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Damping constant of Co/Pt multilayer thin-film media

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ABSTRACT

Gilbert's damping constants, α, of Co(t_{Co})/Pt (1.4 nm) multilayer thin films are investigated by Q-band FMR analysis. α is calculated from the resonance width of the FMR spectrum. With decreasing t_{Co}, the α value decreases from 0.034 ($t_{Co} = 8.7$ nm) to 0.023 ($t_{Co} = 1.8$ nm), and then increases to 0.037 ($t_{Co} = 1.0$ nm). The decrease of α with $t_{Co} > 1.8$ nm is probably due to the eddy current loss effects. The increase of α with $t_{Co} < 1.8$ nm would be caused by the increase of the distortion between the Co and the Pt layers at the interface. When the magnetic field direction was changed from $\theta = 90^\circ$ (parallel to the specimen) to $\theta = 0^\circ$ (perpendicular to the specimen), the α of all the specimens increased, and a sharp step in α was observed around $\theta = 40^\circ$, where the α has the maximum value.

1. Introduction

Fast magnetization reversal in the magnetic recording media is an important factor to realize in high-frequency magnetic recording [1]. The switching time strongly depends on Gilbert's damping constant α [2]. In our previous work, the α values of the Co–Cr–Ta and the Co–Cr–Pt thin films for the recording layer were estimated to be in a range from 0.01 to 0.05, by employing ferromagnetic resonance (FMR) analyses at a frequency of 35 GHz (Q-band) [3,4].

Co/Pt and Co/Pd multilayer thin films have been developed as magneto-optical recording media [5,6]. Recently, these multilayer films have been investigated for high areal density magnetic recording media, patterned media, and heat-assisted magnetic recording media, because of their large perpendicular magnetic anisotropy energy. However, the α values of the multilayer thin films have not been found.

In the present study, we investigate damping constants of Co/Pt multilayer thin films by employing a Q-band FMR analysis.

2. Experimental procedure

2.1. Sample preparation

Co/Pt multilayer thin films were deposited at room temperature at an Ar pressure of 8 mTorr by using an rf magnetron sputtering system. The deposition rates of the Co and the Pt layers were 0.5 and 0.8 nm/min, respectively. The film structure of the specimens was [Co(t_{Co})/Pt (1.4 nm)]$_{12}$/Pt underlayer (50 nm)/Ti seedlayer (10 nm)/glass substrate. The Co layer thickness, t_{Co}, was changed from 0.3 to 8.7 nm.

The perpendicular magnetic anisotropy of the specimens was measured by using the 45° magneto-torque method [7] in the maximum applied magnetic field of 18 kOe. The magnetization curves were measured by using a vibrating sample magnetometer. The film structure was investigated by X-ray diffraction analysis.

2.2. Ferromagnetic resonance analysis

Fig. 1 shows the coordinate system used for the FMR analysis. A uniaxial easy axis in a perpendicular magnetic anisotropy thin film is parallel to the z-axis. The direction of a static external magnetic field $\boldsymbol{H}$ is changed in the y–z plane. The small oscillating magnetic field $\boldsymbol{h}$ of the microwave is applied parallel to the x-axis. When the external field is applied as shown in Fig. 1, the total magnetic free energy per unit volume of the film, E, is given by

$$E = -M_s H(\sin\theta_M \sin\theta_H \sin\phi_M + \cos\theta_M \cos\theta_H) + 2\pi M_s^2 \cos^2\theta_M + K_p \sin^2\theta_M, \quad (1)$$

where θ_M and ϕ_M are the polar and the azimuthal equilibrium angles of the magnetization vector $\boldsymbol{M}$, respectively; M_s is the saturation magnetization, or the amplitude of $\boldsymbol{M}$; H is the external static magnetic field; θ_H and ϕ_H are the polar and the azimuthal angles of the applied field direction, respectively; and K_p is the perpendicular anisotropy constant. The energy includes the

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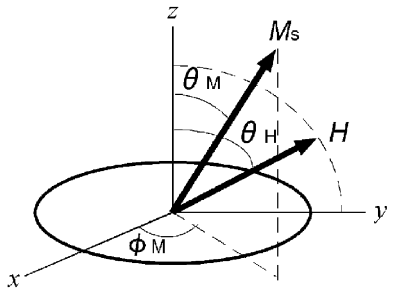

Fig. 1. Schematic picture of the coordinate system used in FMR analysis.

Zeeman energy and the perpendicular anisotropy as well as the demagnetizing contributions.

The FMR condition is generally expressed in terms of the second derivates of the free energy as [8]

$$\left(\frac{2\pi f_r}{\gamma}\right)^2 = \frac{1}{M_s^2 \sin^2\theta_M}\left[\frac{\partial^2 E}{\partial\theta_M^2}\frac{\partial^2 E}{\partial\phi_M^2} - \left(\frac{\partial^2 E}{\partial\theta_M \partial\phi_M}\right)^2\right], \quad (2)$$

where f_r is the resonance frequency and $\gamma(=ge/2m_ec)$ is the gyromagnetic ratio. The resonance condition of the system shown in Fig. 1 can be obtained by using Eqs. (1) and (2). When the resonance field is larger than the saturation field of the specimen, namely $\theta_M = \theta_H$ and $\phi_M = \phi_H$, the resonance condition is given by the following equation:

$$\left(\frac{2\pi f_r}{\gamma}\right)^2 = \left[H_r - \left(4\pi M_s - \frac{2K_p}{M_s}\right)\cos^2\theta\right] \times \left[H_r - \left(4\pi M_s - \frac{2K_p}{M_s}\right)\cos 2\theta\right], \quad (3)$$

where H_r is the resonance field and $\theta = \theta_M = \theta_H$. The resonance field can be determined by the resonance condition given by Eq. (3).

The resonance width ΔH (or the peak–peak line width) in the FMR spectrum can be expressed by using Kittel's theory [9] as

$$\Delta H = \frac{4\alpha\,\pi f_r}{\gamma}. \quad (4)$$

In Eq. (4), the ΔH and the f_r values are experimentally determined from the FMR spectrum. Hence, the α value can be calculated from Eq. (4). The ΔH becomes broader because of the distribution of the H_r. The H_r distribution would be due to magnetic inhomogeneities in a film [10,11], such as distribution of magnetic easy axis directions, fluctuation of magnitude of the saturation magnetizations, and fluctuation of film thickness. The α given by Eq. (4) would be affected by the magnetic inhomogeneities.

The magnetic characteristics of the Co/Pt multilayer thin films are strongly correspondent with the periodic magnetic/nonmagnetic multilayer structures and the interfacial effect between the Co and the Pt. For instance, the macroscopic origin of multilayer perpendicular magnetic anisotropy has been explained mainly by the interfacial anisotropy [12–14], while the microscopic origin of the perpendicular anisotropy was found to be an enhancement of the orbital moment which changes the direction of the spin moment to normal through spin–orbit coupling [15–17]. The spin damping of the Co in the Co/Pt films would also depend on the periodic multilayer film structure. The α given by Eq. (4) would include the multilayer structure effects.

The recording performances of the Co/Pt magnetic recording media are usually discussed by using the magnetic characteristics of the media estimated with the assumption that the Co/Pt recording layers are regarded as homogenous single layers. The main purpose of this work is to compare the damping constants of the Co/Pt recording layers with those of the conventional Co–Cr-based media, not to investigate the origin of the spin damping in the multilayers. Thus, in this work, the Co/Pt multilayers were treated as homogenous single layers for the analysis of the damping constants.

A standard Q-band microwave spectrometer operated at a frequency of 35 GHz (Q-band) was used for the FMR measurements. The static magnetic field was applied between 0 and 20 kOe, and modulated at 100 kHz with a maximum modulation magnetic field of 1 Oe. The direction of the external magnetic field was changed out of plane.

3. Results and discussion

3.1. Co layer thickness dependence of H_r and α

Fig. 2 shows the FMR spectrum of the Co/Pt multilayer thin film with a Co layer thickness of 1.0 nm. The direction of the external magnetic field was parallel to the film plane (that means $\theta = 90^\circ$), and a high-frequency magnetic field with $f_r = 35.1$ GHz was applied perpendicular to the static magnetic field direction. Only a single resonance peak is observed at a resonance field of $H_r = 9.72$ kOe. The ΔH was found to be 8.5×10^2 Oe.

The g factor of the Co/Pt multilayer specimens included in the γ value must be determined in order to calculate the α by Eq. (4). Since the H_r, the M_s, the K_p, the f_r, and the θ values are experimentally determined, the g value can be estimated from Eq. (3). The M_s value of the Co/Pt specimen with $t_{Co} = 1.0$ nm is determined by the VSM measurement to be 6.1×10^2 emu/cm^3, and the K_p value is determined by the torque measurement to be 1.1×10^6 erg/cm^3. The H_r, the f_r, and the θ values, as mentioned above, are determined from the FMR spectrum. The g value is calculated from Eq. (3) to be 2.2, which is similar to that of the bulk Co [18]. The α value of the Co/Pt specimen with $t_{Co} = 1.0$ nm is estimated to be 0.037 ± 0.004 from the ΔH value of 8.5×102 Oe by using Eq. (4). This α value is about two times larger than that of the 10 nm-thick Co single-crystal thin film [20].

The variations of the FMR spectra on applying the external field parallel to the film plane were measured for the Co/Pt specimens with the Co layer thickness ranging from 0.3 to 8.7 nm. A single magnetic resonance peak was observed for each specimen with the Co layer thickness more than 1.0 nm, although the specimens with the Co layer thickness less than 1.0 nm had no resonance peak in the FMR spectra. The α values are calculated from the ΔH values by using Eq. (4). Fig. 3 shows the dependence of H_r and α for the Co/Pt specimens on the magnetic layer thickness t_{Co}. The H_r of the specimens with t_{Co} more than 1.8 nm have almost

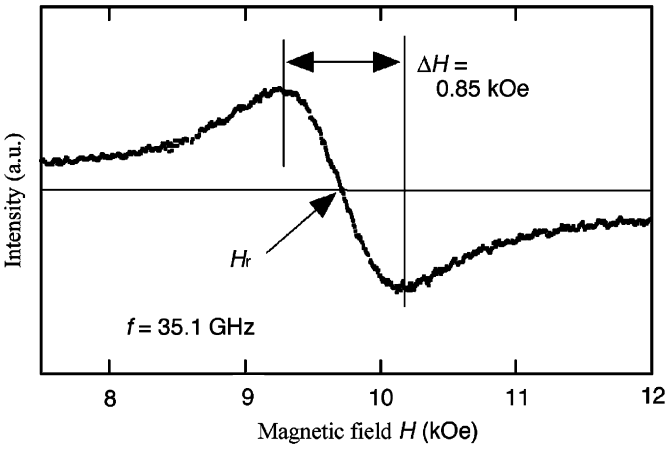

Fig. 2. FMR spectrum of a Co(1.0 nm)/Pt(1.4 nm) specimen.