Oral Session A1 (Tuesday, February 13)

Chair: Satoru Nakatsuji, University of Tokyo

Keynote Talk

10 : 15 - 10 : 55

Kyung-Jin Lee

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Orbital torque and orbital pumping

The orbital Hall effect [1,2] describes the generation of the orbital current flowing in a perpendicular direction to an external electric field, analogous to the spin Hall effect. As the orbital current carries the angular momentum as the spin current does, injection of the orbital current into a ferromagnet can result in torque on the magnetization [3], which provides a way to detect the orbital Hall effect. With this motivation, we examine the current-induced spin-orbit torques in various ferromagnet/heavy metal bilayers by theory and experiment [4]. Analysis of the magnetic torque reveals the presence of the contribution from the orbital Hall effect in the heavy metal, which competes with the contribution from the spin Hall effect. In particular, we find that net torque in Ni/Ta bilayers is opposite in sign to the spin Hall theory prediction but instead consistent with the orbital Hall theory. This orbital torque can enhance net spin-orbit torque via an efficient orbital-to-spin conversion [5]. We also present a theory of orbital pumping [6], which is the Onsager reciprocity of orbital torque.

References

[1] H. Kontani et al., Giant orbital Hall effect in transition metals: Origin of large spin and anomalous Hall effects. Phys. Rev. Lett. **102**, 016601 (2009).

[2] D. Go and D. Jo, C. Kim, and H.-W. Lee, Intrinsic spin and orbital Hall effects from orbital texture. Phys. Rev. Lett. **121**, 086602 (2018).

[3] D. Go and H.-W. Lee, Orbital torque: Torque generation by orbital current injection. Phys. Rev. Research **2**, 013177 (2020).

[4] D. Lee et al., Orbital torque in magnetic bilayers. Nat. Commun. **12**, 6710 (2021).

[5] S. Lee et al., Efficient conversion of orbital Hall current to spin current for spin-orbit torque switching. Commun. Phys. **4**, 234 (2022).

[6] S. Han et al., Theory of orbital pumping. arXiv:2311.00362 (2023).

Oral Session A1 (Tuesday, February 13)

Chair: Satoru Nakatsuji, University of Tokyo

Contributed Oral

10 : 55 - 11 : 15

Observation of current-driven fast magnetic domain-wall motion in noncollinear antiferromagnets

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Antiferromagnets have the natural advantages of ultrafast magnetization dynamics and negligible stray fields compared with ferromagnets, thus appealing for next-generation magnetic domain-wall applications. So far, however, the study of the magnetization dynamics in antiferromagnets has been challenging due to their insensitive magneto-electric responses. Recently, remarkable developments on noncollinear antiferromagnets Mn_3X (X = Sn, Ge) enabled us to detect and manipulate their antiferromagnetic domain states [1-7]. Here, we demonstrate a current-driven magnetic domain-wall motion in a single crystal Mn_3X wire by means of magneto-optical Kerr observation technique [8]. It reveals that Néel-like domain-walls can be accelerated up to 750 m/s with a current density of only 7.6×10^{10} A/m^2. It also shows extremely high mobility compared with ferromagnets and ferrimagnets. Moreover, our theory reveals that the domain-wall motion in noncollinear antiferromagnets is driven by the spin-transfer torque derived from the current-induced nonequilibrium spin accumulation. These our findings open a new route to develop a mechanism responsible for antiferromagnetic domain-wall-based applications.

References

[1] S. Nakatsuji et al., Nature 527, 212–215 (2015).
[2] T. Higo, et al., Nat. Photon. 12, 73–78 (2018).
[3] H. Tsai, et al., Nature 580, 608–613 (2020).
[4] Y. Takeuchi et al., Nat. Mater. 20, 1364–1370 (2021).
[5] T. Higo, et al., Nature 607, 474–479 (2022).
[6] B. Pal et al., Sci. Adv. 8, 24 (2022).
[7] J-Y. Yoon et al., Nat. Mater. 22, 1106–1113 (2023).
[8] M. Wu submitted (2023).

Oral Session A1 (Tuesday, February 13)

Chair: Satoru Nakatsuji, University of Tokyo

Contributed Oral

11: 15 - 11 : 35

Stroboscopic magneto-optical imaging of current-induced domain wall dynamics in ferrimagnet GdFeCo

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Current-induced domain wall motion (CIDWM) is expected to find applications in spintronic devices such as memory and logic. Recently, it is known that CIDWM in ferrimagnetic materials can exceed 1 km/s at the angular momentum compensation point temperature TA [1,2]. A method to visualize such ultrafast dynamics of CIDWM is necessary to understand its physics and achieve accurate manipulation of domain walls (DWs).

Here, we developed a stroboscopic magneto-optical imaging system capable of detecting DW displacements of sub-μm with a time resolution of approximately 160 ps [3]. In our experiment, DWs were generated in a ferrimagnetic GdFeCo/Pt wire by all-optical magnetization reversal and ns current pulses were injected to observe CIDWM. The CIDWM dynamics unveil a time varying DW velocity during the pulse, especially, an acceleration noticeable approximately 1 ns after the start of current injection. These results can largely be attributed to the gradual temperature change caused by Joule heating and an enhanced DW velocity at TA. Our method provides access to the spatial and stochastic magnetization dynamics in sophisticated structures driven by external stimuli and should be applicable to a wide range of current-driven phenomena.

References

[1] Kim, K. et al. Nat. Mater. 16, 1187–1192 (2017).
[2] Caretta, L. et al. Nat. Nanotechnol. 13, 1154–1160 (2018).
[3] Ogawa, K. et al. Phys. Rev. Res. 5, 033151 (2023).

Oral Session A1 (Tuesday, February 13)

Chair: Satoru Nakatsuji, University of Tokyo

Keynote Talk

11: 35 - 12 : 15

Cheng Song

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Electrical 180° switching of Néel vector in altermagnets

Altermagnet is an emerging magnetic phase with alternating spins and spin splitting band structure, thus combining the advantages of both antiferromagnets and ferromagnets [1-3]. However, as crucial components, the electrical detection and electrical 180° switching of the Néel vector as well as the corresponding spin-splitting, are very challenging. We demonstrated that in altermagnets $Mn5Si_3$ [4] and CrSb [5], the unique anomalous Hall effect can be adopted for electrical readout of opposite Néel vectors. We proposed a new mechanism for the electrical 180° switching of the Néel vector via spin-orbit torques by designing asymmetric switching barriers and experimentally achieved it. It is made possible by the fixed chirality between Néel vector and tiny relativistic net moment due to the Dzyaloshinskii-Moriya interaction. Based on their novel readout and manipulation methods, we fabricated prototype Hall devices that can accomplish robust write and read cycles. By suitable design of crystal distortion via strain, field-free and fully electrical switching of altermagnetic Néel vector is realized. Furthermore, controllable Néel vector enables tunable spin-charge interconversion through altermagnetic and inverse altermagnetic spin splitting effect [2,3,6].

References

[1] L. Šmejkal, et al., Phys. Rev. X 12, 040501 (2022)
[2] H. Bai, C. Song, et al. Phys. Rev. Lett. 128, 197202 (2022)
[3] H. Bai, C. Song, et al. Phys. Rev. Lett. 130, 216701 (2023)
[4] L. Han, C. Song, et al. accepted by Sci. Adv.
[5] Z. Y. Zhou, C. Song, et al. In preparation.
[6] Y. Liu, C. Song, Q. Y. Jin, et al. Adv. Optical Mater. 2300177 (2023).