

Electrically Tunable Damping of Antiferromagnetic Nanowires

CNF Project Number: 598-96

Principal Investigator(s): Daniel Ralph

User(s): Matthew Roddy

Affiliation(s): Laboratory for Atomic and Solid State Physics, Cornell University

Primary Source(s) of Research Funding: U.S. Dept. of Energy through the CEEMag Center

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

Research Group Website: ralphgroup.lasp.cornell.edu

Primary CNF Tools Used: GCA 5x g-line Stepper, Angstrom E-Beam Evaporator, Zeiss Supra SEM, Naby NPGS Nanometer Pattern Generator System, Oxford 81 RIE

Abstract:

In spintronics, antiferromagnets are an exciting option for many applications because of their advantages over ferromagnets, including ultrafast dynamics and resistance to stray fields. However, electrical detection and control of antiferromagnetic systems remain challenges. Through the assembly of vander Waals (vdW) materials, we fabricate three terminal heterostructures with a spin-source layer (TaIrTe_4), an antiferromagnet (CrSBr), and a tunnel contact (Graphite), which enables detection of the dynamics through the tunneling resistance. By etching these devices into a nanowire design, we show significant change in the linewidth of the antiferromagnetic resonant response, indicating strong control of the magnetic damping, through the applied current in the spin layer.

Summary of Research:

Spin torque nano-oscillators are magnetic devices that produce a high-frequency output in response to an applied direct current. Nano-oscillators have been realized in nanowire ferromagnetic systems where the intrinsic damping of a ferromagnet layer is offset by an applied spin current [1] and they produce signals at ferromagnetic resonance frequencies (typically in the GHz). An antiferromagnetic nano-oscillator would be highly desirable, as the higher frequency dynamics mean that the output would typically be in the high GHz to THz range that is more difficult to access. Recent results have shown that heterostructures of bilayer CrSBr , an A-type antiferromagnet, interfaced with a spin-source layer exhibits electrically tunable damping where the read-out of dynamics is achieved through changes in tunneling resistance [2].

In this project, we fabricate devices consisting of a TaIrTe_4 spin source layer, which has been shown to possess a large spin-Hall angle [3] interfaced with bilayer CrSBr to perform tunneling Spin-Torque Antiferromagnetic

Resonance (ST-AFMR) measurements. An example schematic of the device and measurement setup is shown in Figure 1.

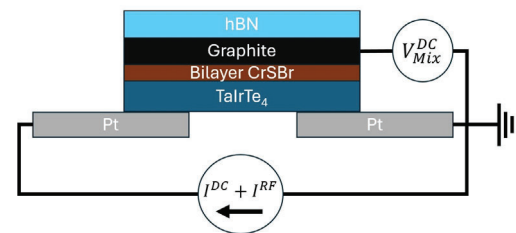


Figure 1: Device schematic showing the bilayer CrSBr tunnel junction with a TaIrTe_4 spin source layer with external sources setup to measure tunneling spin-torque antiferromagnetic resonances.

To begin, alignment grids are fabricated on high-resistivity silicon wafers using the GCA 5x g-line Stepper and the Angstrom e-Beam Evaporator to deposit a layer of Ti/Pd. Then the Zeiss Supra SEM and Naby Nanometer Pattern Generator System (NPGS) are used for e-beam lithography to pattern a set of three contact electrodes. These thin, Ti/Pt electrodes are deposited using the Angstrom e-Beam Evaporator once more to maintain sharp interfaces for the subsequent 2D material stack. Conventional vdW transfer techniques are used to stack and then place the materials on the contact electrodes in the following order: TaIrTe_4 ; bilayer CrSBr rotated approximately 45 degrees off the a-axis; graphite tunnel contact; and hBN to encapsulate the entire heterostructure and prevent air exposure during fabrication. A photograph of the device after stacking is shown in Figure 2a.

In order to fully tune the effective damping from positive to negative values and thereby achieve self-sustained oscillations it is necessary to minimize the device width, so these heterostructures are then etched into a nanowire. This is accomplished by using e-beam lithography with the Zeiss Supra SEM and NPGS to pattern the nanowire design (approximately 500 nm by 4 μm) and multiple

low-power plasma etches of different recipes using the Oxford 81 RIE to etch through each subsequent layer of the heterostructure. A photograph of the device after etching is complete is shown in Figure 2b.

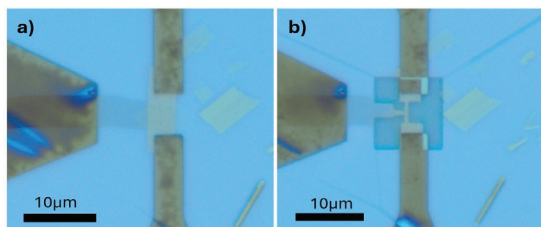


Figure 2: Photographs of the heterostructure a) after stacking and transfer of the vdW materials onto the contact electrodes b) after reactive ion etching into a nanowire.

ST-AFMR measurements are performed at a temperature of 30 K in a liquid He flow-cryostat. As depicted in Figure 1, a combination of RF and DC current is passed through the spin-source layer resulting in both a steady-state and oscillating spin-current incident upon the bilayer CrSBr. By sweeping the strength of a magnetic field along the intermediate axis of the CrSBr, the magnetization of each layer is tilted towards the field until the RF spin-current excites the optical mode response. This response results in an RF frequency change in the tunneling resistance, which mixes with RF leakage current through the tunnel junction to produce a measurable DC mixing voltage which can be detected through a lock-in amplifier. The steady-state DC current through the spin-source layer produces a constant damping or antidamping spin torque that will either enhance or counteract the intrinsic magnetic damping in the CrSBr, resulting in changes to the linewidth of the resonance shape. Example mixing voltage data as the magnetic field is swept are shown for multiple DC bias currents in Figure 3.

For small-angle precession, the resonances can be modeled as a summation of antisymmetric and symmetric Lorentzian line shapes. Fitting the resonances allows for the linewidth to be extracted, which is proportional to the damping of the antiferromagnet. Figure 4 shows the linear decrease in linewidth in response to increasing current, showing changes to the linewidth of 50% in either direction compared to the linewidth when no additional DC current applied.

Fig. 3: DC mixing voltage plotted against external field, at a frequency of 21GHz, showing decreasing resonant linewidth in response to increasing DC bias current through the spin-source layer.

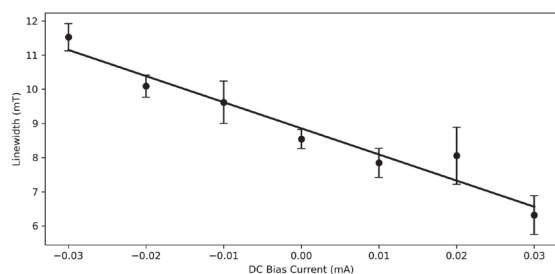
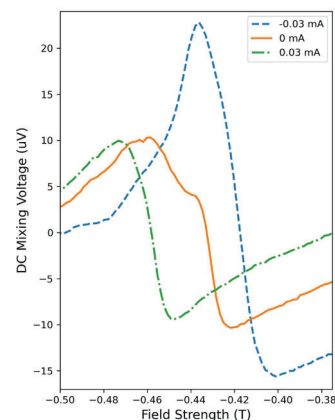


Figure 4: Linewidth extracted from the antiferromagnetic resonances at positive field, at a frequency of 21GHz, as a function of applied DC-bias.

Conclusions and Future Steps:

We have shown a vdW heterostructure that exhibits significant changes to the ST-AFMR linewidth, and therefore the damping, in response to DC currents. Future experiments will seek to establish whether or not we can tune the damping in this system to negative values to create a nano-oscillator. While the excitations in this system are still in the GHz, this would be the first steps toward establishing antiferromagnetic oscillators for ranges of frequencies that are unachievable in conventional ferromagnetic oscillators.

References:

- [1] Smith, A. et. al. Phys. Rev. B 102, 054422 (2020).
- [2] Cham, T. M. J et al. Science 389, 479-482 (2025).
- [3] Bainsla, L., Zhao, B., Behera, N. et al. Nat. Commun. 15, 4649 (2024).