EPJ Web of Conferences 75, 06009 (2014)
DOI: 10.1051/epjconf/20147506009

Effect of layer thickness ratio on magnetization reversal process in stacked media with high coercivity

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Abstract. Effect of thickness ratio and interlayer exchange coupling on time-evolutional magnetization reversal process in stacked media with high coercivity was investigated by utilizing micromagnetic simulation. Regardless of the layer thickness ratio, for each stacked medium the magnetization reversal process is divided into three regions, namely the spin-flop rotation, the incoherent rotation and the coherent rotation along with increase of the interlayer exchange coupling constant $A_{\text{interlayer}}$. In order to get the incoherent rotation region which is suitable for the recording media, it is required that the $A_{\text{interlayer}}$ is between about 1.3×10^{-7} and 2.2×10^{-7} erg/cm for the media with the layer thickness ratio of 1 : 3 and 3 : 1, and that one is between about 1.8×10^{-7} and 2.5×10^{-7} erg/cm for the media with the ratio near 1 : 1.

1 Introduction

The stacked media are still a strong candidate for achieving ultra-high recording density in hard disks with high coercivity [1], [2]. It is important to elucidate magnetization change in soft and hard layers of the stacked media at the time of recording, where interlayer exchange coupling between the layers has an essential role for the magnetization change [3] - [6]. The thickness of the soft layer is generally from about 1/5 to 1/3 of the hard layer in stacked media of commercial hard disks. On the other hand, one of proposed next-generation stacked media has thicker soft layer than the hard layer [7]. However, magnetization reversal process of such stacked medium has not been discussed sufficiently yet. In this study, effect of layer thickness ratio of the soft layer to the hard layer and the interlayer exchange coupling on the time-evolutional magnetization reversal process in the stacked media with high coercivity was investigated by utilizing micromagnetic simulation.

2 Calculation method

In order to investigate the magnetization reversal process in the stacked media, magnetic printing [8] was used as recording technique in the simulation. Fig. 1 shows the simulation model of the magnetic printing used in the study. In magnetic printing, first, the recording layer is magnetized in downward direction by applying the initial magnetic field along the perpendicular direction of recording layer. Then the master medium with a patterned magnetic layer corresponding to signal to record is in contact with the recoding layer, and after that, the printing field is applied along the opposite direction to the initial magnetic field. Finally, the master pattern is printed onto the recording layer. The master pattern has the track width of 30 nm and the bit length of 30 nm. Fig. 2 shows schematic of stacked media. Recording layer consists of the soft and hard layers. The

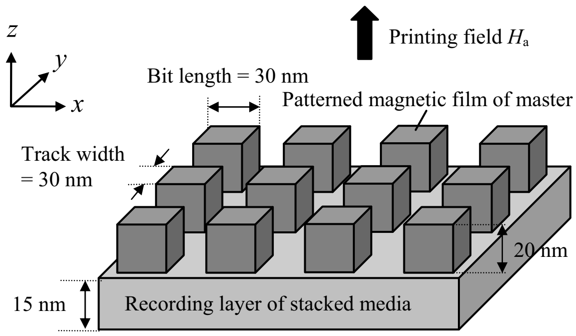

Fig. 1. Simulation model of magnetic printing.

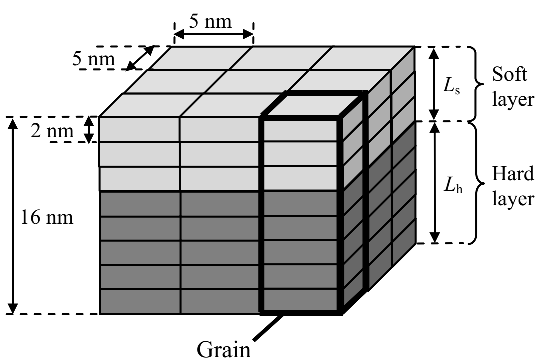

Fig. 2. Schematic of recording layer of stacked media.

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Table 1. Parameters of stacked media used in the study.

Parameters		Soft layer	Hard layer
Thickness (nm)		L_s	L_h (= 16 - L_s)
Saturation magnetization M_s (emu/cm^3)		600	
c-axis distribution $\Delta\theta_{50}$ (deg.)		10	10
Exchange coupling constant ($\times10^{-7}$ erg/cm)	$A_{intergrain}$	1.2	0.5
	$A_{intragrain}$	10.0	
	$A_{interlayer}$	0.3 – 3.0	

Table 2. Parameters of H_k for various layer thickness ratio.

Layer thickness ratio	1 : 3	1 : 1	3 : 1
L_s (nm)	4	8	12
L_h (nm)	12	8	4
H_k of Soft layer (kOe)	8	11	13
H_k of Hard layer (kOe)	22	25	30

recording layer was divided into 5×5×2 nm^3 cubic cells. Exchange lengths of the soft and hard layers are comparable to the cell size in this simulation. Table 1 shows parameters of the stacked media. The total thickness of the stacked media is 16 nm with varying the soft layer thickness L_s and the hard layer thickness L_h. The layer thickness ratio of the soft and hard layers was 1:3 (L_s = 4 nm), 1:1 (L_s = 8 nm) and 3:1 (L_s = 12 nm). The interlayer exchange coupling constant $A_{interlayer}$ was varied from 0.3×10^{-7} to 3.0×10^{-7} erg/cm. The coercivity of these stacked media with each thickness ratio was adjusted to about 10 kOe. Table 2 shows parameters of anisotropy field H_k for various layer thickness ratio. The hysteresis loop of each stacked medium is set to almost the same figure by varying H_k. The time-evolutional magnetization reversal process in the soft and hard layers was analyzed during application of printing field H_a and after removal of the H_a. Printing performance PP was evaluated from the calculated magnetization distribution in the soft and hard layers. The PP in each layer was estimated by using the following definition [9]:

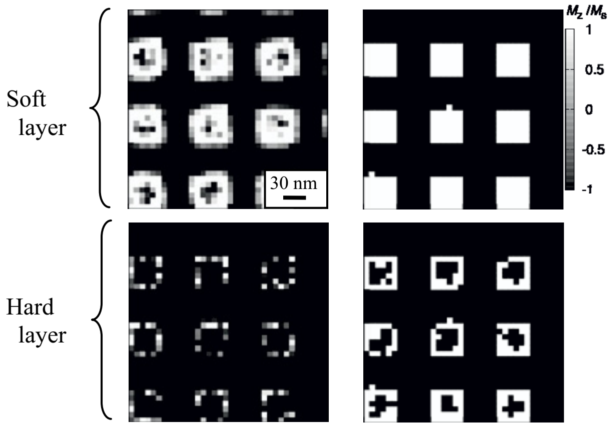
$$\mathrm{PP}\,(\%) = \frac{\sum M_z^{\mathrm{ideal}} M_z^{\mathrm{cal}}}{\sum M_z^{\mathrm{ideal}} M_z^{\mathrm{ideal}}} \times 100, \quad (1)$$

where M_z^{ideal} and M_z^{cal} are z-component of ideally printed magnetization and z-component of calculated magnetization, respectively. The PP means whether the calculated magnetization is close to the ideal magnetization. When the printed magnetization is ideal, the value of PP is 100 %.

3 Results and discussion

Fig. 3 shows magnetization distribution during applying the H_a for the L_s of 4 nm and the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. Figs. 3(a), (b) show the magnetization distribution of each layer for elapsed time of 70 ps and 636 ps after applying the H_a of 4.5 kOe, respectively. Here the H_a of 4.5 kOe is the optimum printing field in this case [10]. In Fig. 3, white area represents M_z/M_s = 1, and black area represents M_z/M_s = 1. When the H_a is applied, the magnetization is reversed first in the soft layer as shown in Fig. 3(a). Then, the magnetization reversal of the hard layer is induced by the magnetization of the soft layer as shown in Fig. 3(b). Fig. 4 shows the time-evolutional PP with a lapse of time in the soft and hard layers for the L_s of 4 nm and the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. It is found that during applying the H_a the magnetization of the soft layer is printed first in accordance with the pattern of master, and that magnetization reversal of the hard layer follows slightly behind that of the soft layer. This magnetization reversal process is equivalent to incoherent rotation [3].

Fig. 5 shows magnetization distribution during applying the H_a for the L_s of 8 nm and the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. Figs. 5(a), (b) show the magnetization distribution of each layer for elapsed time of 70 ps and 641 ps after applying the H_a of 2.5 kOe, respectively. Fig. 6 shows the time-evolutional PP with a lapse of time in the soft and hard layers for the L_s of 8 nm and the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. Although much of the magnetization



(a) Elapsed time of 70 ps after start time of H_a application

(b) Elapsed time of 636 ps after start time of H_a application

Fig. 3. Change in magnetization with a lapse of time. Top figures indicate magnetization distribution in soft layer, and bottom figures indicate that in hard layer (L_s = 4 nm, $A_{interlayer}$ = 1.8×10^{-7} erg/cm).

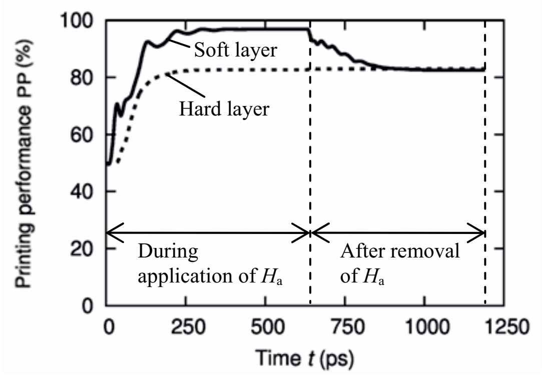
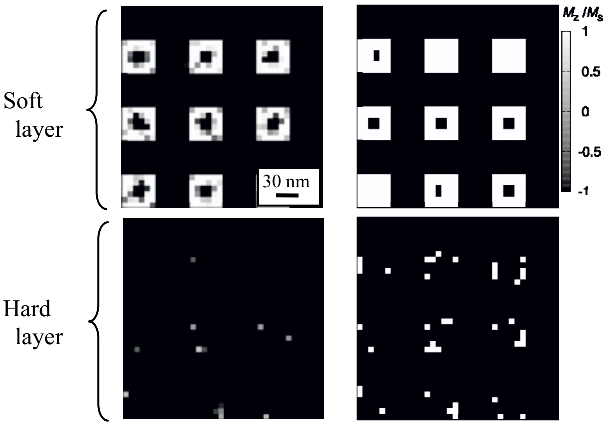


Fig. 4. Printing performance with a lapse of time in soft and hard layers (L_s = 4 nm, $A_{iterlyaer}$ = 1.8×10^{-7} erg/cm, H_a = 4.5 kOe).



(a) Elapsed time of 70 ps after start time of H_a application (b) Elapsed time of 641 ps after start time of H_a application

Fig. 5. Change in magnetization with a lapse of time. Top figures indicate magnetization distribution in soft layer, and bottom figures indicate that in hard layer (L_s = 8 nm, $A_{interlayer}$ = 1.8×10^{-7} erg/cm).

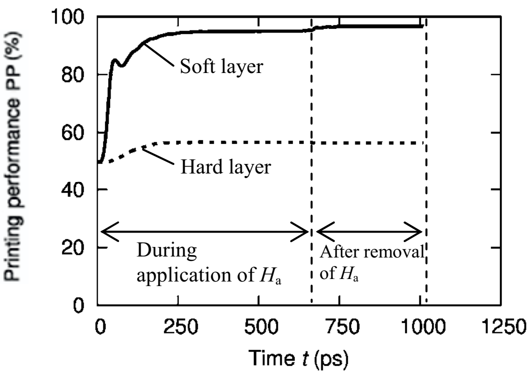


Fig. 6. Printing performance with a lapse of time in soft and hard layers (L_s = 8 nm, $A_{iterlyaer}$ = 1.8×10^{-7} erg/cm, H_a = 2.5 kOe).

of the soft layer is reversed during applying the H_a, magnetization in the hard layer hardly changes as shown in Figs. 5, 6. Namely the magnetization of each layer is independently reversed. This magnetization reversal process is equivalent to spin-flop rotation [3].

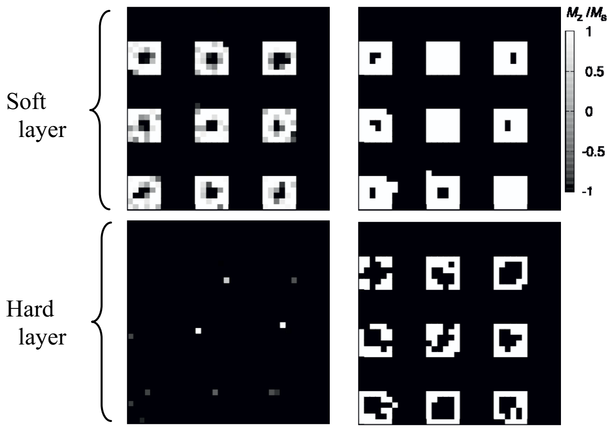
Fig. 7 shows magnetization distribution during applying the H_a for the L_s of 12 nm and the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. Figs. 7(a), (b) show the magnetization distribution of each layer for elapsed time of 70 ps and 743 ps after applying the H_a of 3.5 kOe, respectively. Fig. 8 shows the time-evolutional PP as a function of a lapse of time in the soft and hard layers for the L_s of 12 nm and the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. When H_a is applied, the magnetization is reversed first in the soft layer, and then the magnetization reversal of the hard layer is induced by the magnetization of the soft layer in the same way as the medium with the L_s of 4 nm. This magnetization reversal process corresponds to incoherent rotation.

Herein, the PP_{max}^{s} and PP_{max}^{h} are defined as the maximum values of the PP of the soft layer and the hard layer as shown in Fig. 8, respectively. Fig. 9 shows dependence of the PP_{max}^{s} and the PP_{max}^{h} on the L_s for the $A_{interlayer}$ of 1.8×10^{-7} erg/cm. Due to application of the optimum printing field, the PP_{max}^{s} obtains high values for all L_s. On the other hand, the PP_{max}^{h} obtains high values for the L_s of 4 and 12 nm. When the L_s is 8 nm, the PP_{max}^{h} is minimum. This issue will be discussed as follow.

H_{total} is magnetic field to reverse the magnetization of the hard layer, expressed by

$$\boldsymbol{H}_{total} = \boldsymbol{H}_{ex} + \boldsymbol{H}_{d} + \boldsymbol{H}_{r}\,, \qquad (2)$$

where H_{ex}, H_d and H_r are exchange field, magnetostatic



(a) Elapsed time of 70 ps after start time of H_a application (b) Elapsed time of 743 ps after start time of H_a application

Fig. 7. Change in magnetization with a lapse of time. Top figures indicate magnetization distribution in soft layer, and bottom figures indicate that in hard layer (L_s = 12 nm, $A_{interlayer}$ = 1.8×10^{-7} erg/cm).

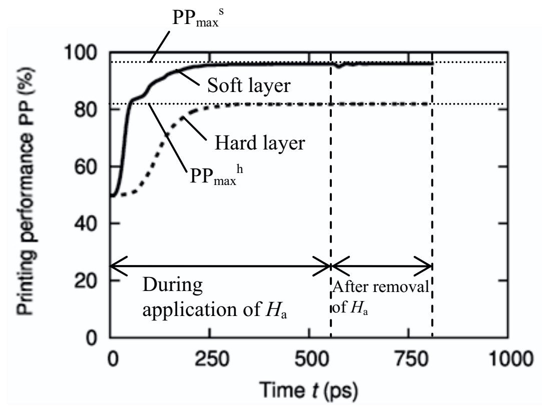


Fig. 8. Printing performance with a lapse of time in soft and hard layers (L_s = 12 nm, $A_{iterlyaer}$ = 1.8×10^{-7} erg/cm, H_a = 3.5 kOe).

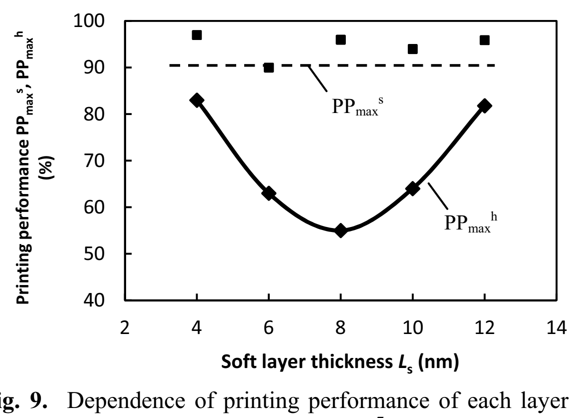


Fig. 9. Dependence of printing performance of each layer on soft layer thickness L_s ($A_{interlayer}$ = 1.8×10^{-7} erg/cm).

field and recording field, respectively. In magnetization reversal process, the anisotropy field H_k is considered to be applied to the opposite direction of the H_{total}. The magnetization reversal occurs when the H_{total} becomes larger than the H_k. For the medium with the L_s of 4 nm, the H_r applied to the hard layer is strong due to small spacing between the master and the hard layer. Therefore, it is inferred that the H_{total} becomes large and the hard layer has high PP_{max}^{h}. For the L_s of 12 nm, although the H_r is not so strong and the H_{ex} is almost the same as that of the medium with the L_s of 4 nm, the hard layer is easy to reverse due to a small grain volume. Therefore, it is inferred that the hard layer has high PP_{max}^{h}. On the other hand, for the L_s of 8 nm, because the H_r is not so strong as that of the medium with the L_s of 4 nm and the volume of a grain of the hard layer is not so small as that of the medium with the L_s of 12 nm, it is inferred that the PP_{max}^{h} of the hard layer is low.

In order to discuss the magnetization reversal in the soft and hard layers, $PP_{max}^{s\text{-}h}$ is defined as $PP_{max}^{s\text{-}h} = PP_{max}^{s} - PP_{max}^{h}$. For the $PP_{max}^{s\text{-}h}$ higher than about 40 %, the magnetization of only the soft layer is reversed, namely magnetization reversal process is the spin-flop rotation. For the $PP_{max}^{s\text{-}h}$ is less than about 5 %, the magnetization in the each layer is reversed almost simultaneously, which is the coherent rotation process. The incoherent rotation which is suitable for the recording media is in the region between the spin-flop and the coherent rotation regions. Fig. 10 shows dependence of the $PP_{max}^{s\text{-}h}$ on the $A_{interlayer}$. For the L_s of 4 and 12 nm, the magnetization reversal process is divided into the spin-flop region for $A_{interlayer}$ < about 1.3×10^{-7} erg/cm, the incoherent region for about $1.3\times10^{-7} < A_{interlayer}$ < about 2.2×10^{-7} erg/cm and the coherent region for $A_{interlayer}$ > about 2.2×10^{-7} erg/cm. On the other hand, for the L_s of 8 nm, the magnetization reversal process is divided into the spin-flop region for $A_{interlayer}$ < about 1.8×10^{-7} erg/cm, the incoherent region for about $1.8\times10^{-7} < A_{interlayer}$ < about 2.5×10^{-7} erg/cm and the coherent region for $A_{interlayer}$ > about 2.5×10^{-7} erg/cm. Above mentioned results show that the magnetization reversal process depends on the layer thickness ratio, and that the $A_{interlayer}$ to get the incoherent rotation has to be set to larger value for the media with the ratio near 1:1.

4 Conclusion

In this study, we investigated the effect of the layer thickness ratio of the soft layer to the hard layer and the interlayer exchange coupling on the time-evolutional magnetization reversal process in the stacked media with high coercivity by utilizing micromagnetic simulation. The results are as follows. Regardless of the layer thickness ratio, for each stacked medium the magnetization reversal process is divided into three regions, namely the spin-flop rotation, the incoherent rotation and the coherent rotation along with increase of the interlayer exchange coupling constant $A_{interlayer}$. In order to get the incoherent rotation region which is suitable for the recording media, it is required that the $A_{interlayer}$ is between about 1.3×10^{-7} and 2.2×10^{-7} erg/cm

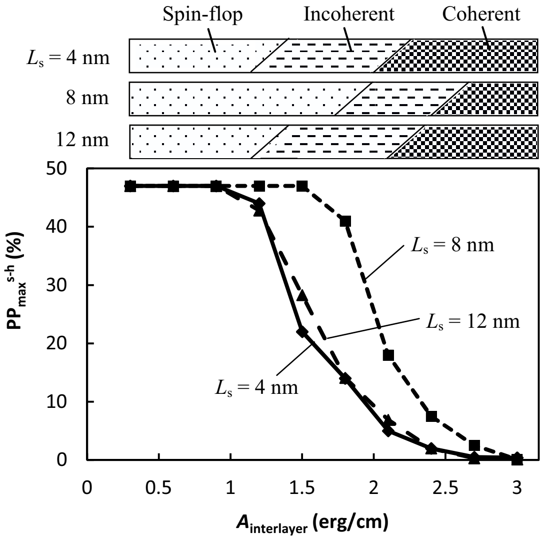


Fig. 10. Dependence of $PP_{max}^{s\text{-}h}$ on $A_{interlayer}$ for various soft layer thickness L_s.

for the media with the layer thickness ratio of 1 : 3 and 3 : 1, and that one is between about 1.8×10^{-7} and 2.5×10^{-7} erg/cm for the media with the ratio near 1 : 1.

Acknowledgment

This work was supported in part by the Grant-in-Aid for Scientific Research (C) (No. 24560394) from the Japan Society for the Promotion of Science (JSPS) of Japan.

References

1. R. H. Victora, and X. Shen: IEEE Trans. Magn., **41**, 2828 (2005).
2. Y. Shiroishi, K. Fukuda, I. Tagawa, H. Iwasaki, S. Takenoiri, H. Tanaka, H. Mutoh, and N. Yoshikawa: IEEE Trans. Magn., **45**, 3816 (2009).
3. Y. Inaba, T. Shimatsu, S. Watanabe, O. Kitakami, S. Okamoto, H. Muraoka, H. Aoi, and Y. Nakamura: J. Magn. Soc. Jpn., **31**, 178 (2007).
4. A. Berger, N. Supper, Y. Ikeda, B. Lengsfield, A. Moser, and E. E. Fullerton: Appl. Phys. Lett., **93**, 122502 (2008).
5. A. Oyama, T. Komine, and R. Sugita: Eur. Phys. J. Woc., **40**, 07003 (2013).
6. A. Oyama, T. Komine, and R. Sugita: J. Magn. Soc. Jpn., **37**, 62 (2013).
7. S. Greaves, Y. Kanai, and H. Muraoka: IEEE Trans. Magn., **45**, 3823 (2009).
8. N. Sheeda, M. Nakazawa, H. Konishi, T. Komine, and R. Sugita: IEEE Trans. Magn., **45**, 3676 (2009).
9. T. Komine, T. Murata, Y. Sakaguchi, and R. Sugita: IEEE Trans. Magn., **44**, 3416 (2008).
10. A. Izumi, Y. Nagahama, T. Komine, R. Sugita, and T. Muranoi: J. Magn. Soc. Jpn., **30**, 184 (2006).