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Systematic investigation of precessional magnetization damping for Ta/CoFeB/MgO thin films with perpendicular magnetic anisotropy

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Abstract

Magnetization precession for CoFeB thin films with perpendicular magnetic anisotropy was detected using all-optical pump-probe method. Gilbert damping constant (α) was evaluated from life-time of magnetization precession. α and/or effective α values were systematically investigated for Ta/CoFeB/MgO samples with different stacking structure, annealing temperature, and CoFeB thickness.

1. Introduction

CoFeB/MgO/CoFeB magnetic tunnel junction (MTJ) has much attractive property for Spin-Transfer-Torque Magnetoresistive Random Access Memory (STT-MRAM). CoFeB/MgO bilayer exhibits perpendicular magnetic anisotropy (PMA), which is caused by interfacial perpendicular magnetic anisotropy. CoFeB/MgO/CoFeB MTJ also shows a large tunnel magneto resistance ratio over 120%[1]. On the other hand, Gilbert damping constant (α) is an important factor for reducing power consumption. PMA materials such as CoPt, FePt have a tendency to show large α. α value for CoFeB thin films with PMA shows 0.027[1]. This value is relatively smaller than those of other PMA materials. However, there are few reports about α for PMA CoFeB. We report that α value was evaluated using all-optical pump-probe method and systematically investigated with different stacking structure, annealing temperature, and CoFeB thickness.

2. Experimental Methods

Samples were fabricated using ultrahigh vacuum magnetron sputtering method. Stacking structures were A: Si/SiO_2 substrate/Ta (5)/MgO (2.2)/$Co_{20}Fe_{60}B_{20}$ (1.2)/Ta (1), B: Si/SiO_2 substrate/Ta (5)/$Co_{20}Fe_{60}B_{20}$ (t_{CoFeB})/MgO (2)/Al (2) (thickness in nm). Samples were annealed with different annealing temperature(T_a), 250, 300, and 350℃. For comparison, Si/SiO_2 substrate/Ta (5)/$Co_{20}Fe_{60}B_{20}$ (t_{CoFeB})/Ta (5) was also fabricated. Magnetic property of the films was measured by vibrating sample magnetometer and superconducting quantum interface device. Time-resolve magneto-optical Kerr effect (TRMOKE) was performed to detect magnetization dynamics using all-optical pump-probe method. Pulse width, frequency, and laser wavelength are ~100 fs, 1 kHz, 800 nm, respectively. Modulation frequency of the pump beam was 360 Hz. Maximum magnetic field is 10 kOe using an electromagnet in the optical system.

3. Experimental Results

Figure 1 shows the typical TRMOKE signals with different field angle (θ_H) which is defined as angle between film normal and applied field direction. Ultrafast demagnetization near zero delay time is caused by pulse heating induced by the incident pump beam. Reduction of demagnetizing field and PMA field changes the effective field direction and magnetization precession can be excited. TRMOKE signals can be fitted as following function

$$A + B\exp(-\nu t) + Amp.\exp(-t/\tau)\sin(2\pi f t + \phi_0) \qquad (1)$$

where, A is offset value, B and ν are magnitude of demagnetization and recovery rate of demagnetization, respectively. $Amp.$ f, τ, ϕ_0 are precession amplitude, frequency, life-time, and initial phase, respectively. Figure 2(a) and (b) show field angle dependence (θ_H) of precession fre-

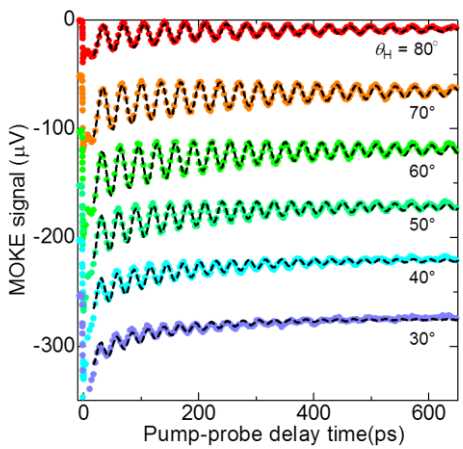

Fig. 1 Typical TRMOKE signals with different field angle(θ_H: between film normal and applied field direction) at fixed applied field about 10 kOe for Ta/CoFeB(1.2)/MgO PMA films.

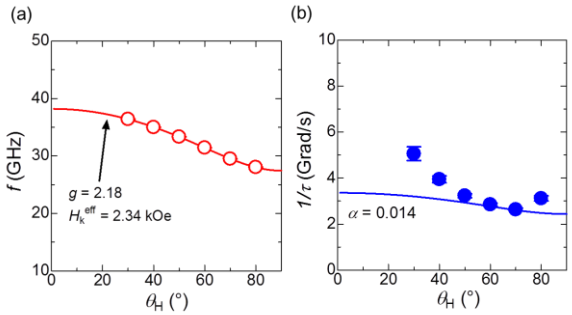

Fig. 2 (a) Precession frequency (f) obtained from fitting as a function of field angle (θ_H). (b) Inverse of life-time ($1/\tau$) obtained from fitting as a function of θ_H. Thin solid lines are data calculated using LLG equation.

quency (f) and inverse of life-time ($1/\tau$), respectively. Thin solid lines in Fig. 2 are data calculated using LLG equation. f can be fitted by calculation and PMA field can be obtained. However, $1/\tau$ obtained from the experimental data cannot be fitted to the calculation. This may be caused by magnetic inhomogeneity in the sample, such as so-called anisotropy distribution, which can apparently decrease life-time of magnetization precession. Here, α value cannot be evaluated from the above analysis. Thus, effective damping constant (α_{eff}) was obtained from f and $1/\tau$ as follows

$$\alpha_{eff} = \frac{1}{2\pi f \tau} \qquad (2)$$

α_{eff} are plotted as a function of θ_H for the case of thick CoFeB films which show in-plane anisotropy as shown in Fig. 3(a). Since observed α_{eff} was isotropic, these values for in-plane anisotropy CoFeB films are may be close to α. Figure 3(b) shows the case of thin CoFeB films which shows PMA. Anisotropic α_{eff} was observed. This behavior indicates that these values for PMA CoFeB films include effect of anisotropy distribution. Therefore, minimum of α_{eff} (α_{eff}^{min}) was evaluated as an upper bound of α.

Figure 4 shows α or α_{eff}^{min} plotted as a function of inverse of CoFeB thickness ($1/t_{CoFeB}$) for Ta/CoFeB/MgO and Ta/CoFeB/Ta films. α which was increased linearly with $1/t_{CoFeB}$ from balk value was observed for in-plane anisotropy CoFeB films. In the case that thickness of ferromagnetic layer is small, α is enhanced by spin-pumping effect. It was also observed that the slope in Ta/CoFeB/Ta films was larger than that in Ta/CoFeB/MgO films. This results indicate that Ta interface mainly increased α, which is scaled by spin mixing conductance. At $1/t_{CoFeB} > 0.8$ nm^{-1} in Fig. 4, large enhancement of α_{eff}^{min} for Ta/CoFeB/MgO films was observed. Since effect of extrinsic relaxation mechanism such as anisotropy dispersion and two-magnon scattering may increase with decreasing thickness. It is considered that there is a large deviation between α and α_{eff}^{min}. High applied field measurement is necessary to evaluate α, because extrinsic relaxation is suppressed by high external field.

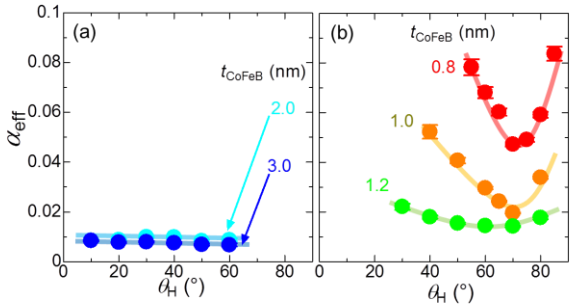

Fig. 3 Field angle (θ_H) dependence of α_{eff} for (a) in-plane anisotropy Ta/CoFeB/MgO films and (b) PMA Ta/CoFeB/MgO films with $T_a = 250$℃.

4. Conclusions

Magnetization precession and damping for Ta/CoFeB/MgO thin films were systematically investigated. It was found that the increase of α for Ta/CoFeB/MgO films is due to Ta interface. At thin CoFeB thickness region, which shows PMA, large enhancement of α_{eff}^{min} was observed. This enhancement may be due to extrinsic relaxation, because α_{eff} shows anisotropic for PMA CoFeB films.

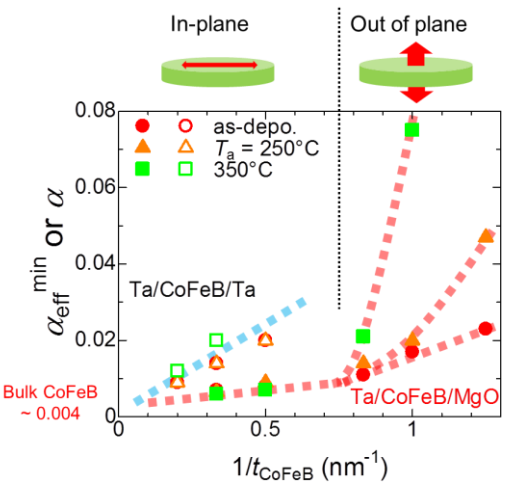

Fig. 4 α or α_{eff}^{min} are plotted as a function of inverse of CoFeB thickness for Ta/CoFeB/Ta and Ta/CoFeB/MgO films. In the case of Ta/CoFeB/MgO samples, films show PMA at the region of $1/t_{CoFeB} > 0.8$ nm

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