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The Interfacial Dzyaloshinskii-Moriya Interaction on Pt/Co/AlO_x multilayer with Ta Buffer Layer

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Abstract

Here, we systematically investigate the interfacial Dzyaloshinskii-Moriya interaction (iDMI) on a Pt/Co/AlO_x multilayer structure by performing Brillouin light scattering (BLS). Especially, Ta buffer layer can enhance the iDMI due to the improved interface between Pt/Co. From the systematic BLS measurements, we observe that the surface anisotropy energy (k_s) and the saturation magnetization (M_s) are significantly improved by the Ta buffer layer. Therefore, the perpendicular magnetic anisotropy (PMA) and the iDMI energy density are also enhanced. Moreover, we obtain the inverse proportionality of the iDMI energy density as a function of tco-1. This fact directly indicates that our measured DMI energy density is purely originated from the interface.

1. Introduction

The Dzyaloshinskii-Moriya interaction (DMI), which has additional anisotropic exchange term [1] has been strongly re-illuminated and experimentally demonstrated because of its tremendous scientific worthies and technical potentials to great prospective spintronic devices based on spin-orbit torque. Recently, there are substantial experiments, which clearly reported the existence of the DM interaction such as the current-induced chiral DW motion [2][3], the field driven DW expansion [4] and DW asymmetric nucleation due to the DMI effect [5] by using Kerr microscopy. However, for the magnetic field and electric current driven DW dynamics measurement cases, their measurements are definitely linked to the perpendicular magnetic anisotropy (PMA). Thus, a radically different approach to measure the iDMI energy density independent to other material parameters is strongly recommended. In this study, we demonstrate PMA energy and the interfacial DMI energy densities on Pt/Co/AlO_x with Ta buffer layer by employing Brillouin light scattering (BLS) measurement which directly can observe existence of the iDM interaction.

2. General Instructions

The sample is deposited on SiO_2 substrate with Ta(4 nm)/Pt(4 nm)/Co(t)/AlO_x(2 nm) by dc-magnetron sputtering and Co layer is wedged type in the range of 1.2~1.8 nm. The magnetic properties of the sample are obtained by BLS with a Sandercock (3+3)-type Fabry-Pérot interferometer. The light source is a single frequency 532 nm a DPSS laser with 300 mW output power. Magnetic field of up to 0.98 T is applied parallel to the film plane and perpendicular to the scattering plane. [6][7] Figure 1 shows the BLS spectrum with a magnetic field H_{ext} = 0.79 T at t_{Co}=1.35 nm. In order to identify the frequency difference (Δf) between Stokes and anti-Stokes, the mirrored curve (Red dots) is overlapped in the spectrum. As shown in Fig. 1, a clear Δf = 2.56 GHz is observed.

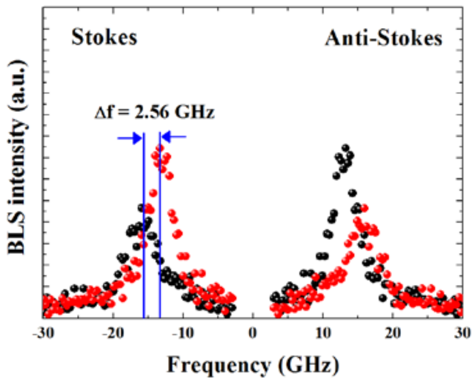

Fig. 1 The BLS spectrum (red spheres are the mirrored image) with H=0.79 T and incident angle θ = 45°

The dependence of spin waves on the applied field has been used to obtain the surface anisotropy energy (Ks) and the saturation magnetization (Ms) with following equations : [8]

$$\left(\frac{\omega}{\gamma}\right)^2 = H\left(H + \left[4\pi M_s\right]_{eff}\right) \quad (1)$$

$$\left(4\pi M_{eff}\right) = 4\pi M_s - \frac{4k_s}{M_s}\frac{1}{t}\ , \quad (2)$$

where, γ is the gyromagnetic ratio (18.47 *GHz*), k_s is the perpendicular uniaxial anisotropy constant, M_s is the saturation magnetization, respectively.

To deduce the magnetic constants from the BLS measurements, we plot the anisotropy energy density as a function of t_{Co} ($K_{eff}\times t_{Co}$ vs. t_{Co}) using eq. (3). [9]

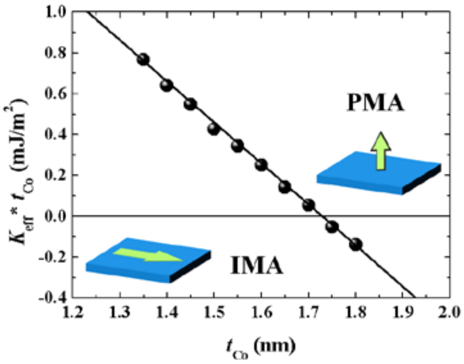

Fig. 2 The $K_{eff}\times t_{Co}$ vs. t_{Co} plot with a linear fitting as the k_s and M_s value from the slope and y-axis crossing. Above t_{Co} > 1.73 nm, the effective anisotropy becomes negative, which means the easy axis of the sample is in-plane.

$$K_{eff} = 2\pi M_s^2 - \frac{2k_s}{t} \qquad (3)$$

As shown Fig. 2, we obtain a slope and y-cross section, which directly corresponds to the volume anisotropy and the surface anisotropy, respectively. the effective uniaxial anisotropy energy K_{eff} decreases with increasing t_{Co}. When the sign changes at t_{Co} = 1.73 nm, this fact reflects that the direction of the magnetic-easy-axis is varied from perpendicular to in-plane. The obtained k_s value is 1.74 mJ/m^2 and M_s is 1790 kA/m. We now highlight that the measured M_s value of the Ta buffered asymmetric structure is almost close to the bulk value of Co.

In order to determine the interfacial Dzyaloshinskii-Moriya (iDM) interaction, we measure the frequency difference (Δf) as a function of magnetic field. The correlation between the frequency difference and the iDMI energy density is expressed as below: [10]

$$\Delta f = \frac{2\gamma D}{\pi M_S} k_x , \qquad (4)$$

where M_s and D is the saturation magnetization and the iDM energy density respectively. The spin wave vector is fixed at k_x = 0.0167 nm^{-1} (θ = 45°) and we obtain the maximum iDM energy density D = 1.66 mJ/m^2 at 1.35-nm-thick sample from the frequency difference as shown in Fig. 3.

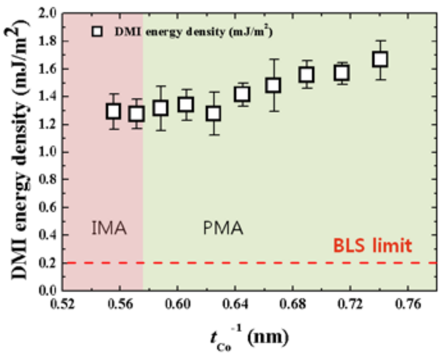

Fig. 3 The iDM energy density (Black squares) as a function of t_{Co}^{-1}.

The measured iDM energy densities from Δf in each Co thickness is drawn in Fig. 3. As the thickness decreases, the iDM energy density has an inverse proportionality to increase Co thicknesses. In this point of view, we confirm that the iDM interaction is originally generated at the interface between Pt/Co and this interface effect is independent to other material parameters such as the perpendicular magnetic anisotropy.

3. Conclusions

In conclusion, using a Brillouin light scattering technique, we have investigated the surface perpendicular anisotropy and the IDM interaction on an inversion symmetry broken structure. From the BLS data, we confirm that the surface anisotropy k_s of 1.74 mJ/m^2 and IDM interaction is a pure interfacial effect with maximum energy density of 1.66 mJ/m^2 for Co with Pt underlayer. Comparing with our previous study [11], we obtain that the surface anisotropy and iDM energy densities are larger than previous one. This fact is that Ta buffer layer exerts to improve perpendicular magnetic anisotropy (PMA) and the iDMI energy density.

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Appendix