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Composite perpendicular magnetic recording media using [Co/PdSi]$_n$ as a hard layer and FeSiO as a soft layer

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We fabricated the composite perpendicular magnetic recording (PMR) media successfully for the first time by combining a nanogranular FeSiO soft layer and a [Co/PdSi]$_n$ hard layer. PdSi spacing layer (0–4 nm) was used to study the exchange coupling effects between the FeSiO(5 nm) and the [Co(0.26 nm)/Pd(1 nm)]$_{14}$ layers in the composite films. Proper coupling occurs when PdSi interlayer is ~0.5 nm. Significant lowering of the coercivity is observed for the composite PMR medium while still maintaining good thermal stability. The results prove the possibility to fabricate a writable PMR medium having an ultrahigh magnetic anisotropy constant K_u value. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1853194]

I. INTRODUCTION

Longitudinal magnetic recording may finally be limited to around 200–300 Gbit/in.[2] due to many constraints. In order to achieve higher density recording, perpendicular magnetic recording was proposed about 20 years ago[1] and is now considered as a promising candidate to extend recording density to 1 Tbit/in.[2].[2] Using traditional scaling technology to increase the areal density, materials with ultrahigh K_u (K_u, magnetic anisotropy constant), such as ordered FePt alloys, are considered to be useful as perpendicular recording media.[3] However, the high writing field required will be a serious problem, since it is roughly proportional to K_u/M_s (where M_s is the saturation magnetization) that far exceeds the currently obtainable PMR head writing field.[4] Tilted magnetic recording has been proposed to alleviate this problem.[5,6] By adjusting the easy axis to 45° from perpendicular direction, the switching field is decreased to 0.5 H_k as compared with H_k in the perpendicular case. However, in spite of the advantages of the tilted media, its fabrication difficulty blocks it from wide use in practical applications. Thus, new media structures that are easier to fabricate and retain the lower writing field properties of 45° tilted media are quite attractive. Recently, a composite PMR medium consisting of two vertically exchange-coupled magnetic layers (one layer is magnetically soft and other layer is magnetically hard) within each grain has been proposed to address this problem.[7,8] This bilayer structure uses a magnetically soft and hard layer that is different from the traditional soft underlayer used with PMR media since there exists an exchange coupling between vertically-adjacent grains in the soft and hard layers. With proper exchange-coupling, the soft layer will rotate first under the external field while at the same time providing an exchange field to the hard layer thus tilting the magnetization of the hard layer away from its easy axis, forming a dynamic tilted media. In this study, we have fabricated the composite PMR media by combining a nanogranular magnetic soft layer (in the present study FeSiO) and a magnetic hard layer (in the present study [Co/Pd]$_n$). The microstructure and the magnetic properties are presented in this paper.

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II. EXPERIMENT

The magnetic soft layer and the hard layer were deposited using an 8-target dc magnetron sputtering system. Pure Fe, Co, Pd, Si were used as cosputtering targets. Pure argon (99.999%) and mixture gas of oxygen and argon (O_2/Ar 10 vol%) were used as working gas. The substrate was a Corning cover glass. The base pressure of the sputtering chamber was 3×10^{-7} Torr. Sputtering pressure was 3×10^{-3} Torr for FeSiO and 8.5×10^{-3} Torr for [Co/Pd]$_n$, respectively. The magnetic properties were measured using a vibrating sample magnetometer (VSM). The grain sizes were observed using transmission electron microscopy (TEM). The electrical resistivity was measured using a four-probe method.

III. RESULTS AND DISCUSSION

It has been reported that a granular microstructure is formed in CoSiO films.[9] Here, nanogranular FeSiO ultrathin films were fabricated using Si and oxygen doping as well as tuning the film thickness. Silicon was doped by cosputtering a pure Si with a pure Fe target. When the film thickness is fixed, increasing the flow ratio of $O_2/(Ar+O_2)$ results in a continuous decrease of the magnetization. When the $O_2/(Ar+O_2)$ ratio was increased to 1.8% or even larger, the remanent magnetization dropped to 0 abruptly and the film became superparamagnetic, as shown in Figs. 1(a) and 1(c). Figure 2 shows the relationship between the film resistivity and O_2 gas flow ratio in Ar sputtering gas. An abrupt jump of the electrical resistivity occurred while $O_2/(Ar+O_2)$ was 1.8%, which confirms the superparamagnetic behavior in the film. TEM images revealed that an isolated nanogranular structure with an average grain size of 5.4 nm was formed in the film as shown in Fig. 3.

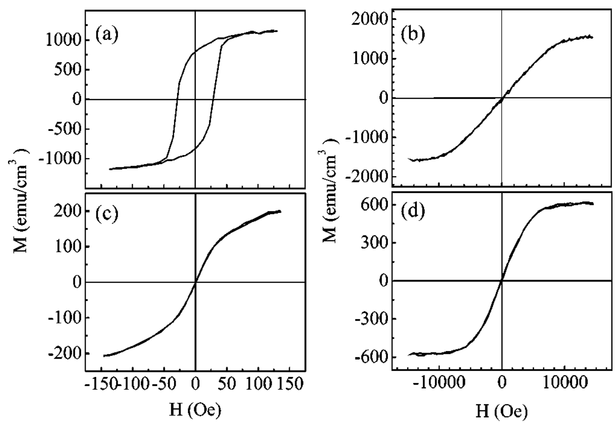

FIG. 1. Hysteresis loop of FeSiO(10 nm)/Glass. (a) and (b): $O_2/(Ar+O_2)=1.5\%$. (c) and (d): $O_2/(Ar+O_2)=1.8\%$. (a) and (c) were measured in the longitudinal direction; (b) and (d) were measured in the perpendicular direction.

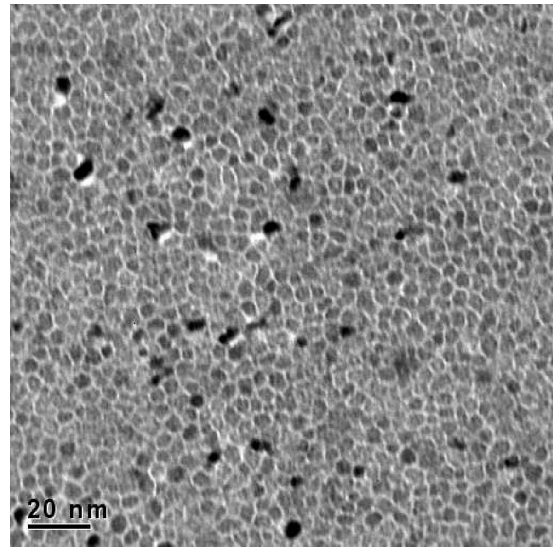

FIG. 3. TEM bright field image of FeSiO(10 nm)/amorphous carbon. The average grain size is 5.4 nm.

The hard layer structure is Si(1 nm)/[Co(0.26 nm)/PdSi(1 nm)]$_{14}$/Pd–SiO_2(4 nm)/RuAl(4 nm)/Glass. A seed layer of RuAl was employed to grow the $[Co/Pd]_n$ hard layer. RuAl has a B2 crystal structure with strong bonding forces between Ru and Al, which results in very small crystallite sizes.[10,11] SiO_2 and pure Si were doped into the Pd initial layer and the Pd multilayer, respectively, to form the granular structure in the film thus decreasing the exchange coupling between grains.[12,13] TEM images revealed the same average grain size ($D\sim 7.8$ nm) and grain size distribution ($\Delta D/D\sim 20\%$) for Si(1 nm)/[Co(0.26 nm)/PdSi(1 nm)]$_{14}$/Pd-SiO_2(4 nm)/RuAl(4 nm) and Si(1 nm)/FeSiO(5 nm)/PdSi(t nm)/[PdSi(1 nm)/Co(0.26 nm)]$_{14}$/Pd-SiO_2(4 nm)/RuAl(4 nm) within the testing tolerance. The average grain size of FeSiO was expanded from 5.4 nm on the amorphous substrate to 7.8 nm on the granular $[Co/PdSi]_n$ layer. This result confirms a columnar growth of the magnetic soft FeSiO grain on a magnetically hard $[Co/PdSi]_n$ grain.

The exchange coupling strength between the $[Co/PdSi]_n$ hard grain and the FeSiO soft grain was manipulated through a PdSi interlayer. Figure 4 shows the coupling dependence of coercivity for Si(1 nm)/FeSiO(5 nm)/PdSi(t nm)/[PdSi(1 nm)/Co(0.26 nm)]$_{14}$/Pd-SiO_2/RuAl(4 nm)/Glass. The minimum coercivity field H_c happens at $t=0.5$ nm, with $H_c=1.75$ kOe, while for the strong coupling case ($t=0$ nm), H_c is increased to 2.91 kOe. For the exchange-decoupled case ($t=4$ nm), $H_c=4.05$ kOe, which is very near to the original value of a single hard layer ($H_c=4.35$ kOe).

Figures 5(a)–5(c) show the hysteresis loop of a single hard layer, the proper coupling case ($t=0.5$ nm), and the decoupled case ($t=4$ nm). For the proper coupling case, uniform switching behavior is observed, while for the decoupling case (c), the switching is divided into 2 phases very clearly. The soft region is reversed first, starting from 5 kOe, with a slope $a_{\rm soft}=1.1(\alpha=4\pi(dM/dH)|_{H=H_c})$, which is the slope for the switching along the hard axis direction of the soft grain as shown in Fig. 2(d). After the switching of the soft region is finished, the switching behavior of the hard layer is shown, with a slope of $\alpha_{\rm hard}=1.5$, which is the same as the slope of the hard layer case as shown in Fig. 5(a).

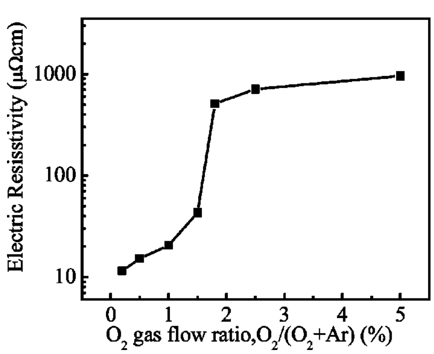

FIG. 2. Relationship between the electrical resistivity of FeSiO films and the O_2 gas flow ratio in sputtering gas.

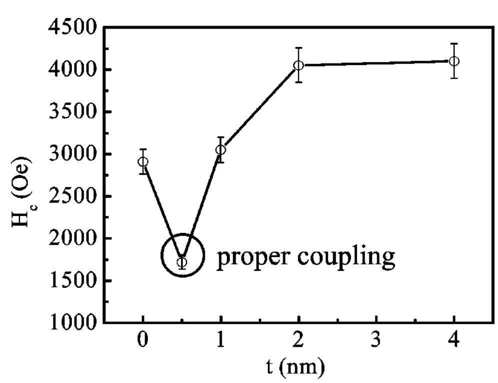

FIG. 4. Coupling dependence of H_c (t: thickness of PdSi interlayer).

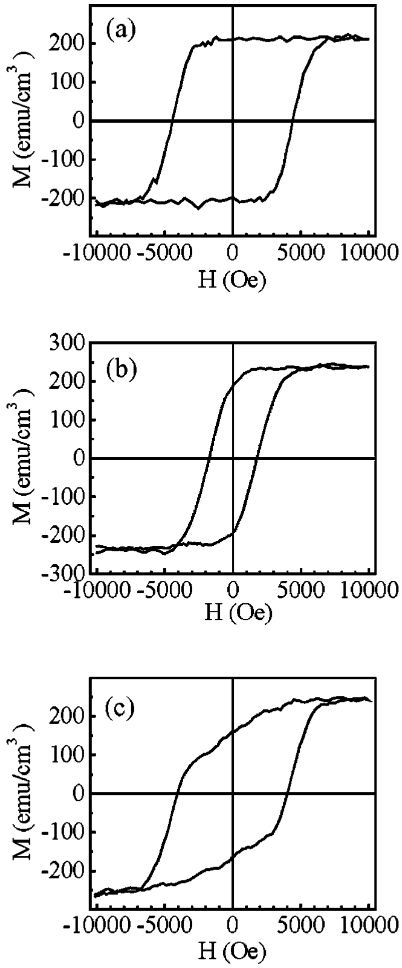

FIG. 5. Hysteresis loop in the perpendicular direction. (a) Si(1 nm)/[PdSi(1 nm)/Co(0.26 nm)]$_{14}$/Pd–SiO$_2$/RuAl(4 nm)/Glass; (b) and (c) Si(1 nm)/FeSiO(5 nm)/PdSi(t nm)/[PdSi(1 nm)/Co(0.26 nm)]$_{14}$/Pd-SiO$_2$(4 nm)/RuAl(4 nm)/Glass. t=0.5 nm and 4 nm for (b) and (c), respectively.

The decrease of the coercivity for the proper coupling case may be understood in the following way. When the hard and soft regions are strongly coupled together, the switching field can be expressed as

$$H_{c,\mathrm{strong}} = H_c \frac{M_h t_h}{M_s t_s + M_h t_h}. \quad (1)$$

Here, M and t denote the magnetization and thickness of each region. Subscript s and h denote the soft and the hard region, respectively. H_c is the coercivity field of the hard layer only. In our experiment, M_h=210 emu/cm^3, t_h =17.5 nm, M_s=400 emu/cm^3, t_s=5 nm. Thus $H_{c,\mathrm{strong}}$ =2.80 kOe. This is very near to the experimental value (2.91 kOe) for t=0 nm, which is thought to be the strong coupling case. For the proper coupling case (t=0.5 nm), the switching process may be different from this. Application of reversed field initially causes the magnetization of the soft region to rotate and thus changes the angle of the effective field (including the applied field and the exchange field) applied to the hard region, forming a dynamic tilted media. At a critical point, which is very similar to the 45° tilted media case, the hard region is switched at about half of the original coercivity field. The observed value (1.72 kOe) is somewhat lower than this number (2.17 kOe), which may be due to the partially exchange coupling in the hard layer (since α_{hard} is 1.5, not 1.0 for the fully exchange decoupled).

The thermal stability factor was obtained from the dynamic coercivity versus time test. Using the well known Sharrock equation,[14] the ratio of $K_u V^* / k_B T$ was fitted.[15] Here, V^* is the activation volume. For the single hard layer case and the exchange-decoupled case, the thermal stability ratios are 74 and 71, respectively. For the proper coupling case, $K_u V^* / k_B T$ is 58. It is lower than the decoupled case and the single hard layer case, but the ratio of the thermal stability factor over the switching field for the proper coupled case (composite media) is about two times of the hard layer only case (pure perpendicular media). Thus once high K_u materials like ordered FePt are used for PMR media in near future, writable media with high thermal stability could be achieved based on the composite PMR media design.

IV. CONCLUSIONS

The composite PMR medium has been fabricated successfully for the first time by combining the nanogranular FeSiO soft layer and the [Co/PdSi]$_n$ hard layer. Proper exchange coupling occurred when the PdSi interlayer was ~0.5 nm. Significant lowering of the coercivity field was observed for the composite media while still keeping high thermal stability. The results proved that it is possible to fabricate a writable perpendicular recording media with ultrahigh K_u value.

ACKNOWLEDGMENTS

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