

Out-of-plane spin component produced by magnetic ordering

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Principal Investigator(s): Daniel C. Ralph

User(s): Xiaoxi Huang

Affiliation(s): Department of Physics, Cornell University

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Contact: dcr14@cornell.edu, xh384@cornell.edu

Primary CNF Tools Used: Heidelberg MLA 150 Maskless Aligner, AJA Sputter Deposition

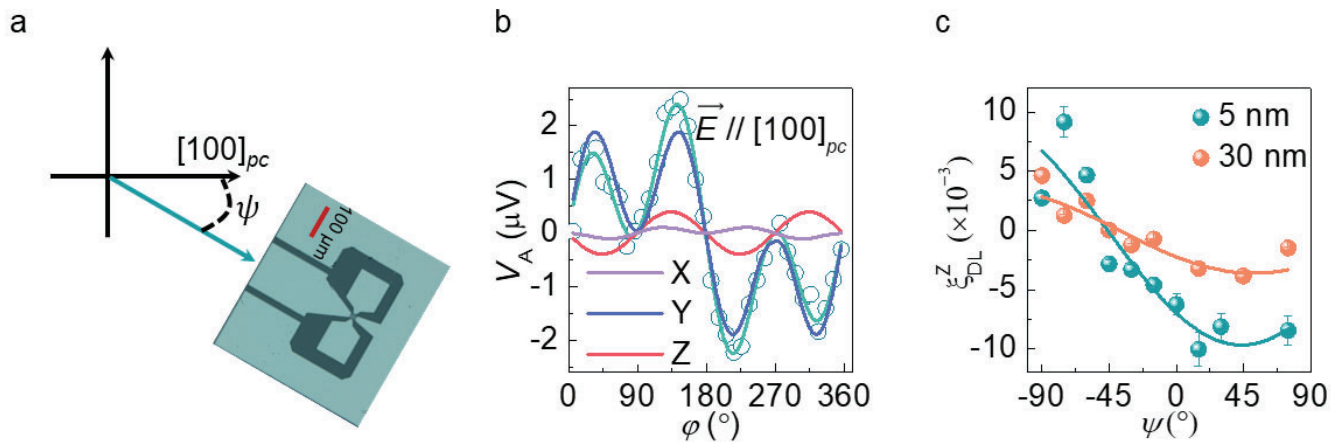


Figure 1: Out-of-plane anti-damping torque generation. a) A schematic demonstration of the in-plane crystallographic study. b) A signature of the out-of-plane anti-damping torque, $\sin 2 \Psi$ component. c) ξ_{DL}^Z as a function of in-plane electric field angle.

Figure 2 | Non-local excitation and detection of coherent magnons.

Abstract:

Micron-sized devices made with the Heidelberg MLA maskless laser direct writer and AJA sputter system were used to study spin currents and magnon currents generated as a consequence of magnetic ordering. We experimentally observed that a canted magnetic moment produces an out-of-plane damping-like torque from SrRuO₃ thin films.

Summary of Research:

Magnetic materials with perpendicular magnetic anisotropy (PMA) are the most promising materials for high-density magnetic memory; and the efficient magnetization switching of PMA-magnets is enthusiastically pursued by Spintronics researchers because it has the potential to realize energy-efficient high-density information storage. Fortunately, an out-of-plane spin component borne by a spin current is theoretically predicted and experimentally demonstrated to be able to drive efficient anti-damping switching of the magnetization of a PMA magnet [1]. Our primary

research goal is to find materials that efficiently produce spin currents or magnon currents with an out-of-plane spin component and ultimately to demonstrate the efficient switching of magnetization of PMA-magnet pillars with diameters as small as 100 nm. Our search for such materials has been centered around materials that have magnetic order, including both ferromagnetic and anti-ferromagnetic order. To detect spin current generation and the specific spin orientations that are allowed for these materials, micron-sized devices such as spin-torque ferromagnetic resonance (ST-FMR) devices and non-local magnon excitation and detection devices are patterned using these materials.

The ST-FMR device is shown in Fig. 1a. Bar structures with dimension of $20 \mu\text{m} \times 70 \mu\text{m}$ are patterned with the Heidelberg MLA maskless laser direct writer. Then contacts made of Ti/Pt are deposited on the patterns in an AJA sputtering system. An example of spin current generated because of magnetic order is the unconventional spin-orbit torque generation from SrRuO₃. SrRuO₃ thin films when grown on (001)-oriented SrTiO₃ substrates

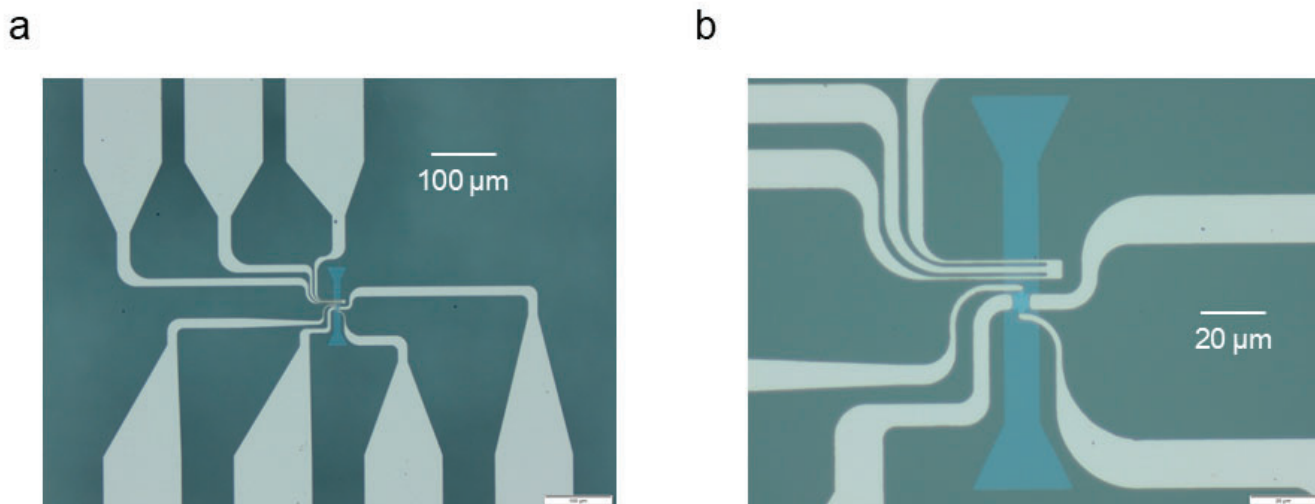


Figure 2: Non-local excitation and detection of coherent magnons.

exhibit canted magnetization and ferromagnets with magnetic moment canted out of the plane are predicted to be able to produce tilted spin currents with tilted spin polarization [2]. We measured the spin-orbit torque generated by SrRuO₃ is on ST-FMR devices (Fig. 1a). When the rf current and oscillating magnetoresistance are mixed together, a dc mixing voltage is produced. The anti-symmetric component of the mixing voltage is contributed by the out-of-plane torques. A signature of the out-of-plane anti-damping torque is observed for electric field applied along [100]pc (Fig. 1b). To investigate the origins of out-of-plane anti-damping torque, the ST-FMR measurements were repeated on devices with intermediate Ψ angles for the orientation of the applied electric field relative to the [100]pc crystal direction (Fig. 1a). The out-of-plane anti-damping torque efficiency ξ_z/DL has the angular dependence shown in Fig. 1c, which indicates that two different mechanisms contribute to the out-of-plane torque (the spin anomalous Hall effect and the planar Hall spin current) This is the most exciting and important finding of our work so far and this work is currently under review.

Another pathway to produce out-of-plane spin component is to utilize coherent magnons, as a circularly polarized magnon in a magnetic material will have a net spin angular momentum aligned with magnetization

[3]. We study the excitation and detection of coherent magnons on devices shown in Fig. 2, where coherent magnons are excited by a microwave-current-induced Oersted field and detected by spin-torque-induced harmonic Hall voltages. The ground-signal-ground waveguide on the excitation side has a minimum dimension of 1 μm and the Hall device on the detection side is of dimension 4 μm × 1 μm.

Conclusions and Future Steps:

Magnetic ordering plays a crucial role in producing out-of-plane damping-like torques. We plan to publish the work on SrRuO₃ and to study the out-of-plane spin component produced by coherent magnons.

References:

- [1] David MacNeill et al, Nat. Phys. 13, 300 (2017).
- [2] Tomohiro Taniguchi et al, Phys. Rev. Lett. 3, 044001 (2015).
- [3] Jiahao Han et al, Science 366, 1121 (2019).