Low Temperature Detection of Spin Pumping and Background Effects

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Introduction:

Over the last 20 years, the field of Spintronics has seen many discoveries beginning with Giant Magnetoresistance, now used in computer drives, and many hope, heading in the direction of an ultimate goal of the spin transistor. In pursuing this goal, one of the primary challenges lies in the efficient spin injection from a ferromagnet(FM) to a semiconductor(SC). The current method of spin injection, injection through electrical current, suffers a large inefficiency due to the mismatch in impedance between FM metals and SCs. In 2007, Brataas et. al proposed a theoretical model in which spin injection could be realized through dynamic spin exchange between a ferromagnetic and a non-magnetic structure(1). This theory, free from the impedance mismatch problem, has therefore been searched for in many experiments over the last 5 years.

The experimental realization of this theory, known as spin pumping was reported in 2011 by the group Saitoh et. al. who found that at room temperatures, they could inject spin into Si with high efficiency as well as providing tunability through an electrical bias(2). We believe however, that their results are not entirely related to spin pumping for several reasons. First, the measured signals reported are as large as those reported in all metal systems. One of the primary factors in the efficiency of spin pumping is the spin mixing conductance, an interfacial property dependent on the two materials interfaced. This value is known to be smaller in FM/SC systems than in all metallic systems leading to questions of possible background effects. Second, the paper gives very little analysis as to background effects which we believe could be significant, among these effects, AMR and TAMR. Because these measurements are done while the FM is driven to ferromagnetic resonance, both AMR and TAMR can generate DC voltages through time averaging. Our goal with this project was to analyze several of these background effects through their known dependence on temperature a position.

Experiment:

In order to understand the background effects through their known dependence on temperature and position, the primary task for this project was to develop a cryostat with the abilities to perform spin pumping measurements below 70K. In order to accomplish this task, we needed two things, the ability to drive ferromagnetic resonance in the sample, and the ability to position the sample relative to the electromagnetic waves in the waveguide. The first task is challenging due to the question of thermal load. With one end of the waveguide at room temperature and the other at 70K, this is a large temperature gradient and the waveguide must thus be chosen carefully. Additionally, in order to run the cryostat, a vacuum of the order of 10^{-6} torr must be maintained so the waveguide must be vacuum sealed. The second problem is made difficult by the space limitation inside of a flow cryostat. In previous experiments of this type, a waveguide with a slot cut through one side has been used which allows for linear motion along the direction of EM wave propagation. This method is useful primarily because it does not alter the surface currents that accompany the EM wave along the waveguide shell.

In order to vary the position of the sample, we designed a sample mount to attach to the coldfinger of a flow cryostat. The sample mount was built using OFHC copper in order to maintain a consistent temperature between the sample, thermometer, and heater. An insert was placed on the end of the copper block to act as the short of the microwave waveguide forming one end of a rectangular microwave cavity. In order to insert the sample, a G10 rod was built through the short with the sample on the end. By setting the G10 rod with a set screw, the sample could be fixed at a specific location, as well as moved through the waveguide. So far, the temperature dependence of our signal has been our primary focus, and we have therefore not tested the position dependence.

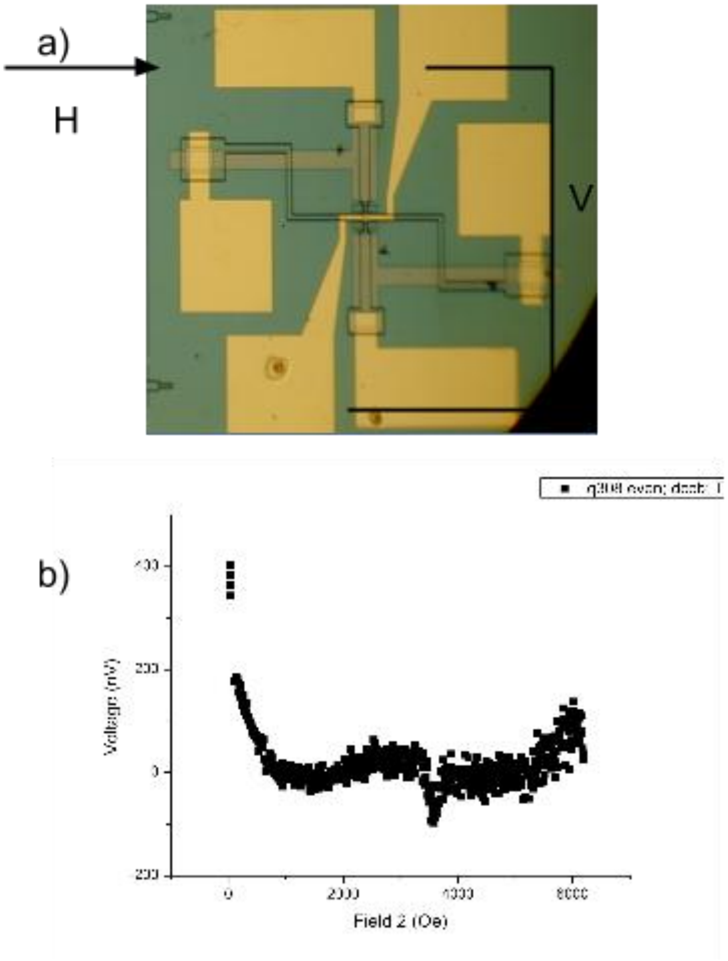

Figure 1: (a) Photograph of the device used to test the apparatus. Measurement was performed between a FM center contact and a FM outer contact. (b) Interface measurement at 300K with a 2nd order background subtracted due to heating.

In order to drive ferromagnetic resonance in the sample, we set up a waveguide circuit composed of a Gunn diode for microwave propagation, a Faraday isolator to protect the Gunn diode from reflections, a kapton pressure window to maintain vacuum in the cryostat, and a stainless steel waveguide to thermally isolate the sample in the cryostat. The waveguide window is designed for pressures up to an atmosphere, the inward pressure on a cryostat vacuum can. Additionally, the thermal conductance of stainless steel, 16 W/m.K, provided 5 times better thermal isolation than brass, the typical choice for waveguide tubing. In order to verify that the microwave electronics and modifications to the cryostat worked, the interface voltage, a signal measured previously in our samples was performed. In figure 1, the measurement geometry can be seen as well as the measurement of the FMR peak. In this sample, the resonance peak between 3500 and 4000 Oe matches our expectations from the FMR resonance spectrum seen in previous measurements. Additionally, the low field peak fits with data taken previously and is due to Tunneling Anisotropic Magnetoresistance. This peak is due to the direction of magnetization changing at low field. The peak occurs due to the background changing with this changing orientation.

Following room temperature verification of the apparatus, measurements were performed at low temperatures. Seen in figure 2 is the same measurement from figure 1 done at 120 K. This showed that the interface resonance peak did not change significantly over this temperature range. On the other hand, it would appear that the low field TAMR signal changed significantly with the difference in temperature. This is as expected since TAMR has been shown to have a temperature dependence. Since the measurement at 120 K, we have taken the cryostat down to 60 K, however as of yet this has been the threshold. Currently, temperature stability as well as base temperature are the two areas that remain to be improved.

Conclusions:

While the measurements on the apparatus are not finished, the measurements have shown us that the apparatus will provide the necessary features for looking at background effects that occur in spin pumping. In order to understand these effects further, measurements of the interface signal at lower temperatures as well as inverse spin hall measurements at low temperatures will be done. As we proceed forward, I see two main areas that we will devote our attention to; we want to develop experiments that will allow us to better understand the TAMR resonance peak, and second, we want to improve both the base temperature of 60 K and also improve our ability to stabalize the temperature.

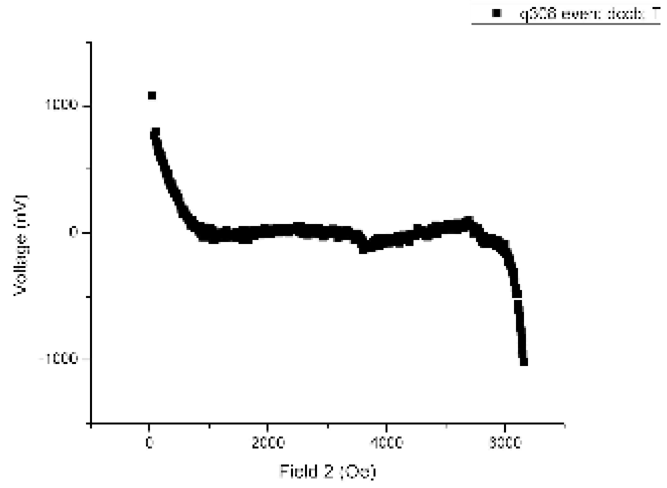

Figure 2: Interface signal measured at 120 K with a 1st order background subtracted. It is difficult to see, but the resonance signal is 80nV. This is similar to the signal at 300K.

The UROP provided me with a great experience as I proceed forward next year in graduate school. Through the UROP I was able to work independently on a research project which demanded that I learn a lot about both experimental methods as well as current research in spin transport. During this project, I think that the main skill that I gained was the ability to be self motivated in my research. Unlike many projects done in school where deadlines were imposed by the course, I was required to set my own deadlines and force myself to meet them. For the most part, I feel that I was able to do this successfully, though during times such as the design process which was long, I had more difficulty. I believe that with my responsibilities in graduate school, this experience will prove to be invaluable as I work independently in a research lab. Additionally, I would like to thank the graduate students Changjiang Liu, Chad Geppert, Kevin Christie, Andrew Galkiewicz.

References

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(2)K. Ando, S. Takahashi, J. Ieda, H. Kurebayashi, T. Trypiniotis, C.H.W Barnes, S. Maekawa, & E. Saitoh, Electrically Tunable Spin Injector Free from the Impedence Mismatch Problem, *Nature Materials* **10**, 655–659(2011)