Effective damping factor for CoPtCr–SiO₂ perpendicular magnetic recording medium with partially switched magnetic domains

S. Hinata^{*,**}, S. Saito^{**}, M. Takahashi^{**} and M. Sahashi^{**}

^{*} Research fellow of Japan Society for the Promotion of Science (PD)

^{**} Department of Electronic Engineering, Graduate School of Engineering, Tohoku University,
6-6-05, Aza-Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan

For the microwave assisted magnetic recording media design, effect of magnetization reversal and intergranular exchange coupling on effective damping factor (α_{eff}) was investigated by Q-band FMR for Co₈₄Pt₁₆Cr₁₀–8mol (SiO₂) granular media. Two kinds of media A and B, with small and large intergranular exchange coupling, were investigated. As a result, it was found that: 1) Magnitude of the normalized intergranular exchange coupling field (H_{ex}/H_k) was 0.2 and 0.35 for the medium A and B, respectively. 2) For the medium A, α_{eff} was significantly increased from 0.03 to 0.11 with decreasing normalized magnetization $|M|/M_s$ from 1 to 0.4. At the same time, for the medium B, α_{eff} was increased from 0.05 to just 0.07. 3) Origin of difference of α_{eff} increment is considered that difference of distribution and magnitude of the intergranular exchange coupling.

Key words: Effective damping constant, Ferromagnetic resonance, Co-based granular film, Q-band magnetic cavity method, Minor loop

1. Introduction

Recently, experimental results regarding Microwave Assisted Magnetic Recording (MAMR) for CoPt-based granular media have been reported [1–4]. From the view point of the media design for the MAMR, evaluation of the damping factor α is important because it corresponds to the precession of the magnetization under microwave irradiation. α for MAMR media should be adjusted at an optimum value [5] because a magnetization with too small or large α causes too long relaxation time or no precession under the microwave irradiation. In actual writing situation, effective value of α (α_{eff}) thought to be affected by dipole interaction and intergranular exchange coupling at the bottom of each magnetic grains, since each magnetic grain's magnetic isolation is generally not totally separated [6–7] (figure 1), and up- and downwardly magnetized domains are mixed in the medium to increase the homogeneity of dipole interaction field. However, there are few reports on such a relationship between α_{eff} and the magnetic domain state. In this research, α_{eff} was investigated under existence of the reversed domains for the media with different magnetic isolation of magnetic grains, by evaluating Q-band ferromagnetic resonance (FMR) linewidth using magnetic cavity method [8–10].

2. Experimental procedure

2.1 Film deposition

All the samples used in the present study were fabricated on glass substrates by a dc magnetron sputtering equipment (Canon–Anelva, C3010 P7–UHV) at room temperature. The film structure was C (7 nm)/Co₇₄Pt₁₆Cr₁₀–8 mol (SiO₂) (16 nm)/Ru (20 nm)/Pt (6 nm)/Ta (5 nm)/ substrate. Details of Ar gas pressure during Ru sputtering will be described later.

2.2 Evaluation of magnetic properties

Magnetic properties were measured by using a vibrating sample magnetometer (VSM), a magnetic polar Kerr system, and an FMR measurement system (Bruker, E-500). For evaluation of saturation magnetization M_s , volume of the nonmagnetic oxide boundary was counted in the volume of the film. During the FMR measurements, 34-GHz microwave (Q-band: fixed) were applied such that the a.c. magnetic field component were parallel to the film plane, and an d.c. external field was applied along the film normal. A lock-in technique using a 15-Oe amplitude modulation of the external field was employed to reduce the FMR signal noise. Thus, the obtained signal represents the derivative of FMR with respect to the external field. Anisotropy field H_k and g -factor were simultaneously derived from the FMR field ($H_{\text{DC}}^{\text{res}}$) under perpendicular and horizontal external field to the film plane [8–10]. The α_{eff} was evaluated by

$$\alpha_{\text{eff}} = \Delta H_{\text{DC}}^{\text{res}} \gamma / 2\omega, \quad (1)$$

where $\Delta H_{\text{DC}}^{\text{res}}$ is full width at half maximum of the integrated FMR signal which derived from $\sqrt{3} \times (H_{\text{DC}}^{\text{A}} - H_{\text{DC}}^{\text{B}})$. H_{A} and H_{B} are local minimum and maximum field of the differential form of the FMR signal, respectively.

Fig. 1 Schematic of the granular medium with (a) upwardly saturated state and (b) mix state of up- and downward magnetization.

In this study, broadening of the linewidth is treated as an increase of α_{eff} .

2.3 Evaluation of effective field under existence of reversed domain

Magnetic domain of the media was controlled by changing magnitude of a returning field (H_{ret}) in the minor loop. Relationship between remanent magnetization and H_{ret} was used for deriving the magnetization during FMR measurement [9–10]. Intergranular exchange coupling field H_{ex} was evaluated from the $H_{\text{DC}}^{\text{res}}$ as follows. Figure 2 shows model of FMR signals at various magnetization states. The outmost M - H loop is a full loop. Black resonance peaks correspond to upwardly magnetized high-switching field (H_{sw}) grains [9–10]. Kittel mode resonance, which is coherent resonance of the total magnetization, is determined by

$$\omega\gamma = H_{\text{DC}}^{\text{res}} + H_{\text{eff}} \quad [11]. \quad (2)$$

Where ω , γ , and H_{eff} denotes the microwave angular frequency, the gyromagnetic ratio of the grain and internal field which is resonating magnetic grain feels, respectively. Then H_{eff} is given by

$$H_{\text{eff}} = H_k - (4\pi M - N_z M_s) - N_z M_s - H_{\text{ex}} \quad (3)$$

$$= H_k - 4\pi M - H_{\text{ex}}. \quad (4)$$

Second and third terms on the right-hand side of eq. (3) denote the mean dipole interaction field, the self-demagnetization field, respectively [9–10]. N_z is the demagnetization factor of a grain for normal direction to the film plane. The dipole interaction field is approximated by subtracting the self-demagnetization field from the average demagnetizing field. Thus the second term on the right-hand side of eq. (4) represents the average demagnetization field of the film. $H_{\text{DC}}^{\text{res}}$ decreases with decreasing M due to reduction of the mean demagnetizing field $4\pi M$. When M is further decreased, another series of resonances can be observed (gray resonance peaks). These resonances correspond to downwardly magnetized low- H_{sw} grains [9–10] because it continues to downward-Kittel mode resonance. Furthermore, according to eq. (2) and (3), magnitude of H_{ex} can be also derived from the $H_{\text{DC}}^{\text{res}}$,

$$\omega\gamma - H_{\text{DC}}^{\text{res}} = H_k - 4\pi M - H_{\text{ex}}. \quad (5)$$

When eq. (5) is normalized by H_k ,

$$(\omega\gamma - H_{\text{DC}}^{\text{res}})/H_k = (1 - 4\pi M/H_k) - H_{\text{ex}}/H_k. \quad (6)$$

In eq. (6) left side $(\omega\gamma - H_{\text{DC}}^{\text{res}})/H_k$ indicates H_{eff}/H_k and $(1 - 4\pi M/H_k)$ is known value. Thus H_{ex}/H_k can be derived by subtracting $(1 - 4\pi M/H_k)$ from the $(\omega\gamma - H_{\text{DC}}^{\text{res}})/H_k = H_{\text{eff}}/H_k$.

3. Results and discussion

In this study, magnetic isolation between each magnetic grain in CoPtCr-SiO₂ granular film was

Fig. 2 Schematic of the FMR signal with various magnetization state. Insets show histogram of the switched magnetic grains for each switching field.

Fig. 3 Normalized polar magneto optical Kerr loops for the Co₇₄Pt₁₆Cr₁₀-8mol (SiO₂) granular medium A ($P_{\text{Ar}}^{\text{Ru}} = 8.0$ Pa) and B ($P_{\text{Ar}}^{\text{Ru}} = 0.6$ Pa)

changed by changing Ar gas pressure $P_{\text{Ar}}^{\text{Ru}}$ during Ru sputtering (medium A: $P_{\text{Ar}}^{\text{Ru}} = 8.0$ Pa, medium B: $P_{\text{Ar}}^{\text{Ru}} = 0.6$ Pa), because the magnetic isolation is mainly determined by the degree of intergranular connection between each magnetic grain at bottom part of the magnetic layer, and it is affected by surface topology of the underlayer determined by $P_{\text{Ar}}^{\text{Ru}}$ [6–7, 12–16].

3.1 Full- and minor loop for media with different magnetic isolation

Figure 3 shows normalized polar magneto optical Kerr loops for CoPtCr-SiO₂ medium (a) A and (b) B. For (a), saturation field H_s , squareness S , coercivity H_c and slope at around coercivity $4\pi|dM/dH|$, which inversely correspond to the magnetic isolation [17], were around 10 kOe, 1.0, 4.8 kOe, and 2.94, respectively. For (b), H_s , S , H_c and $4\pi|dM/dH|$ were 6.5 kOe, 1.0, 3.4 kOe and 4.55, respectively. M_s for both the media were evaluated as 630 emu/cm³ by using the VSM.

3.2 FMR analysis under reversed domains

3.2.1 FMR signals

Figure 4 shows FMR signals for the medium A at various magnetization states. Top and bottom signals correspond to signals for upwardly and downwardly saturated state, respectively. For the upwardly magnetized state, FMR peak with linewidth of 500 Oe was observed at external field of 2.4 kOe. With

proceeding the magnetization reversal, the FMR peak shifted to lower field side, and its linewidth increased. This tendency was nearly the same for the downwardly magnetized grains.

3.2.2 Intergranular exchange field

H_{ex} was quantitatively confirmed from the FMR signal. Figure 5 shows dependence of normalized effective field H_{eff}/H_k on normalized mean demagnetizing field $|4\pi M|/H_k$ for CoPtCr-SiO₂ medium A and B. The upper horizontal axis corresponds to normalized magnetization $|M|/M_s$. The rightmost and leftmost states correspond to up/ downwardly saturated and demagnetized states, respectively. Solid circle and open square indicate value for up- and downwardly magnetized grains, respectively. Bold line shows $1 - |4\pi M|/H_k$ in eq (6). For the medium A, H_{eff}/H_k was 0.52 for the upwardly saturated state. And it increased with decreasing $|4\pi M|/H_k$. According to an extrapolated line of H_{eff}/H_k among $|4\pi M|/H_k$ showed that H_{eff}/H_k took around 0.80 for demagnetized state. At the same time, difference between $(1 - |4\pi M|)/H_k$ and H_{eff}/H_k was increased from 0 to 0.20. From above result, H_{ex}/H_k though to increases with increasing number of the switched grains, assuming that eq. (6). For downwardly magnetized grains, tendency was nearly the same as above result. For the medium B, tendency was nearly the same but absolute value of H_{ex}/H_k was larger value of around 0.36 at demagnetized state.

3.2.3 Effective damping factor

Figure 6 shows dependence of normalized linewidth $\Delta H_{DC}^{res}/H_k$ on $|M|/M_s$ for CoPtCr-SiO₂ medium A and B. Right vertical axes correspond to α_{eff} . The solid circle and the open square indicate value for up- and downwardly magnetized grains, respectively. $\Delta H_{DC}^{res}/H_k$ of up- and downwardly magnetized grains for the medium A is clearly increased from 0.03 to around 0.15 with decreasing $|M|/M_s$ from 1 to 0.60. At the same time, α_{eff} of up- and downwardly magnetized grains increased from 0.03 to around 0.11. For the medium B, α_{eff} of up- and downwardly magnetized grains increased from 0.05 to just 0.07 under the same magnetization. Hereafter, above α_{eff} change due to magnetization change is defined as $\Delta\alpha_{eff}^M$.

3.3 Effect of P_{Ar}^{Ru}

Origin of difference of the $\Delta\alpha_{eff}^M$ between medium A and B is considered. This difference comes from difference of distribution of the effective field, since only M is changed for each medium. Thus origin of the difference is thought to be magnetization reversal state, or distribution of effective field. In detail, distribution of size of the reversed domains are different between medium A and B by difference of clustering degree due to different H_{ex} [18] discussed in 3.1 and 3.2.2. By such size distribution of the reversed domains affect to sum of 1) dipole interaction field, 2) self-demagnetization

Fig. 4 FMR signals for CoPtCr-SiO₂ granular medium with $P_{Ar}^{Ru} = 8.0$ Pa with various magnetization state.

Fig. 5 Dependence of normalized H_{eff} on mean demagnetizing field $4\pi M$ for CoPtCr-SiO₂ granular medium A ($P_{Ar}^{Ru} = 8.0$ Pa) and B ($P_{Ar}^{Ru} = 0.6$ Pa). Upper horizontal axis correspond to normalized magnetization $|M|/M_s$.

Fig. 6 Dependence of normalized FMR linewidth $\Delta H_{DC}^{res}/H_k$ on normalized magnetization $|M|/M_s$ for CoPtCr-SiO₂ granular medium A ($P_{Ar}^{Ru} = 8.0$ Pa) and B ($P_{Ar}^{Ru} = 0.6$ Pa). Right vertical axis correspond to effective damping factor α_{eff} . Solid circle and open square indicate value for up- and downwardly magnetized grains, respectively.

Fig. 7 Schematic models for the granular medium A ($P_{Ar}^{Ru} = 8.0$ Pa) and B ($P_{Ar}^{Ru} = 0.6$ Pa).

field, and 3) H_{ex} for each domain.

For example, if reversed domain size distributes from single grain to multi grains, sum of the 1) dipole interaction field and 2) self-demagnetization field are cannot approximate as $4\pi M$ because the dipole interaction field fluctuates by position of the domain. 3) H_{ex} also fluctuates with the domain size distribution increases, since it proportional to the facing length between up- and downwardly magnetized domains [19]. Moreover, even though size of the domains are almost the same, H_{ex} fluctuates by distribution of degree of the magnetic isolation between each grain. In 3.2.3, $\Delta\alpha_{eff}^M$ for the medium B was smaller than that of the medium A, even though the medium B though to have larger reversed domain size compared with the medium A due to its larger H_{ex} . Thus dominant factor for the difference of $\Delta\alpha_{eff}^M$ is thought to be distribution of the H_{ex} .

Figure 7 shows schematic models for the granular medium A and B. For both the media, magnetic grains are exchange coupled in bottom initial growth part of the magnetic layer [6–7]. For the medium A, generally distribution of intergranular exchange coupling exists in the bottom part due to the distribution of the Ru surface roughness. Thus α_{eff} thought to rapidly increases with magnetic reversal. On the other hand, for the medium B, strong intergranular exchange coupling occurs in the bottom part due to insufficient magnetic isolation for each magnetic grain due to small-surface-roughness underlayer [12–13, 15–16]. For such a strong-intergranular exchange coupling magnetic grains, the effect of distributon of intergranular exchange couple on the degree of the FMR is almost constant [20]. Thus it is conceivable that the α_{eff} hardly increases with magnetic reversal, compared with the medium A.

4. Conclusion

Effect of magnetization reversal and intergranular exchange coupling on effective damping factor α_{eff} was investigated by Q-band ferromagnetic resonance for $Co_{84}Pt_{16}Cr_{10}$ -8mol (SiO_2) granular media. Two kinds of media A and B, which have defferent intergranular exchange coupling, were investigated. As a result, it was found that: 1) Magnitude of the normalized intergranular exchange coupling field H_{ex}/H_k at demagnetization state were 0.20 and 0.35 for the medium A and B, respectively. 2) α_{eff} was significantly

increased from 0.03 to 0.11 with decreasing normalized magnetization $|M|/M_s$ from 1 to 0.4 for the medium A. At the same time, α_{eff} was increased from 0.05 to just 0.07, for the medium B. 3) Origin of difference of α_{eff} increment is considered that difference of distribution and magnitude of the intergranular exchange coupling. Thus homogenous interexchange coupling is necessary to reduce the magnetization dependence of the α_{eff} .

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