Spin Torque Ferromagnetic Resonance with the Spin Hall Effect

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Abstract:

The goal of this REU project was to measure the film thickness dependence of spin-torque ferromagnetic resonance (ST-FMR) induced by the spin Hall effect. The spin Hall effect occurs when a current is sent through a conducting, nonmagnetic material, and spin-up and spin-down electrons are separated on either side of the material. This creates what is called a spin current, transverse to the electron current. In this research, the spin Hall effect was used as a source for spin injection in a nonmagnetic, conducting metal to create magnetic precession in an adjacent ferromagnetic film. The purpose of these experiments was to help achieve a better understanding of the spin Hall effect in various materials and the dynamics of spin Hall induced ST-FMR. Photolithography, ion milling and sputter deposition were used to define bilayer structures with contact pads. With these devices, we measured the ferromagnetic resonance signal to quantitatively determine the spin current injection and spin Hall angle.

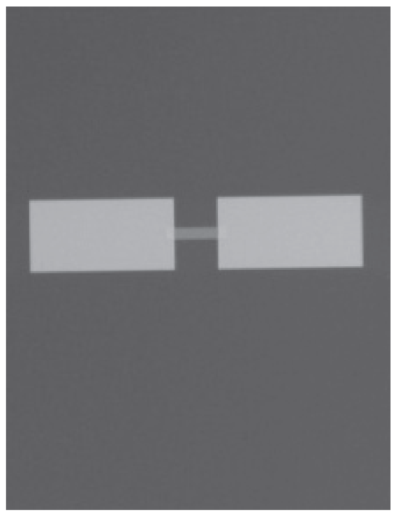

Figure 1: An image of the bilayer device between to copper contacts.

Introduction:

Spin transfer by the spin Hall effect has already been demonstrated in research performed by both the Ralph and Buhrman groups at Cornell. Past experiments in the area of spin manipulation have used magnetic materials in order to create spin current and to inject spin angular momentum into ferromagnetic materials. What is unique about this project is that we used the spin Hall effect in a nonmagnetic material to create this spin current, which is more energy efficient and a novel way of doing spin manipulation.

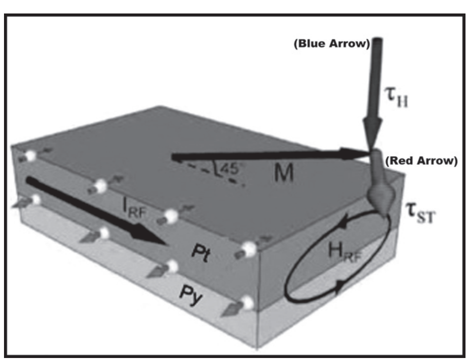

Figure 2: An illustration of what is happening in the device during the measurement process [1].

Experimental Procedure:

There were several steps to the fabrication process for the spin torque device. The first step involved sputtering different thicknesses of permalloy (Py) for each device made (varying from about 4 nm to 7 nm for four different devices) and then 3 nm of platinum (Pt). We did our first lithography step to define the basic device structure with ion milling. After this, a second lithography step is done to deposit the contact metals of Ti, Cu and Au onto the surface using e-beam evaporation.

Figure 1 shows an actual device upon which we did our measurements. Figure 2 demonstrates what was happening in the device during the measurement process. The incoming radio frequency current is indicated by I_{RF}. The colored arrows indicate two different torque vectors that were acting on the magnetic moment of the Py; the blue vector represents the torque associated with the Oersted field of the I_{RF}, and the red represents the torque associated with the spin transfer from the SHE. The result of these two torques was an oscillation of the magnetic moment of the Py.

For the ferromagnetic resonance (FMR) measurement set up of our device, a signal generator created a radio frequency voltage across the spin Hall metal. The output was a DC voltage that gave the resonance signal.

We exposed the sample to a scanning magnetic field. A resonance peak was then induced at a certain magnetic field, which was read via the DC voltage signal out, as shown in Figure 3. This process was performed for only three out of four of the different device thicknesses, as the 7 nm sample returned high resistivity readings and very noisy resonance data. This could have been due to any number of errors in the fabrication process, including particulates or resist residue being on the sample before depositing contacts.

The curve was fit to an equation (3) from Liu, et al. [2].

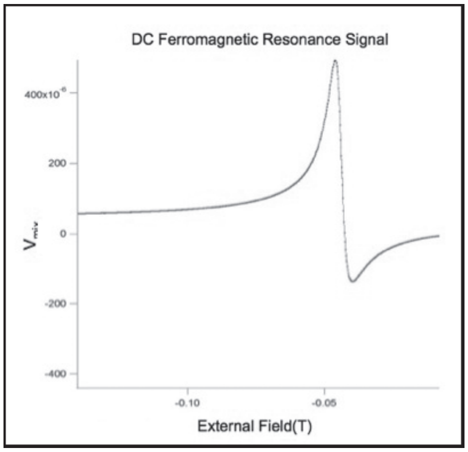

Figure 3: Represents the resonance curve, fit to an equation from Liu, et al. [2].

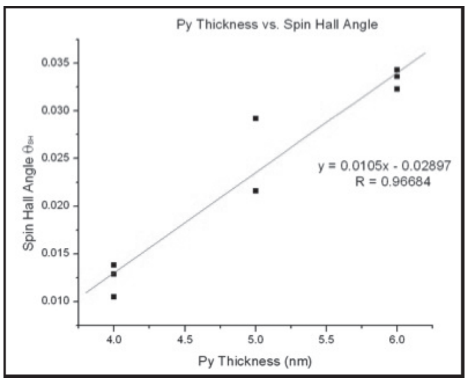

Figure 4: The correlated data after fitting and spin Hall angle calculations.

Results and Conclusions:

We calculated the spin Hall angle for each device fabricated by decomposing the resonance signal we found from ferromagnetic resonance measurements. Using non-linear graph fitting with the aforementioned equation, we split the resonance signal into its asymmetric component, which represented Spin Transfer, and its anti-symmetric component, which represented the Oersted field from the current. We then took the ratio of these two separate signals to find the spin Hall angle of each device for different thicknesses. Figure 4 represents the correlated data that we found.

Ultimately a positive correlation between spin Hall angle and ferromagnetic layer thickness was found, as shown in Figure 4. There were a couple of issues with the data collected however. The first problem was that the spin Hall angle found for every device was much lower than expected, with the highest value recorded at 0.034, whereas previous spin Hall measurements have shown a spin Hall angle for platinum as large as 0.07 [2]. This was likely due to the fact the demagnetization constant Meff was not measured for each device.

It is believed that this correction could eliminate the positive correlation in the data and return no change in the spin Hall angle for varying thickness. Further measurements are necessary to determine these values.

Future Work:

If this positive correlation between ferromagnetic thickness and the spin Hall angle remains correct after parameter corrections, it will likely motivate further investigation into thickness dependence of the spin Hall angle.

Acknowledgments:

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References:

[1] Luqiao Liu, Chi-Feng Pai, Y. Li, H. W. Tseng, D. C. Ralph, and R. A. Buhrman, Science 336, 555-558 (2012).

[2] Luqiao Liu, Takahiro Moriyama, D. C. Ralph, and R. A. Buhrman, Phys. Rev. Lett. 106, 036601 (2011).