Spin-Orbit Torques from $SrRuO_3$-$SrIrO_3$ Epitaxial Heterostructure

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Abstract:

Spin-orbit torques can be generated in two different ways: the Rashba-Edelstein effect and the spin Hall effect. These effects generally occur in trilayer heterostructures consisting of an oxide, ferromagnet, and heavy metal layer. $SrRuO_3$-$SrIrO_3$ heterostructures grown on varying substrates (NGO, STO, DSO, and GSO) should generate a spin-orbit torque at the interface. Spin torque ferromagnetic resonance and second harmonic Hall voltage measurements will be used to determine the effect that dominates the spin-orbit generation at the heterostructure's interface.

Summary of Research:

The purpose of the study was to determine the spin-orbit torques generated by a heterostructure consisting of a ferromagnetic layer coupled with a heavy metal layer. Strontium ruthenate (SRO) and strontium iridate (SIO) were chosen as the ferromagnetic and heavy metal layers, respectively. SRO is a 4d transition metal oxide that behaves as a ferromagnet below 150 K, and SIO is a 5d transition metal oxide with strong spin-orbit coupling. The heterostructures will be grown on different substrates, which will affect the magnetization of the ferromagnetic thin film. The mechanisms in which the torques can be generated is through the Rashba-Edelstein effect or the spin Hall effect.

To measure the films, they must be patterned via photolithography, deposited with metal (typically platinum) contacts, and ion milled to isolate channels on the sample. Two devices were made to test the spin-orbit torques: ST-FMR devices and Hall bars. All device fabrication was done at the Cornell NanoScale Science & Technology Facility (CNF).

If the samples depend on the thickness of the ferromagnetic layer, then the spin-orbit torques will generated via the spin Hall effect; otherwise, the Rashba-Edelstein effect (REE) will be the reason for the spin-orbit torques. Similar to the splitting of charges on opposite lateral ends in the classical Hall effect, the spin Hall effect (SHE) separates spin-up and spin-down electrons on the lateral surface. Figure 1 shows the SHE and the spin current generated from it, which flips the magnetic moment of the ferromagnetic layer. On the other hand, the Rashba effect occurs when the spin band splits since there exists a structural inversion asymmetry.

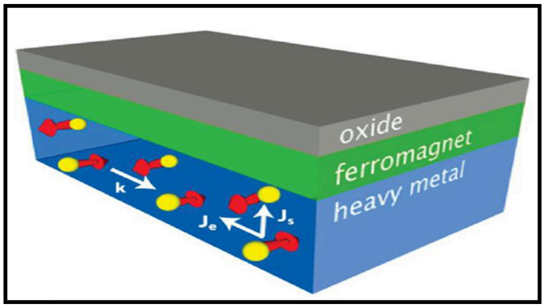
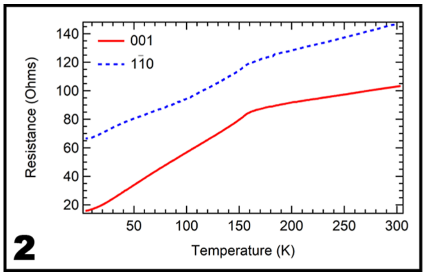


Figure 1: Spin-orbit torques are generated in an oxide, ferromagnet, and heavy metal trilayer. The spin Hall effect occurs when conduction electrons flow through the heavy metal layer drift due to their spin polarization and generate a spin current that flips the magnet moment of the ferromagnet.

The Rashba effect is thickness independent, meaning the change in layer size of the ferromagnet or heavy metal will not affect the spin-orbit torque. REE can manipulate



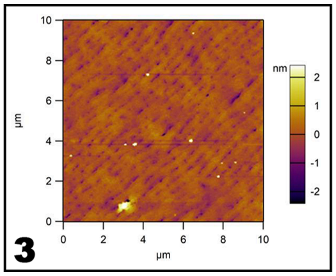


Figure 2, left: The resistance versus temperature of the SRO-SIO heterostructure shows an anisotropy in direction since <001> and <110> have a difference of ~50 Ohms at each temperature. Figure 3, right: The SRO-SIO heterostructure has step-terraces on the surface of the film. The step height of a step-terrace is 0.2 nm. There are some defects on the film, such as the 2 nm bump.

the magnetization of a material by flowing a charge current through the ferromagnetic layer, which generates a net spin accumulation.

Results and Conclusions:

One sample was grown on August 5, and was characterized with atomic force microscopy (AFM), x-ray diffraction (XRD), and transport measurements to ensure a high quality heterostructure was grown. The transport measurements of SRO-SIO heterostructure showed an anisotropy of 50 Ohms between measurements of [001] and [110]. Figure 2 shows the anisotropy measured in the film and a distinct resistance versus temperature curve similar to that of SRO. AFM was then performed to check the film surface for any surface defects that would explain the anisotropy in the bilayer. Figure 3 shows clear step-terrace formations of the SIO layer with some bumps which may correspond to a defect from the ruthenium layer that propagated to the surface layer. XRD was used to determine the thickness of the layers and to check coherence of the strain between the layers. Figure 4 shows the reciprocal space map of the SRO-SIO film, which demonstrates the coherence in the strain throughout the heterostructure. No significant conclusions were made since the growth of the heterostructure occurred five days before the close of the program. The transport characterization showed an anisotropy which may suggest that the spin Hall magnetoresistance will also show an anisotropic behavior. No conclusions can be made about the spin orbit torque generation yet since the samples have not been fabricated with devices.

Future Work:

Once several heterostructures are grown in growth module 1 and 2 (GM1 and GM2), the sample will have devices fabricated on it at CNF. A mask will be made for the Hall bars, the ferromagnetic resonance measurements, and potentially spin Hall magnetoresistance measurements. Spin torque ferromagnetic resonance (ST-FMR) measurements will be taken to study the effects off the spin orbit torque generated by the heavy metal and ferromagnet. The ST-FMR measurements will be taken with the setup in Professor Dan Ralph's group. Second harmonic Hall voltage measurements will be used to confirm the results from the ST-FMR. Depending on the results, angle-resolved photoelectron spectroscopy will be used to observe the band structure of the heterostructure and see if the spin Hall effect is evident from it. Both the second harmonic Hall voltage and spin Hall magnetoresistance measurements will be performed on the Vector magnet supplied by Professor Ralph. From these Hall measurements, the ST-FMR results will be compared to ensure the same conclusion is reached in terms of the spin-orbit torque generation at the interface of the bilayer.

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References:

[1] D.Bhowmik, O.Lee, L.You, and S.Salahuddin, Department of Electrical Engineering and Computer Sciences, University of California Berkeley, John Wiley & Sons, Ltd.

[2] D.MacNeill, G.Stiehl, M.Guimarães, N.Reynolds, R.Buhrman, and D.Ralph. Physical Review B 96, 054450 (2017).

[3] Matsuno, et al., "Interface-driven topological Hall effect in $SrRuO_3$-$SrIrO_3$ bilayer", Sci. Adv. (2016).

[4] M.Hayashi, J.Kim, M.Yamanouchi, H.Ohno, "Opportunities at the Frontiers of Spintronics", Phys.Review B 89, 144425 (2014).

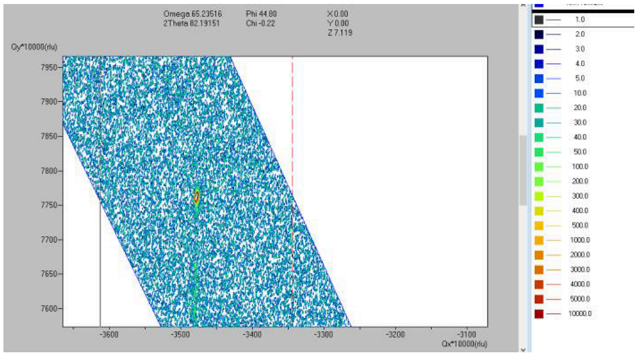
Omega 65.23516
2Theta 82.19151
Phi 44.80
Chi -0.22
X 0.00
Y 0.00
Z 7.119

Figure 4: Reciprocal space maps of the <113> peak shows that the SRO-SIO heterostructure is strained coherently throughout the layers.