Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp75-76

Enhancement of Spin-orbit Torque by CoO_x Layer Insertion into Co/Pt Interface

Kento Hasegawa[1], Yuki Hibino[1], Motohiro Suzuki[2], Tomohiro Koyama[1] and Daichi Chiba[1]

[1] The Univ. of Tokyo
7-3-1, Hongo, Bunkyo, Tokyo 113-8656, Japan
Phone: +81-3-5841-1166 E-mail: khasegawa@cblb.t.u-tokyo.jp
[2] Japan Synchrotron Radiation Research Institute
1-1-1, Kouto, Sayo, Hyogo 679-5198, Japan

Abstract

We report the significant enhancement of the spin-orbit torque (SOT) in a Co/Pt structure by partially oxidizing the Co-side interface. The SOTs for an interface-oxidized and unoxidized Co/Pt samples were determined by a harmonic Hall measurement. The interface-oxidized sample was found to be superior in both the damping- and filed-like SOTs even though the insulating CoO_x layer exists at the Co/Pt interface. One possible origin of the enhancement of the SOT is the efficient spin current injection from the Pt into the Co layer caused by the insertion of the CoO_x layer into the interface.

1. Introduction

Improving the efficiency of the spin-orbit torque (SOT) in ferromagnet (FM) /heavy metal (HM) structures is an issue for future magnetic memory devices since the SOT enables the ultra-fast magnetization switching [1,2]. In this study, the effect of the oxidation layer insertion on the SOT has been investigated using Co/CoO_x/Pt structures.

2. Experiments and Results

The Ta(3.0 nm)/Pd(3.0 nm)/Co(t_{Co}) layers were deposited from the bottom side on a thermally-oxidized Si substrate, where t_{Co} was varied from 0.9 (0.4) to 1.0 (0.6) nm for the interface-oxidized (unoxidized) samples. For the interface-oxidized (IO) sample, the surface of the Co layer was exposed to air to form the CoO_x layer. Subsequently, the 2.7-nm-thick Pt, which can generate the spin current through the spin Hall effect, was deposited onto the oxidized Co surface. For the unoxidized (UO) sample, the Pt layer was deposited continuously under vacuum onto the metallic Co layer. From the measurement of the areal magnetic moment, the effective thickness of the CoO_x layer in the IO sample was determined to be ~0.5-0.7 nm.

The damping-like (DL) and field-like (FL) SOT effective fields for the IO and UO samples were determined using a harmonic Hall measurement [3]. Note that the thermoelectric contribution to the second harmonic Hall voltage was subtracted from the result. Figure 1(a) and 1(b) show the DL and FL effective fields (H_{DL} and H_{FL}), respectively, as a function of the current density flowing in the Pt layer (j_{Pt}) for the IO and UO samples with the similar areal magnetic moment. The DL (FL) torque for the IO sample was larger by a factor of ~4 (~10) than that for the UO sample.

To compare the SOTs between samples with various Co thicknesses, the SOT efficiencies $\xi_{DL(FL)}$ were determined using the following equation:

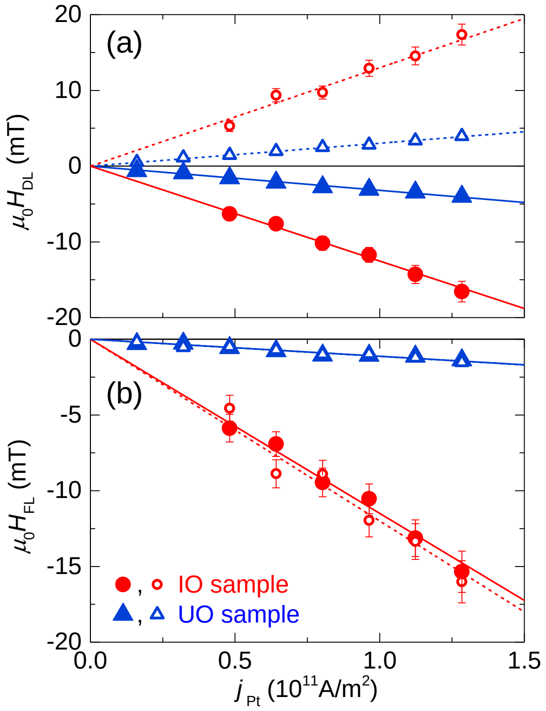

Fig. 1. (a) The DL and (b) FL effective fields as a function of the current density flowing in the Pt layer for the IO and UO samples. The filled and open symbols represent the results for the up- and down-magnetized states, respectively.

$$\xi_{DL(FL)} = \frac{2e}{\hbar}\mu_0 M_s t_{Co}^{eff.} \left|\frac{H_{DL(FL)}}{j_{Pt}}\right|, \qquad (1)$$

where e, $\hbar$, M_s and $t_{Co}^{eff.}$ are the electron charge, the Dirac constant, the saturation magnetization and the effective ferromagnetic Co thickness, respectively. $\mu_0|H_{DL(FL)}/j_{Pt}|$ was determined from the slope of the linear fitting in the Fig. 1. Figure 2 shows $\xi_{DL(FL)}$ as a function of the areal magnetic moment $M_s t_{Co}^{eff.}$ for the IO and UO samples with various $t_{Co}^{eff.}$. The result shows that $\xi_{DL(FL)}$s for the IO samples are always larger even with the different $t_{Co}^{eff.}$. $\xi_{DL(FL)}$ for the UO samples are consistent with the previously-reported values in the Co/Pt systems, whereas that for the IO samples are considerably larger than the values reported in the various

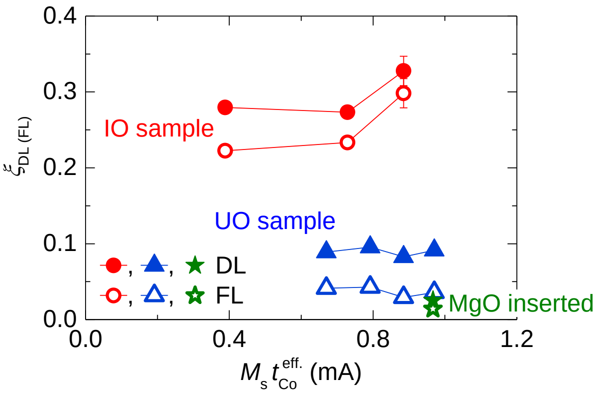

Fig. 2. The SOT efficiencies for the IO and UO samples as a function of the areal magnetic moment. The results for the Co/Pt sample with a 0.8 nm-MgO insertion layer are also shown.

systems with the Pt layer [4,5]. In addition, it is noteworthy that the ratios of the ξ_{FL} to the ξ_{DL} (ξ_{FL} /ξ_{DL}) for the IO samples are clearly larger than those for the UO samples.

3. Discussion

Finally, the possible origins of the enhancement of the SOT by the interface oxidation is discussed. First, the efficient spin current transmission at the Co/Pt interface due to the existence of the CoO_x spacer layer is plausible. It is known that the insertion of the antiferromagnetic insulator layer, such as NiO and CoO, into the FM/HM interface can largely enhance the spin mixing conductance at the interface even above a Néel temperature [6]. Thus, in our case the insertion of the CoO_x layer may enhance the spin mixing conductance, *i.e.*, the transparency of the spin current at the interface and lead to the enhanced SOTs.

To examine this mechanism, we prepared another Co/Pt sample with a nonmagnetic MgO insertion layer with the thickness of 0.8 nm. As a result of the harmonic Hall measurement, $\xi_{DL(FL)}$s were found to be smaller than those for the UO samples (see Fig. 2). This result emphasizes that the magnetic property of the insertion layer is important for improving the spin current transmission.

Second, we paid attention to the proximity induced magnetic moment in the Pt layer [7] for the IO and UO samples. The smaller induced magnetic moment in the IO sample were confirmed by the X-ray magnetic circular dichroism (XMCD) measurement. Since the elimination of the induced magnetic moment has been suggested to enhance the spin Hall angle in Pt [8], the decreased magnetic moment in the IO sample can be additional factor for enhancing SOTs.

In addition, the modulation of the Rashba effect originating from the potential gradient near the interface is possibly relevant to the present results [9], particularly to the very large enhancement of the FL torque. The increase of ξ_{FL}/ξ_{DL} for the IO samples is probably attributed to the enhancement of Rashba effect, which mainly contribute to the FL SOT [10].

4. Conclusion

We reported that the interface oxidation is an effective way to improve the SOT efficiencies in the Co/Pt structure. Because the enhancement of the SOT is crucial to achieve the efficient SOT-induced magnetization switching, the interface oxidation could play an important role in the development of the future magnetic memory devices.

Acknowledgements

The authors thank Y. Guan, M. Mizumaki and S. Ono for their technical help. This work was partly supported by JSPS KAKENHI (Grant Nos. 25220604, 16J03105 and 15H05702), The Sumitomo Foundation, and Spintronics Research Network of Japan. Part of the work was performed using facilities at the Cryogenic Research Center, The University of Tokyo. X-ray spectroscopy was performed at SPring-8 with the approval of the Japan Synchrotron Radiation Research Institute (Proposal Nos. 2017A0925 and 2017B0925).

References

[1] I. M. Miron, K. Garello, G. Gaudin, P. J. Zermatten, M. V Costache, S. Auffret, S. Bandiera, B. Rodmacq, A. Schuhl, and P. Gambardella, Nature **476** (2011) 189.
[2] K. Garello, C. O. Avci, I. M. Miron, M. Baumgartner, A. Ghosh, S. Auffret, O. Boulle, G. Gaudin, and P. Gambardella, Appl. Phys. Lett. **105** (2014) 212402.
[3] M. Hayashi, J. Kim, M. Yamanouchi, and H. Ohno, Phys. Rev. B **89** (2014) 144425.
[4] C.-F. Pai, Y. Ou, L. H. Vilela-Leão, D. C. Ralph, and R. A. Buhrman, Phys. Rev. B **92** (2015) 064426.
[5] M.-H. Nguyen, D. C. Ralph, and R. A. Buhrman, Phys. Rev. Lett. **116** (2016) 126601.
[6] W. Lin and C. L. Chien, Phys. Rev. Lett. **118** (2017) 067202.
[7] M. Suzuki, H. Muraoka, Y. Inaba, H. Miyagawa, N. Kawamura, T. Shimatsu, H. Maruyama, N. Ishimatsu, Y. Isohama, and Y. Sonobe, Phys. Rev. B **72** (2005) 054430.
[8] W. Zhang, M. B. Jungfleisch, W. Jiang, Y. Liu, J. E. Pearson, S. G. E. te Velthuis, A. Hoffmann, F. Freimuth, and Y. Mokrousov, Phys. Rev. B **91** (2015) 115316.
[9] Y. Hibino, T. Hirai, K. Hasegawa, T. Koyama, and D. Chiba, Appl. Phys. Lett. **111** (2017) 132404.
[10] P. M. Haney, H.-W. Lee, K.-J. Lee, A. Manchon, and M. D. Stiles, Phys. Rev. B **87** (2013) 174411.