Direct Spin Detection in Heavy Metals Using Picosecond Current Pulses

Travion Capers[1], Akshay Pattabi[2], Dr. Jeffrey Bokor[2]
[1]*Department of Electronics Engineering, Norfolk State University, Virginia 23504, USA*
[2] *Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, California 94720, USA*
Email: traycapers@yahoo.com

A charge current through a heavy metal with strong spin orbit coupling can generate spin current flowing opposite to the applied charge current. These polarized spinning electrons will accumulate on the surfaces of the metal with opposite spin orientation on opposite surfaces; this process is known as Spin-Hall Effect (SHE). When a ferromagnet is generated on such a metal, those accumulated spins diffuse into the magnet and can switch its magnetization, which has applications in magnetic memory devices. To detect the spin accumulations directly on the heavy metal surface without a ferromagnet, we use a technique known as magnetization-induced second harmonic generation (MSHG). From this technique, we expect to observe the contrast in spin orientation or Asymmetry at the surfaces of the sample. The Asymmetry is a proportional representation of magnetic moment of the accumulated spins at the surfaces and interfaces of the metal. Such a direct observation enables us to unearth the physics of spin accumulation, such as the spin life-time and spin diffusion length.

Introduction

Magnetic properties serve as promising methods of universal memory storage. Using magnetic memory has proven to be more efficient than existing methods of memory storage. Currently, electronic devices use silicon chips that utilize binary bits to store memory. These chips are volatile and need constant supply of power to retain its state. On the other hand, magnets are nonvolatile and do not require any power to retain its polarity. Being so, there are multiple methods in spintronic studies which capitalize on spin polarized currents to directly impact the magnetization of a magnet. Magnetization can be switched in ultrafast time scales using very little energy by manipulation a concept mentioned previously known as Spin-Hall Effect (SHE). This has been proven to be the most efficient method of bit switching found thus far for such devices. Even though it is known that the generated polarized spins from the SHE have the ability to effect the magnetization of a magnet, there is still much to be discovered directly about the physical properties of these spins. Most methods of studying involve the usage of a ferromagnet grown on top of the heavy metal and observing the interaction of the spins through the ferromagnet. This is not a reliable means of testing because it is based off the ideal assumption that all polarized spins at the surface of the heavy metal will diffuse through the ferromagnet, but this is not accurate. Even the weakest ferromagnet can potentially reflect polarized spins from diffusing through. For this reason, testing without a ferromagnet is necessary in order to directly understand the behavior of such electrons. A method known as Magnetization-induced Second Harmonic Generation (MSHG) has been introduced for such purposes. The direct testing of these electrons can lead to the optimization of the SHE method of switching and ultimately can lead to minimization in memory devices.

Methods

Harmonic reflections are waves with frequencies that are multiples of the frequency of a fundamental wave and are generated once that fundamental comes in contact with a material as shown in Figure 1. Direct detection of the electrons at the surface can be effectively measured using the MSHG testing method because the second harmonic is only generated at surfaces and interfaces; the polarized spinning electrons accumulate at the surfaces and interfaces as well. My testing set up consisted of two lasers – pump and probe. Through a series of mirrors and optical lens, these laser beams can be positioned to come in contact with the sample where needed. Figure 2 shows the path of the beams. Harmonics are can be generated from or fundamental waves

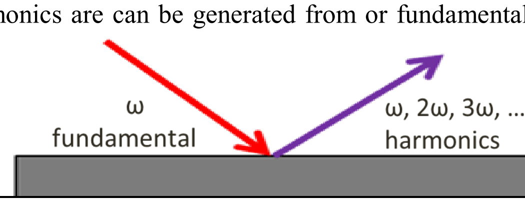
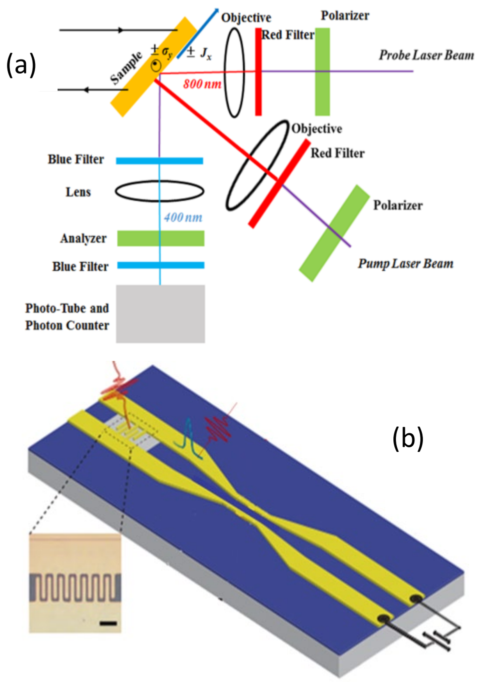


Fig 1: Representation of a fundamental wave reflecting off a surface and generating harmonics that are multiples of the original fundamental's frequencies

Fig 2: (a) Schematic of the magnetization-induced second generation set-up. The current *J* is applied along the *x* direction and the spin orientation is perpendicular in the *y* direction. (b) Image of the sample. The pump is focused on the semiconductor to create current pulses and the probe beam hits the platinum transmission line.

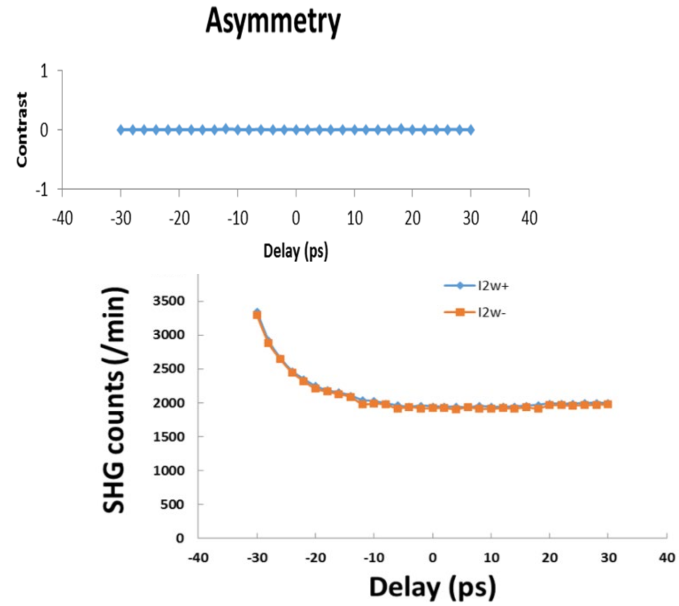


being positioned through the imaging optics thus the red filters are to cancel out any other signal from coming in contact with the sample. The blue filters are to block any signal other than the second harmonic from being measured by the photo tube.

Data

By measuring the intensity the second harmonic when the spin are oriented in one direction versus the same intensity when the spins are oriented in the opposite direction we can calculate a value of Asymmetry. Asymmetry is a measure of magnetization at the surfaces and interfaces and can be considered as the contrast of spins. This is mathematically shown in Equation 1. Unfortunately through the multiple weeks of testing, I was unable to obtain reliable data from the measured Asymmetry values. It was expected that there would be a contrast in count orientation. The higher the contrast means the higher the Asymmetry and ultimately the higher the magnet moment of the heavy metal. However, my results showed no contrast of spins. Figure 3 shows that my Asymmetry values were zero for each delay point in the current pulse and the identical number of spins in the positive and negative orientation.

Fig 3: (a) Plot of the spin intensity of the second harmonic when the spins are oriented in one direction versus the opposite orientation. (b) Plot of the Asymmetry values



$$A = \frac{I^{2\omega}(+\sigma) - I^{2\omega}(-\sigma)}{I^{2\omega}(+\sigma) + I^{2\omega}(-\sigma)} \propto \sigma_y \qquad (1)$$

Conclusion

There is undeniable potential for success in this project. MSHG has been used to measure expected values of Asymmetry when the current pulses are in nanosecond time scales. I believe the samples were not durable enough for the applied picosecond current pulse or the laser beam intensities. Additional time, adjusted methods and further testing is needed to form conclusions about the spin lifetime.

References

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