Dependence of Current-Induced Effective Rashba Field and Perpendicular Magnetic Anisotropy on Thickness of Ferromagnetic Layer

K.-S. Lee[1,2]*, B. C. Min[1], W. S. Kim[2], J. H. Lee[1], K. J. Lee[2], K.-H. Shin[1]
[1] Spin Device Research Center, Korea Institute Science and Technology, Seoul, 136-791, Korea
[2] Departments of Materials Science and Engineering, Korea University, Seoul 136-713, Korea

I. Introduction

Manipulation of local magnetization by means of electric currents has attracted considerable interest due to its rich physics and potential applications for a new class of spintronic devices. It was theoretically proposed that Rashba-type spin-orbit coupling (SOC) caused by inversion symmetry breaking yields a new type of current-induced effective magnetic field [1], i.e. Rashba field of which direction is perpendicular to both directions of current-flow and inversion symmetry breaking. The existence of this Rashba field in the structure consisting of non-magnetic metal | ferromagnetic metal | oxide was recently confirmed by an experiment [2].

Rashba SOC is caused by built-in electric field at the interface of two materials. In metallic systems, this electric field is probably confined at the interface due to a number of free electrons. In other words, the current-induced spin torque caused by Rashba SOC would be a surface torque. If this is correct, its magnitude at a given current density is expected to be inversely proportional to the thickness of metallic ferromagnet. On the other hand, it is well known that the interface between a ferromagnetic metal and a non-magnetic layer can provide a sizable perpendicular magnetic anisotropy, which is also caused by the interfacial SOC [3]. This interfacial anisotropy can find an important application for high-density perpendicular magnetic random access memory [4].

Because both Rashba field and interfacial perpendicular anisotropy are caused by the SOC probably restricted at the interface, these two phenomena could be closely related with each other. However, the detailed understanding of their correlation is left unaddressed. To address this issue, we experimentally investigated the dependence of Rashba field and perpendicular magnetic anisotropy on the thickness of ferromagnetic layer in this work.

2. Experimental

Experiments were carried out on Pt (3 nm) | Co (tConm)|MgO (2nm) deposited on a thermally oxidized Si wafer. The Co layer thickness, tCo was varied from 0.6nm to 1.2nm with a step of 0.1nm. Thickness-dependent change in the perpendicular magnetic anisotropy was investigated using the GST (Generalized Sucksmith-Thompson) method [5], which allows us to determine anisotropy constants, K1 and K2 values. We adopted the method proposed in Ref.[6] to investigate effect of the ferro magnetic film thickness(tCo) on the Rashba field(HRa).

3. Result and Discussion

Fig. 1(a) shows the results obtained from the GST method for three samples which show clear perpendicular magnetic anisotropy. Fig. 2(b) shows Rashba field versus applied current density for the three samples. The Rashba field is linearly dependent on the current density as predicted by theory [1]. The results of thickness-dependent perpendicular magnetic anisotropy and Rashba field are summarized in Fig. 2. The Rashba field was obtained at the current density of 106A/cm2. The product of perpendicular anisotropy (=K1+K2) and tCo is about 1.65±0.07 erg/cm^2. This value of (K1+K2)*tCo obtained from our samples (Pt|Co|MgO) is similar to that of Pt|Co|AlOx[2] but much smaller than that of Ta|CoFeB|MgO[4]. It should be noted that (K1+K2)*tCo is almost independent of tCo, indicating that it originates from the interfacial anisotropy. However, the product of Rashba field and tCo significantly decreases within creasing tCo. It implies that the current-induced spin torque caused by Rashba SOC is not simply a surface torque, which is inconsistent with theoretical prediction. We speculate that it would be related to the length scale of charge or spin transport, such as mean-free path and spin diffusion length. To be more conclusive, measurements of HR ain more wide ranges of tCo is inprogress. Another interesting point in our experimental results is that HRa of Pt|Co|MgO structure is about 1.2kOe per108A/cm2, which is 8 times smaller than that determined from the thermally assistive nucleation of domain walls in Pt|Co|AlOx structure[2] and 2.4 times smaller than that determined from the same method used in our experiment in Pt|Co|AlOx structure[6].

4. Conclusion

Effects of Co layer thickness on perpendicular anisotropy and Rashba field were experimentally investigated. We found that the perpendicular anisotropy in Pt|Co|MgO structure is the interfacial anisotropy as well known, whereas the Rashba field cannot be simply described by a surface current-induced spin torque. We also found that the Rashba field of Pt|Co|MgO structure is smaller than that of Pt|Co|AlOx, implying that it would be possible to find a new material system having a more significant Rashba field in metallic ferro-magnets.

5. References

[1] A. Manchon and S. Zhang, Phy. Rev. B 78, 212405 (2008) ; Phys. Rev. B 79, 094422 (2009).

[2] I. M. Miron et al., NatureMater. 9, 230 (2010).

[3] S. Monso et al., Appl. Phys. Lett. 80, 4157 (2002).

[4] S. Ikeda et al., Nature Mater. 9, 721 (2010).

[5] S. Okamoto et al., Phys. Rev. B 66,24413 (2002).

[6] U. H. Pi etal.,Appl .Phys. Lett. 97, 162507 (2010).