Study of Magnetic Field Determined from Vanishing Rotational Hysteresis Loss in CoCrPtB Perpendicular Thin Film Media

著者	齊藤　伸
journal or publication title	Journal of applied physics
volume	91
number	10
page range	8351-8353
year	2002
URL	http://hdl.handle.net/10097/35352

doi: 10.1063/1.1452278

JOURNAL OF APPLIED PHYSICS VOLUME 91, NUMBER 10 15 MAY 2002

Study of magnetic field determined from vanishing rotational hysteresis loss in CoCrPtB perpendicular thin film media

Shin Saito,[a] Yoshihiro Sato, Fumikazu Hoshi, David D. Djayaprawira,
and Migaku Takahashi
Department of Electronic Engineering, Graduate School of Engineering, Tohoku University,
Sendai 980-8579, Japan

The magnetic field determined from vanishing rotational hysteresis loss of CoCrPtB perpendicular thin film media was experimentally investigated. It was clarified that (1) in $Co_{72}Cr_{16}Pt_8B_4$ media with d_{mag} of less than 200 nm and $Co_{64}Cr_{24}Pt_8B_4$ media with d_{mag} of less than 100 nm, a homogeneous structure was realized, except for the existence of an initial growth region. (2) For both media, the perpendicular rotational hysteresis loss, W_r, the maximum field of W_r, H_p, and the field where $W_r = 0$, $H_{W_{r=0}}$, increased with an increase in d_{mag}. (3) For both media, $H_{W_{r=0}}/H_k^{\mathrm{grain}}$ increased with an increase in d_{mag} and saturated at a magnitude of about 1. (4) For the medium with thin magnetic film thickness, at applied field of $H_{W_{r=0}} < H < H_k^{\mathrm{grain}}$, a multidomain state was realized in the torque measurement in spite of no observation of loss of rotational hysteresis. This is considered to be due to the existence of thermal agitation between the multidomains.
[DOI: 10.1063/1.1452278]

I. INTRODUCTION

For CoCr-based longitudinal recording media, it is suggested that the magnetic field where rotational hysteresis loss (W_r) vanishes ($H_{W_{r=0}}$) corresponds to the magnetic anisotropy field (H_k) of magnetic grains in a medium.[1,2] This phenomenon has been used to determine H_k for longitudinal media. On the other hand, for perpendicular recording media, magnetic anisotropy field H_k has been determined from $2K_u/M_s$,[3,4] rather than $H_{W_{r=0}}$. Therefore, it is interesting to find the relationship between $H_{W_{r=0}}$ and H_k. However, no experimental data or physical discussions of $H_{W_{r=0}}$ for CoCr-based perpendicular media have been reported yet. In this article, the dependence of $H_{W_{r=0}}$ on the magnetic film thickness, d_{mag}, was experimentally evaluated and $H_{W_{r=0}}$ is compared with H_k for CoCrPtB perpendicular media. Furthermore, the physical meaning of $H_{W_{r=0}}$ is discussed.

II. EXPERIMENTAL PROCEDURE AND ANALYSIS

$Co_{72}Cr_{16}Pt_8B_4$ and $Co_{64}Cr_{24}Pt_8B_4$ media (hereafter simply called medium A and medium B) were fabricated by the dc magnetron sputtering method on 65 mm diam glass substrates using a so-called ultraclean sputtering system.[5] The substrate was heated by a quartz lamp and the heating temperature was 350 °C for medium A and 200 °C for medium B, respectively. These were the temperatures at which the perpendicular coercivity shows a maximum value for both material systems with $d_{\mathrm{mag}} = 50$ nm. The sputtering was done under Ar pressure of 6.7×10^{-1} Pa. d_{mag} of media A and B was varied from 5 to 200 nm. The underlayer and the protective layer were Ta with thickness of 25 nm and C with thickness of 7 nm, respectively.

The magnetic hysteresis loops and perpendicular magnetic anisotropy were evaluated by a vibrating sample magnetometer (VSM) and a high sensitivity torque magnetometer, respectively. Prior to torque measurement, the media were ac demagnetized. W_r was evaluated from perpendicular torque curves with an increase in magnetic field from 1 to 20 kOe. $H_{W_{r=0}}^{\mathrm{inc}}$, which is the field in which W_r vanished, was determined using a W_r vs $1/H$ plot.[2] W_r was also evaluated with decreases in magnetic field from 20 to 1 kOe and $H_{W_{r=0}}^{\mathrm{dec}}$, which is the field where W_r appeared, was determined using the same method. It is clarified that $H_{W_{r=0}}^{\mathrm{inc}}$ and $H_{W_{r=0}}^{\mathrm{dec}}$ showed almost the same value. In this article, the $H_{W_{r=0}}^{\mathrm{dec}}$ is represented as $H_{W_{r=0}}$. The saturated torque coefficient of the twofold component, $L_{2\theta}^{\mathrm{sat}}$, was obtained by extrapolating the coefficient versus the $1/H$ curve to $H \rightarrow \infty$. By taking into account the self-energy caused by the demagnetizing field, the experimentally obtained total perpendicular magnetic anisotropy of the whole film, $K_{u\perp}^{\mathrm{exp}}$, can be expressed as

$$K_{u\perp}^{\mathrm{exp}} = L_{2\theta}^{\mathrm{sat}} + 2\pi M_s^2. \tag{1}$$

the uniaxial magnetic anisotropy of columnar grains, K_u^{grain} and the thickness of initial growth layer, d_{ini} for the present media are evaluated by $K_{u\perp}^{\mathrm{exp}} \times d_{\mathrm{mag}}$ vs d_{mag} plot.[6,7]

---

[a] Electronic mail: ssaito@ecei.tohoku.ac.jp

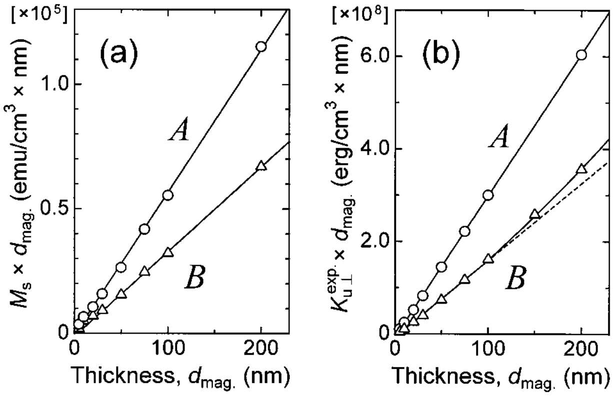

FIG. 1. (a) $M_s \times d_{\mathrm{mag}}$ vs d_{mag} plot and (d) $K_{u\perp}^{\exp} \times d_{\mathrm{mag}}$ vs d_{mag} plot for media A, $Co_{72}Cr_{16}Pt_8B_4$, and B, $Co_{64}Cr_{24}Pt_8B_4$, prepared on a Ta underlayer.

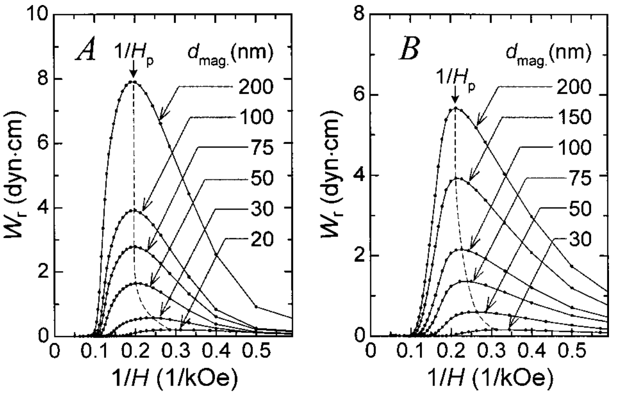

FIG. 2. Rotational hysteresis losses for media A, $Co_{72}Cr_{16}Pt_8B_4$, and B, $Co_{64}Cr_{24}Pt_8B_4$, prepared on a Ta underlayer with various magnetic film thicknesses.

The average H_k^{grain} was calculated from

$$H_k^{\mathrm{grain}} = 2K_u^{\mathrm{grain}}/M_s. \tag{2}$$

III. RESULTS AND DISCUSSION

In Fig. 1(a), the product of the saturation magnetization to the magnetic film thickness, $M_s \times d_{\mathrm{mag}}$, for media A and B is plotted against d_{mag}. For both media, it is found that $M_s \times d_{\mathrm{mag}}$ increases proportionally, with d_{mag} crossing zero. M_s was determined from the gradient of the $M_s \times d_{\mathrm{mag}}$ vs d_{mag} plot, which gave a value of 570 emu/cm^3 for medium A and 330 emu/cm^3 for medium B, respectively. In Fig. 1(b), the product of the perpendicular magnetic anisotropy to the magnetic film thickness, $K_{u\perp}^{\exp} \times d_{\mathrm{mag}}$, for media A and B is plotted against d_{mag}. For medium A, $K_{u\perp}^{\exp} \times d_{\mathrm{mag}}$ increases linearly with an increase in d_{mag}, with a positive intersection at the d_{mag} axis. The values of K_u^{grain} and d_{ini} evaluated are 2.98×10^6 erg/cm^3 and 1.9 nm, respectively. On the other hand, for medium B, $K_{u\perp}^{\exp} \times d_{\mathrm{mag}}$ increases linearly with an increase in d_{mag} within the 10–100 nm range. For $d_{\mathrm{mag}} > 150$ nm, the relation between $K_{u\perp}^{\exp} \times d_{\mathrm{mag}}$ and d_{mag} becomes slightly linearly quadratic. The values of K_u^{grain} determined for medium B are 1.45×10^6, 1.52×10^6, and 1.58×10^6 erg/cm^3 for media with d_{mag} of less than 100, 150, and 200 nm, respectively. This suggests that there is a slight heterogeneity of the microstructure along the film depth in *c*-plane-oriented columnar grains. The d_{ini} was determined to be 2.6 nm.

In Table I, the intrinsic magnetic properties of columnar grains, M_s, K_u^{grain}, and H_k^{grain}, the thickness of initial growth layer, d_{ini}, and perpendicular magnetic properties, H_c (50 nm) and α (50 nm), for both media are summarized. Here, H_c (50 nm) and α (50 nm) are the coercivity and the slope of the magnetization curve versus the magnetic field at the coercivity ($4\pi M/H$ at $H = H_c$) of the media with $d_{\mathrm{mag}} = 50$ nm, respectively. The magnitude of α (50 nm) shows low values of 1.3 and 1.1 for media A and B, respectively, which means that intergranular exchange coupling is weak.

In Fig. 2, the values of perpendicular rotational hysteresis loss, W_r, for media A and B with various film thicknesses are shown as a function of the inverse applied field $1/H$. In both media, W_r appears at low $1/H$ (large field), increases with an increase in $1/H$ (decreasing field), reaches a maximum, and then decreases. For both media A and B, the maximum value of W_r increases with an increase in d_{mag}, and the inverse applied field, $1/H_p$, where W_r takes a maximum, is shifted toward the lower $1/H$ side (higher field). $1/H_{W_{r=0}}$ is also shifted toward the lower $1/H$ side with an increase in d_{mag}. $H_{W_{r=0}}$ was determined by fitting W_r with a quadratic function in the range of $W_r^{\max}/3 - W_r^{\max}/20$.

In Fig. 3, the dependence of $H_{W_{r=0}}/H_k^{\mathrm{grain}}$ on d_{mag} is shown for media A and B. For medium A with $d_{\mathrm{mag}} = 10$ nm, $H_{W_{r=0}}/H_k^{\mathrm{grain}}$ shows only a small value of 0.46. With an increase in d_{mag}, $H_{W_{r=0}}/H_k^{\mathrm{grain}}$ gradually increases and saturates at a magnitude of 0.94 with d_{mag} more than 100 nm. Almost the same tendency was observed in medium B, since $H_{W_{r=0}}/H_k^{\mathrm{grain}}$ increases from a small value of 0.51 with $d_{\mathrm{mag}} = 20$ nm, and saturates at 0.99 with d_{mag} more than 100 nm. Therefore, it was clarified that (1) in the thick d_{mag} region with d_{mag} of more 100 nm, $H_{W_{r=0}}$

TABLE I. Intrinsic magnetic properties of columnar grains, M_s, K_u^{grain}, and H_k^{grain}, and thickness of the initial growth layer, d_{ini}, and perpendicular magnetic properties, H_c (50 nm) and α (50 nm), for CoCrPtB media. For medium B, M_s, K_u^{grain}, and H_k^{grain} with d_{mag} of less than 100 nm are summarized.

	Medium	M_s (emu/cm^3)	K_u^{grain} (erg/cm^3)	H_k^{grain} (kOe)	d_{ini} (nm)	H_c(kOe) (50 nm)	α (50 nm)
A	$Co_{72}Cr_{16}Pt_8B_4$/Ta (25 nm)	570	2.98×10^6	10.5	1.9	2.8	1.3
B	$Co_{64}Cr_{24}Pt_8B_4$/Ta (25 nm)	330	1.45×10^6	8.8	2.6	1.3	1.1

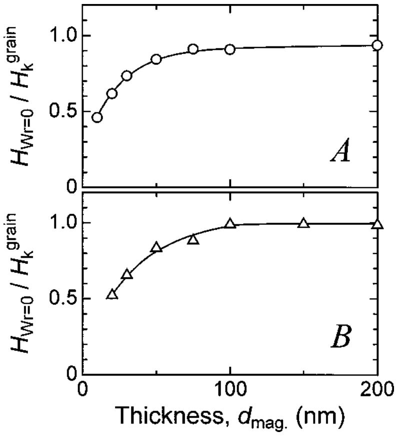

FIG. 3. $H_{Wr=0}$ normalized by H_k^{grain} as a function of the magnetic film thickness for media A, $Co_{72}Cr_{16}Pt_8B_4$, and B, $Co_{64}Cr_{24}Pt_8B_4$, prepared on a Ta underlayer.

becomes close to about H_k^{grain} ($H_{W_{r=0}}/H_k^{\mathrm{grain}} \approx 1$); (2) in the thin d_{mag} region with d_{mag} of less than 100 nm, $H_{W_{r=0}}$ gradually decreases from H_k^{grain} with a decrease in d_{mag}, although the average values of intrinsic magnetic properties of columnar grains in media, such as M_s, K_u^{grain}, and H_k^{grain}, were constant as shown in Fig. 1 and Table I. The fact that the average value of H_k^{grain} is independent of the film thickness suggests that the distribution of the anisotropy field of the columnar grains is not the dominant factor in the thickness dependence of $H_{W_{r=0}}$.

Since we know that, in these perpendicular media, the switching of magnetization, which is the origin of torque loss, occurs around the direction of hard magnetization which is parallel to the film plane the M–H loops in this direction were analyzed to understand the magnetization state in the media at $H_{W_{r=0}}$. In Fig. 4, the M–H loops measured parallel to the film plane are shown for media A and B with $d_{\mathrm{mag}} = 20$, 50, and 200 nm. Before measurement, both media were saturated by applying a magnetic field of 15 kOe. In each loop, saturated field, H_{sat}, and $H_{W_{r=0}}$ for the media are shown by arrows. According to the M–H loops, for the media in the present study, H_{sat} almost corresponds to H_k^{grain}. In the M–H loops for medium A, $H_{W_{r=0}}$ with $d_{\mathrm{mag}} = 200$ nm is close to H_{sat}. With a decrease in d_{mag} of up to 20 nm, the difference between H_{sat} and $H_{W_{r=0}}$ becomes larger. The same tendency can be found in medium B. These results indicate that for thin media with $H_{W_{r=0}}$ less than H_k^{grain}, even though a field as large as $H_{W_{r=0}}$ is applied, the magnetic moments still do not saturate toward the film plane direction. This suggests that during torque measurement with an applied field larger than $H_{W_{r=0}}$ and less than H_k^{grain}, there are multidomains with magnetic moments tilting upward and downward toward the film plane when the applied field is parallel to the plane of the film.

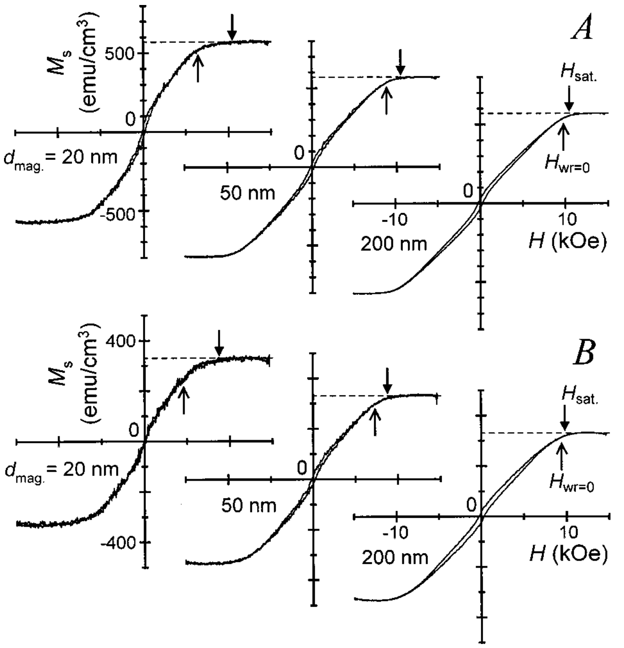

FIG. 4. M–H loops measured parallel to the film's plane for media A, $Co_{72}Cr_{16}Pt_8B_4$, and B, $Co_{64}Cr_{24}Pt_8B_4$, prepared on a Ta underlayer with film thicknesses of 20, 50, and 200 nm. In each loop, $H_{Wr=0}$ and saturated field, H_{sat}, for the media are shown by arrows.

Finally, we discuss the physical meaning of $H_{W_{r=0}}$. For the thick media with d_{mag} of more than 100 nm, the value of $H_{W_{r=0}}$ is close to H_k^{grain}, as if the sample were not influenced by the demagnetization field. This is only true if the magnetization configuration in the stable state is the demagnetized state with the magnetization aligned perpendicularly, and if the magnetization configuration in the unstable state is the saturated state with magnetization aligned parallel to the plane of the film. For the thin media with d_{mag} of less than 100 nm, with a decrease in d_{mag} the value of $H_{W_{r=0}}$ becomes smaller than H_k^{grain}. In other words, for the thin media at applied field larger than $H_{W_{r=0}}$ but less than H_k^{grain}, W_r does not appear, even though the magnetic moments are realized in multidomain states during torque measurement. We conclude that this phenomenon is caused by thermal agitation, that is, the magnetization reversal between upward and downward domains at thermal equilibrium, which does not contribute to the rotational hysteresis loss.

[1] D. M. Paige, S. R. Hoon, B. K. Tanner, and K. O'Grady, IEEE Trans. Magn. **MAG-20**, 1852 (1984).
[2] M. Takahashi, T. Shimatsu, M. Suekane, M. Miyamura, K. Yamaguchi, and H. Yamasaki, IEEE Trans. Magn. **28**, 3285 (1992).
[3] K. Ouchi and S. Iwasaki, IEEE Trans. Magn. **MAG-23**, 2443 (1987).
[4] N. Inaba, Y. Uesaka, and M. Futamoto, IEEE Trans. Magn. **36**, 54 (2000).
[5] M. Takahashi, A. Kikuchi, and S. Kawakita, IEEE Trans. Magn. **33**, 2938 (1997).
[6] S. Saito, D. Hasegawa, F. Hoshi, D. D. Djayaprawira, and M. Takahashi, Appl. Phys. Lett. **80,** 811 (2002).
[7] S. Saito, D. Hasegawa, D. D. Djayaprawira, and M. Takahashi, J. Magn. Soc. Jpn. **25**, 583 (2000) (in Japanese).