Micromagnetic study of magnetic printing onto various slave media

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Abstract. In this paper, the micromagnetic analysis of magnetic printing onto various slave media, such as the coupled granular-continuous media (CGC) and exchange coupled composite media (ECC) was carried out. In the single-layered granular medium, the magnetization patterns are printed on the slave medium corresponding to the master patterns, but defects appear in the center of the magnetization pattern in this case. On the other hand, in the CGC and ECC media, there is no defect in the center of the magnetization patterns due to the effect of a capping layer. The bit squareness in ECC medium is superior to those of the other media. It is clarified that the magnetic printing can be applied onto various media.

1. Introduction
Perpendicular magnetic recording media are currently used in hard disk (HD) drives, and the search for higher recording densities continues. In order to achieve high areal density, various recording media, such as coupled granular-continuous (CGC)[1], exchange coupled composite (ECC)[2], and so on, have been developed by some authors. These composite media consist of several layers with different magnetic properties in order to improve writability and thermal stability. On the other hand, discrete track media (DTM)[3] and bit patterned media (BPM) have been also investigated for achieving ultra-high recording density. But, the development of the fabrication process is a serious issue to realize DTM and BPM.

Servo track writing onto various media becomes a serious issue as the recording density increases. Magnetic printing is a strong candidate for writing servo signal with high speed, high accuracy and low cost to fulfill the requirements for high density HDs[4][5]. Although the servo signals in DTM and BPM may be embedded in HDs, magnetic printing is still a strong candidate for the composite media such as CGC and ECC. However, the influence of the recording media (slave media) structure on magnetic printing characteristics has not been discussed yet. In this paper, the micromagnetic analysis of magnetic printing onto various slave media was carried out.

2. Calculation model
The bit printing characteristics onto various composite media were investigated in this study. The slave medium is uniformly magnetized by applying an initial magnetic field along the perpendicular direction to the recording layer at the first stage of printing process. The patterned master medium is contacted with the slave medium and the printing field $H_a$ is applied along the
opposite direction of the initial magnetic field. Then, the uneven patterns of the master medium is printed onto the slave medium as magnetization pattern. Figure 1 shows the calculation model of the printing by the master medium with dot pattern. There are $3 \times 3$ dot patterns of master medium and slave medium in this calculation region. The magnetic pattern of FeCo film has a saturation magnetization of 1900 emu/cm$^3$ and a permeability of 100. The patterned magnetic film was assumed to be periodic dots with dimensions of 30 nm $\times$ 30 nm $\times$ 50 nm and a pitch of 100 nm. These dimensions were optimized in order to magnetically print the pattern with the bit length of 50 nm and the track width of 50 nm.

For perpendicular recording media consisting of a 20 nm recording layer, three types of recording layer, (i) single-layered (SL) media, (ii) CGC media, and (iii) ECC media, were compared. The calculation model of composite recording layer (slave medium) such as CGC and ECC is shown in Fig.2. This model consists of 15 nm-thick granular layer and 5 nm-thick capping layer. When the magnetic properties of a capping layer is the same as that of the granular layer, the medium is a single-layered granular medium. When a capping layer is a continuous layer and magnetically hard, and the capping and the granular layers are coupled with a coupling strength of $A_{IL}$, the medium is a CGC medium. When a capping layer is a soft or semi-hard granular layer with intergrain exchange coupling constant of $A_{IG}$, the medium is an ECC medium.

Figure 1. Calculation model of printing by master medium with dot pattern.

The magnetic parameters in each recording layer are shown in Table 1, where $H^k_g$ is an anisotropy field in the granular layer, $H^k_c$ is an anisotropy field in the capping layer, $A^k_{IG}$ is an intergrain exchange coupling constant in the granular layer, $A^k_{IL}$ is an intergrain exchange coupling constant in the capping layer and $A_{IL}$ is an interlayer exchange coupling constant between the capping and granular layers. Various recording layers have been proposed by some authors as mentioned above. Since these recording layers are based on different concepts about recording density, thermal stability and writability, the magnetic properties of these recording layer are different. The anisotropy field dispersion was set to 10 % of $H^k_c$ in each case. The ECC#1 has the soft magnetic layer with weak interlayer coupling as the capping layer. The ECC#2 has the semi-hard magnetic layer as the capping layer. By arranging the magnetic parameters as shown in Table 1, all of these media have the coercivity of about 4.5 kOe and the slope at the coercivity, $4\pi dM/dH|_{H=H_c}$ of about 3.

The recording field of the printing in the application of printing field was calculated by the finite element method. Magnetization distributions in various printed slave media were calculated by micromagnetic simulation. The printing performance (PP) was evaluated by the following definition[5]:

$$PP = \frac{\sum_{\text{whole}} M_{ideal}^z M_{calc}^z}{\sum_{\text{whole}} M_{ideal}^z M_{ideal}^z},$$  \hspace{1cm} (1)
Table 1. Magnetic parameters in three types of recording layer

| Media  | $M_s$ [emu/cm$^3$] | Anisotropy field [kOe] | Exchange coupling [$\times 10^{-6}$ erg/cm] |
|--------|-------------------|------------------------|------------------------------------------|
|        |                   | $H_E^G$ | $H_C^f$ | $A_{IG}^G$ | $A_{IG}^C$ | $A_{IL}$ |
| SL     | 600               | 11      | 11      | 0.15       | -           | -         |
| CGC    | 600               | 11      | -       | 0.01       | 1.0         | 0.5       |
| ECC#1  | 500               | 15      | 0       | 0.2        | 0.2         | 0.7       |
| ECC#2  | 500               | 12      | 5       | 0.2        | 0.2         | 0.7       |

where $M_{ideal}^z$ and $M_{calc}^z$ are the $z$-component of ideal magnetization and calculated magnetization, respectively. And the bit squareness (BS) of printed patterns was also evaluated by the following definition:

$$BS = \frac{\sum_{cell \in edge} M_{ideal}^z M_{calc}^z}{\sum_{cell \in edge} M_{ideal}^z M_{ideal}^z}. \quad (2)$$

If the printed magnetization is the ideal magnetization distribution, these evaluated values are 100%.

3. Results and discussion

Figure 3 shows the magnetization distributions of single-layered granular, CGC and ECC media, respectively. These magnetizations were printed by the application of each optimum printing field to be about 1 kOe lower than the coercivity. In the single-layered granular medium, the magnetization patterns are printed on the slave medium corresponding to the master patterns, but there are some defects in the center of the magnetization patterns. On the other hand, in the CGC and ECC media, there is no defect in the center of the magnetization patterns since the magnetization of the capping layer reverses more easily than that of hard magnetic granular layer. Moreover, in the CGC medium, the printed magnetization pattern percolates to the surrounding region, while the squareness of printed pattern is better than that of CGC in the ECC medium.

The printing performance and the bit squareness in three types of composite media are shown in Figs. 4 and 5, respectively. The printing performance onto composite media is very sufficient except ECC with soft capping layer, and the performance reaches up to about 90%. The bit squareness is also sufficient except ECC with soft capping layer. The bit squareness in ECC with semi-hard capping layer is superior to the other media. The bit squareness will be improved when the anisotropy dispersion and c-axis distribution are improved. Therefore, it is clarified that the magnetic printing can be applied onto various media.

4. Conclusions

In this paper, the micromagnetic analysis of magnetic printing onto various slave media was carried out. In the single-layered granular medium, the magnetization patterns are printed on the slave medium corresponding to the master patterns, but there are some defects in the center of the magnetization patterns. On the other hand, in the CGC and ECC media, there is no defect in the center of the magnetization patterns due to the effect of a capping layer. The bit squareness in ECC medium is superior to those of the other media. It is clarified that the magnetic printing can be applied onto various media.
Figure 3. Magnetization distributions of (a) single-layered granular medium, (b) CGC medium, and (c) ECC medium with a hard capping layer (ECC#2), which were printed by each optimum printing field.

Figure 4. Dependence of printing performance on the printing field in the composite media.

Figure 5. Dependence of bit squareness on the printing field in the composite media.

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References
[1] Greaves S. J, Muraoka H, Sonobe Y, Schabes M, Nakamura Y, 2001 J. Magn. Magn. Mater. 235 418.
[2] Victora R. H, Shen X, 2005 IEEE Trans. Magn. 41 537.
[3] Soeno Y, Moriya M, Kaizu A, Takai M, 2005 IEEE Trans. Magn. 41 3220.
[4] Sugita R, Kinoshita T, Saito O, Murano T, Nishikawa M, and Nagao M, 2000 IEEE Trans. Magn. 36 2285.
[5] Komine T, Murata T, Sakaguchi Y, and Sugita R, 2008 IEEE Trans. Magn. 44 3416.