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# Optical Study on Fast Magnetization Dynamics in Perpendicularly Magnetized Pt/Co/Pt Trilayer Films

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## 1. Introduction

Several groups had reported low critical current density in spin-transfer torque switching in CPP-GMR or TMR devices with perpendicularly magnetized electrodes [1,2]. These devices are expected to be applied to gigabits non-volatile magnetic random access memory, the so-called Spin-RAM, in which it is required that the critical current density is bellow $10^6$ A/cm$^2$. The critical current density is considered to be proportional to magnetic damping constant $\alpha$, which characterizes a time constant for damped magnetization precession in ferromagnets, thus it is significant to investigate magnetic damping for various perpendicularly magnetized films. Several magnetic alloys and multilayers show large perpendicular magnetic anisotropy (PMA) but there is few reports for magnetic damping in PMA materials. It is well known that $[Co/Pt]_N$ multilayer exhibits high-PMA and PMA depends on Co and Pt layer thickness and the number of layer $N$. Recently, the number of layer $N$ dependence of magnetic damping for $[Co/Pt]_N$ was investigated by optical method [3]. Magnetic damping constant in Pt/Co/Pt trilayer films has also been evaluated from domain wall motion [4]. In both cases, magnetic damping constant was significantly large and the $\alpha$ values ranged from 0.1 to 0.3. In this study, in order to understand deeply the mechanism and correlation between PMA and magnetic damping, we investigated Co layer thickness dependence of magnetic damping constant for Pt/Co/Pt perpendicularly magnetized films using all-optical pump-probe technique.

## 2. Experimental Method

The Pt/Co/Pt trilayer films were deposited on naturally oxidized Si substrate at room temperature using magnetron sputtering method. The Pt buffer and capping layer thicknesses were 5 and 2 nm, respectively, and Co layer thickness was varied from 4 to 0.5 nm. Structural analysis was performed by X-ray diffraction.

We measured all-optical time-resolved magneto-optical Kerr effect (TRMOKE) using a standard optical pump-probe set-up with Ti: sapphire laser combined with regenerative amplifier (wavelength of 800 nm, pulse width less than 120 fs). S-polarized probe light was almost normally incident on a film surface and time variation of magnetization was detected by polar magneto-optical Kerr effect (PMOKE). TRMOKE was measured with applying magnetic field of 4 kOe and the angle $\theta_H$ between applied magnetic field and direction normal to film was varied from 0° to 80°.

## 3. Experimental Results and discussion

In X-ray diffraction measurements for Pt/Co/Pt films, Pt (111) diffraction peak was observed for all films, so that films are considered to be (111)-textured polycrystalline. From static PMOKE measurements, it was confirmed that Pt/Co($d_{Co}$)/Pt films were magnetized perpendicularly at $d_{Co}$ < 1 nm. A typical PMOKE hysteresis loop at $d_{Co}$ = 0.8 nm is shown in Fig. 1(a), in which coercivity was 290 Oe and effective PMA field $H_{k,eff}$ was 2.1 kOe. Effective PMA field $H_{k,eff}$ was estimated from the data of angular variation of PMOKE and the $H_{k,eff}$ values were proportional to the inverse of Co layer thickness, which indicates that PMA in our Pt/Co/Pt films originates from the interfacial anisotropy.

Figure 1(b) shows the representative TRMOKE signals for a Pt/Co(0.8 nm)/Pt film. Magneto-optical (MO) signal decreases suddenly in sub-ps time regime and subsequently exhibits damped oscillation. The oscillation period and signal intensity are decreasing systematically with decreasing $\theta_H$ and these variations are consistent with the fact that an easy-axis is perpendicular to film plane, so that it is confirmed that these oscillation signals correspond to that for damped magnetization precession.The precession frequency $f$ and decay time $\tau$ for Pt/Co/Pt films were evaluated from the TRMOKE data by fitting the damped harmonic function superposed on a double-exponential decay. And then, the experimental data of $f$ *vs.* $\theta_H$ and $1/\tau$ *vs.* $\theta_H$ were fitted to those calculated using Landau-Lifshitz-Gilbert equation taken into account an effective PMA [5].

Figure 2 shows the evaluated magnetic damping constant $\alpha$ as a function of inverse of Co layer thickness $d_{Co}$. In the case that Co layer thickness is larger than 1 nm, the $\alpha$ value is proportional to $1/d_{Co}$ and its increment was comparable to that for Pt/$Ni_{80}Fe_{20}$/Pt films [5,6], while the slope of $\alpha$ *vs.* $1/d_{Co}$ changes at $d_{Co}$=1 nm and becomes larger significantly at $d_{Co}$ < 1 nm. It had been considered that enhanced magnetic damping in thin ferromagnetic film in contact with Pt layer can be caused by spin pumping mechanism [7]. However, the rapid increase of $\alpha$ at $d_{Co}$ < 1 nm seems to be due to a different mechanism. Magnetic easy

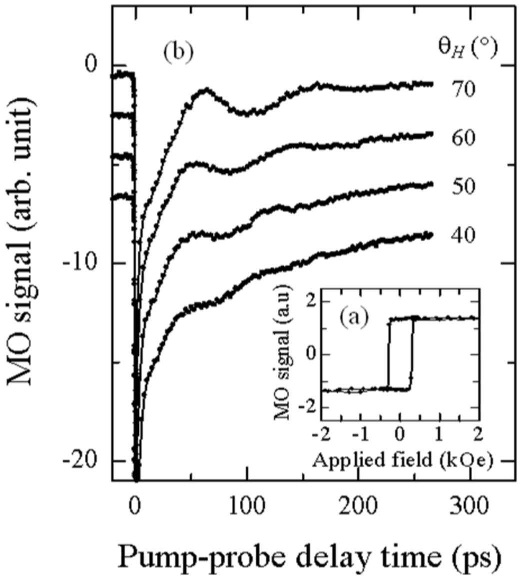


Fig. 1 (a) Polar Magneto-optical Kerr effect (PMOKE) loop for a Pt/Co(0.8 nm)/Pt film with a magnetic field applied along the film normal, (b) Time resolved MOKE signals for the Pt/Co(0.8 nm)/Pt film with various angle $\theta_H$ between applied magnetic field and direction normal to film.

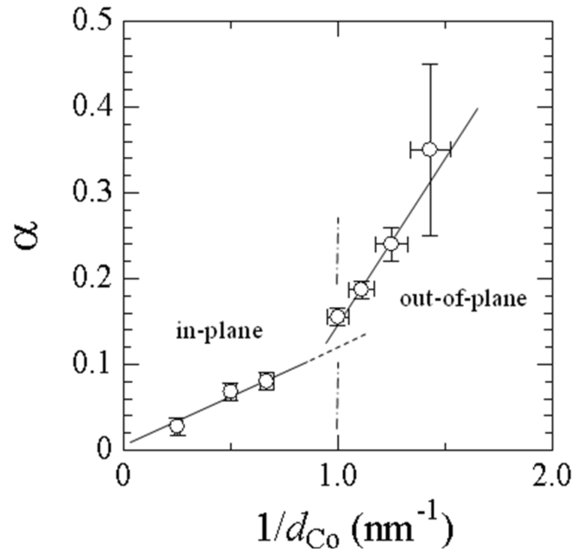


Fig. 2 Magnetic damping constant $\alpha$ for Pt/Co($d_{Co}$)/Pt films as a function of the inverse of Co layer thickness $d_{Co}$. Solid and broken lines are visual guides.

axis switched from in-plane to out-of-plane around $d_{Co}$ = 1 nm in our Pt/Co/Pt films, so that the enhanced magnetic damping might be related to spin reorientation transition which is driven by strong PMA induced by an enhanced orbital moment due to Co3d–Pt5d hybridization across interfaces. Therefore, it is likely that the enhanced magnetic damping in perpendicularly magnetized Pt/Co/Pt films originate from the enhanced spin-orbit torque across interfaces through Co3d–Pt5d hybridization [8].

Magnetic damping constant estimated from the observation of domain wall motion in Pt/Co(0.5-0.8 nm)/Pt films is around 0.3 [4], which is very close to our value. On the other hand, damping constant for $[Co(0.4 nm)/Pt(0.8 nm)]_2$ multilayer was ~0.1 [3], which is rather smaller than ours. It will be further subject to study in detail on the effect of the number of layer *N* and Pt layer thickness on magnetic damping constant for $[Co/Pt]_N$ multilayer.

## 4. Conclusions

Fast magnetization precession and damping for the perpendicularly magnetized Pt/Co/Pt films have been investigated using optical pump-probe method. The effective PMA field was linearly dependent of $1/d_{Co}$, while magnetic damping constant increased rapidly below $d_{Co}$ = 1 nm, at which magnetic easy axis switched from in-plane to out-of-plane.

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