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Influence of Geometrical and Magnetic Parameters on Magnetization Behavior for a Hard/Soft Magnetic Composite Pillar

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A hard/soft magnetic composite pillar array medium is proposed for the ultra high density recording medium. Magnetization reversal process for a single hard/soft magnetic composite pillar in the medium is calculated using the Landau-Lifshitz-Gilbert equation. In the case that the pillar size which corresponds to 1 Tbits/inch^2 or higher areal recording density, magnetization vectors for the soft magnetic unit do not form a domain wall nor a vortex. Hence, noise caused by the domain wall or the vortex for the soft magnetic unit is considered to be none. Magnetization reversal of the soft magnetic unit helps the magnetization reversal for the hard magnetic unit, reducing the effective coercivity for the hard magnetic unit greatly. Accordingly saturation recording to the high-K_u hard magnetic material used for perpendicular magnetic recording will be realizable.
Key words: CPA media, Hard/soft magnetic composite pillar, LLG equation, Vortex, Exchange interaction

1. INTRODUCTION

The growth of areal recording density for the hard disk drive is remarkable. Magnetic grains which compose a magnetic thin film are required to be smaller in order to achieve much higher areal recording density. Small magnetic grains, however, have less magnetic energy, which tends to be thermally unstable magnetization. Hence magnetic material with higher magnetic anisotropy energy (K_u) is required to obtain thermal stability. However, high-K_u material requires extraordinarily strong magnetic fields for the signal recording. These problems are called "trilemma", which the development of magnetic recording is now facing[1]. Patterned media which is composed of patterned hard magnetic material as bits aligned on a continuous soft magnetic underlayer, is considered to be a future recording media candidate for 1 Tbits/inch^2 or higher areal recording density[2,3]. The authors already proposed a new patterned media which is composed of patterned soft magnetic material as well as the hard magnetic material(Fig. 1)[4]. The media is called hard/soft magnetic composite pillar array media (CPA media). The CPA media is considered to be less noisy compared with the conventional recording media, because the soft magnetic unit is small enough not to create a magnetic domain wall nor a vortex which tend to generate noise in reproducing process. Noise is necessary to be smaller, because signal output decreases with increasing the areal recording density unless the value of the signal to ratio required for the signal processing is reduced. The CPA media is considered to have another specific feature that magnetization of the soft magnetic unit helps magnetization reversal of the hard magnetic unit even though the hard magnetic unit consists of thermally stable high-K_u material[5]. In this paper, magnetization behavior of a single hard/soft magnetic composite pillar is simulated using micromagnetic calculation and discussed in terms of geometrical and magnetic parameters of the pillar.

2. CALCULATION MODEL

Magnetization behavior is calculated using a micromagnetic simulator based on the Landau-Lifshitz-Gilbert (LLG) equation. In the micromagnetic simulation, the hard/soft magnetic composite (cylindrical) pillar shown in Fig. 1 is approximated by a pillar with a square cross section as shown in Fig. 2. The length of a side for the top square surface of the pillar is defined as D(variable), consequently the area of the recording dot becomes as D^2. Depth-direction lengths of the hard and soft magnetic units are set to 10 nm and L_S(variable). In the simulation, a cell size is fixed to 2.5×2.5×2.5 nm^3. The external applied magnetic field, magnetic anisotropy, magnetostatic and exchange fields are included as the effective fields in the LLG equation. The anisotropy field and the saturation magnetization for hard magnetic material are assumed to be 18 kOe and 1000 emu/cc. The

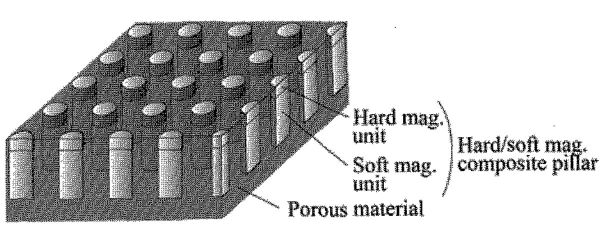

Fig. 1 Schematic view of hard/soft magnetic composite pillar array medium.

saturation magnetization for the soft magnetic pillar is 1200 emu/cc. The exchange constants for both the hard magnetic unit and the soft magnetic unit are assumed to be 1.0×10^{-6} erg/cm for cells. The exchange constant between the hard and soft magnetic units is defined as A_{int}(variable). In the simulation, the uniform external field is applied in parallel to the pillar depth direction. The strength of the external applied field is gradually changed with time at a field changing rate small enough compared with the magnetization vector motion.

3. RESULTS AND DISCUSSION

3.1 Magnetization hysteresis curve

Figure 3 shows the magnetization hysteresis curve for the single hard/soft magnetic composite pillar. The pillar top size, D, is 12.5 nm, the length of the soft magnetic unit, L_S, is 25 nm, and the exchange constant between the hard and soft magnetic units, A_{int}, is 0. The magnetization of the hard/soft magnetic composite pillar is saturated initially in the up direction by 20 kOe of the external applied field, and the magnetization curve is calculated as a function of the external applied field in the down direction. The magnetization for the hard and soft magnetic units separately switches as shown in Fig. 3. The effective coercivity for the hard magnetic unit is defined as H_{ch}, which stands for the magnetic field that the average magnetization for the hard magnetic unit is 0 in the applied field direction. The screen shots of the magnetization vectors at (a), (b), (c), (d) and (e) in the magnetization hysteresis curve, are shown in Fig. 4. Figure 4(a) is the one corresponding to the point(a) in Fig. 3, where both the hard and soft magnetic units are saturated in the upper direction. Figures 4(b) and (c) corresponding to the beginning((b) in Fig. 3) and near the end((c) in Fig. 3) of magnetization reversal for the soft magnetic unit, respectively. Figures 4(d) and (e) corresponding to the beginning((d) in Fig. 3) and after the end ((e) in Fig. 3) of magnetization

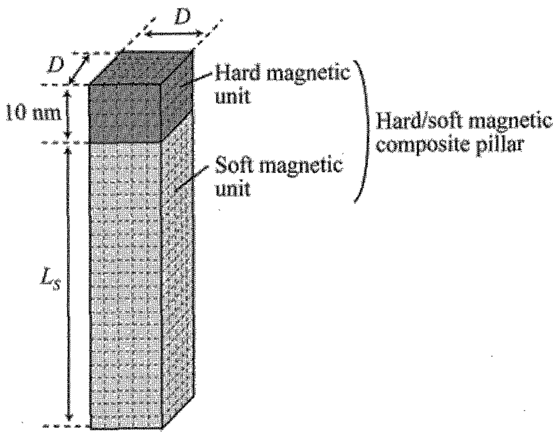

Fig. 2 Model of single hard/soft magnetic composite pillar employed for calculation.

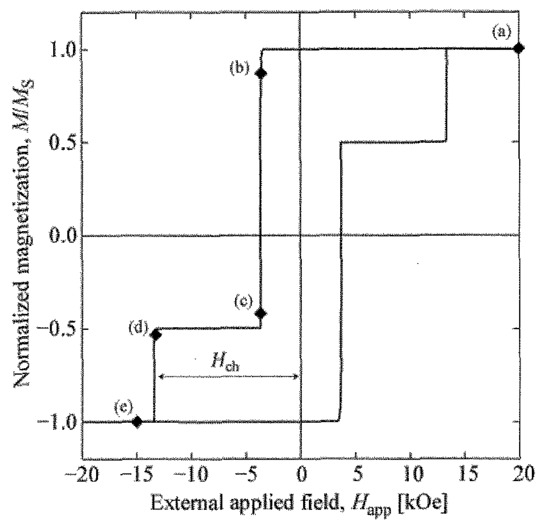

Fig. 3 Magnetization hysteresis curve for single hard/soft magnetic composite pillar.

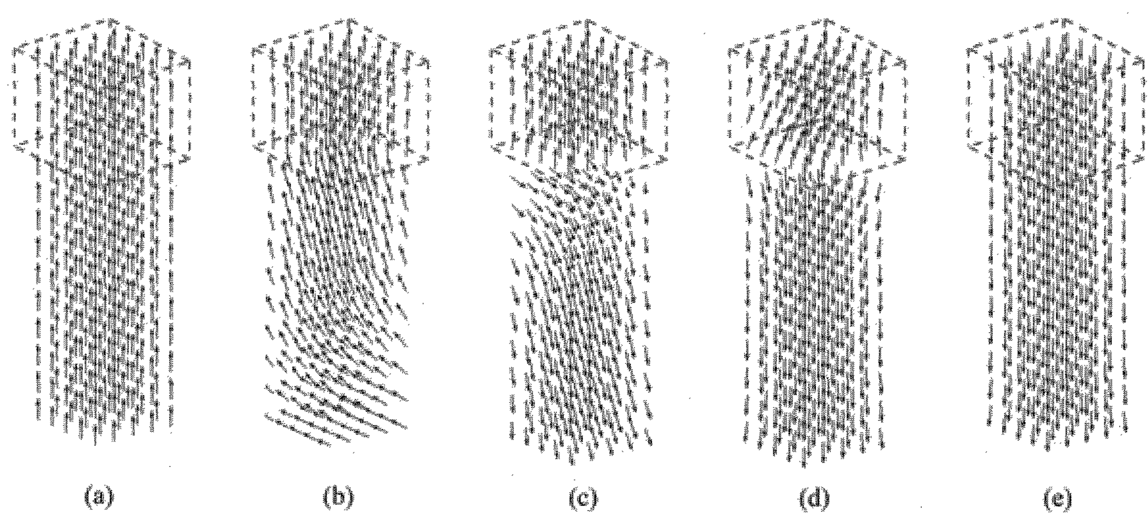

Fig. 4 Screen shots of magnetization vectors for hard/soft magnetic composite pillar. (a), (b), (c), (d) and (e) correspond to those shown in Fig. 3.

reversal for the hard magnetic unit, respectively. The magnetization vectors surrounded by the broken lines are for the hard magnetic unit. As seen in Fig. 4, the magnetization reversal starts at the bottom of the soft magnetic unit. This is because the magnetization vectors for the top of the soft magnetic unit are pinned at the initial magnetization direction by the hard magnetic unit. Figure 4 also indicates that the magnetization for the soft magnetic unit incoherently rotates, and the magnetization reversal is not due to domain wall motion. The magnetization reversal of the hard magnetic unit, however, is the coherent magnetization rotation for the calculated pillar size.

3.2 Effects of the aspect ratio for the pillar

Figure 5 shows magnetization curves for the hard/soft magnetic composite pillar with the pillar top size, D, as a parameter. The soft magnetic unit length, L_S, is fixed to 25 nm and the exchange constant between the hard and soft magnetic units, A_{int} is 0 in this calculation. Magnetization of the soft magnetic unit abruptly reverses at a specific magnetic reverse field in the case of D equal to or smaller than 12.5 nm. On the other hand, the magnetization of the soft magnetic unit gradually reverses with increasing the applied reverse fields when D is equal to or larger than 25 nm. The behavior of the magnetization reversal for the soft magnetic unit depends on the pillar size. Figure 6 shows magnetization vectors for D of 37.5 nm at 1 kOe of magnetic reverse field. In Fig. 6, only odd number layers for the soft magnetic unit are shown. Vortex formation of the magnetization vectors is seen in the figure. The decrease of aspect ratio(L_S/D), with increasing D, causes the larger demagnetizing field in the depth direction of the pillar. A vortex state is formed to reduce the magneto-static energy. The effective coercivity for the hard magnetic unit decreases with the increasing demagnetizing field. The magnetostatic field of the soft magnetic unit interacting with the hard magnetic unit also reduces the effective coercivity for the hard magnetic unit.

The vortex formation is affected by the pillar top size, D. In the case that D is equal to or smaller than 12.5 nm, magnetization vectors do not form the vortex even though the aspect ratio is as small as 0.4. The reason is considered that the magnetization does not have much energy to form a vortex because of the small pillar top size. The strength of the exchange interaction between neighboring cells is also considered to affect the formation of the vortex. Further investigation is required to discuss the formation of the vortex in detail.

No magnetic domain walls are observed for the calculated pillar as shown in Figs. 5 and 6. However, when D is equal to or greater than 25 nm, magnetization of the soft magnetic unit changes with a relatively small applied field as shown in Fig. 5. The change in the magnetization of the soft magnetic unit due to weak stray fields likely induces noise in the reproducing process. The pillar top size, D, of the patterned media is required to be below half of a dot pitch [6]. Therefore, for the CPA media for 1 Tbits/inch^2 the pillar top size, D becomes to 12.5 nm. Thus, the noise generated by stray fields is considered to be negligible for the CPA media for the 1 Tbits/inch^2 or higher. However, the noise which might be generated by geometric factors such as the distribution of the pillar size must be considered.

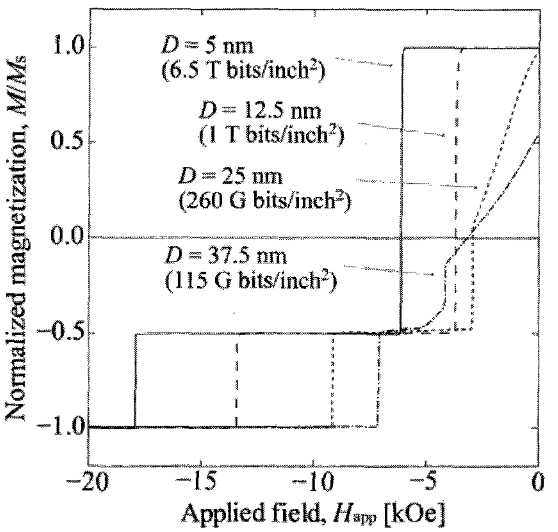

Fig. 5 Magnetic hysteresis curves of single hard/soft magnetic composite pillar as a function of pillar top size, D. (L_S=25 nm, A_{int}=0)

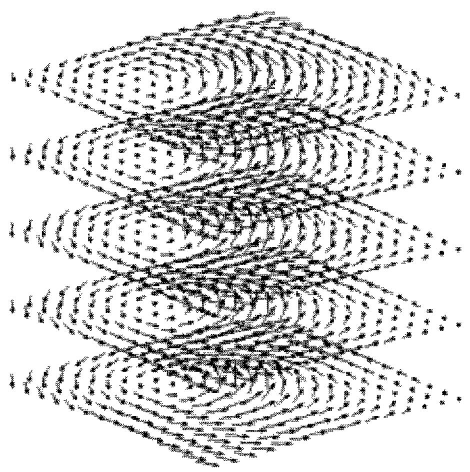

Fig. 6 Magnetization vector configuration for soft magnetic unit. (D=37.5 nm, L_S=25 nm, A_{int}=0)

3.3 Reduction in effective coercivity for hard magnetic unit

Figure 7 shows the dependence of the effective coercivity of the hard magnetic unit, H_{ch}, on the length of the soft magnetic unit with a parameter of the exchange constant between the hard and soft magnetic units. In this calculation, the pillar top size, D, is 12.5 nm. For L_S is 0 nm, i.e. in the case when the hard magnetic unit only exists, H_{ch} is about 16 kOe. A_{int} is 0 erg/cm means that the hard/soft magnetic composite pillar does not have exchange interaction between the hard and soft magnetic units. The reduction in H_{ch} in the case of 0 erg/cm of A_{int} shown in Fig. 7, is due to the magnetostatic interaction fields generated by the soft magnetic unit. H_{ch} decreases with increasing L_S up to 25 nm and becomes constant for L_S above 25 nm. The reduction in H_{ch} is larger when A_{int} is larger, which implies that the large exchange constant is an important parameter for the hard magnetic unit to achieve the magnetization reversal easily by recording head fields. 25 nm of L_S is long enough to obtain the effect of the soft magnetic unit to enhance the magnetization reversal for the hard magnetic unit as shown in Fig. 7. In conclusion, Fig. 7 implies that H_{ch}, is controllable to a designed value by the values of L_S and A_{int}.

The interesting magnetization reversal mechanism for the CPA media is that the magnetization reversal starts at the bottom of the soft magnetic unit, which strongly affects the effective coercivity of the hard magnetic unit. If the magnetization at the bottom of the soft magnetic unit reverses with a weak applied field, the effective coercivity of the hard magnetic unit greatly decreases. Controllable H_{ch} is desirable for the saturation recording of high-K_u media for ultra high density recording.

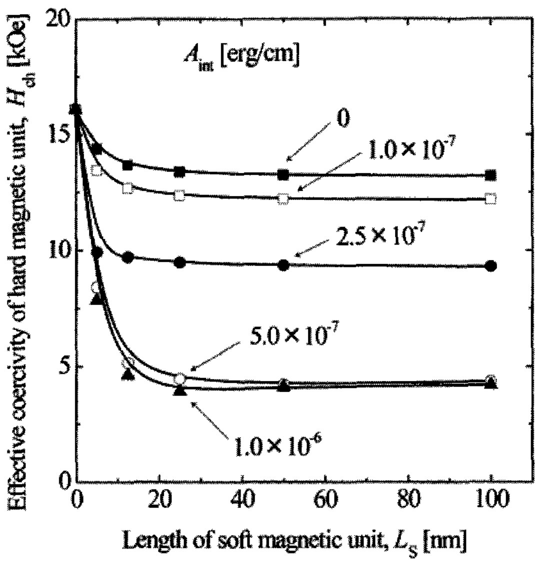

Fig. 7 Dependence of effective coercivity for hard magnetic unit on length of soft magnetic unit.

4. CONCLUSION

Magnetization reversal of a single hard/soft magnetic composite pillar is simulated using micromagnetic calculation. No magnetic domain walls or vortex appear in the single hard/soft magnetic composite pillar of which the size corresponds to 1 Tbits/inch^2 or higher areal recording density. Hence, noise caused by a domain wall or a vortex for the soft magnetic unit is considered to be none. It was proved that magnetization reversal of the soft magnetic unit is the most important to control the effective coercivity of the hard magnetic unit, for the hard/soft magnetic composite pillar array media system. The effective coercivity for the hard magnetic unit is also found to be greatly reduced by the strong exchange interaction between the hard and soft magnetic units, which helps saturation recording to the high-K_u hard magnetic material to be used for perpendicular magnetic recording by limited head field strength.

5. References

[1] H. J. Richter, *Appl. Phys.*, **40**, R149-R177 (2007).

[2] R. L. White, R. M. H. New, R. F. W. Pease, *IEEE Trans. Magn.*, **33**, 990-995(1997).

[3] H. J. Richter, A. Y. Dobin, R. T. Lynch, D. Weller, R. M. Brockie, O. Heinonen, K. Z. Gao, J. Xue, R. J. M. v. d. Veerdonk, P. Asselin, M. F. Erden, *Appl. Phys. Lett.*, **88**, 222512(2006).

[4] T. Tanaka, S. Murakami, K. Oshiro, H. Fujimori, H. Kurisu, M. Matsuura, and S. Yamamoto, *Abstract of Spring Meeting of Japan Society of Powder and Powder Metallurgy*, 138 (2006).

[5] T. Tanaka, J. R. Kim, J. Matsuzaki, H. Kurisu and S. Yamamoto, *Digests of PMRC2007*, 224-225(2007).

[6] N. Honda, K. Yamakawa, and K. Ouchi, *IEEE Trans. Magn.*, **43**, 2142-2144(2007).

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