Study Unconventional Spin-Orbit Torque Generation on Micron-Sized Devices Fabricated with Photolithography

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Primary CNF Tools Used: DWL 66fs, AJA Sputter Deposition

Abstract:

Micron-sized devices made with DWL 66fs direct writer and AJA sputter system were used to study spin currents generated with magnetic ordering. We experimentally observed that antiferromagnetic ordering plays a significant role in enhancing spin current generation efficiency in $PdCrO_2$ thin films and canted magnetic moment produces out-of-plane damping-like torque in $SrRuO_3$ 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 are enthusiastically pursuit by Spintronics researchers, as it has the potential to realize energy-efficient high-density information storage. Fortunately, out-of-plane spin component borne by a spin current is theoretically predicted and experimentally demonstrated to be able to drive the efficient anti-damping switching of magnetization of a PMA-magnet [1]. Our primary research goal is to find materials that efficiently produce spin currents with out-of-plane spin component and ultimately 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 orderings, including both ferromagnetic and anti-ferromagnetic orderings.

Two successful trials have been made on $PdCrO_2$, which an anti-ferromagnet below 37 K, and $SrRuO_3$, which is a ferromagnet below 150 K. To detect spin current generation and the specific spin orientations allowed in these materials, micron-sized devices such as spin-torque ferromagnetic resonance (ST-FMR) devices and Hall bar devices are patterned on these materials.

The devices for ST-FMR and Hall measurements-established techniques for spin-orbit torque characterization [2] is shown in Figure 1 and Figure 2. Bar structures with dimensions of

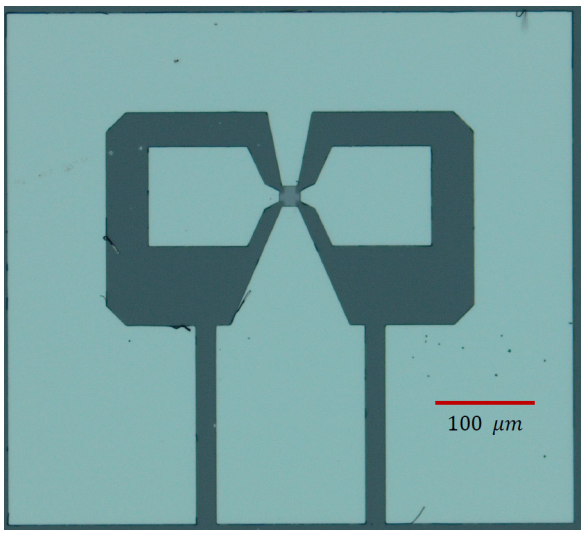

Figure 1: Spin torque ferromagnetic resonance device.

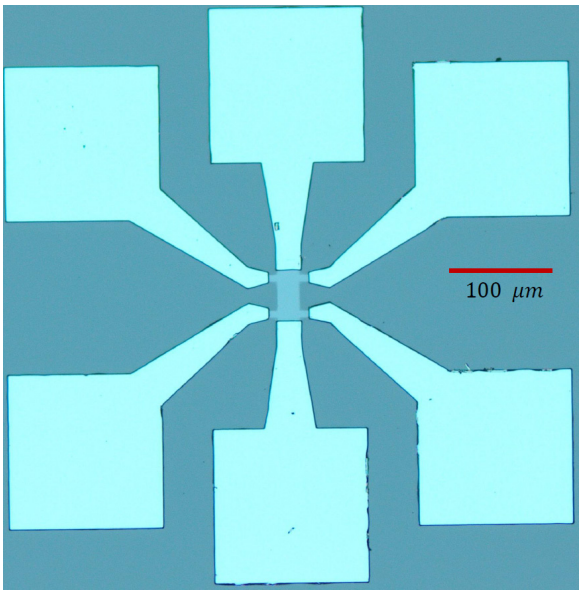

Figure 2: Hall device for second Harmonic Hall measurements.

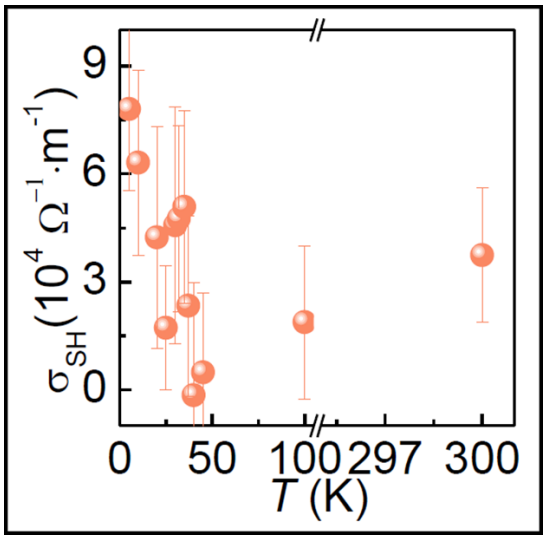

Figure 3: Spin Hall conductivity as a function of temperature for a 2 nm $PdCrO_2$ thin film.

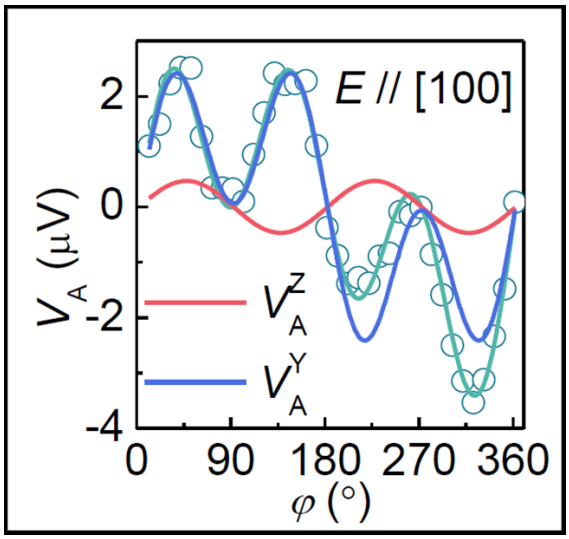

Figure 4: The anti-symmetric component of the mixing voltage for a 5 nm $SrRuO_3$ sample. The device is oriented parallel to [100] direction in the plane and the measurements were carried out at 110 K.

10 x 40μm and 20 x 70μm are patterned with Heidelberg DWL 66fs laser direct writer. Then contacts made of Ti/Pt were deposited on the patterns in an AJA sputtering system. Spin current generation in $PdCrO_2$ were successfully detected with such devices; and the spin current generation efficiency as a function of temperature in $PdCrO_2$ is shown in Figure 3. A strong dependence of spin current generation on temperature is observed. Intriguingly, a strong upturn of spin current generation efficiency is seen at approximately the Neel temperature of $PdCrO_2$, implying the critical role that antiferromagnetic ordering plays in generating spin currents.

A manuscript on this work has been composed and is to be submitted soon. Another example on spin current generated with magnetic ordering is unconventional spin-orbit torque generation in $SrRuO_3$. $SrRuO_3$ thin films when grown on (001)-oriented $SrTiO_3$ substrates are shown to 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 [3]. The spin-orbit torque generation in $SrRuO_3$ is conducted on ST-FMR devices (Figure 1). 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. The fitting of the anti-symmetric voltage detected in $SrRuO_3$ thin films requires a *sin*2φ component (Figure 4), which is the signature of the out-of-plane damping like torque produced by the out-of-plane component of the spin polarization. This is the most exciting and important finding of our work so far and we are actively preparing a manuscript on this matter.

Conclusions and Future Steps:

Magnetic ordering plays a crucial role in either enhancing spin current generation or producing out-of-plane damping-like torques. We anticipate finishing characterizing the unconventional spin-orbit torque generation in these materials and start demonstrating magnetization switching PMA-magnetic nano-pillars.

References:

[1] David MacNeill, et al., Nat. Phys. 13, 300 (2017).

[2] Luqiao Liu, et al., Science 336, 555 (2012).

[3] Tomohiro Taniguchi, et al., Phys. Rev. Lett. 3, 044001 (2015).