Separation of Artifacts from Spin-Torque Ferromagnetic Resonance Measurements of Spin-Orbit Torque for the Low-Symmetry Semi-Metal $ZrTe_3$

CNF Project Number: 598-96

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Primary Source(s) of Research Funding: National Science Foundation/Division of Materials Research, Agency for Science Technology and Research (Singapore)

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Primary CNF Tools Used: Zeiss Supra SEM, Nabity Nanometer pattern generator, AJA sputter deposition, CVC SC4500 even-hour evaporator

Abstract:

We report measurements of spin-orbit torque generated by exfoliated layers of the low-symmetry semi-metal zirconium tritelluride ($ZrTe_3$), using the spin-torque ferromagnetic resonance (ST-FMR) technique. When the $ZrTe_3$ has a thickness greater than about 10 nm, artifacts due to spin pumping and/or resonant heating cause the standard ST-FMR analysis to give inaccurate values, indicating incorrectly that the spin-orbit torque depends strongly on the $ZrTe_3$ layer thickness. Artifact-free measurements can still be achieved over a substantial thickness range by the method developed recently to detect ST-FMR signals in the Hall geometry as well as the longitudinal geometry. For $ZrTe_3$/Permalloy samples, we measure a conventional in-plane antidamping spin torque ratio $\xi_{\parallel}^{DL} = 0.015 \pm 0.003$, and an unconventional in-plane field-like torque ratio $\xi_{\parallel}^{FL} = 0.003 \pm 0.001$. The out-of-plane antidamping torque is negligible.

Summary of Research:

We illustrate, using $ZrTe_3$/Permalloy bilayers, that extra care is required when employing the spin-torque ferromagnetic resonance (ST-FMR) technique in devices with thicker spin-orbit layers, because the magnitude of artifacts due to spin pumping and resonant heating grow relative to the spin-orbit-torque signals as a function of increasing layer thickness. One signature of such artifacts is an apparent dependence of the spin-torque efficiency on the spin-orbit layer thickness for layers much thicker than a typical spin diffusion length. We demonstrate that a recently-introduced modification of the ST-FMR technique [1], in which the ST-FMR signals are measured in the Hall geometry [2,3] as well as the usual longitudinal geometry, allows more-accurate measurements of the spin-orbit torques, separated from artifacts due to spin pumping and resonant heating. The device geometries for the measurements are shown in Figure 1.

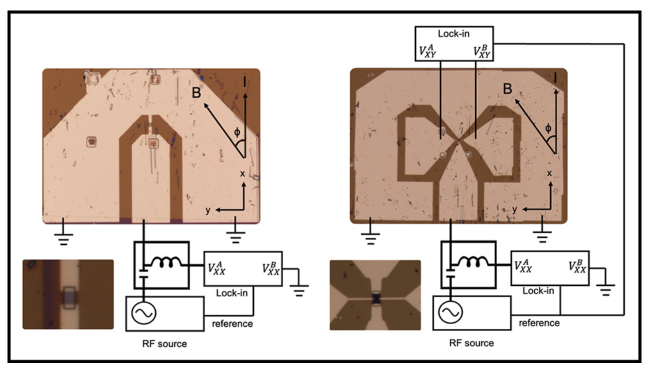

Figure 1: Schematic of a) conventional ST-FMR and b) Hall ST-FMR experimental set-ups. An additional lock-in amplifier connected across the hall leads of the device is used to read out the mixing voltage due to the change in PHE and AHE resistances.

The results of this (incorrect) standard analysis, which neglects artifact effects, are shown in Figure 2 as a function of the thickness of the $ZrTe_3$ layer. For the thinnest $ZrTe_3$ layers, the standard in-plane antidamping torque efficiency $\xi_{\parallel}^{DL}$ is weakly positive, with a value $\xi_{\parallel}^{DL} = 0.015 \pm 0.002$ for the 3 nm $ZrTe_3$ layer, but as a function of increasing $ZrTe_3$ thickness it becomes negative, with strong thickness dependence through 100 nm. At the largest $ZrTe_3$ thicknesses, the apparent magnitude of $\xi_{\parallel}^{DL}$ appears to become extremely large $|\xi_{\parallel}^{DL}| > 0.4$, even larger than the value for pure W.

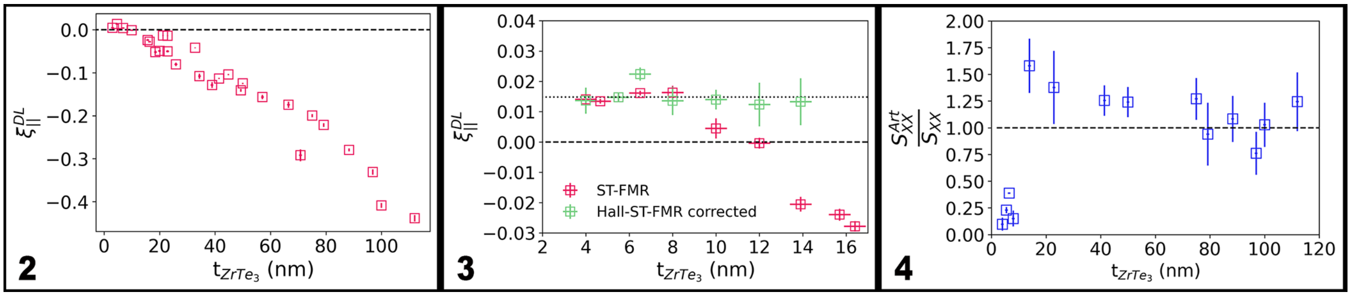

Figure 2, left: Thickness dependence of the apparent in-plane antidamping spin torque efficiency based on the incorrect standard analysis that neglects artifact from spin pumping and resonant heating. Figure 3, middle: Artifact corrected efficiency from Hall-ST-FMR for t_{ZrTe3} *< 15 nm, showing negligible thickness dependence and absence of a sign change as* t_{ZrTe3} *> 10 nm. Figure 4, right: Ratio between* V_{art} *and* V_S *for* t_{ZrTe3} *> 15nm.* V_{Art} *was on the same order of magnitude as* V_S*, indicating that the apparent large antidamping torque signal observed for thicker flakes is likely spin-pumping dominated.*

Properly accounting for spin pumping artefacts using the Hall-ST-FMR technique, we obtain the artefact corrected efficiency $\xi_{\parallel}^{DL} = 0.015 \pm 0.003$ as shown by the dotted line in Figure 3, largely independent of device thickness for t_{ZrTe} < 15 nm. Beyond $ZrTe_3$ thicknesses of 15 nm, the artifact voltages are too large to make an accurate determination of the spin-orbit torque, but it is clear that the apparent thickness dependence of this efficiency in the range t_{ZrTe} > 15 nm is due entirely to the effects of the artifact voltages, as shown in Figure 4. The non-conventional torques also remain largely independent of thickness, with values that agree with the conventional STFMR analysis.

Conclusion and Future Steps:

In summary, we have used ST-FMR to investigate the spin-orbit torques generated by exfoliated flakes of the low-symmetry semi-metal $ZrTe_3$ for a wide range of layer thicknesses in $ZrTe_3$/Py(6 nm) devices. We find that the "standard" ST-FMR analysis, which neglects the effects of artifacts due to spin pumping and resonant heating, gives incorrect values of the in-plane anti-damping torque efficiency $\xi_{\parallel}^{DL}$ for $ZrTe_3$ layers thicker than 15 nm. For the thickest layers, this incorrect standard analysis can overestimate the magnitude of $\xi_{\parallel}^{DL}$ by more than an order of magnitude, and it indicates an unphysical strong dependence of the torque efficiency on layer thickness. ST-FMR measurements in the Hall geometry demonstrate that this strong apparent thickness dependence is due entirely to artifacts from spin pumping and/or resonant heating, not a true dependence of the spin-orbit torque on layer thickness. For $ZrTe_3$, the Hall ST-FMR measurements yield torque efficiencies $\xi_{\parallel}^{DL} = 0.015 \pm 0.003$ for the conventional in-plane antidamping torque and $\xi_{\parallel}^{FL} = 0.003 \pm 0.001$ for the unconventional in-plane field-like torque.

We suggest that ST-FMR measurements in the Hall geometry should be used as a standard technique to allow a clear separation of spin pumping and resonant heating artifacts from true spin-orbit-torque signals.

References:

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