ST-FMR measurements of low-symmetry van der Waals material $TaIrTe_4$

CNF Summer Student: Danaan Perry
Student Affiliation: Department of Physics, University of Illinois at Urbana-Champaign

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Principal Investigator(s): Daniel Ralph, Cornell University

Mentor(s): Matthew Roddy

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Contact: dcr14@cornell.edu, danaanp2@illinois.edu, msr285@cornell.edu

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Primary CNF Tools Used: Heidelberg MLA 150 Maskless Aligner, AJA Ion Mill, AJA Sputter Deposition, Veeco Icon AFM

Abstract:

Efficient magnetic memory requires compact storage through out-of-plane polarization as well as an energy-efficient write path. The write mechanism we are investigating uses out-of-plane spin-orbit torques (ZSOTs) to switch the magnetization of a thin ferromagnetic layer. These ZSOTs are not possible to generate in many materials due to symmetry restrictions; to overcome this, we study the low-symmetry van der Waals material $TaIrTe_4$. The current literature indicates that $TaIrTe_4$ produces strong ZSOTs, but measured values of the efficiency are inconsistent. The goal of this project is to fabricate test devices including $TaIrTe_4$ so that the efficiency of the ZSOT can be measured using the technique of spin-torque ferromagnetic resonance (ST-FMR).

Summary of Research:

Intro/Background

This project aims to contribute to the development of a write path for more energetically and spatially efficient magnetic memory. We can achieve this using the spin Hall effect. This effect occurs when running a conventional current through some spin source layer which generates a spin current that separates opposing spins on opposite surfaces of the spin source layer. This spin current can apply a torque onto the polarization of the ferromagnet, causing this magnetization to rotate. This effectively changes the state of the bit.

We are looking to examine the efficiency of TaIrTe4 as a spin source. $TaIrTe_4$ is a low-symmetry van der Waals material. This low-symmetry property gives it the potential to produce out-of-plane torques (ZSOTs) that are most efficient for switching the state out-of-plane polarized magnets needed for improved high-density memories. Current literature indicates that $TaIrTe_4$ not only produces ZSOTs, but that they are relatively strong. However, different measured values of $TaIrTe_4$'s spin Hall efficiency are inconsistent, motivating this initial exploration to validate $TaIrTe_4$'s potential as a spin source.

Fabrication

Our fabrication process begins by exfoliating flakes of $TaIrTe_4$ onto a Si/SiO_2 substrate. Bulk crystals of $TaIrTe_4$ are adhered to scotch tape and pressed onto pieces of silicon wafer. $TaIrTe_4$ is air-sensitive, so we prepared samples in a glove box to prevent air exposure before transferring to the load lock of our sputter system where exfoliation was performed. The set-up for this procedure is shown in Figure 2a. This apparatus allowed for the tape to be peeled off in vacuum as samples were loaded into the main chamber. As a van der Waals material, small, thin flakes of $TaIrTe_4$ remain stuck to the silicon, providing uniform, single crystalline thicknesses. We then deposit 4 nm of Permalloy (Py) as our ferromagnetic layer and a 2 nm Ta capping layer to prevent air exposure. We then searched for thin, even, and at a minimum 5x5 µm flakes using an optical microscope (Figure 2c). Using the Veeco Icon AFM we confirm the actual thicknesses of chosen flakes and move forward with samples that were 40 nm or less.

We then used the Heidelberg MLA 150 to perform photolithography and the AJA Ion Mill to etch our Hall bars. When milling we incorporated breaks to avoid overheating the flakes or burning the resist. We again performed lithography to pattern the contacts. Before depositing our contacts using the AJA sputter system we do a 15 minute Ar plasma clean to remove any Ta oxide and create a better connection between our Hall bar and contacts. Finally we deposit about 60 nm of Ti/Pt to create the finished device shown in Figure 1.

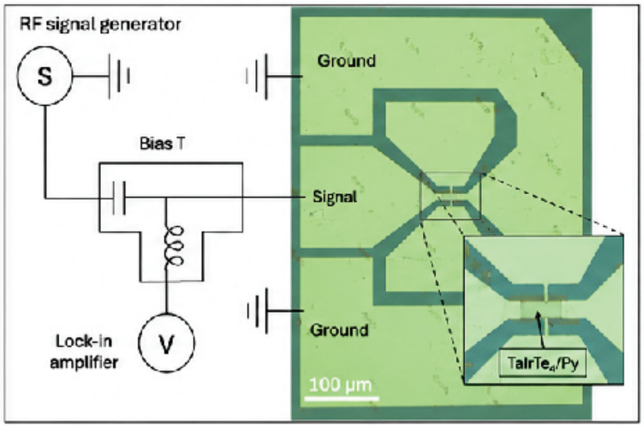

Figure 1: A completed device with GSG (ground-signal-ground) contacts for ST-FMR measurements. The enlarged area gives a closer look at the TaIrTe4/Py stack. To the left is a diagram depicting the set-up used for ST-FMR measurements.

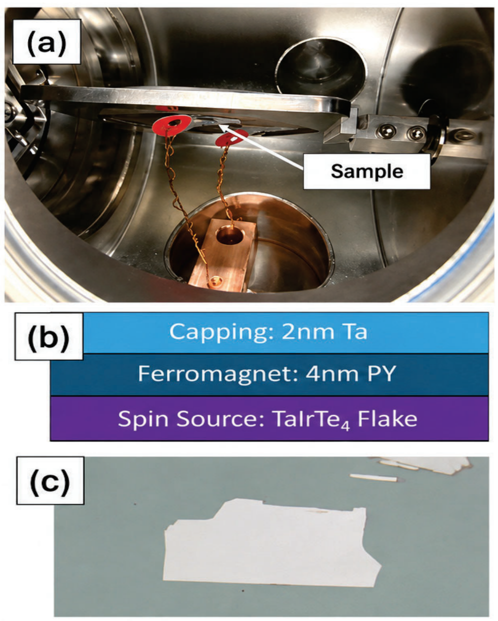

Figure 2: (a) Exfoliation apparatus in the load lock of the sputter system. (b) A complete stack consisting of a TaIrTe4 flake 20-40 nm in thickness, 4 nm Py ferromagnetic layer, and 2 nm Ta capping layer. (c) Image taken on an optical microscope of a flake with dimensions of approximately 10x20 µm.

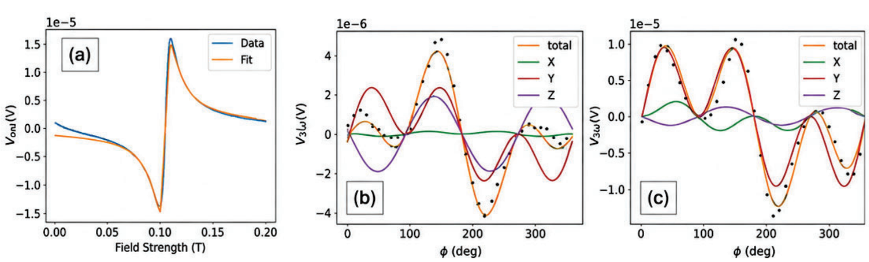

Figure 3: (a) Vmix vs. Bext results at an applied angle of 30° degrees. In blue is the raw data and in orange the Lorentzian fit. (b) and (c) display the angular dependence for the symmetric (b) and antisymmetric (c) components of Vmix. The orange line is the total fit to the raw data in blue. The green, red, and purple lines then represent the X, Y, and Z components of the total as in Equation 1.

Results

We performed spin-torque ferromagnetic resonance (ST-FMR) measurements. ST-FMR works by measuring a changing voltage (Vmix) caused by anisotropic magnetoresistance of the ferromagnetic layer. Vmix can then be graphed against the external magnetic field (Bext) and the resulting shape is a Lorentzian, pictured in Figure 4a, consisting of symmetric and antisymmetric components. These components can be separated, and their amplitudes graphed versus the angle at which the field was applied. The resulting angular dependences are shown in Figures 4b and 4c and defined by the following functions.

$$S_{total} = S^{Y} cos(\phi)\ sin(2\phi) + S^{X} sin(\phi)\ sin(2\phi) + S^{Z} sin(2\phi) \quad (1)$$

$$A_{total} = A^{Y} cos(\phi)\ sin(2\phi) + A^{X} sin(\phi)\ sin(2\phi) + A^{Z} sin(2\phi) \quad (2)$$

The ZSOTs discussed are the Z-components in the above functions, with amplitudes SZ or AZ. We are primarily concerned with the symmetric component which we see has a significant contribution from the Z-component. These results therefore indicate that $TaIrTe_4$ does produce ZSOTs, the strength of which can be determined by further analysis.

Conclusions and Future Steps:

To conclude, we fabricated functioning $TaIrTe_4$/Py devices with $TaIrTe_4$ flakes ranging from 20-40 nm thickness for ST-FMR measurements. Our initial analysis determined that $TaIrTe_4$ does produce ZSOTs and with further measurements and analysis the strength of these torques will be determined. The next steps for this include Raman spectroscopy measurements to determine the crystal axis of the samples and determine the dependence of observed ZSOTs on crystal orientation. Then taking additional measurements, such as resistivity, to obtain all variables needed to formally calculate the spin Hall conductivity of our samples.