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) 13:30 ~ 17:00 🏛 K303 (講義棟)

## [14p-K303-1~13] 10.2 スピン基盤技術・萌芽的デバイス技術

山田 貴大(東工大)、 日置 友智(東大)

🏷 奨励賞エントリー 🏷 英語発表

13:30 ~ 13:45

[14p-K303-1]

### Influence of magnetization direction on the intrinsic Gilbert damping in the V/Fe/MgO multilayer

〇(D)Jieyi Chen[1], Shoya Sakamoto[1], Hidetoshi Kosaki[1], Erkang Wei[1], Tempei Hatajiri[1], Shinji Miwa[1,2] (1.ISSP-UTokyo, 2.TSQS-UTokyo)

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🏷 奨励賞エントリー

13:45 ~ 14:00

[14p-K303-2]

### Effect of additive element on light-helicity induced magnetization dynamics in $Co_{1-x}Y_x$ (Y = Pt, Pd, Ni) alloy

〇抜井 康起[1,2]、飯浜 賢志[3]、石橋 一晃[1,2]、水上 成美[2,4] (1.東北大工、2.東北大AIMR、3.名大工、4.東北大CSIS)

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🏷 奨励賞エントリー 🏷 英語発表

14:00 ~ 14:15

[14p-K303-3]

### Investigation of tunable Co/Pt spintronics THz emitter by ionic gating

〇Yuu Maruyama[1], Weipeng Wu[2], Ryo Ohshima[1,3], Yuichiro Ando[1,3], Benjamin Jungfleisch[2], Masashi Shiraishi[1,3] (1.Kyoto Univ., 2.Delaware Univ., 3.CSRN Kyoto Univ.)

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14:15 ~ 14:30

[14p-K303-4]

### Nonreciprocity of Spin Wave with Small Wavenumber in Ferromagnetic Bilayer

〇(B)Shion Yoshimura[1], Kento Yasui[1], Shugo Yoshii[1], Ryo Ohshima[1], Masashi Shiraishi[1] (1.Kyoto Univ.)

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🏷 奨励賞エントリー

14:30 ~ 14:45

[14p-K303-5]

### Asymmetric attenuation of surface acoustic waves by magnetic layers with compositional gradients

〇佐藤 駿輝[1]、芳井 崇悟[1]、大島 諒[1]、白石 誠司[1] (1.京大工)

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🏷 奨励賞エントリー 🏷 英語発表

14:45 ~ 15:00

[14p-K303-6]

### Investigation of origin of spin wave nonreciprocity

〇Haruka Komiyama[1], Kotaro Taga[1], Ryusuke Hisatomi[1,2,3], Hiroki Matsumoto[1], Hideki Narita[1,3], Shutaro Karube[1,2,3], Yoichi Shiota[1,2], Teruo Ono[1,2] (1.ICR, Kyoto Univ., 2.CSRN, Kyoto Univ.,

3.PREST, JST)

🏷 奨励賞エントリー 🏷 英語発表

15:15 ~ 15:30

[14p-K303-7]

Effective magnetic field by orbital torque in Pd/$Co_2$MnGa perpendicular magnetization films

〇Takaya Koyama[1], Kenta Watanabe[1], Tetsuya Uemura[1], Michihiko Yamanouchi[1] (1.Hokkaido Univ.)

🏷 英語発表

15:30 ~ 15:45

[14p-K303-8]

Single- and two-mode squeezing of magnons by parametric pumping

〇Tomosato Hioki[1,2,3], Mehrdad Elyasi[2], Kaito Tojo[1], Koujiro Hoshi[4,3], Eiji Saitoh[1,2,3,4] (1.Dept. Appl. Phys., Univ. Tokyo, 2.AIMR, Tohoku Univ., 3.CEMS, RIKEN, 4.Inst. AI and Beyond, Univ. Tokyo)

🏷 奨励賞エントリー 🏷 英語発表

15:45 ~ 16:00

[14p-K303-9]

Ultrastrong coupling of on-chip magnon polaritons in a YBCO superconducting resonator

〇(D)Shugo Yoshii[1,2], Manuel Muller[3], Ryo Ohshima[1,2], Yuichiro Ando[1,2,4], Matthias Althammer[3], Hans Huebl[3], Masashi Shiraishi[1,2] (1.Kyoto Univ., 2.CSRN, Kyoto Univ., 3.WMI, 4.Osaka Metropolitan Univ.)

🏷 英語発表

16:00 ~ 16:15

[14p-K303-10]

Spin Hall effect in Platinum deposited by atomic layer deposition for 3D magnetic race-track memory

〇Namhai Pham[1], Ishida Ken[1], Kota Sato[1] (1.Ins. Sci. Tokyo)

🏷 英語発表

16:15 ~ 16:30

[14p-K303-11]

Investigation on the current induced domain-wall motion in Pt/GdFe wires for thinner GdFe region

〇Masaaki Tanaka[1], Takuto Sakamoto[1], Toshiki Tokuyama[1], Hirofumi Tozuka[1], Syuta Honda[2], Hiroyuki Awano[3], Ko Mibu[1] (1.Nagoya Inst. Tech., 2.Kansai Univ., 3.Toyota Tech. Inst.)

🏷 奨励賞エントリー 🏷 英語発表

16:30 ~ 16:45

[14p-K303-12]

Demonstration of current-induced spin-orbit torque magnetization switching in electrodeposited CoPt ultrathin film

〇(DC)Tongshuang Huang[1], Shinji Isogami[2], Takanori Shirokura[1], Md. Mahmudul Hasan[3], Mikiko Saito[3], Jun Uzuhashi[2], Tadakatsu Ohkubo[2], Shinya Kasai[2], Shigeki Nakagawa[1], Yota Takamura[1] (1.Science Tokyo, 2.NIMS, 3.Waseda Univ.)

🏷 奨励賞エントリー 🏷 英語発表

16:45 ~ 17:00

[14p-K303-13]

# Néel Vector Rotation Driven by Spin-Orbit Torque in Amorphous Ferrimagnetic GdCo Thin Films

〇Tetsuma Mandokoro[1], Yoichi Shiota[1,2], Tomoya Ito[1], Hiroki Matsumoto[1], Hideki Narita[1], Ryusuke Hisatomi[1,2], Shutaro Karube[1,2], Teruo Ono[1,2] (1.ICR, Kyoto Univ., 2.CSRN, Kyoto Univ.)

# Influence of magnetization direction on the intrinsic Gilbert damping in the V/Fe/MgO multilayer

**ISSP-UTokyo[1], TSQS-UTokyo[2]**

**°Jieyi Chen[1], Shoya Sakamoto[1], Hidetoshi Kosaki[1], Erkang Wei[1], Tempei Hatajiri[1], and Shinji Miwa[1,2]**

**E-mail: jieyi@issp.u-tokyo.ac.jp**

The intrinsic Gilbert damping constant in magnetic multilayers could be a signature of the spin current generation in the spin-pumping effect [1]. In such research, materials with *strong* spin-orbit coupling, such as 5*d* heavy metals, are usually employed. Recently, the orbital-pumping effect, which works as a source of orbital current generation, has been reported in materials with 3*d* transition metals with *weak* spin-orbit coupling [2]. We have also reported that the intrinsic Gilbert damping in the V/Fe/MgO multilayer is influenced by MgO overlayer thickness, which may be related to the orbital magnetic moment in the system [3]. In this study, we report the intrinsic Gilbert damping of the V/Fe/MgO system with changing the magnetization direction.

We fabricated epitaxial V/Fe/MgO multilayers using molecular beam epitaxy [Fig. 1(a)]. The magnetization dynamics were characterized by the time-resolved magneto-optical Kerr effect (TR-MOKE). The setup of the TR-MOKE system and the measured magnetization dynamic for MgO 0.5 nm thickness at fixed field angles of 10˚, 20˚, and 30˚ are shown in Fig. 1(b) and 1(c). We found that the intrinsic Gilbert damping strongly depends on the magnetization direction. The details on the magnetization direction and Fe thickness dependence will be discussed.

This work was partly supported by JSPS KAKENHI (Grants Nos. JP22H00290, JP22H04964, JP22K18320, and JP23H01833), Spin-RNJ, JST-Mirai Program (JPMJMI20A1), JST-ASPIRE (No. JPMJAP2317), X-NICS (No. JPJ011438), and JST-SPRING (No. JPMJSP2108).

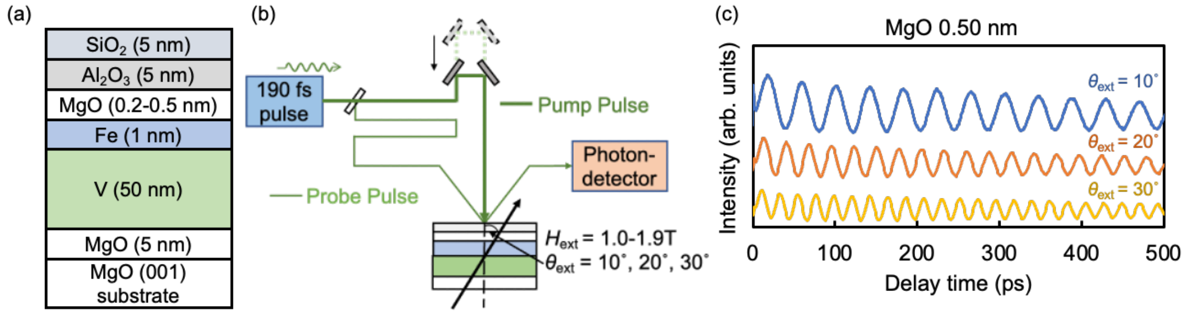

Fig. 1. (a) Schematic of the multilayers. (b) Setup of the TR-MOKE.

(c) Magnetization dynamics of the Fe/MgO (0.5 nm) measured at $\theta_{ext}$ = 10˚, 20˚, and 30˚.

[1] S. Mizukami *et al.*, Phys. Rev. B **66**, 104413 (2002).

[2] H. Hayashi, *et al.*, Nat. Electron. **7**, 646-652 (2024).

[3] J. Chen *et al.*, *The 85th JSAP Autumn Meeting*, 16p-D61-1, Niigata, 2024, 9 (2024).

# Effect of additive element on light-helicity induced magnetization dynamics in $Co_{1-x}Y_x$ (Y = Pt, Pd, Ni) alloy

**[1]Dept. of Appl. Phys., Tohoku Univ., [2]WPI-AIMR, Tohoku Univ., [3]Dept. of Mater. Phys., Nagoya Univ.,**
**[4]CSIS, Tohoku Univ.**
**°Kouki Nukui[1,2,*], Kazuaki Ishibashi[1,2], Satoshi Iihama[3], Shigemi Mizukami[2,4]**
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Magnetization control using light has drawn considerable attention for diverse magnetic applications, including laser-assisted magnetic recording and optically writable spintronic memory [1]. Among these, helicity-dependent all-optical switching (HD-AOS) enables direct manipulation of ferromagnetic metal magnetization by tuning the helicity of incident light [2]. Although multiple mechanisms have been proposed for HD-AOS, accumulating evidence suggests that light-induced effective magnetic fields and spin polarization exert both field- and damping-like torques on magnetization [3,4]. More recently, our group reported that electron orbitals can also be generated by light helicity, as demonstrated by time-resolved magneto-optical Kerr effect (TRMOKE) measurements of CoPt alloy thin films [5].

In this study, we systematically investigate light-helicity-induced magnetization dynamics in Co1−xYx (Y = Pt, Pd, Ni) thin films. These samples were grown on thermally oxidized Si substrates via ultrahigh vacuum magnetron sputtering, with compositions finely tuned by co-sputtering. We conducted TRMOKE measurements under a 2 T in-plane magnetic field, observing magnetization precession initiated by circularly polarized pump pulses. Figure 1(a) shows a representative waveform from Co-Pt alloy films, fitted with a damped sinusoidal function to derive the oscillation amplitude A and phase φ. Figure 1(b) plots φ against x, revealing a clear increase in φ with x, which points to a damping-like torque arising from helicity-driven orbital generation. Further details of these findings and the underlying physics will be discussed in our presentation.

This work was partially supported by JSPS KAKENHI, JST PRESTO, MEXT X-NICS, the Asahi Glass Foundation, and the Murata Science Foundation. K.N. and K.I. gratefully acknowledge the support of GP-spin at Tohoku University.

[1] H. Becker, *et. al.*, IEEE J. Sel. Top Quant. Electron **26**, 8300408 (2019).
[2] C.-H. Lambert, *et. al.,* Science **345**, 1337 (2014).
[3] G.-M. Choi, *et. al.,* Nat. Commun. **8**, 15085 (2017).
[4] P. Němec, *et. al.,* Nat. Phys. **8**, 411 (2012).
[5] K. Nukui, *et. al.,* Phys. Rev. Lett. **134**, 016701 (2025).

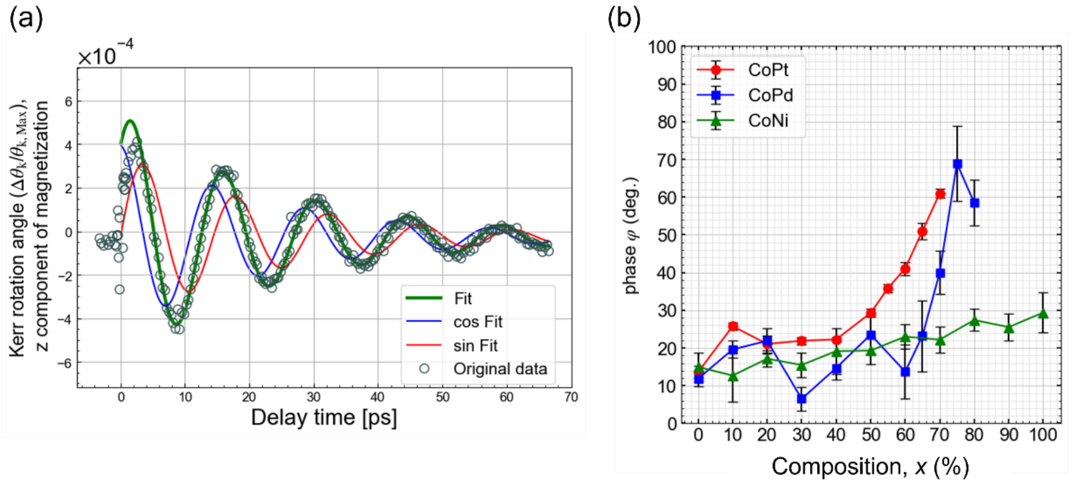

Figure 1 (a) Typical data for light-helicity induced magnetization dynamics in CoPt alloy thin film. (b) Oscillation phase $\varphi$ plotted as a function of composition of additive elements $x$.

# Investigation of tunable Co/Pt spintronics THz emitter by ionic gating

**Kyoto Univ. [1], Delaware Univ. [2], CSRN Kyoto Univ. [3],**

**°Yuu Maruyama[1], Weipeng Wu[2], Ryo Ohshima[1, 3], Yuichiro Ando [1, 3],**

**Benjamin Jungfleisch[2], and Masashi Shiraishi[1, 3]**

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Spintronics THz emitter (STE) is gathering a lot of attention as a broad band THz source made of ferromagnet metal (FM) / heavy metal (HM) bilayer structure [1]. In the THz emission process, a spin current is injected from the FM layer to the HM layer and is converted to a charge current, where the spin-orbit interaction (SOI) plays a critical role in determining the intensity of the THz signal. It has been believed that the SOI is material specific and is not easy to control externally. However, by applying an ionic gating technique, the inverse spin Hall effect and the Hanle magnetoresistance in nanometer-thick Pt single layer were modulated due to the modulation of the SOI [2, 3]. These results suggest realization of the tunable STE, which facilitates future applications of STE and the other spintronic devices. To explore the possibility, we investigated tunability of STE by applying an ionic gating technique.

Figure 1 illustrates the measurement setup. Two Co (2 nm)/Pt (2 nm) bilayer films were fabricated simultaneously on a double-polished sapphire substrate using an electron beam deposition. One film was used as STE, while the other was used as the gate electrode. To apply strong gate electric fields, we put ionic gel, which is the mixture of ionic liquid (DEME-TFSI) and gelling agent [2, 3]. THz signals were measured by the THz time-domain spectroscopy at room temperature with changing the gate voltage $V_G$. Figure 2 shows the $V_G$ dependence of the THz signals. The amplitude of the THz signals obviously changed depending on the $V_G$ [4]. Further discussion about its underlying physics will be carried out in the presentation.

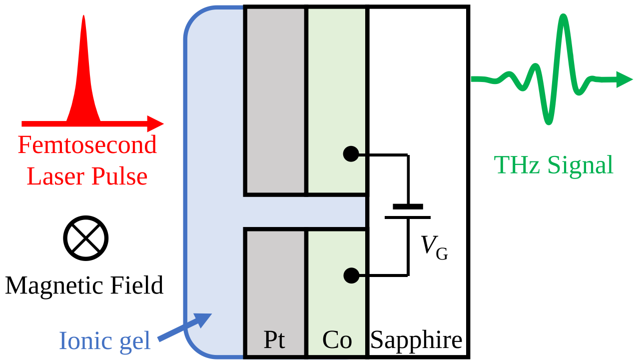

Fig. 1. Measurement setup

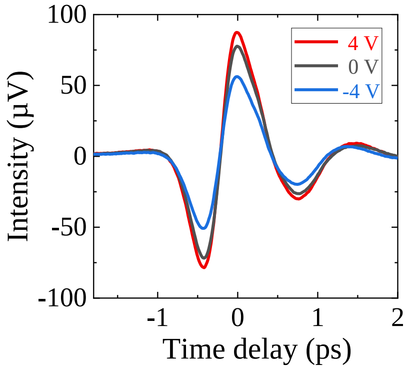

Fig. 2. $V_G$ dependence of the THz signals

[1] W. Wu *et al.*, *J. Appl. Phys.* **130**, 091101 (2021). [2] S. Dushenko *et al.*, *Nat. Commun.* **9**, 3118 (2018).
[3] Y. Maruyama *et al.*, *Appl. Phys. Express* **16**, 023004 (2023). [4] Y. Maruyama *et al.*, *in preparation.*

# Nonreciprocity of Spin Wave with Small Wavenumber in Ferromagnetic Bilayer

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E-mail: yoshimura.shion.56i@st.kyoto-u.ac.jp

Spin wave has been attracting attention as a new information carrier due to its low energy consumption in propagation and high frequency response (GHz to THz) [1]. Especially, achieving unidirectional propagation of the spin wave is a crucial step for building blocks such as isolators and circulators, which are essential for data processing [2]. One approach for realizing this is to utilize frequency nonreciprocity. Whilst several systems have been proposed to induce frequency nonreciprocity, a ferromagnetic (FM) bilayer exhibits considerably large frequency difference despite its simple structure [3]. However, achieving significant nonreciprocity so far requires a large wavenumber, at which the group velocity tends to decrease as the dipole interaction becomes weaker and the fast Damon-Eshbach (DE) mode couples with the flat standing spin wave mode [4]. In this study, we investigated an influence of FM bilayer film thickness on frequency nonreciprocity as a function of wavenumber, which provides the guiding principle for achieving frequency nonreciprocity at small wavenumbers.

$SiO_2$ (50 nm)/MgO (3 nm)/Co ($l$/2 nm)/$Ni_{81}Fe_{19}$ ($l$/2 nm) was prepared on a $SiO_2$/Si substrate by using electron beam deposition (MgO, Co, $Ni_{81}Fe_{19}$) and RF magnetron sputtering ($SiO_2$), and coplanar waveguides (CPWs) of Au (100 nm)/Ti (3 nm) were equipped (see Fig. 1). Transmission spectra of spin waves ($S_{21}$ and $S_{12}$) were measured by using a vector network analyzer (VNA), where the frequency range was set to be 300 kHz to 18 GHz with the power of 5 dBm. An external magnetic field was applied to the sample in the $y$ direction and was swept from 0 mT to 100 mT. Figure 2(a) shows the colormap of $|\Delta S_{ij}|=|S_{ij} - S_{ij}\ (0\ \mathrm{mT})|$ (i, j = 1, 2 or 2, 1) when $l$ = 100 nm, where the frequency difference of -1.04 GHz was obtained. The dispersion relations of several modes were calculated by using the Landau-Lifshitz equation [3], and the wavenumber and the mode of this spin wave were identified. The measurement result and the theoretical curves of different film thicknesses are plotted in Fig. 2(b), which indicates that strong nonreciprocity is realized at a small wavenumber. The detailed discussion will be given in the presentation.

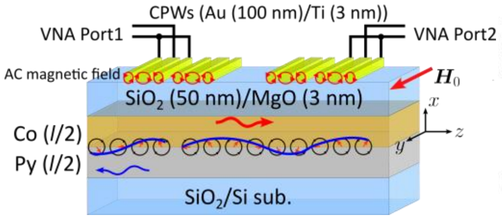

Fig. 1 Sample structure

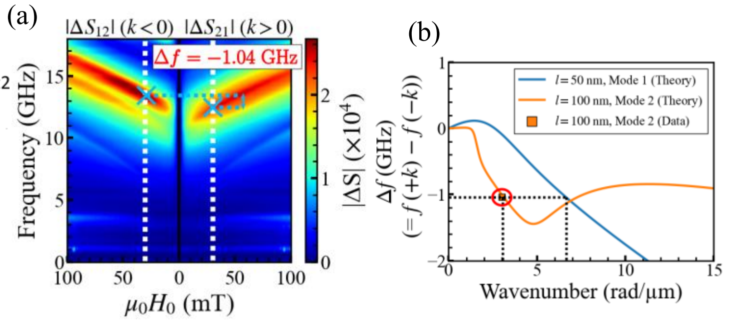

Fig. 2 (a) Colormap when $l$ = 100 nm (b) Comparison of frequency nonreciprocity with different thicknesses ($\mu_0 H_0$ = 30 mT)

[1] A. Mahmoud *et al.*, J. Appl. Phys. **128**, 161101 (2020). [2] D. Jalas *et al.*, Nat. Photon. **7**, 579 (2013).
[3] M. Grassi *et al.*, Phys. Rev. Appl. **14**, 024047 (2020). [4] M. Kostylev *et al.*, J. Appl. Phys. **113**, 053907 (2013).

# 組成勾配を導入した磁性層による表面弾性波の非対称な減衰
# Asymmetric attenuation of surface acoustic waves by magnetic layers with compositional gradients

京大院工 ○佐藤 駿輝，芳井 崇悟，大島 諒，白石 誠司
Kyoto Univ. ○Shunki Sato, Shugo Yoshii, Ryo Ohshima and Masashi Shiraishi
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Surface acoustic wave (SAW) is mechanical vibrations that propagate locally on a solid surface and is used in devices such as high-performance filters. In the context of spintronics, SAWs interact with magnetization in large magneto-strictive materials like Ni and Co via the magnetoelastic coupling to excite spin waves. The attenuation of SAW, induced by spin wave excitation is known to be asymmetric in both the direction of propagation and a direction of an external magnetic field [1]. Several studies attribute this asymmetry to the shear strain components in SAWs, which are asymmetric in the propagation direction. In particular, Tateno et al. observed that the asymmetry in attenuation becomes more pronounced by increasing the ratio of shear components to symmetric longitudinal components [2]. However, to add a Si layer with several hundred nm in thick is required for achieving it, and the detailed mechanism for the asymmetry remains elusive. In this study, a composition gradient was introduced in a 20 nm thick magnetic layer, expecting that static strain from the gradient can enhance the asymmetry.

The measurement setup is shown in Fig. 1. We fabricated inter digital transducers (IDTs) on a piezoelectric $LiNbO_3$(LN) substrate for SAW excitation and detection, and a magnetic film of LN/$[Co/Ni]_4$((4/1)(3/2)(2/3)(1/4) nm)/MgO(2 nm) between the IDTs. When an AC voltage is applied to the IDTs using a vector network analyzer, SAWs are excited due to the inverse piezoelectric effect. The SAWs excite spin waves in the magnetic layer and lose energy in it. The SAWs that pass through the magnetic layer are then detected electrically in the pair of IDTs via the piezoelectric effect. The so-called non-reciprocal characteristics were investigated by normalizing the amplitudes of $S_{21}$ and $S_{12}$, which have different propagation directions. The results are shown in Fig.2, where the enhanced asymmetry compared to a Ni monolayer is successfully realized. Further details will be presented during the discussion.

[1] R. Sasaki et al. Phys Rev. B **95**, 020407(R) (2017). [2] S. Tateno et al. Phys Rev. Appl.**13**, 034074 (2020).

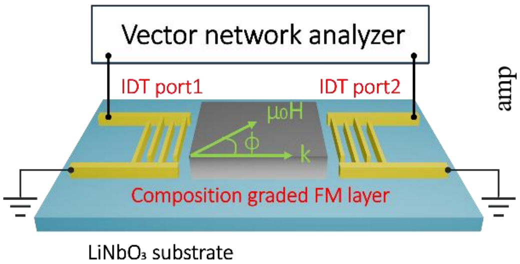

Fig. 1 Experiment setup

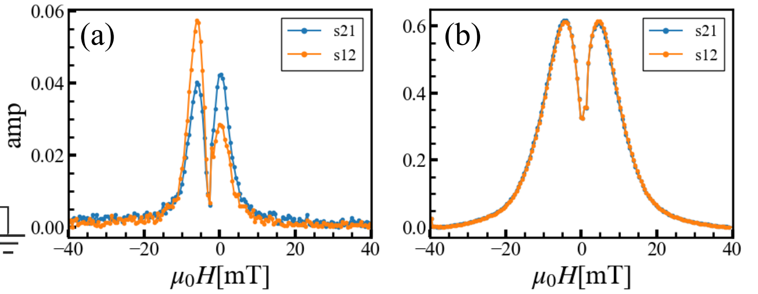

Fig. 2 Comparison of the Magnetic Field Dependence of SAW Attenuation in (a) a FM Layer with a Composition Gradient (left, $\phi$ =-10 °) and (b) a Ni Single Layer (right, $\phi$ =45 °)

# Investigation of origin of spin wave nonreciprocity

**ICR, Kyoto Univ. [1], CSRN, Kyoto Univ.[2], PRESTO, JST [3]**

**°Haruka Komiyama[1], Kotaro Taga [1], Ryusuke Hisatomi [1,2,3], Hiroki Matsumoto[1],**

**Hideki Narita[1,3], Shutaro Karube[1,2,3], Yoichi Shiota[1,2] and Teruo Ono[1,2]**

**E-mail: komiyama.haruka.64v@st.kyoto-u.ac.jp**

Spin wave nonreciprocity, defined as the difference in characteristics depending on the propagation direction, provides functionality to magnonic devices. Spin wave nonreciprocity has primarily been studied using electrical measurements. However, it is difficult to identify the origin of nonreciprocity with this method because the signal contains contributions from both excitation and propagation effects. In addition, previous studies have focused only on specific magnetic field configurations. In this study, we use conventional electrical measurements and optical imaging measurements to observe the spatial distribution of spin waves while sweeping the magnetic field angle to investigate the origin of spin wave nonreciprocity [1].

We perform electrical measurements to study the angle dependence of spin wave nonreciprocity using the setup shown in Fig. 1(a). Transmission coefficients $S_{21}$ and $S_{12}$ are obtained by using a vector network analyzer (VNA) under an in-plane magnetic field $H_{\mathrm{DC}}$ at an angle $\theta$. As shown in Fig. 1(b), the nonreciprocity $\kappa_e$, defined as the ratio of the amplitude of the transmission coefficients, increases around 10° and 30°. The theoretical nonreciprocity model $\kappa_t$, which considers only the asymmetry of spin wave excitation efficiency as the origin, explains the increase in the nonreciprocity $\kappa_e$ around 10° but not around 30°, suggesting another origin of spin wave nonreciprocity: propagation asymmetry.

To confirm this hypothesis, we carry out magneto-optical Kerr effect (MOKE) measurements [2] to observe the spatial distribution of spin waves propagating along the $\pm x$ direction. We find that the propagation length asymmetry increases around 30°. Based on optical measurement results, the nonreciprocity $\kappa'$, which considers both excitation and propagation asymmetry, reproduces the nonreciprocity $\kappa_e$ over 30° in Fig. 1(b). These results indicate that spin wave nonreciprocity originates from both excitation and propagation asymmetry.

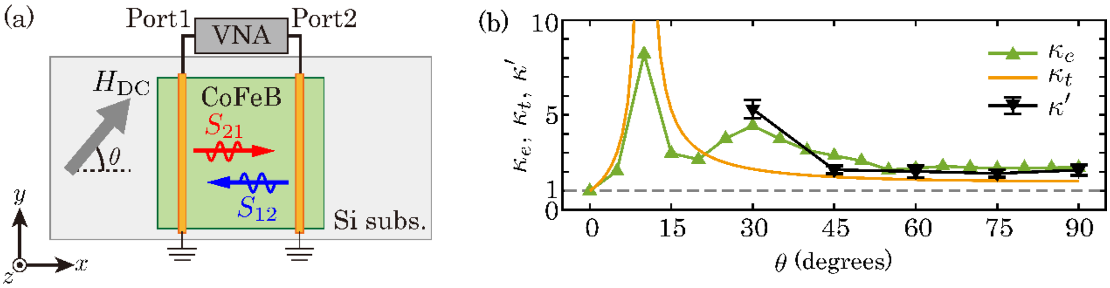

Fig. 1 (a) Experimental setup and device for observing spin wave nonreciprocity by electrical measurements. (b) Angle $\theta$ dependence of the nonreciprocity $\kappa_e$, $\kappa_t$, and $\kappa'$ at 50 mT.

[1] H. Komiyama *et al.*, J. Magn. Soc. Jpn., **49**, 13-16 (2025).
[2] Y. Shiota *et al.*, Appl. Phys. Lett., **116**, 192411 (2020).

# Effective magnetic field by orbital torque in Pd/$Co_2$MnGa perpendicular magnetization films

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○Takaya Koyama, Kenta Watanabe, Tetsuya Uemura, and Michihiko Yamanouchi
E-mail: eequalmcsquared@eis.hokudai.ac.jp

Three terminal spintronics devices based on nonmagnetic metal/ferromagnet heterostructures are promising for next-generation electronics. Orbital torque (OT) has recently attracted much attention for writing information to such spintronics devices. Heterostructures composed of Weyl ferromagnets are expected for reducing current density required for the writing operation because orbital current can be efficiently converted to spin current through strong spin orbit interaction (SOI) in Weyl ferromagnets. However, OT induced in Weyl ferromagnets has not been clarified yet. In this work, we investigated it by comparing the current-induced torque in a perpendicularly magnetized Pd/Weyl ferromagnet $Co_2$MnGa (CMG) with that in Pd/weak-SOI ferromagnet $Co_2$MnSi (CMS).

Two stacking structures composed of, from the surface side, Pd (3.0 nm)/CMG (1.8 nm), and Pd (3.0 nm)/CMS (0.8 nm) were deposited on an MgO (001) substrate. Both stacking structures were processed into Hall-bar-shaped devices with a 2 μm-wide channel and a pair of Hall probes. Out-of-plane hysteresis loops were measured by applying a constant current $I$ under an in-plane magnetic field $H_x$. along the channel direction while sweeping the perpendicular magnetic field $H_z$. The center of the hysteresis loop was shifted along the $H_z$-axis depending on $I$ and $H_x$ for both stacking structures. According to an early study [1], the shift amount corresponds to the effective magnetic field $H_{\mathrm{eff}}$ originating from spin-orbit torque and/or OT exerted on domain walls, which were created during magnetization reversal. The $H_{\mathrm{eff}}$ increased (decreased) almost linearly with increasing $I$ under a positive $H_x$ for Pd/CMG (Pd/CMS), which indicates the $H_{\mathrm{eff}}$ is equivalent to $H_z$ for both stacks, and the direction of $H_{\mathrm{eff}}$ in Pd/CMG is opposite to that in Pd/CMS. Recent first-principles calculations have predicted Pd has a positive spin Hall conductivity and a negative orbital Hall conductivity [2], and the direction of $H_{\mathrm{eff}}$ in Pd/CMS is in agreement with that induced by the predicted spin current. These results indicate OT dominates the torques induced by in-plane current in Pd/CMG.

This work was supported in part by JSPS KAKENHI (22K18961), MEXT X-NICS (JPJ011438), MEXT ARIM (JPMXP1224HK0020), JST CREST (JPMJCR22C2).

References
[1] J. Han, *et al*., Appl. Phys. Lett. **119**, 212409 (2021).
[2] D. Go, *et al*., Phys. Rev. B, **109**, 174435 (2024).

# Single- and two-mode squeezing of magnons by parametric pumping

# マグノンのパラメトリック励起による単一・2モードスクイージング

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Magnetization dynamics in thermal equilibrium fluctuate randomly due to thermal effects, making it impossible to predict the magnetization orientation in the next moment. However, in nonequilibrium states, these fluctuations can stop being complete random and exhibit a hidden order, forming correlations. This ordered state, called "squeezing," has potential applications in quantum operations and heat engines exceeding classical limits. While squeezing has been observed in systems like phonons and photons, it has not been previously demonstrated in magnons, the quasiparticles of magnetic excitations.

In this study, we achieved magnon squeezing, creating correlations between magnetization dynamics at different surfaces of the magnetic thin film. To realize this, we used parametric excitation, where an oscillating magnetic field with twice the ferromagnetic resonance frequency generates magnetization oscillations. In terms of quasiparticles, this corresponds to a process where one microwave photon produces two magnons. When the magnons have different frequencies but their sum matches the oscillating field's frequency, this is called a non-degenerate process, which can lead to the formation of correlations between the magnons.

We used a thin film of the ferromagnetic insulator $Y_3Fe_5O_{12}$ (YIG) with a thickness of 1.4 μm, fabricated into a disk shape and coated with platinum. Due to asymmetry in electromagnetic boundary conditions on the film's surfaces, the dispersion relation for magnons breaks spatial inversion symmetry, resulting in different frequencies for surface-localized magnon modes on the top and bottom surfaces. By applying a microwave magnetic field with twice the resonance frequency, we excited magnetization dynamics and, by slightly adjusting the external magnetic field strength, successfully achieved non-degenerate parametric excitation, generating magnons localized on different surfaces.

The results demonstrate magnon squeezing and its ability to generate correlations in magnetic systems, offering new opportunities for studying correlated dynamics. Further details will be presented during the discussion.

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# Ultrastrong coupling of on-chip magnon polaritons in a YBCO superconducting resonator

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Magnon polariton, a strong coupling between electromagnetic microwave (photons) and quantized spin waves (magnons), has been fascinating research with regard to the light-matter interaction. In the context of light-matter interaction, the achievement of the ultrastrong coupling regime represents a crucial milestone for exploration of the veiled quantum phenomena induced by counter-rotating terms (CRTs) [1]. Since the CRTs are capable of generating their squeezed states, there has been a strong anticipation that they will serve as the foundational physics in the next generation of quantum technologies. Despite the existence of multiple reports on the realization of ultrastrong coupling in magnon polaritons, the majority of studies have been constrained to bulk $Y_3Fe_5O_{12}$ [2, 3]. In this study, we demonstrate the achievement of ultrastrong coupling of magnon polariton within thin metallic ferromagnetic film on high-$T_C$ $YBa_2Cu_3O_7$ (YBCO) resonator, where the Bloch-Siegert shift, the signature of the existence of CRTs, was successfully observed [4].

The ferromagnetic films of NiFe alloy (Py) with the stacking order of $SiO_2$ (10 nm) / MgO (2 nm) / Py (30 nm) / Ti (3 nm) / $SiO_2$ (20 nm) were mounted onto the superconducting resonator made of high-$T_C$ YBCO, where the layers were deposited by using electron-beam deposition except for sputtered $SiO_2$ capping and buffer layer. The superconducting resonator with the ferromagnetic films is introduced into cryostat, which was cooled down to 10 K. The external magnetic field was swept between ± 145 mT, and a microwave was applied at a power of 0 dBm and with a frequency range of 4.8-5.4 GHz (Fig. 1). Figure 2 shows the normalized transmission spectra, $\Delta S_{21}$, of magnon polariton for the sample, where the coupling strength ($g$) is estimated to be 674 MHz and the ratio, $\eta = g/\omega$, exceeds 0.1, entering ultrastrong coupling regime. The system also demonstrates the Bloch-Siegert shift, the energy shifts due to the existence of CRTs.

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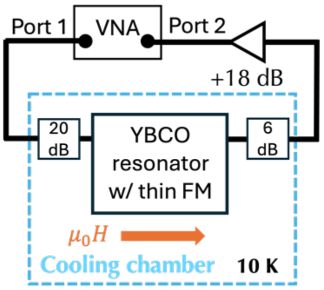

Fig. 1 Schematic of measurement.

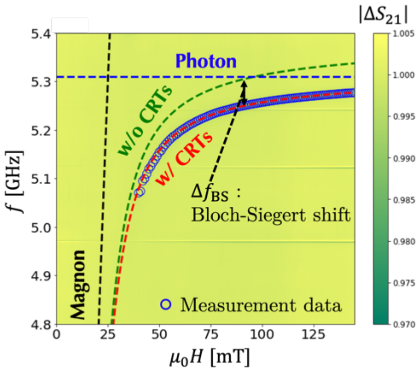

Fig. 2 Transmission spectra of magnon polariton within 30 nm-thick Py film.

# Spin Hall effect in Platinum deposited by atomic layer deposition for 3D magnetic race-track memory

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Magnetic domain wall motion driven by spin-orbit torque (SOT) in two-dimensional thin-film memory has been extensively researched. However, increasing magnetic memory density on a single chip necessitates a transition to three-dimensional architectures, such as three-dimensional (3D) racetrack memory. So far, implementation of such structure is hindered by the limitations of conventional physical vapor deposition techniques such as sputtering, thermal evaporation, and molecular beam epitaxy, which are incapable of achieving uniform film deposition over complex three-dimensional surfaces. In this work, we systematically investigate the surface morphology, electrical, and spintronic properties of Pt thin films deposited by ALD on c-plane sapphire substrates with film thickness $t_{\mathrm{Pt}}$ from 1.4 nm to 10.6 nm. Quantitative evaluation of electrical conductivity, spin Hall angle and spin Hall conductivity was carried out by 4-terminal method and high-field second harmonic technique. Figure 1 shows the spin Hall angle, electrical conductivity, and spin Hall conductivity of ALD-grown Pt at various thicknesses. We found that the electrical conductivity of Pt remained relatively constant, whose value (~ $1.8\times10^{6}\ \Omega^{-1}\mathrm{m}^{-1}$) was lower than that of Pt deposited by magnetron sputtering when the film thickness is below 7 nm. Strikingly, it suddenly increases from around 7 nm, and with further thickening to approximately 10.6 nm it is as high as $7.0\times10^{6}\ \Omega^{-1}\mathrm{m}^{-1}$ approaching that of bulk-Pt. Consequently, the efficient spin Hall conductivity of ALD-grown Pt is relatively low ($0.2 \sim 0.6\times10^{5}\ \hbar/2e\ \Omega^{-1}\mathrm{m}^{-1}$) for Pt film thicknesses less than 7 nm, but it suddenly increases for thicker films, reaching $2.5 \sim 3.0\times10^{5}\ \hbar/2e\ \Omega^{-1}\mathrm{m}^{-1}$. This behavior is attributed to the intrinsic morphology of Pt thin films grown by ALD on sapphire, where ultrathin film (< 7 nm) contains small islands, while thicker films is smoother thanks to the coalescence of islands. Our results demonstrate the potential of ALD for 3D SOT applications, while outlining future work needed to refine ultra-thin film (< 7 nm) deposition processes.[1)]

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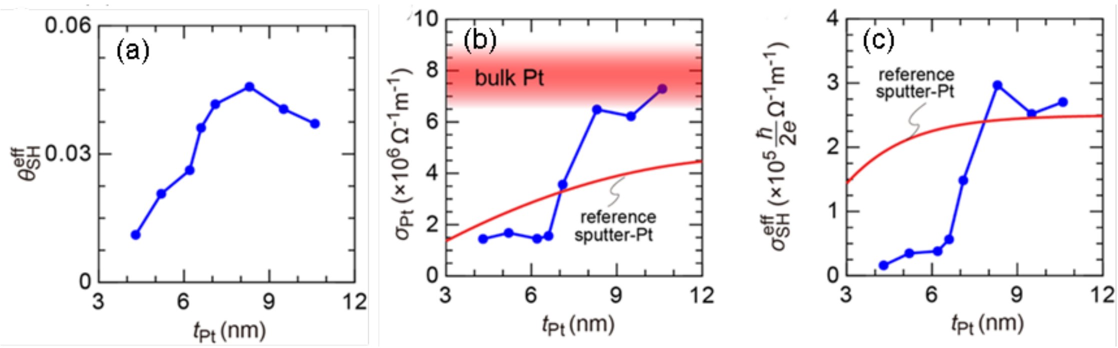

Figure 1. Thickness dependence of (a) spin Hall angle, (b) electrical conductivity, and (c) spin Hall conductivity of ALD-grown Pt thin films. The red solid lines in (b) and (c) represent reference data of sputter-deposited Pt.

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# Investigation on the current induced domain-wall motion in Pt/GdFe wires for thinner GdFe region

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Electric-current-induced movements of domain walls in magnetic wires are paid attention because of the curiosity from their potential as new spintronics devices, such as racetrack memories. It is possible to achieve speed-up and low power consumption for these memories with increase of the domain-wall velocity. Recently, a domain-wall velocity greater than 1000 m/s was observed for perpendicularly magnetized ferrimagnetic GdFe wires [1]. In this study, we investigated the dependence of the domain-wall velocity on the GdFe thickness for a thinner region in order to realize high velocity of the domain wall movement.

Pt (3 nm)/GdFe (*t*) wires with 10 μm in width were fabricated on thermally oxidized Si substrates with SiN (3 nm) buffer layers using electron-beam lithography, sputtering, and a lift-off method. Wires with GdFe thicknesses *t* of 8, 10, 15, and 20 nm were prepared. Note that the Gd compositions are set to 29% for the wire with $t = 8$ nm and 26% for the wire with $t = 10$, 15, and 20 nm because the optimum Gd compositions for stabilizing the perpendicular magnetic anisotropy vary depending on the film thickness. The coercive forces of the wires with $t = 8$, 10, and 15 nm were almost the same. The velocities of the domain walls were measured by Kerr microscopy with applying periodic current pulses.

Figure 1 shows the current-dependence of domain-wall velocity for these wires. The domain-wall velocity increases with an increase in the current, and the increase rate increases with a decrease in the GdFe film thickness. For wires with $t = 10$, 15, and 20 nm, the rate of increase as a function of the current slows down, and the velocity does not increase above 1500 m/s. In contrast, for the wire with $t = 8$ nm, the velocity increased smoothly with increasing current, and a high velocity of more than 5000 m/s was observed. These findings demonstrate that ultrathin GdFe films with the thicknesses below 10 nm enable high-speed domain-wall movement.

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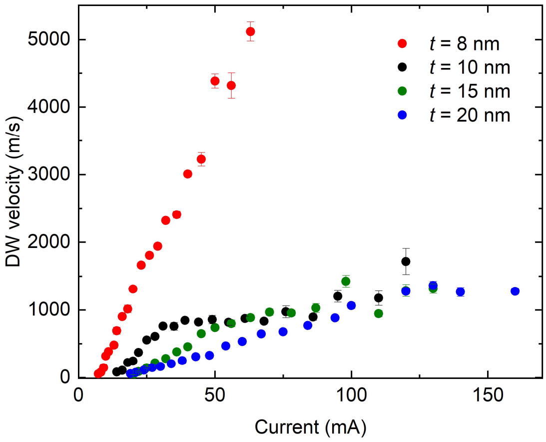

Fig.1 Current- and GdFe-thickness-dependence of domain-wall velocity.

# CoPt めっき膜における電流誘起スピン軌道トルク磁化反転の実証

# Demonstration of current-induced spin-orbit torque magnetization switching in electrodeposited CoPt ultrathin film

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A three-dimensional magnetic domain wall motion memory (3D-DWMM) device with artificial ferromagnet was recently proposed as a next-generation storage device [1]. Electrodeposition offers a promising method to form high aspect ratio magnetic nanopillars for 3D-DWMM, in which the write operation is spin-orbit torque magnetization switching (SOT-MS). To date, we have developed a pulse electrodeposition technique for CoPt thin films with perpendicular magnetic anisotropy (PMA) [2] and demonstrated spin-orbit torque (SOT) in the CoPt layer [3]. Here, we present the first demonstration of current-induced SOT-MS for an electrodeposited CoPt layer, unveiling a potential of electrochemical deposition for spintronics devices.

The stack structure was Ta (3 nm)/$Co_{70}Pt_{30}$ (2.8 nm)/Pt (18 nm)/Ti (5 nm)/$SiO_2$/Si substrate. A cross-sectional bright field (BF-) scanning transmission electron microscopy (STEM) image (Fig. 1) revealed the formation of a continuous layer. The interface between Pt and CoPt layers was abrupt, and thus efficient spin injection was expected. Figure 2 shows anomalous Hall effect (AHE) signals under an out-of-plane magnetic field ($H_{\mathrm{ext}}$) for a Hall bar of the stack structure (shown as the inset), manifesting strong PMA of the CoPt layer. Figure 3 shows $R_{\mathrm{AHE}}$ as a function of injected current under $H_{\mathrm{ext}}$ parallel to the current. The transition at approximately $\pm 30\times10^{10}$ A/m$^2$ clearly indicated the SOT-MS. The curves exhibited clockwise and anticlockwise switching loop under positive and negative $H_{\mathrm{ext}}$, respectively. This behavior is consistent with theoretical predictions [4] and experimental results [5]. This work demonstrates the feasibility of write operation via SOT in 3D-DWMM, and highlights potential applications of electrodeposition in spintronics.

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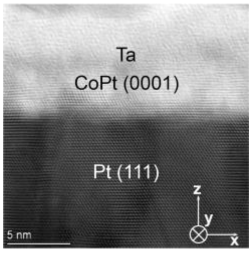

Fig. 1 STEM image.

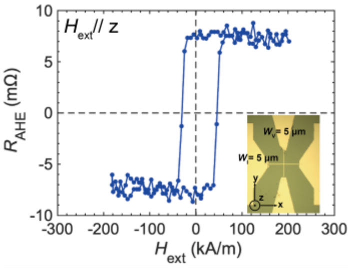

Fig. 2 AHE signals

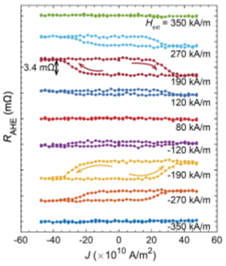

Fig. 3 Current-induced SOT-MS.

# Néel Vector Rotation Driven by Spin-Orbit Torque in Amorphous Ferrimagnetic GdCo Thin Films

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Spin superfluidity is a novel phenomenon for low-dissipation transportation of spin angular momenta with a magnetization rotation in a plane [1,2]. Since magnetic dipolar interactions disturb the long-distance transportation of the magnetization rotation, antiferromagnetic materials serve as a better platform to study the spin superfluidity than ferromagnets. Observing this phenomenon requires the continuous rotation of an antiferromagnetic Néel vector within its magnetic easy plane [1,2]. While the control of the Néel vector by spin-orbit torque has been widely studied [3-5], the Néel vector rotation has not been demonstrated because the energy barrier of magnetocrystalline anisotropy hampers the Néel vector rotation [5]. To overcome this problem, we used an amorphous ferrimagnet GdCo that is free from magnetocrystalline anisotropy and the magnetic dipolar interaction at the magnetization compensation temperature. In ferrimagnet, the magnetic moments of the two sublattices are confined to a plane perpendicular to the applied magnetic field ($H_{\mathrm{ext}}$) when $H_{\mathrm{ext}}$ exceeds a spin-flop transition field, forming a pseudo-magnetic easy plane.

We deposited a film stack of Ta(5)/$\mathrm{Gd_{0.28}Co_{0.72}}$(3)/Pt(5) (unit: nm) trilayer on a thermally oxidized Si substrate by using DC magnetron sputtering. The buffer Ta layer and the capping Pt layer serve as the spin current sources to apply a spin-orbit torque (SOT). The films were micro-fabricated into Hall bar devices. GdCo layer holds magnetic easy axis perpendicular to the film plane, as confirmed by magnetic field sweeps of the anomalous Hall resistance. We measured an anomalous Hall resistance with applying a pulse current of 10-μs-duration under the magnetic field of 8 T in the film plane, which is sufficient to induce spin-flop transition at 240 K. When the pulse current exceeded the threshold, the anomalous Hall resistance exhibited stochastic binary switching. We infer that the Néel vector rotation was driven by SOT during the pulse current application and eventually relaxes along the out-of-plane direction, randomly pointing either upward or downward. To elaborate this behavior, we also performed the homodyne detection of the Néel vector rotation with a microwave current in a Hall geometry. We found that the rotation frequency was in the range of several GHz. Our results provide strong evidence of the continuous rotation of Néel vector.

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