Understanding Ultrafast Switching with All-Optical Switching(AOS) & Anomamlous Hall Effect(AHE)

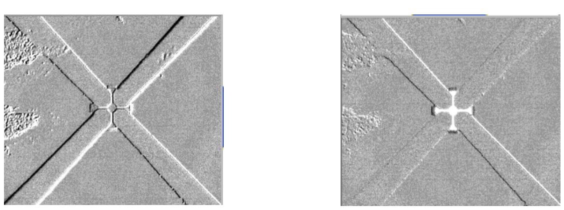
Claudia Robinson[1], Amal El-Ghazaly[2], and Jeffrey Bokor[2]
[1]Department of Computer Engineering, Jackson State University
[2]Department of Electrical Engineering and Computer Science, University of Califronia Berkeley
Email: j00618967@students.jsums.edu, aelghazaly@berkeley.edu, jbokor@berkeley.edu

Abstract — Recently GdCo has been found as a new material in which ultrafast magnetization switching could be observed. To demonstrate this switching capability, we electrically contact and measure single nanodots down to 50nm, determining their magnetization state before and after laser excitation. In this approach, we apply a current to an Anomalous Hall Effect (AHE) crossbar and simultaneously excite the GdCo nanomagnetic dot in the center of the crossbar with a laser pulse. By observing a switch in the AHE voltage across the magnetic dot as the dot is hit with the laser, we therefore demonstrate the ability to electrically detect all-optical switching of a single nanomagnetic dot's magnetization.

Index Terms – All-Optical Switching (AOS), Anomalous Hall Effect (AHE), single-shot switching.

I. Introduction

The need for faster computing speeds calls for the use of ultrafast switching at the nanoscale level. To make a viable ultrafast magnetic memory, ultrafast switching needs to be efficient in two aspects: all-optical switching (AOS) and electrical readout using the Anomalous Hall Effect (AHE). AOS was tested in thin films of unpatterned magnetic material and found to all-optically switch its magnetization, despite having high coercivity [3]. Yet, there are some hinderances to ultrafast switching. While AOS is a popular technique, it was discovered that for some excitation wavelengths AOS is irreversible and a single, 40 femtosecond pulse results in permanent magnetic reversal, another challenge to achieving faster switching [1,4]. Higher wavelength and increasingly shorter laser pulses are best for direct optical switching [3,5]. This is needed to understand how to use AOS and AHE at the nanoscale level. We want to



approach ultrafast switching where we can use AOS on an AHE crossbar and measure AHE for nanodots down to 50nm. Theory suggests that the AHE has a higher signal for perpendicular magnetic materials [3]. Since the AHE signal is generated by the material in a crossbar configuration, a current applied can generate enough AHE voltage to indicate magnetizations switching [2]. Each time the crossbar is shot with a laser, the magnetization should switch along with the AHE voltage and the switching should be a reversible process. Therefore, AHE can be used to electrically detect the AOS of magnetic materials at nanoscale dimensions.

II. Fabrication Process

Our devices are created through a meticulous fabrication process of two parts: photolithography and electron-beam lithography. We start with a substrate made of silicon and grow 100nm of silicon dioxide (SiO_2) as an insulation layer. The sample is then spin-coated with photoresist and coated with titanium (Ti) and gold (Au) thin film layers; 5nm of Ti and 50 nm of Au are evaporated and lifted off. The electron-beam lithography process starts with the sample being spin-coated with electron-beam resist for electron-beam patterning of the GdCo layer in the middle of the Ti and Au contact pads, after which the magnet is sputtered to create a material stack of Ta(3nm)/Pt(3nm)/GdCo(10nm)/Pt(3nm). The electron-beam resist is then lifted off from the magnet and the entire substrate is coated with 5nm of SiO_2 to prevent the sample from oxidation.

III. Methods

A device is loaded onto a sample stage and viewed using Magnetic Optic Kerr Effect (MOKE) microscopy. We focus on an AHE crossbar and flip a magnet behind the sample stage to check for MOKE contrast. When there is evident contrast of the crossbar, we shoot the sample with a single shot of the laser and find the optimal laser power for switching magnetization. We measure the AHE resistance by connecting the crossbar to an AC current source and a lock-in amplifier. The current source applies a 1µA current at a frequency of 341 Hz and feeds the reference frequency to the lock-in amplifier to measure AHE voltage. Once we measure the voltage, we determine the AHE resistance of the nanodot based on the ratio of the measured voltage and applied current. We use AHE and an electromagnet to measure a hysteresis loop of the magnetic nanodot in terms of resistance as a function of the magnetic field. This allows us to find the resistance values of the opposite magnetization states.

Figure1: MOKE image of 5um crossbar before laser excitation

Figure2: MOKE image of 5um crossbar after laser excitation

IV. Discussion

The r... ...It p... switching is possible and can be measured by the Anomalous Hall Effect. We focused on a wire-bonded crossbar in MOKE. A wire-bonded crossbar relates to the device coordinate of the sample and avoids wasting time in trying to test every crossbar in the sample to view which crossbar is best detected through AHE. We found the switching power for consistent optical switching to be approximately 50 mW. After measuring the incidence area of the pump laser beam (approximately .471cm^2). We calculated the fluence in mW/cm^2 from:

$$F=\frac{□□□□□\ (□□)}{□□□□\ (□□^2)}$$

samples measured in Figure 3 are the single-shot samples; each laser pulse shot on the single-shot sample switches the magnetization from up to down without any manipulation of the sample itself, as seen in B and D of Figure 3. On the other hand, the samples in Figure 4 are the demagnetization samples, each laser pulse shot demagnetizes the sample (to a random magnetization state, M=0) from a magnetization state of either up or down, initially manually set with a magnet and then shot with the laser, as seen in D, E, and F of Figure 4. This also explains why the demagnetization samples have a zero measurement between the two high and low AHE resistance states corresponding to the magnetized up and down states. As shown in the figures, the demagnetization processes occur as easily as the single shot process measurements, shown Figure 3. Some hysteresis loops were nosier than others, which relates to the device's size.

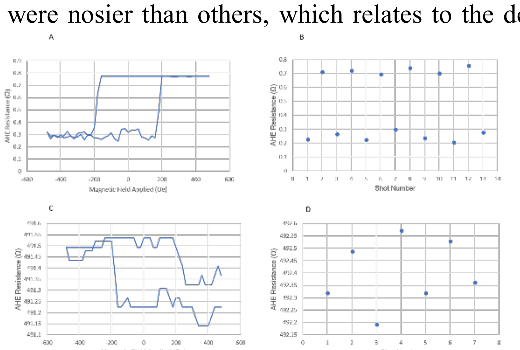


Figure3 depicts the hysteresis loops and single shot measurements for the single-shot switching samples. A.) Hysteresis loop for sample, size 5um B.) Single shot measurements for 5um sample C.) Hysteresis loop for sample, size 800nm D.) Single shot measurement of 800nm sample

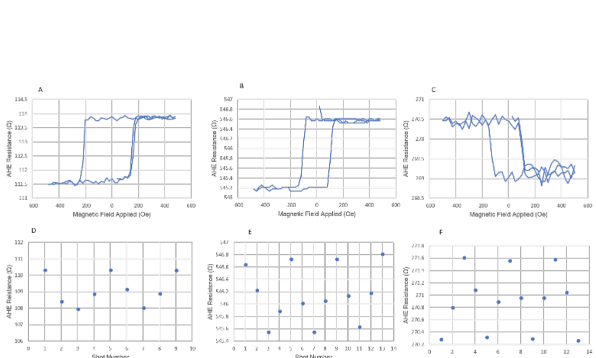


Figure4 presents measurements of the demagnetization samples. A.) Hysteresis loop of sample, size 500nm. B.) Hystersis loop of sample, size 1um C) Hysteresis loop of sample, size 5um D) Single shot measurements of 500nm sample E) Single shot measurement of 1um sample F) Single shot measurement of 5um sample

We initially determined to optically switch samples down to 50nm, but smallest size of the sample that we could measure was 500nm. We hypothesize that the material composition of the samples is the reason we had a difficult time gaining results from samples at the sizes projected. We understand now that the material composition is vital if we want to achieve AOS with good AHE in the future at the size we want it. To specify, the material is GdCo, but a different composition of GdCo is used in the demagnetization sample. Even though the material from the demagnetization samples is different, we could still detect single-shot switching and found a nice trend of switching, the best being from D in Figure4 from the 500nm sample. It was also a challenge to decipher which hysteresis loops and single shot measurements were best. As mentioned, the device size of the sample correlate to the noise of the sample. We found that smaller devices were harder to measure because it produces more noise, while the larger devices did not produce as much noise. As seen in Figures 3 and 4, the larger the devices become, the messier the hysteresis loops are and more scattered the single shot measurements. The results collected; however, do imply that AOS is possible even if the material composition of the device is not ideal, but we must consider the material as a higher priority if we want to have the maximum effect of AOS on devices smaller than 500nm.

V. Conclusion

Ultrafast switching is the most promising pathway to magnetic memory. While we want a universal memory to be fast, dense, and energy efficient, we first must be sure that it is capable of such processes at the nanoscale via AOS and AHE. If we can detect AOS at devices as small as 50nm, universal memory will be an astonishing technological advancement in the future.

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