Determining the Spin Hall Angle of Gadolinium

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Abstract:

The spin Hall effect is observed when electrons from a charge current are deflected based on their spin orientation, causing an accumulation of spins on the boundaries of a material. The spins can then exert a torque on an adjacent ferromagnetic material, potentially manipulating the orientation of the magnetization. It has been found that manipulating nanomagnets through spin transfer torques is much more practical than using a magnetic field. Therefore, spin transfer torques present advantages in non-volatile magnetic memory applications [1]. Spin-torque ferromagnetic resonance (STFMR) measurements were performed on various gadolinium-ferromagnetic multilayers, and the spin Hall angle was extracted. The anisotropic magnetoresistance (AMR) of Py and CoFeB was measured. The saturation magnetization, the conductivity of Gd, and the x-factor were also measured for use in analysis. It was found that the spin Hall angle of Gd is 2%.

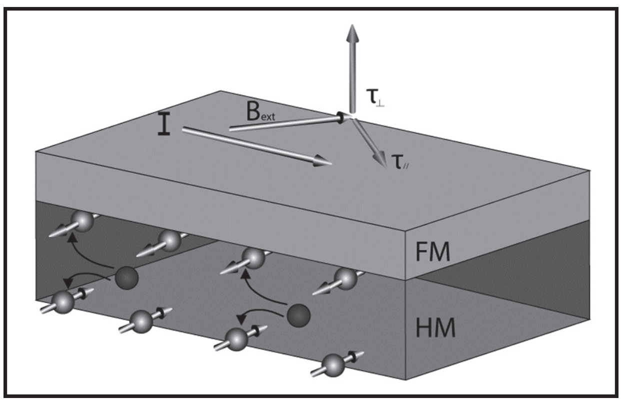

Figure 1: Stack device of a heavy metal (HM) and a ferromagnetic material (FM). Electrons deflected based on their spin orientation. Torque exerted on adjacent layer magnetization can be observed.

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Introduction:

Technology is rapidly evolving, presenting a need for a universal memory that is nonvolatile, has a high storage density, and has a fast access time. One solution for this is magnetoresistive random access memory (MRAM). In MRAM, information is stored in the magnetization state of a nanomagnet; this information is read and written electronically. Research has successfully developed a way to easily read the state, but manipulating the state effectively still poses a problem. One method of manipulating the magnetization state being explored in current research is spin transfer torques. Spin transfer torques are caused by the spin Hall effect. The spin Hall effect is observed when electrons from a charge current are deflected based on their spin orientation, causing an accumulation of spins on the boundaries of a material. The spins can then exert a torque on an adjacent ferromagnetic material, potentially manipulating the orientation of the magnetization as seen in Figure 1. The effectiveness of the spin Hall effect in a given material is described by the spin Hall angle, a ratio of the generated spin current to the applied charge current.

Experimental Procedure:

Material stacks of 10 nm of gadolinium (Gd) and 5 to 10 nm of a ferromagnetic material were deposited on a sapphire wafer through sputter deposition. Permalloy (a NiFe alloy) or cobalt iron boron (CoFeB) were used as the ferromagnetic layer. Hall bars were then patterned through

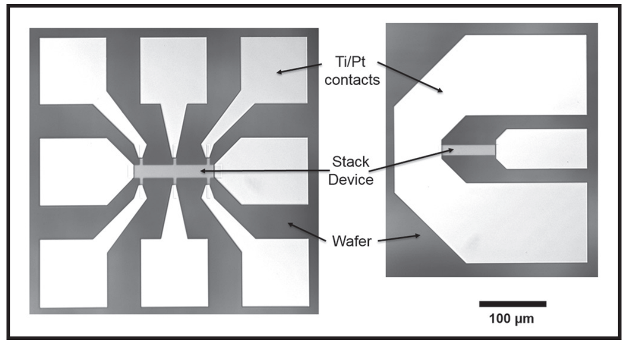

Figure 2: (Left) Device geometry used for STFMR measurements. (Right) Device geometry used for resistance measurements. The Hall bars shown are 80 µm by 24 µm.

optical photolithography and ion milling procedures. Platinum contacts were deposited through sputter deposition. Various device geometries were fabricated to accommodate electrical measurement set ups, as seen in Figure 2.

Devices were characterized using spin-torque ferromagnetic resonance (STFMR) measurements. An RF ground-signal-ground probe was connected to the device. A fixed microwave frequency was applied to the sample while sweeping an in-plane magnetic field from -0.25 T to 0.25 T. The magnetization of the ferromagnet precessed due to the oscillating current induced torque, which yielded an oscillating anisotropic magnetoresistance (AMR). The AMR and applied ac current were used to calculate the mixing voltage. This mixing voltage was recorded against the magnetic fields over a range of applied frequencies [2].

AMR is observed when the resistance of a material has a dependence on the angle between the current direction and the magnetization direction. Since this angle changes during STFMR measurements, the AMR of each sample was characterized in order to properly analyze the spin Hall angle.

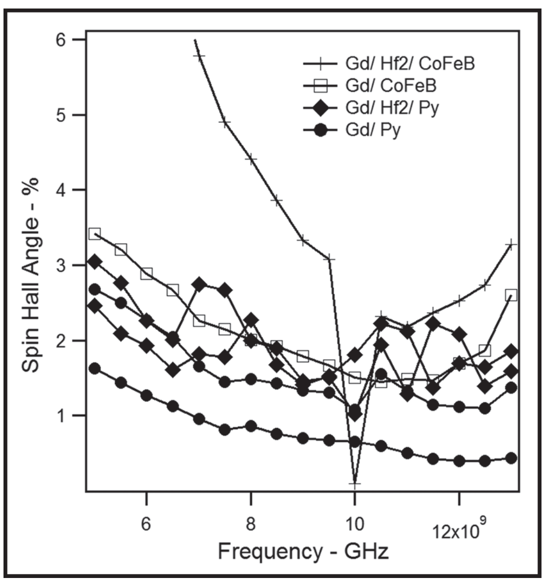

Figure 3: Compiled results of spin Hall angle analysis for six different devices. Spin Hall angle axis is cut off at 5% in order to better see what is recorded around 2%.

The saturation magnetization, conductivity of gadolinium and x-factor (a ratio of stack resistance to the resistance of gadolinium) were measured for use in the analysis.

Results and Conclusions:

This analysis was run on four different sample stacks. The results of the analysis are compiled in Figure 3. It was determined that the spin Hall angle of gadolinium is about 2%. There is a sign ambiguity that would require further analysis to determine whether the spin Hall angle is positive or negative. Based on the resistance measurements of the sample stacks, there likely is a problem with Py grown on Gd. However, a 2 nm Hf spacer seems to alleviate this in the Gd/Py samples; this problem is not seen in the Gd/CoFeB samples.

Future Work:

More analysis will be done on other devices to ensure the accuracy of the spin Hall angle. The sign of the spin Hall angle will also be further explored. The difficulty of growing Py on Gd will also be examined to determine why the problem occurs.

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References:

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