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Effect of Co layer thickness on the magnetic properties of $Tb_{30}Co_{70}/SiN_x/Co$ thin films

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ABSTRACT

The SiN_x (20 nm)/$Tb_{30}Co_{70}$ (90 nm)/SiN_x (5 nm)/Co (3–37 nm)/SiN_x (10 nm)/Si multilayer films are deposited on naturally oxidized Si wafer by magnetron sputtering. The saturation magnetization (M_s) of the multilayer films is increased with the thickness of high M_s ferromagnetic Co layer. The perpendicular coercivity ($H_{c\perp}$) value is increased with Co layer thickness as the thickness of the Co layer is lower than 15 nm and then decreases drastically when the thickness of the Co layer further increased. The increase of the $H_{c\perp}$ value is owing to the interlayer exchange effect [Li Zhang, Physica B 390 (2007) 373] between TbCo and Co layers. Co under-layer with in-plane magnetic anisotropy would pin the magnetic moment of the TbCo layer near by the Co layer and cause the value of $H_{c\perp}$ to increase. However, as the Co layer is thicker than a critical thickness, the $H_{c\perp}$ value of the multilayer film would decrease. Therefore, the Co layer with in-plane magnetic anisotropy and soft magnetic properties is expected to dominate the magnetic properties of the multilayer films.

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1. Introduction

Heat-assisted magnetic recording (HAMR) method had been proposed for future ultra-high density magnetic recording [1–3]. Very small recording bit size is needed for an ultra-high density magnetic recording. However, the decrease of recording bit size is limited by the thermal stability of recording bit.

Amorphous TbCo alloy film is a promising candidate for HAMR medium due to its excellent perpendicular anisotropy and large $H_{c\perp}$. Moreover, the amorphous TbCo without grain boundaries is expected to have low noise and large signal-to-noise ratio. However, the saturation magnetization (M_s) of the ferrimagnetic TbCo film is too small (~150 emu/cm^3) for GMR head to readout.

In this paper, we investigate the magnetic properties of sputtered TbCo/SiN_x/Co multilayer films and discuss its potential for HAMR medium application. A ferromagnetic Co layer with large M_s is introduced under the TbCo alloy film in an attempt to enhance the M_s of multilayer films. The exchange coupling effect at the interface of the hard and soft magnetic layers is revealed in the *M*–*H* loop.

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2. Methods

The SiN_x (20 nm)/$Tb_{30}Co_{70}$ (90 nm)/SiN_x (5 nm)/Co (3–37 nm)/SiN_x (10 nm)/Si multilayer films were deposited on nature-oxidized Si (1 0 0) wafer at room temperature. In which the SiN_x is used to prevent TbCo and Co from oxidization and diffusion between the TbCo layer and Co layer during the HMAR writing process [3]. The TbCo film was fabricated by dc magnetron co-sputtering (base pressure was 5×10^{-7} Torr) of pure Tb (99.95%) and Co (99.95%). The power of magnetron gun of Co and Tb was kept at 2.32 and 0.99 W/cm^2, respectively. The Co film was also fabricated by dc magnetron. The power of the magnetron gun of the Co target was kept at 2.96 W/cm^2. The SiN_x film was prepared by rf magnetron sputtering of the Si_3N_4 target. The power of the magnetron gun of the Si_3N_4 target was kept at 4.93 W/cm^2. The Ar pressure P_{Ar} was kept at 3 mTorr for TbCo and Co films deposition.

The thickness of the film was measured by an atomic force microscope. The composition of the film was estimated by an energy dispersive spectrometer. The cross-sectional image of films was observed with a transmission electron microscope. Magnetic properties of the films were measured by using a vibrating sample magnetometer with a maximum applied field of 15 kOe.

3. Results and discussion

The HRTEM cross-sectional image of the $SiN_x/Tb_{30}Co_{70}/SiN_x$/Co (37 nm)/$SiN_x$/Si multilayer film shows that the TbCo film is still

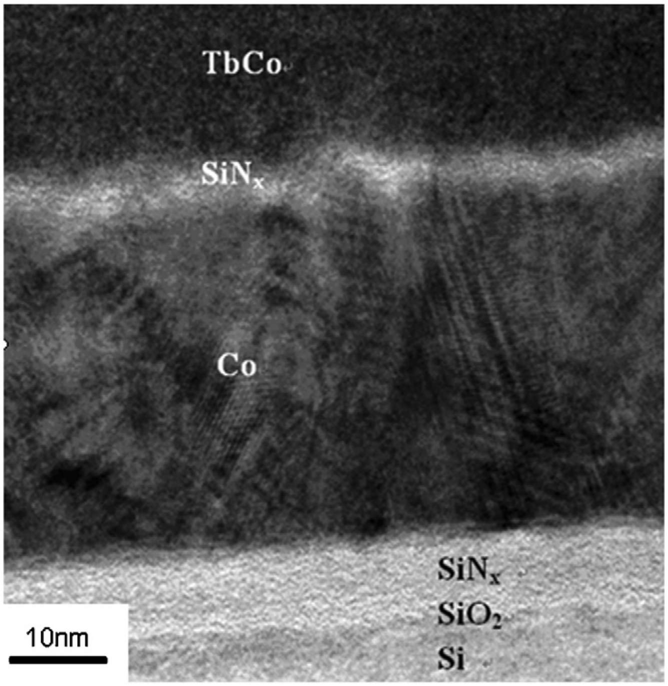

Fig. 1. The cross-sectional HRTEM image of the $SiN_x/Tb_{30}Co_{70}$ (90 nm)/SiN_x (5 nm)/Co (37 nm)/SiN_x (10 nm)/Si multilayer.

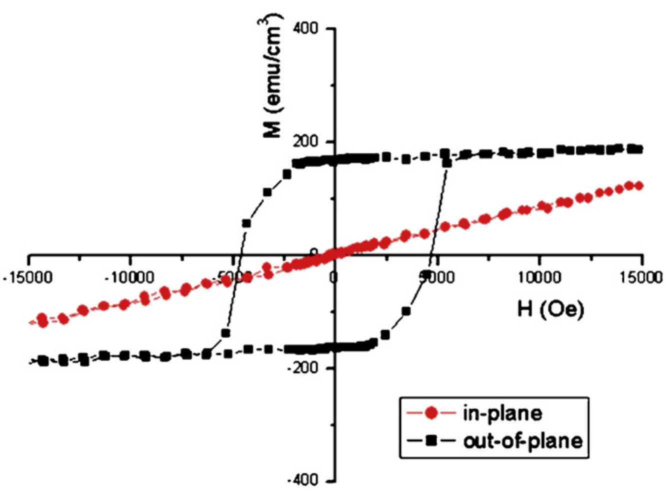

Fig. 2. M–H loops of the $SiN_x/Tb_{30}Co_{70}$ (90 nm)/SiN_x/Si multilayer film.

kept at amorphous state after introducing the Co under layer, as shown in Fig. 1. The roughness between SiN_x and TbCo causes increase in the coercivity of multilayer films due to creation of pinning sites [4].

Fig. 2 shows the M–H loops of the $SiN_x/Tb_{30}Co_{70}$ (90 nm)/SiN_x/Si multilayer film. The TbCo film has excellent perpendicular anisotropy and large $H_{c\perp}$. However, the M_s of the TbCo film is too small.

The M–H loops of the $SiN_x/Tb_{30}Co_{70}/SiN_x/Co/SiN_x$ multilayer film with 9 nm of ferromagnetic Co layers are shown in Fig. 3. Because the two layers reverse independently in the in-plane direction, there are two different switching fields and a large step was observed in the in-plane M–H loop. The magnetic moment of the Co layer reversed at small field (less than 500 Oe). But, the magnetic moment reversion of TbCo occurred at larger switching field. However, when the field is in the out-plane direction, the

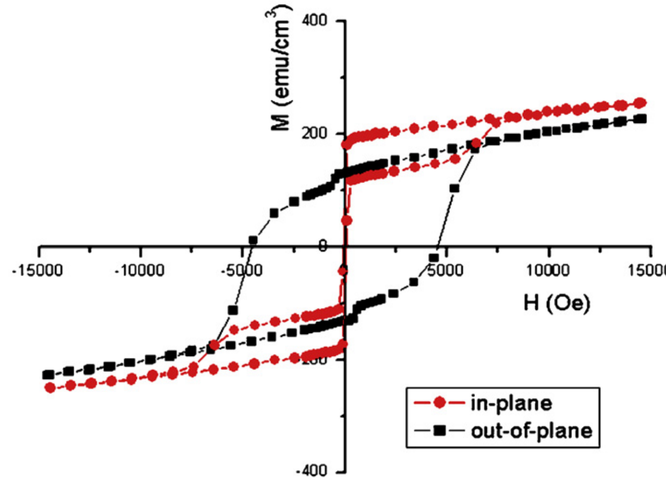

Fig. 3. M–H loops of the $SiN_x/Tb_{30}Co_{70}$ (90 nm)/SiN_x/Co (9 nm)/SiN_x/Si multilayer film.

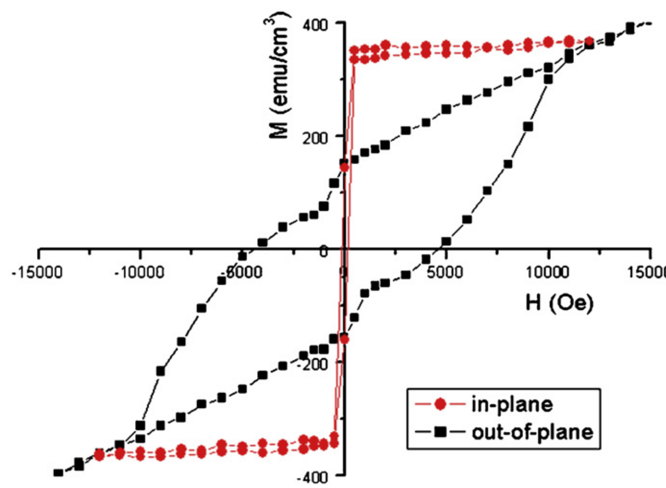

Fig. 4. M–H loops of the $SiN_x/Tb_{30}Co_{70}$ (90 nm)/SiN_x/Co (37 nm)/SiN_x/Si multilayer film.

two layers reversed almost simultaneously due to the strong coupling effect [5], and only a small step is observed at 500–1000 Oe field.

When the thickness of the Co under-layer in TbCo/SiN_x/Co multilayer films exceeded the critical thickness, the $H_{c\perp}$ value decreased as shown in Fig. 4. The Co layer thickness of Fig. 4 is 37 nm. Large loss of perpendicular anisotropy in the TbCo/SiN_x/Co multilayer film occurs. Because the two layers reverse independently, a small step is observed at about 1000 Oe field.

Because the TbCo and Co layer have magnetic anisotropies perpendicular and parallel to the film, respectively, the coupling effect make the magnetic moments dispersive around the TbCo/SiN_x/Co interface, as shown in Fig. 5 [6]. The out-plane squareness of the multilayer film is reduced as Co under-layer is being introduced.

It was found that the $H_{c\perp}$ value of the TbCo/SiN_x/Co multilayer films is increased with increase in the thickness of the Co layer, as shown in Fig. 6. The exchange coupling effect exists between TbCo and Co layers [7]. The Co layer has in-plane magnetic anisotropy, it would affect part of the TbCo layer which is near by the Co layer varying from perpendicular to in-plane anisotropy and form a pinned TbCo layer, as shown in Fig. 5. The exchange coupling effect will increase the $H_{c\perp}$ value of multilayer films. However, when the Co layer is thicker than a critical thickness, the Co layer

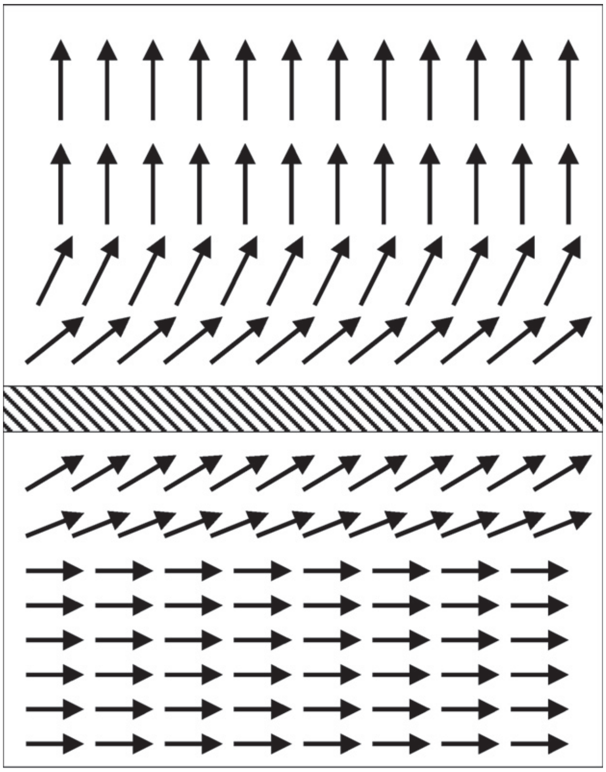

Fig. 5. Exchange effect between TbCo and Co layers.

with in-plane magnetic anisotropy and soft property would dominate the magnetic properties of the multilayer films and the $H_{c\perp}$ value would decrease seriously. Therefore, the interlayer exchange effect would increase with the thickness of the Co under-layer. The multilayer film with critical thickness of the Co layer would have maximum $H_{c\perp}$ value. But, when the Co layer is thicker than a critical thickness, the magnetic properties of ferromagnetic Co would overcome the exchange effect.

The saturation magnetization of the TbCo/SiN_x/Co multilayer films is increased with increase in the thickness of the Co layer, as shown in Fig. 6. The enhancement of M_s is due to the increase of the volume fraction of the ferromagnetic Co layer, which has much larger value of M_s than that of the ferrimagnetic TbCo layer.

4. Conclusions

Introducing a ferromagnetic Co under-layer with thickness lower than a critical thickness under the TbCo alloy film could

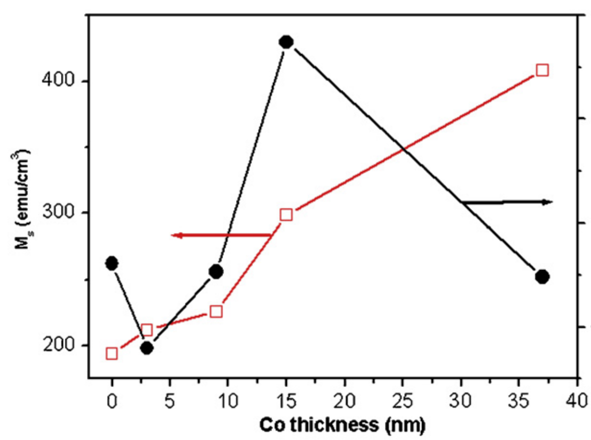

Fig. 6. Effects of Co layer thickness on the M_s and $H_{c\perp}$ value of the SiN_x/$Tb_{30}Co_{70}$/SiN_x/Co/SiN_x/Si multilayer films.

enhance its M_s and $H_{c\perp}$ values. The enhancement of M_s is due to the increase of the volume fraction of the ferromagnetic Co layer. An exchange coupling effect was found between a TbCo hard magnetic layer and a soft Co layer. The increase of $H_{c\perp}$ value is owing to the exchange coupling effect. But, the TbCo and Co layers have magnetic anisotropy in different directions; the coupling effect makes the magnetic moment become dispersive around the TbCo/SiN_x/Co interface and the out-plane squareness decrease.

Acknowledgements

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