11:30

[14a-K303-9]

Anomalous Nernst effect in $(NiFe/Cu)_{10}$ multilayers

〇JUNUEI CHAN[1], BOWEN QIANG[1], Toshio Miyamachi[1], Masaki Mizuguchi[1] (1.Nagoya university)

Chirality-induced magnetoresistance driven by molecular vibration

東大物性研 [1], 東大 TSQS[2], 産総研新原理 [3], 大阪公立大工 [4], 分子研 [5], 名大工 [6]
○三輪 真嗣 [1,2], 山本 竜也 [3], 永田 崇 [1], 坂本 祥哉 [1], 木村 健太 [4], 志賀 雅亘 [1],
Weiguang Gao[1], 山本 浩史 [5], 井上 圭一 [1], 竹延 大志 [6], 野崎 隆行 [3], 大戸 達彦 [6]
ISSP-UTokyo[1], TSQS-UTokyo[2], AIST[3], OMU[4], IMS[5], Nagoya Univ.[6]
°S. Miwa[1,2], T. Yamamoto[3], T. Nagata[1], S. Sakamoto[1], K. Kimura[4], M. Shiga[1],
W. Gao[1], H. M. Yamamoto[5], K. Inoue[1], T. Takenobu[6], T. Nozaki[3] & T. Ohto[6]
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Over the past decades, the interaction between chiral organic molecules and spin polarization, termed chirality-induced spin selectivity, has been extensively reported [1]. Although these phenomena are significant, their microscopic origins are to be debated. At the JSPS Spring Meeting 2024, we presented findings on chirality-induced magnetoresistance in an electrochemical cell using camphor sulfonic acid (CSA). In this study, we delve into the microscopic aspects of these findings.

Our electrolyte solution is composed of H_2O, (*S*)- or (*R*)-CSA and KCl [2]. In this setup, CSA is a chiral molecule and induces magnetoconductance (MC) effect, while KCl acts as an achiral supporting electrolyte. We employed a multilayer electrode structure consisting of CoPt (8 nm), and Au (0-5 nm) as shown in Fig. 1. Initially, we explored the MC effect by varying the thickness of the Au layer and observed that the MC ratio oscillates with the Au thickness. The variation strongly implies the Ruderman-Kittel-Kasuya-Yosida (RKKY)-like magnetic interaction between the chiral molecules and the ferromagnetic electrode. Our first principles calculation indicates that molecular vibration leads to chirality-dependent spin polarization in the molecules and induces the MC effect [3].

A part of this work was supported by JSPS-KAKENHI (Nos. 22K18320, 22H04964, and JP24H02234), JST-ASPIRE (No. JPMJAP2317), Spintronics Research Network of Japan (Spin-RNJ), and MEXT Initiative to Establish Next-Generation Novel Integrated Circuit Centers (X-NICS) (No. JPJ011438).

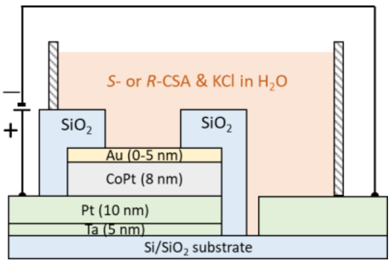

Fig. 1 Schematic of the sample.

[1] R. Naaman *et al.*, Nat. Rev. Chem. **3**, 250 (2019).
[2] T. S. Metzger *et al.*, Angew. Chem. Int. Ed. **59**, 1653 (2020).
[3] S. Miwa *et al.*, arXiv: 2412.03082

Short-term memory property in non-substituted lattice mismatched iron garnet-based room temperature spin-glass

Univ. Tokyo, ° Md Shamim Sarker*, E M K Ikball Ahamed, Haining Li, Zhiqiang Liao, Yang Dongxun, Siyi Tang, Hiroyasu Yamahara, Munetoshi Seki, and Hitoshi Tabata

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A spin glass (SG) is defined by a frozen spin state at low temperatures, arising from the interplay of randomness and frustration in magnetic interactions. This state also exhibits an aging memory effect, creating a history-dependent property. This distinctive feature offers an opportunity to emulate the functions of the human brain, leveraging a similar Hamiltonian framework. Our objective is to investigate the spin dynamics of ultra-low power data carriers (magnons) in the spin glass system at a frozen state to develop a reservoir computing system that mimics the ultra-low power operation of the human brain. However, the spin frozen state in spin glasses (SG) only appears at extremely low temperatures, limiting their practical and low-power applications. Therefore, we aim to explore the potential for developing optimal room temperature spin glass materials by manipulating the disorder within garnet-based ferrimagnetic materials. For further study of magnetization dynamics, we began with yttrium iron garnet (YIG:$Y_3Fe_5O_{12}$) due to its exceptionally low Gilbert damping constant.

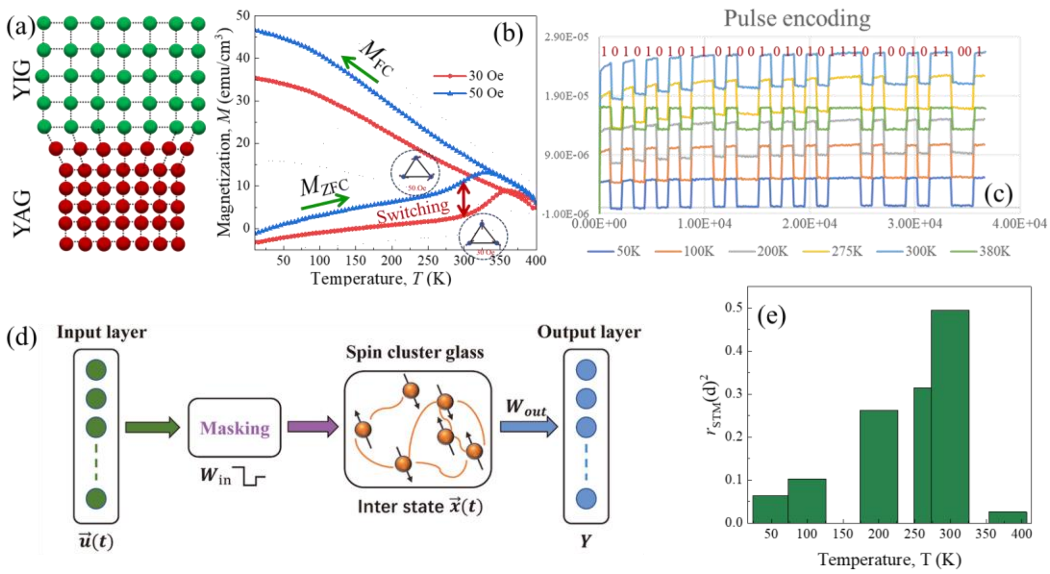

Figure 1. (a) Schematic of compressively strained YIG/YAG thin films. (b) Zero field cooling (ZFC)-Field cooling (FC) behavior under different DC magnetic field. (c) Data encoding using distinct glass states. (d) model of basic reservoir computing framework. (e) memory capacity at different glass states.

We have fabricated compressively strained 80 nm YIG thin films on YAG (001)-substrate with a lattice mismatch of 2.96% using PLD (Fig. 1(a)). We investigated and observed the bifurcation temperature (T_g) of field cooling (FC) and zero field cooling (ZFC) properties in YIG/YAG above room temperature (Fig. 1(b)) due to the growth-induced lattice expansion which breaks the symmetry in the ferrimagnetic order. Further AC characterization revealed the presence of cluster spin glass properties with a cluster size of approximately 1 nm. To confirm these memory properties, we encoded binary data (1 and 0) between two distinct freezing states at different temperatures (eg. 50 K, 100 K, 200 K, 275 K, 300 K, and 380 K) using applied magnetic fields (50 Oe for "1" and 30 Oe for "0"). The magnetic response, in terms of magnetization relaxation, is depicted in Fig. 1(c). We further fed this response into a basic reservoir computing model (Fig. 1(e)), where the reservoir is designed to mimic the magnetic interactions of the spin glass [1]. We investigated the memory capacity of the spin glass and observed short-term memory at all temperatures below the T_g (325 K at 50 Oe). However, no memory properties were observed at temperatures above T_g (380 K). Furthermore, Fig. 1(e) indicates that the memory capacity is highest near T_g. Further investigation to develop a complete neuromorphic system will be pursued in future studies.

Acknowledgement

This research was partially supported by Institute for AI and Beyond for the University of Tokyo and JST-CREST Grant Number JPMJCR22O2, Japan. JSPS KAKENHI (Grant Number, 23KF0139, JP23H04099, JP22K18804, JP20H05651).

References: [1] Z. Liao et al. Sci. Rep, 13 5260 (2023)

磁気カイラルメタ分子による巨大非相反透過

Giant nonreciprocal transparency by magnetochiral metamolecules

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理研 SPring-8[5]，東北大学際研 [6]，東北大応物 [7]
○(M1) 三田健太郎 [1]，児玉俊之 [2]，上田哲也 [3]，中西俊博 [4]，澤田桂 [5]，千葉貴裕 [6,7]， 冨田知志 [1,2]
Tohoku Univ.[1], Kyoto Inst. Tech.[2], Kyoto Univ.[3], RIKEN[4]
○K. Mita[1], T. Kodama[1], T. Ueda[2], T. Nakanishi[3], K. Sawada[4], T. Chiba[1], S. Tomita[1]
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物質の光応答は、その系の対称性と関係している。例えば、空間反転対称性の破れは光学活性を、時間反転対称性の破れはファラデー効果を引き起こす。さらに、これらの対称性が同時に破れた系では、偏光に依存しない方向複屈折 (磁気カイラル効果) が生じる。これまで、私たちは銅螺旋構造とイットリウム鉄ガーネット (YIG) 円柱からなる磁気カイラルメタ分子を作製し、導波管を用いたマイクロ波透過測定でフォトンとマグノンの超強結合状態であるマグノンポラリトンを観測してきた [1,2]。今回、試料と測定系の最適化により、磁気カイラルメタ分子を用いて非常に大きな非相反透過を観測することに成功したので報告する。

図 1(a) に直径 2 mm、長さ 5 mm の YIG 円柱に、0.55 mm の銅線を 4/3 回転巻き付けて作製した磁気カイラルメタ分子を示す。メタ分子を導波管 WR90 中に配置し、ベクトルネットワークアナライザーを用いてマイクロ波の複素透過係数である S パラメーターを測定した。図 1(b) は導波管内のメタ分子の配置を示しており、この場合、マイクロ波の電場は円柱の長手方向と平行にある。電磁石を用いて外部直流磁場を z 軸正の方向に印加した。$|S_{21}|$ はマイクロ波が z 軸正の方向に伝搬する場合、$|S_{12}|$ は z 軸負の方向に伝搬する場合の透過係数である。

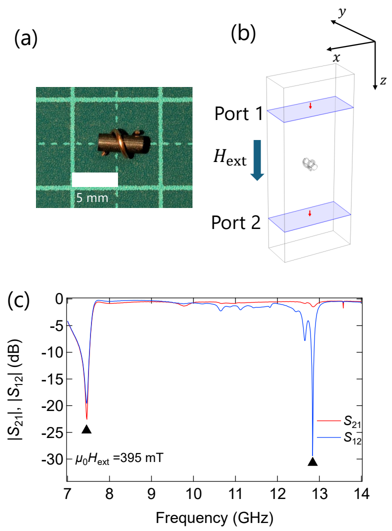

図 1: (a) Magneto-chiral metamolecule. (b) Measurement setup of the y-axis-oriented metamolecule placed in a waveguide. (c) $|S_{21}|$ and $|S_{12}|$ spectra under DC magnetic fields 395 mT

図 1(c) に外部磁場が 395 mT の場合の $|S_{21}|$（赤線）と $|S_{12}|$（青線）を示す。7.46 GHz と 12.84 GHz に銅コイルの構造共鳴（フォトン）と YIG の磁気共鳴（マグノン）が結合したマグノンポラリトンに起因する信号が見られる。12.84 GHz に着目すると、磁場と伝搬方向が反平行な $|S_{12}|$ ではマイクロ波が 28 dB だけ減衰するのに対し、磁場と伝搬方向が平行な $|S_{21}|$ ではマイクロ波が透過する一方向透過が実現されている。この一方向透過は、巨大な移動媒質効果に起因することが有効分極テンソルの計算 [3] から示唆された。

この研究は科研費（JP24H02232,23K13621, 22K14591）、JST-CREST（JPMJCR2102）によって支援されている。黒澤裕之博士による助言に感謝する。

[1] 三田、他　2024 年第 71 回応用物理学会春季学術講演会, 25a-P01-2
[2] Mita *et al*., Phys. Rev. Applied, in press.
[3] Kodama *et al*., Opt. Mat. Expr. 14, 2499 (2024).

Nonlocal Electrical Detection of Reciprocal Orbital Edelstein Effect

Weiguang Gao [1]*, Liyang Liao[1], and YoshiChika Otani[1,2,3]
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Abstract

The orbital Edelstein effect[1–3], where the charge current induces nonequilibrium orbital moment, offers a promising method to manipulate nanomagnets efficiently using light elements[1,4–8]. Despite extensive research, understanding the Onsager reciprocity of orbital transport—fundamentally rooted in the second law of thermodynamics and time-reversal symmetry—remains elusive. Here, we present our research that experimentally demonstrates the Onsager reciprocity of orbital transport in an orbital Edelstein system[2,4–6] by utilizing nonlocal measurements. This method enables the precise identification of the chemical potential generated by orbital accumulation, avoiding the limitations associated with local measurements. Remarkably, we observe that the direct and inverse orbital-charge conversion processes produce identical electrical voltages, confirming Onsager reciprocity in orbital transport. Additionally, we find that the orbital decay length, approximately 100 nm at room temperature, is independent of Cu thickness and decreases with lowering temperature, revealing a distinct contrast to spin transport behavior[7].

1. El Hamdi, A. *et al.* Observation of the orbital inverse Rashba–Edelstein effect. *Nat. Phys.* **19**, 1855–1860 (2023).
2. Go, D. *et al.* Orbital Rashba effect in a surface-oxidized Cu film. *Phys. Rev. B* **103**, L121113 (2021).
3. Park, S. R., Kim, C. H., Yu, J., Han, J. H. & Kim, C. Orbital-Angular-Momentum Based Origin of Rashba-Type Surface Band Splitting. *Phys. Rev. Lett.* **107**, 156803 (2011).
4. Kim, J. *et al.* Nontrivial torque generation by orbital angular momentum injection in ferromagnetic-metal/ Cu / Al 2 O 3 trilayers. *Phys. Rev. B* **103**, L020407 (2021).
5. Kim, J. *et al.* Oxide layer dependent orbital torque efficiency in ferromagnet/Cu/oxide heterostructures. *Phys. Rev. Materials* **7**, L111401 (2023).
6. Ding, S. *et al.* Harnessing Orbital-to-Spin Conversion of Interfacial Orbital Currents for Efficient Spin-Orbit Torques. *Phys. Rev. Lett.* **125**, 177201 (2020).
7. Kimura, T., Sato, T. & Otani, Y. Temperature Evolution of Spin Relaxation in a NiFe / Cu Lateral Spin Valve. *Phys. Rev. Lett.* **100**, 066602 (2008).

Nonlinear Hall Effects in the Presence of the Chiral Spin Textures

T. Tasaki[1,2], T. Dohi[1], K. V. De Zoysa[1], K. Saijo[1,2], H. Ohno[1,3,4,5], and S. Fukami[1,2,3,4,5,6]

RIEC, Tohoku Univ.[1], Graduate School of Engineering, Tohoku Univ.[2], WPI-AIMR, Tohoku Univ.[3], CSIS, Tohoku Univ.[4], CIES, Tohoku Univ.[5], InaRIS[6]

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Chiral topological spin textures, exemplified by chiral domain walls (DWs) and magnetic skyrmions, have recently attracted attention as a building block in future spintronic devices due to the capability that their dynamics can be efficiently controlled by electrical means [1]. Recent studies suggested that the strongly pinned in-plane magnetized domains and topological spin textures exhibit higher-order nonlinear Hall effects, possessing potential for reservoir computing [2]. However, a detailed understanding of its origin has been elusive. Here, we prepared $[Pt/Co/W]_{15}$ multilayer stacks on thermally oxidized Si substrates, expected to host chiral spin textures with high depinning energy [3], and observed an unconventional nonlinear Hall response distinct from that of monodomain states [4].

Firstly, systematic magnetization measurements of the $[Pt/Co/W]_x$ systems [Fig. 1] suggests a formation of chiral Néel DWs associated with a large interfacial Dzyaloshinskii-Moriya interaction and long-range dipole interaction for x = 15. Subsequently, the harmonic (1st and 2nd-order) transverse resistance in $[Pt/Co/W]_{15}$ is measured [Fig. 2], showing a finite 2nd-order Hall resistance $R^{(2f)}$ (f = 3.33 kHz) near zero magnetic fields. Remarkably, we find a symmetric component of $R^{(2f)}$, which was not observed in the previous study [2]. In the presentation, we will discuss the detailed analysis of the results in terms of the chirality, spin topology, and the contribution of the current-induced torque.

This work is partly supported by JSPS Kakenhi, JST-ASPIRE, and MEXT X-NICS.

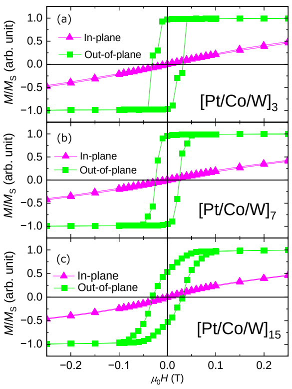

Fig. 1 In-plane and out-of-plane magnetization curves of (a) $[Pt/Co/W]_3$, (b) $[Pt/Co/W]_7$, and (c) $[Pt/Co/W]_{15}$.

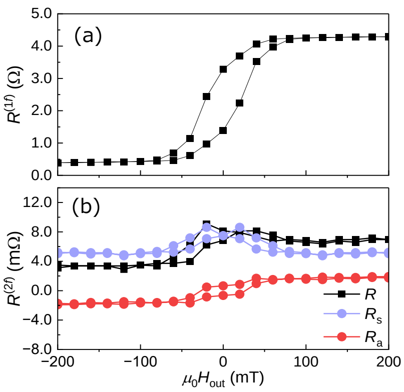

Fig. 2 Out-of-plane field dependence of $R^{(nf)}$ under an AC. (a) n = 1, (b) n = 2, J_0 = 9.31×10^{10} A/m^2. Black markers are raw data. Blue (red) markers in (b) are the symmetric (anti-symmetric) component R_s (R_a).

References

1) X.Z. Yu *et al.*, Nat. Commun. **3**, 988 (2012). 2) T. Hori *et al.*, Phys. Rev. Mater. **8**, 044407 (2024). 3) V. Jeudy *et al.*, Phys. Rev. B. **98**, 054406 (2018). 4) J. Kim *et al.*, Nat. Mater. **12**, 240 (2013).

Probing the spin texture of topological surface states using current-induced magneto-optical Kerr effect

The Univ. of Tokyo[1], Mie Univ. [2], ○Shunzhen Wang[1], Ryota Miyazaki[1], Yuta Kobayashi[1], Masashi Kawaguchi[1], Kohji Nakamura[2] and Masamitsu Hayashi[1]

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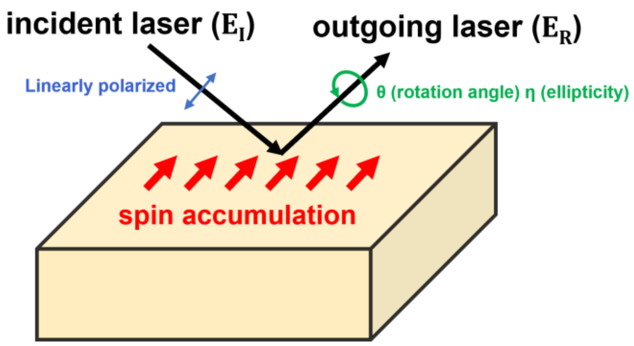
Topological insulators (TIs) have attracted considerable attention for their spin-momentum-locked topological surface states (TSS). This unique property has sparked significant effort to exploit the surface states for electrical manipulation of magnetization of an adjacent magnetic layer. However, majority of the studies on current-induced spin accumulation in TIs rely on spin torque measurements which require attaching a ferromagnetic layer on top of TIs. This may influence the characteristics of the TSS. The magneto-optical Kerr effect (MOKE), which can be used to detect spin (and orbital) accumulation directly, has yielded intriguing results in semiconductors [1] and metals [2-5]. Studies on current induced spin/orbital accumulation in TIs, however, are limited. Here we use MOKE to study the spin texture of TSS.

3D topological insulator $(Bi_{1-x}Sb_x)_2Te_3$ thin films are grown using molecular beam epitaxy (MBE). Magneto-optical Kerr measurements are performed using a homemade setup. An alternative (AC) current was applied to the sample and the corresponding Kerr rotation and ellipticity signals were detected using a balanced photo-detector. The Kerr signal linearly increases with the current applied to the sample: see Fig. 1. The magnitude of the Kerr signal was found to be significantly larger than that found in metals. We measure the Kerr signal against the Bi: Sb composition to study the Fermi level dependence of the current induced spin accumulation. In the presentation, we discuss interpretation of the experimental results.



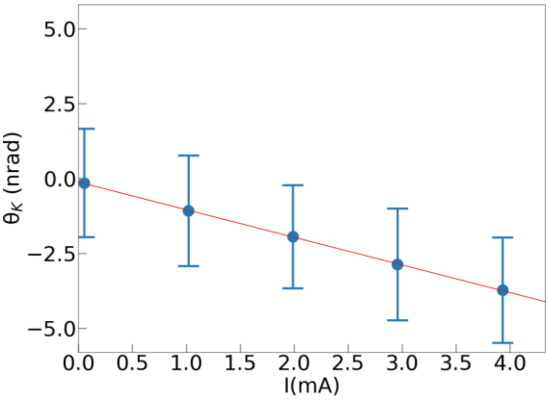


Fig. 1: Schematic illustration (left) and Detected Kerr signal (θ_{MOKE}) in a TI sample (right).

[1] Kato et al. Science 306, 1910 (2004). [2] Stamm et al. Phys. Rev. Lett. 119, 087203 (2017). [3] Choi et al. Nature 619, 52 (2023). [4] Marui et al. Phys. Rev. B 108, 144436 (2023). [5] Lyalin I, et al. Phys. Rev. Lett. 131,156702 (2023).

Observation of the orbital Hall effect in Si using spin-torque ferromagnetic resonance (II)

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The orbital Hall effect (OHE), where an application of an electric field gives rise to the transverse flow of orbital angular momentum, has been attracting tremendous attention. Whereas the spin-orbit torque (SOT) driven by the spin Hall effect requires, in principle, heavy materials with a large spin-orbit coupling (SOC), the OHE takes place even in light elements, which can circumvent the limitation of the material choice for SOT devices [1,2]. Although the OHE has been mainly studied in light transition metals with the *s-d* orbital hybridization such as Ti [2], the OHE is observable in a wide variety of materials with orbital hybridization, given that the hybridization is the key for orbital current generation. In this study, the OHE in Si, which is semiconductor and has the *s-p* orbital hybridization, is investigated by using spin-torque ferromagnetic resonance (ST-FMR).

Figure 1 shows the device structure and the measurement setup. A 100 nm-thick (001)-silicon-on-insulator substrate is used to fabricate ST-FMR devices made of Si/Ni bilayer. Doping concentration of phosphorous in Si is approximately 5×10^{19} cm^{-3}, i.e. the Si is degenerated and n-type. All measurements were carried out at room temperature. Figure 2 shows a DC voltage V_{DC} measured under the ferromagnetic resonance condition of the Ni in the Si(70 nm)/Ni(10 nm) device as a function of an external magnetic field B_{ext}. The frequency of the rf current was 5 GHz, where the magnetic field (φ) was applied along $\varphi = 45°$ for the rf current direction. The damping torque efficiency per unit electric field ξ^E_{DL}, which is an index of the magnitude of OHE in Si, was calculated to be 75 Ω^{-1}cm^{-1} from the amplitude of the V_{sym} component exhibiting the sin2φcosφ dependence. The Si thickness dependence of the ξ^E_{DL} was measured (see Fig. 3) and the orbital decay length in Si was estimated to be 17.8 ±5.9 nm. Monotonic increase of the the ξ^E_{DL} as a function of the Ni thickness supports our assertion of successful creation of the orbital current in Si.

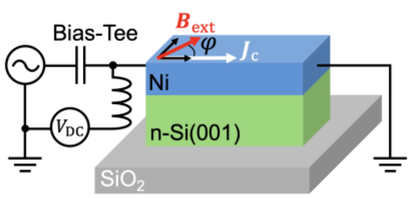

Fig. 1 ST-FMR measurement setup.

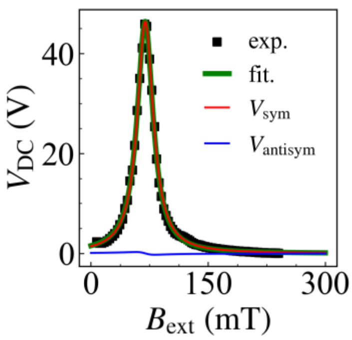

Fig. 2 B_{ext} dependence of V_{DC}.

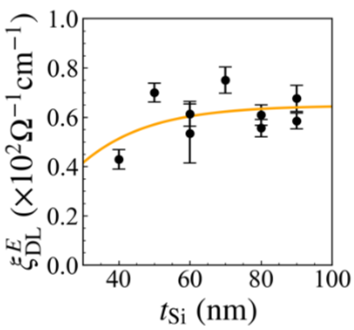

Fig. 3 Si thickness dependence.

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Enhancement of the anomalous Nernst effect by nano-porous structures

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The anomalous Nernst effect (ANE) is one of the thermoelectric conversion phenomena commonly observed in ferromagnets and expected as next-generation energy harvesting technologies. A characteristic of this effect is that the direction of the electric field generated by thermoelectric conversion is perpendicular to the temperature gradient. By utilizing the anomalous Nernst effect, it is now possible to fabricate highly flexible and simple-structured devices with a degree of freedom that was previously unattainable. However, the conversion efficiency of the ANE is too small to use practically, and it is a large issue to enhance the scattering of electrons for the ANE. Recently, we have reported the enhancement of the ANE in the granular thin films[1]. Therefore, we hypothesized that by creating unique nanostructures in ferromagnets, we could enhance the electron scattering. The porous structure is well known as materials with large amounts of pores. In this study, we investigated the ANE for the porous Co thin films with different pore sizes and investigated porosity-dependence on the ANE.

We prepared porous Co thin films by vapor phase dealloying method[2] and studied the crystallographic structures using scanning electron microscope (SEM). The Nernst voltage was measured by a physical property measurement system (PPMS) with a perpendicular magnetic field to the film plane at room temperature. Figure 1 shows a SEM image of the porous Co thin films, which was post-annealed at 620°C for 30 seconds. The bright and dark regions are Co and pore, respectively. It is confirmed that nanoporous films are successfully obtained and averaged pore size was approximately 33 nm. We calculated the transverse thermoelectric conductivity (α_{yx}), which reflects the magnitude of the ANE and plotted it as a function of the pore size in Figure 2. The ANE in Co porous structure was enhanced with decreasing the pore size. By utilizing the deep learning model, we also investigated the correlation between the ANE and characteristic structures of the porous films.

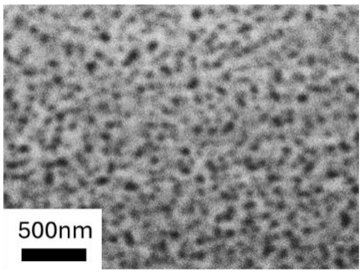

Fig. 1 SEM image of porous Co thin film.

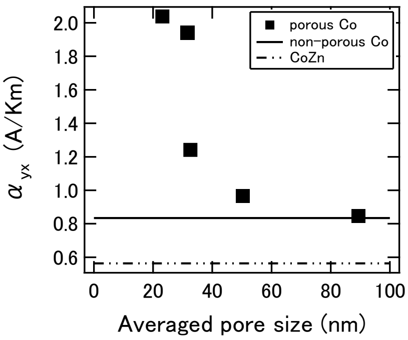

Fig. 2 α_{yx} plotted as a function of pore size.

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Anomalous Nernst effect in $(NiFe/Cu)_{10}$ multilayers

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Introduction

The anomalous Nernst effect (ANE), one of the thermoelectric effects in a magnet, is recently attracting growing interest as it has great potential for the next generation of high-efficiency energy harvesting applications[1]. However, reported thermopower of ANE is not enough for the applications to date. Thus, it is important to design a new class of materials that exhibit a large ANE. It has been reported that the ANE can be improved by multilayer structures[2]. In addition, the interlayer exchange coupling (IEC) is also interesting phenomenon in multilayer structures. Therefore, we suppose that studying the impact of IEC on ANE will lead to an understanding of ANE in multilayer structures.

In this study, we prepared $(NiFe/Cu)_{10}$ multilayer thin films with different thickness of Cu, and investigated the relationship between IEC and ANE.

Experimentals

$(NiFe/Cu)_{10}$ multilayers were prepared by using a magnetron sputtering. A thickness of NiFe was fixed to 1.8 nm and a thickness of Cu was varied between 0.5-1.4 nm. A physical property measurement system (PPMS) was used for the measurement of magnetoresistance (MR), ANE and AHE (anomalous Hall effect). MR was measured by applying a direct current of 0.1 mA at room temperature and the saturation magnetic field of each sample was estimated. ANE and AHE were measured by applying an external magnetic field of -50,000 to 50,000 Oe in the out-plane direction of samples. The relationship among ANE, AHE and IEC in $(NiFe/Cu)_{10}$ multilayers was investigated in detail.

Results

Magnitude of ANE in $(NiFe/Cu)_{10}$ multilayers drastically changed with increasing a thickness of Cu. This change almost corresponded to that of the Seebeck effect. This result implies the correlation between ANE and IEC. On the other hand, no relation was observed between ANE and AHE. Mechanism of ANE in the multilayer samples will be discussed.

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