Spin Torque Efficiency of Cobalt Iron Boron

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Primary CNF Tools Used: Autostep i-line stepper, AJA sputter deposition, DISCO dicing saw

Abstract:

A spin polarized current is generated in a ferromagnet via the anomalous Hall effect (AHE) when an electric field is applied. The polarisation of the spins depend on the polarisation direction of the spin majority band, which can be controlled by applying an external magnetic field. Unlike spin currents generated in heavy metals where the spin polarisation is constrained by symmetry to be in plane, an out-of-plane component may be present. This enables high efficiency spin torque switching of magnets with perpendicular magneto-anisotropy. In this project, we investigate the charge to spin conversion efficiency of cobalt iron boron (CoFeB).

Summary of Research:

We quantify the spin torque efficiency of CoFeB by measuring the spin torque induced oscillation of a second CoFeB layer with perpendicular magnetic anisotropy, separated from the in-plane magnetised source layer by a titanium spacer layer. Similar work has been done using both CoFeB and permalloy spin source layers [1].

The CoFeB(4nm)/Ti(2nm)/CoFeB(1nm) heterostructures were first deposited by magnetron sputtering. Hall bars were then defined and etched out of the deposited thin film heterostructure using photolithography (Autostep i-line stepper) and ion-milling. Following this, a second level of photolithography was done and a second round of magnetron sputtering (AJA sputter deposition), to deposit titanium and platinum contact pads. A schematic of the heterostructure is shown in Figure 1. The fabricated devices were then measured on a projected field magnet probe station, where a sinusoidal voltage was applied across the hall bar and the transverse hall voltage whilst sweeping the external field strength and direction.

The longitudinal electric field generates a spin polarized current in the source layer, which flows in the transverse direction into the upper readout layer. As the spin polarized current travels into the ferromagnet, the local magnetization causes transverse components to dephase and transfer spin angular momentum in the process, applying a torque on the ferromagnet. This torque is also known as the anti-damping (AD) torque, and has the form $\tau \propto m \times (m \times \sigma)$. A second type of torque can also arise from the accumulation of spins at the interface between layers, and results in a field-like (FL) torque with the form $\tau \propto m \times \sigma$, where σ is the spin polarisation vector. This effective magnetic field due to these torques can be quantified using the Harmonic Hall method [2], where the ratio between the gradient of the second harmonic and the curvature of the first harmonic is proportional to the effective magnetic field.

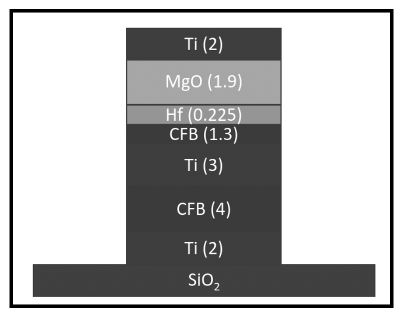

Figure 1: Schematic of the thin-film heterostructure deposited using magnetron sputtering. The two cobalt iron boron (CoFeB) layers are separated by a titanium spacer to minimise exchange coupling. A hafnium (Hf) dusting layer and a layer of magnesium oxide (MgO) was deposited on the top CoFeB layer to promote perpendicular magnetoanistropy (PMA) in the top magnet. Ti layers were used as capping layers below and on top of the heterostructure to prevent oxidation during the litho process.

To separate the AD torque from the FL torque, we apply an external magnetic field to tilt the out-of-plane magnetization of the readout magnet parallel and perpendicular to the current, such that only the AD torque and FL torques are non-zero respectively [3].

We compared the effective fields generated from the torques on the top magnetic layer with and without the bottom magnetic layer and found that there was a small but non-negligible effective field generated by the bottom CoFeB layer. Plots showing the variation of effective fields with the applied voltage are shown in Figures 2 and 3. Both the AD and FL torques increase with applied voltage and while the AD torque changes sign with mz, the FL torque remains the same sign, as expected from the formulae above.

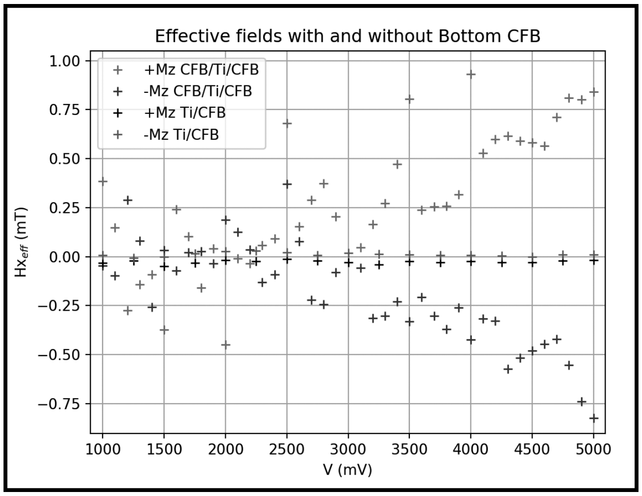

Figure 2: Anti-damping effective fields comparison with and without the CoFeB spin source layer. The effective field changes sign with the magnetization ofthe readout magnet (blue and red points), with both plots showing some voltage dependence, in contrast with the sample without the bottom CoFeB layer (black and green points). (See pages vi-vii for full color version.)

Conclusion and Future Steps:

We have measured effective fields induced when a longitudinal current is applied through the ferromagnet CoFeB, supporting the theory that AHE in ferromagnets could lead to spin torque transfer via a spin polarized current. However, we have yet to confirm that this spin transfer torque does indeed have the same spin polarisation as the source magnet. This can be verified by sweeping the external field within the x-y plane and measuring the corresponding angular dependence of the spin torque driven oscillation of the upper readout magnet. In addition, other spin torque measurement techniques such as Spin torque ferromagnetic resonance, may be used to remove some of the thermal artifacts in the second harmonic measurement that may give an inaccurate effective field calculation.

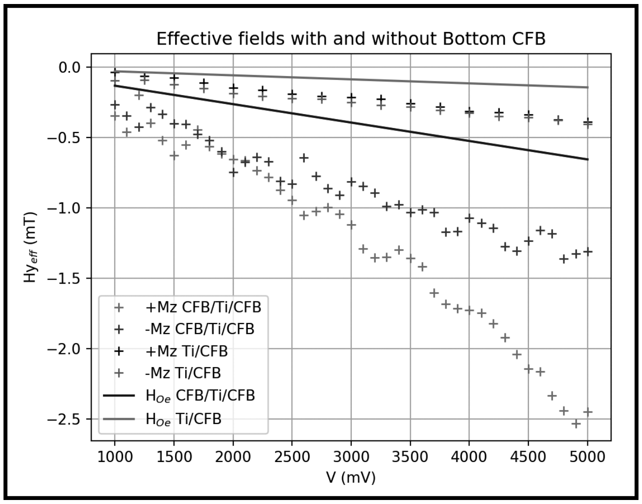

Figure 3: Field-like effective fields comparison with and without the CoFeB spin source layer. The effective field do not change sign with the magnetization of the readout magnet (blue and red points), with both plots showing some voltage dependence, in contrast with the sample without the bottom CoFeB layer (black and green points). The expected Oersted fields are plotted (blue and grey lines) to show that the measured effective fields are not solely a result of current induced Oersted fields. (See pages vi-vii for full color version.)

References:

[1] Seung Heon C. Baek, Vivek P. Amin, Young Wan Oh, Gyungchoon Go, Seung Jae Lee, Geun Hee Lee, Kab Jin Kim, M.D. Stiles, Byong Guk Park, and Kyung Jin Lee. Spin currents and spin-orbit torques in ferromagnetic trilayers. Nature Materials, 17(6):509-513, June 2018.

[2] Masamitsu Hayashi, Junyeon Kim, Michihiko Yamanouchi, and Hideo Ohno. Quantitative characterization of the spin-orbit torque using harmonic Hall voltage measurements. Physical Review B-Condensed Matter and Materials Physics, 89(14), April 2014.

[3] Kevin Garello, Ioan Mihai Miron, Can Onur Avci, Frank Freimuth, Yuriy Mokrousov, Stefan Blugel, Stephane Auffret, Olivier Boulle, Gilles Gaudin, and Pietro Gambardella. Symmetry and magnitude of spin-orbit torques in ferromagnetic heterostructures. Nature Nanotechnology, 8(8):587-593, 2013.