Spin Hall Magnetoresistance in W/CoFeB/MgO structure

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1. Introduction

Heavy metal/CoFeB/MgO heterosturctures with large perpendicular magnetic anisotropy(PMA) have been known to exhibit efficient current-induced magnetization switching by in-plane current injection[1]. The origin of magnetization switching by current is typically ascribed to the interfacial contribution of CoFeB/MgO and a large spin-orbit coupling(SOC) of a heavy metal underneath where both the Rashba[2] and the spin Hall effect[3] play an important role. We investigated magnetoresistacnce for such stack by utilizing tungsten(W) as a heavy metal layer because of the giant spin Hall effect of W due to large spin Hall angle compared to other heavy metal such as Ta and Pt[4].

2. Experiment

W and $Co_{32}Fe_{48}B$ are sequentially sputtered on an oxidized silicon substrate by DC magnetron sputtering at 3 mTorr. On top, MgO layer is deposited by RF magnetron sputtering at 10 mTorr. Finally, 1nm Ta layer was deposited as capping layer to prevent MgO layer from being over-oxidized. After the sputtering processes, subsequent thermal annealing procedure was followed at 250 °C for 30 min.

The magnetic properties of the films were characterized by Vibrating Sample Magnetometer(VSM). For electrical measurement, 5µm Hall bar structure was patterned by the photo-lithography and etched by the ion milling. Subsequently, Ru top electrode was fabricated by sputtering and lift-off method. The anomalous Hall resistance(AHR) and the anisotropic magnetoresistance(AMR) were measured simultaneously by injecting ac current under in-plane magnetic fields tilted a few degree out of film plane(Fig. 2a).

3. Result and Discussion

First, a considerable PMA(~0.2 erg/cm^2) was achieved in W(5)/CoFeB(0.8, 1.0, 1.2, 1.4)/MgO(1.6) structure by VSM(Fig. 1a); numbers in the parenthesis have nanometer unit. Such PMA is sufficient for high thermal stability and low critical current for magnetization switching[5].

For the sample with 1.2nm CoFeB thickness, the AHR was measured under in-plane magnetic fields in the direction of both x and y(Fig. 2b). However, the AMR was measured in the samples only under the magnetic field along y direction(Fig. 2c). Recently, this phenomenon, called spin Hall magnetoresistance(SMR), has been reported in thin films using YIG as ferromagnetic layer[6][7]. We measured much lager SMR for CoFeB than previous studies for YIG.

To clarify the results, W(5)/CoFeB(3.0)/MgO(1.6) sample with in-plane magnetic anisotropy along x direction was prepared(Fig. 2d). The planar Hall resistance(PHR) was measured due to in-plane magnetization(Fig. 2e), and SMR was also observed(Fig. 2f).

The same measurements were done for other samples possessing the PMA, and similar results were obtained(Fig. 3).

4. Conclusion

Effective magnetic fields induced by in-plane current injection in heavy metal/CoFeB/MgO heterostructures, causing current-induced magnetization switching or domain wall motion mostly, originate from the spin-Hall and the Rashba effect. Since the symmetry of effective fields arising from those two effects is the same, decoupling of each contribution is difficult. By employing tungsten as a bottom layer in such heterostructures, the contribution of spin Hall effect can be differentiated due to large spin Hall angle of tungsten.

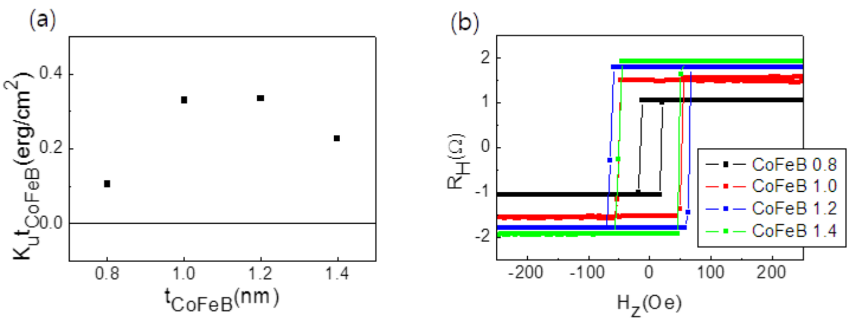

Fig 1. Characterization of magnetic properties.

(a) Perpendicular magnetic anisotropy energy, (b) Anomalous Hall resistance under magnetic field perpendicular to the film in W(5)/CoFeB(t)/MgO(1.6). t=0.8, 1.0, 1.2, 1.4nm.

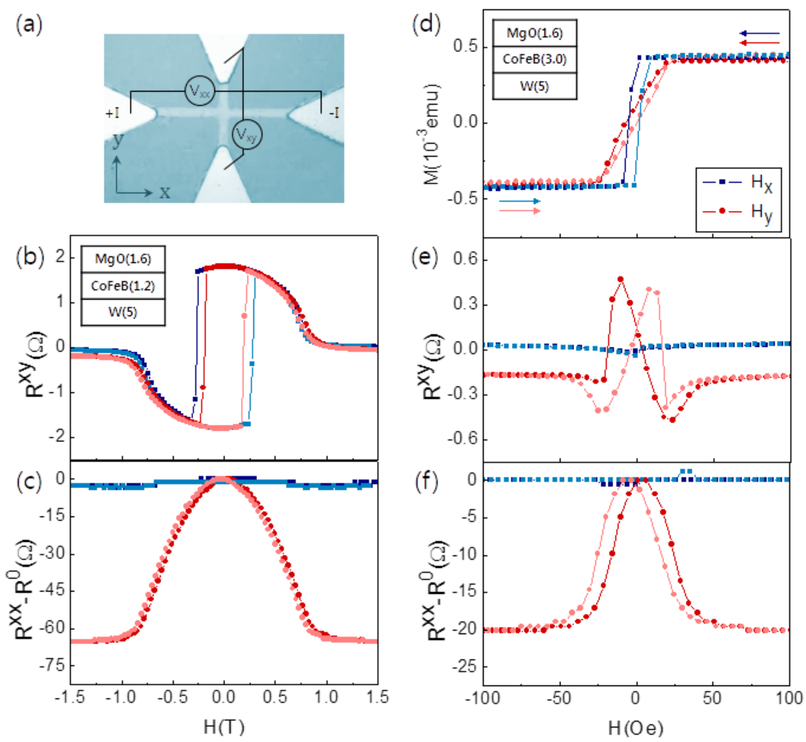

Fig 2. Device schematic and magnetoresistance measurment.

(a) Hall bar geometry. (b) Anomalous Hall resistance and (c) spin Hall magnetoresistance under in-plane magnetic fields along x or y direction for W(5)/CoFeB(1.2)/MgO(1.6) with PMA. (d) VSM measurement, (e) anomalous Hall resistance and (f) spin Hall magnetoresistance under in-plane magnetic fields along x or y direction for W(5)/CoFeB(3.0)/MgO(1.6) with in-plane anisotropy.

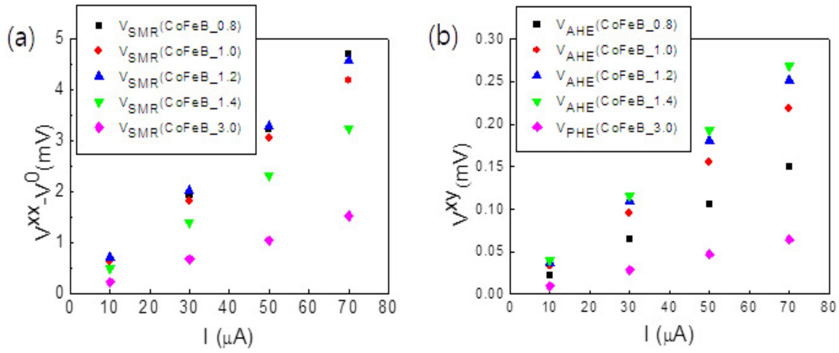

Fig 3. Magnetoresistacne measurment for various ferromagnetic layer thicknesses and current levels.
(a) Spin Hall voltage under in-plane magnetic field along y direction.
(b) Anomalous or planar Hall voltage under in-plane magnetic field along y direction.

5. Refernce

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