Chromium to Optimize Spin-Orbit Torques on Magnetic Devices

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Abstract:

Magnetoresistive random access memory (MRAM) relies on storing information in the magnetization states of nanomagnets. This presents a need for an effective and localized technique for manipulating the magnetic orientation of nanomagnets. One possible method of doing so is to employ spin-transfer torques, which can be generated through the spin Hall effect (SHE). SHE is observed when a charge current is applied to a metal with strong spin-orbit coupling, causing electrons to be deflected according to their spin orientations. These spins accumulate along the boundaries of the metal, giving rise to a transverse spin current that can subsequently exert a spin-transfer torque on an adjacent ferromagnetic layer. Samples with a Cr layer and a $Co_6Fe_2B_2$ or Py ferromagnetic layer were fabricated. Spin-torque ferromagnetic resonance (ST-FMR) and vibrating sample micrometer (VSM) measurements were performed on the devices. The findings suggest that the spin Hall angle of Cr is at least 1.8 percent.

Introduction:

Magnetoresistive random access memory (MRAM) is a strong contender in the quest to identify a source of high-density, non-volatile memory storage. Precisely reorienting a nanomagnet's magnetization continually challenges researchers. Current-induced spin-transfer torques in heavy metals can be used to locally manipulate the magnetic orientation of magnetic devices extremely efficiently [1]. Current-induced spin-transfer torques are a product of spin currents, which can be induced by the spin Hall effect (SHE). The ratio of the induced spin current to the applied charge current, otherwise known as the spin Hall angle, is a common figure of merit for how effectively a material can generate spin-transfer torques given some applied charge current. Previous research has suggested that chromium may have a large spin Hall angle, making it a particularly interesting material to study [2].

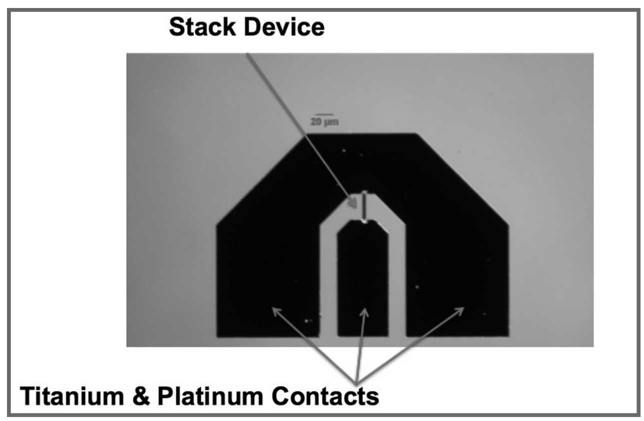

Figure 1: Device geometry used for ST-FMR measurements.

Experimental Procedure:

We began our device fabrication process by sputter depositing a 7 nm or 8 nm chromium (Cr) layer and a 2 to 10 nm ferromagnetic layer onto approximately 1 cm by 1 cm sapphire wafer pieces. Permalloy (Py) or cobalt iron boron ($Co_6Fe_2B_2$) was used for the ferromagnetic layer. A 2 nm aluminum capping layer was deposited in order to prevent the lower layers from oxidizing. We proceeded to pattern $Cr/Co_6Fe_2B_2$ and Cr/Py ST-FMR devices onto our samples through optical lithography and ion etching techniques. Finally, titanium (Ti) and platinum (Pt) contacts were deposited onto the devices via sputter deposition, followed by a lift off process to remove the excess Ti/Pt and leave behind only the contacts.

We faced a variety of challenges during the fabrication and measurement processes, including: adhesion issues of the Ti/Pt contacts, resonant frequency peaks that were presented at amplitudes far smaller than expected, and highly resistive devices. These issues, combined with observations that photoresist may have been stuck under the contact pads causing adhesion issues, lead us to believe that our devices are somewhat compromised.

Measurements on our devices comprised mainly spin-torque ferromagnetic resonance (ST-FMR). We began our ST-FMR measurements by lowering an RF probe to the Ti/Pt electrical contacts on our devices. We then applied a charge current of controllable radio frequency, and swept an in-plane magnetic field between -0.20 T and 0.20 T. Subsequently, we observed a resonant frequency peak due to the interaction between the current-induced torques and the precession frequency of the ferromagnetic layer. This precession in the ferromagnetic layer's magnetization yielded an oscillating anisotropic magnetoresistance (AMR). The combination of the RF resistance oscillation with the RF frequency created a DC mixing voltage, which we measured over a variety of controllable frequencies.

In addition to the ST-FMR measurements, we also spent time characterizing the AMR of the devices and determining the saturation magnetization of $Co_6Fe_2B_2$ and Py. AMR occurs when the electrical resistance is dependent upon the angle between the direction of the current and the direction of the magnetization. Because applied spin torques rotate the magnetization during ST-FMR, it was necessary to characterize the AMR of the devices. Additionally, it was necessary to obtain the saturation magnetization for $Co_6Fe_2B_2$ and Py using a vibrating sample micrometer (VSM) — because as saturation magnetization increased, the ease with which we reoriented the magnet decreased.

Results and Conclusions:

The results of our analysis on our Cr 8 nm/Py 5 nm device can be seen in Figure 2. These results suggest that the spin Hall angle of chromium is at least approximately 1.8 percent. Because we observed very strange resistance values in our measurements for the Cr 7 nm sample and the Cr with Py sample, it is likely that our initial calculation for the spin Hall angle may have been somewhat inflated. Thus, we made a more conservative guess for the shunting factor, giving us a value of about 1.8 percent for the angle. These resistance issues, coupled with the fabrication issues we faced, suggest that there is quite a bit of room for improvement for creating more successful devices.

Future Work:

More devices should be fabricated using a more gentle process in order to ensure more accurate results. Additional ST-FMR measurements should be done on more reliable $Cr/Co_6Fe_2B_2$ and Cr/Py samples in order to more accurately determine the spin Hall angle of Cr.

CNF Tools Used:

Class 1 resist spinners, Class 2 resist spinners, 5X stepper, AJA sputterer, Oxford 81/82.

Acknowledgments:

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References:

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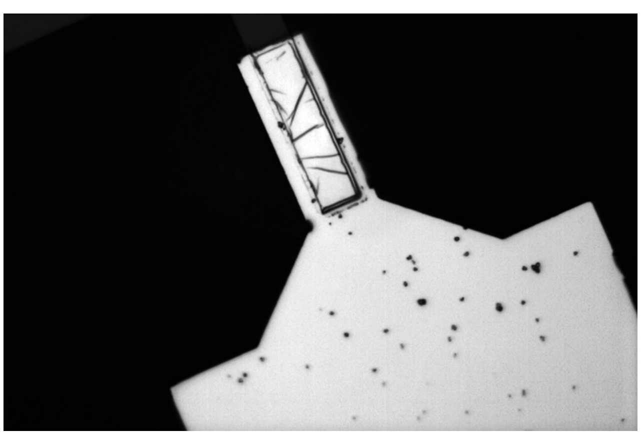

Figure 2: Roughness/wrinkles beneath contact pads on ST-FMR device for Cr 7nm/$Co_6Fe_2B_2$ 10 nm sample suggest that photoresist may be stuck under contact pads.

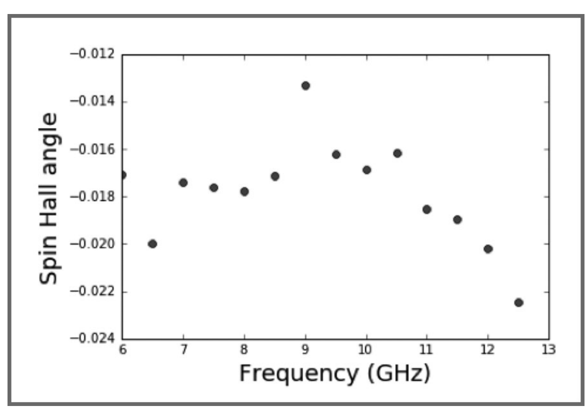

Figure 3: Spin Hall angle data Cr/Py device.