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Numerical analysis of perpendicular magnetic printing for hard disks beyond 2 Tb/in^2

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Abstract

A micromagnetic analysis of magnetic printing onto an exchange-coupled composite (ECC) media was performed with a data signal density of over 2 Tb/in^2. Magnetic printing is a promising method of recording a servo signal onto an ECC media with data signal densities beyond 2 Tb/in^2. The printing performance was close to 100% at servo signal densities of 1.0 and 1.7 Tb/in^2. There was an optimum intergrain coupling strength in ECC media at each servo signal density, and as the servo signal density increased, the optimum intergrain coupling strength became weaker.

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1. Introduction

Motivated by increased demand for large-capacity, high-density hard disks (HDs), a method of realizing HDs with storage densities beyond 2 Tb/in^2 has been investigated. Perpendicular magnetic printing, which can write a servo signal at high speed, high accuracy, and low cost, has been studied [1]. T. Murata et al. showed that perpendicular magnetic printing at 1 Tb/in^2 is feasible [2], [3]. In their work, a single-layer medium with high coercivity, which is different from that used in practical HDs, was assumed as the recording layer. It was reported recently that shingled magnetic recording [4] makes it possible to write at over 2 Tb/in^2 on an exchange-coupled composite (ECC) media [5]. In this study, the feasibility of perpendicular magnetic printing onto an ECC media with a data signal density over 2 Tb/in^2 was investigated using micromagnetic simulations.

2. Simulation

Figure 1 shows the model of magnetic printing used for the calculations performed in this study. Table 1 shows the parameters of the master medium. The patterned magnetic films had a saturation magnetization of 1900 emu/cm^3,

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a thickness of 40 nm, and a track pitch of 25 nm. The period of pattern in the cross-track direction is 50 nm, which is twice as a track pitch. The bit length of the patterned magnetic films was set to 25, 15 or 10 nm. The corresponding servo signal density was 1.0, 1.7, or 2.5 Tb/in^2, respectively. The bit length of a servo signal is usually 2 or 3 times as long as that of the corresponding data signal. Therefore, in the case of the above servo signal densities, the recording density of the data signal was above 2.0, 3.4, or 5.0 Tb/in^2, respectively. The master medium was divided into $2.5 \times 2.5 \times 2.5$ nm^3 cells. Table 2 shows the parameters of the recording layer, which was assumed to be an ECC medium [6]-[8]. The intergrain exchange coupling constant was set to 0 to 2×10^{-7} erg/cm. The interlayer exchange coupling constant was set 3×10^{-7} erg/cm. It was reported that, by using this value, the medium has the lowest H_c and the optimum printing performance [9]. The recording layer was divided into $5 \times 5 \times 5$ nm^3 cells. The magnetic spacing of 2.5 nm was assumed, which corresponds to the sum of overcoat layers of the master medium and the HD. Printing performance was estimated in the same manner as in previous reports [2], [3].

$$\text{Printing performance (\%)} = \frac{\iint M_z^{\text{ideal}} M_z^{\text{cal}}\, dxdy}{\iint M_z^{\text{ideal}} M_z^{\text{ideal}}\, dxdy} \times 100 \tag{1}$$

The printing performance was evaluated using eq. (1), where M_z^{ideal} is the z-component of an ideally printed magnetization and M_z^{cal} is the z-component of the calculated magnetization. If the recording layer is ideally magnetized, this value becomes 100%.

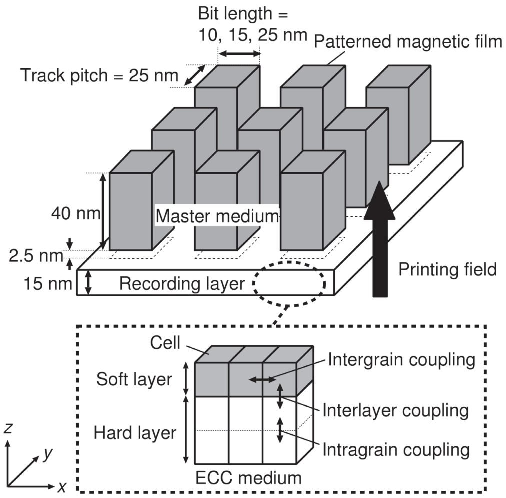

Fig. 1 Simulation model.

Table 1 Parameters of the master medium.

Parameters	Master medium
Thickness [nm]	40
M_s [emu/cm^3]	1900
H_k [kOe]	0
A [$\times 10^{-7}$erg/cm]	10

Table 2 Parameters of the recording layer.

Parameters	Recording layer	
	Hard layer	Soft layer
Thickness [nm]	10	5
M_s [emu/cm^3]	400	400
H_k [kOe]	15	5
ΔH_k [kOe]	1.5	0.5
$\Delta\theta_{50}$ [deg.]	10	10
$A_{\text{intragrain}}$ [$\times 10^{-7}$erg/cm]	10	–
$A_{\text{interlayer}}$ [$\times 10^{-7}$erg/cm]	3	
$A_{\text{intergrain}}$ [$\times 10^{-7}$erg/cm]	0 – 2	0 – 2

3. Results and discussion

Figure 2 shows the perpendicular component of the recording field along the center of the track. The printing field H_a was set to 4 kOe. The recording field is the sum of the printing field and the stray field from the master medium. The recording field at the contact area, which was the area immediately beneath the dots in the master medium, was strong while the recording field at the non-contact area was weak. As the servo signal density increased, the minimum magnetic field became stronger. Figure 3 shows the peak-to-valley value of the recording field. As the printing field increased, the peak-to-valley value of the recording field tended to saturate because the magnetization of the master medium saturated under a strong printing field. As the servo signal density increased, the peak-to-valley value of the recording field decreased at the same printing field.

Figure 4 shows magnetization distributions of a printed recording layer at 1.7 Tb/in^2. The white area represents $M_z/M_s = 1$, and the black area represents $M_z/M_s = -1$. The initial magnetization of the recording layer was set to $M_z/M_s = -1$. When the intergrain exchange coupling constant $A_{\text{intergrain}}$ was 0.6×10^{-7} erg/cm, the magnetization pattern was clearly printed. For weaker intergrain coupling, the magnetization pattern was noisy. For stronger intergrain coupling, there were connections of the reversed and the non-reversed regions. Figure 5 shows the dependence of printing performance on the intergrain exchange coupling constant. There was an optimum intergrain coupling strength in ECC media at each servo signal density. Increasing the servo signal density, reduced the optimum strength of the intergrain coupling.

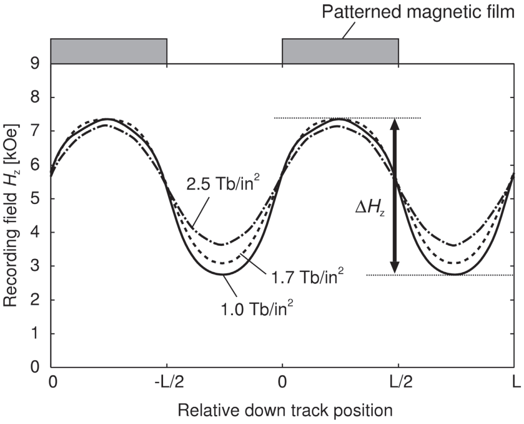

Fig. 2 Perpendicular component of the recording field along the center of the track at various servo signal densities. $H_a = 4$ kOe.

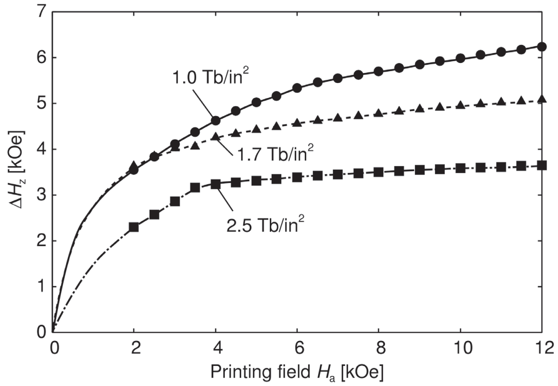

Fig. 3 Peak-to-valley value of the perpendicular component of the recording field ΔH_z as a function of the printing field H_a.

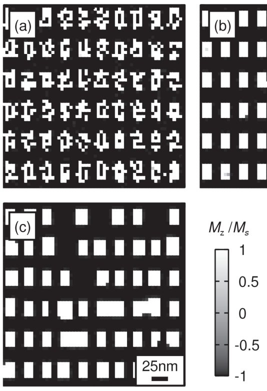

Fig. 4 Magnetization distributions of the printed recording layer at 1.7 Tb/in^2 with various intergrain exchange coupling constant: (a) 0, (b) 0.6, and (c) 1.2 [$\times 10^{-7}$ erg/cm].

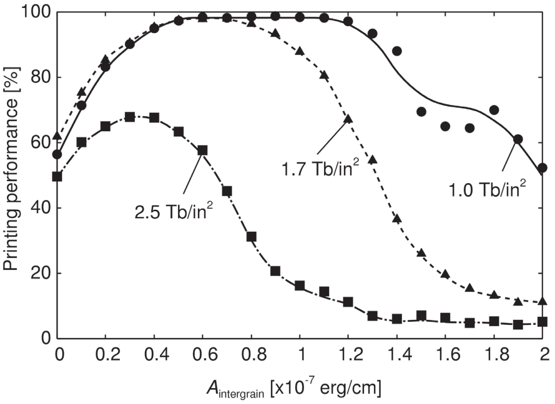

Fig. 5 Dependence of the printing performance on intergrain exchange coupling constant. $H_a = 4$ kOe

Figure 6 shows magnetization distributions of printed recording layers with various servo signal densities. The printing field and the intergrain exchange coupling constant were set to the optimum value for each density. As shown in Figs. 6(a) and (b), the magnetization of the recording layer was clearly reversed over the area in contact with the patterned parts of the master medium, while the initial magnetization of the recording layer was preserved in the non-contact area. These results indicate that it is possible to write a servo signal on an ECC media with a data signal density of a few Tb/in^2 using the magnetic printing. However, in the case of Fig. 6 (c), the printed patterns of the recording layer were unclear. This is because the peak-to-valley value of the recording field became smaller as the recording density increased. Figure 7 shows the printing field dependence of printing performance for various servo signal densities. Intergrain exchange coupling constant was set to the optimum value for each density. The optimum printing field changed little, even when the recording density was increased. When the optimum printing field was applied, the printing performance was almost 100% at 1.0 and 1.7 Tb/in^2, and about 70% at 2.5 Tb/in^2.

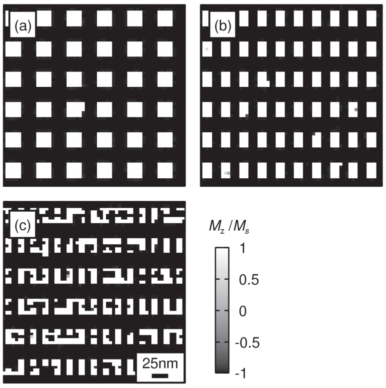

Fig. 6 Magnetization distributions of printed recording layers with various signal densities: (a) 1.0, (b) 1.7, and (c) 2.5 Tb/in^2. Intergrain exchange coupling constant: (a) 0.8, (b) 0.6, and (c) 0.4 [× 10^{-7} erg/cm].

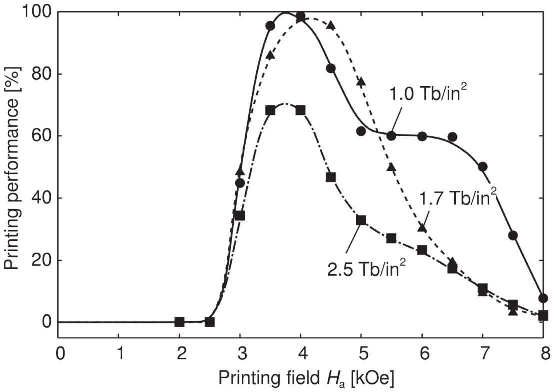

Fig. 7 Printing field dependence of the printing performance for various servo signal densities. Intergrain exchange coupling constant: (1.0 Tb/in^2) 0.8, (1.7 Tb/in^2) 0.6, and (2.5 Tb/in^2) 0.4 [× 10^{-7} erg/cm].

4. Conclusion

Micromagnetic analysis indicated that magnetic printing onto an ECC medium is a promising method of writing servo signals with data signal densities above 2 Tb/in^2 was carried out. The printing performance was almost 100% at servo signal densities of 1.0, and 1.7 Tb/in^2. There was an optimum intergrain coupling strength in ECC media at each servo signal density. As the servo signal density increased, the optimum strength of intergrain coupling decreased.

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