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Control of magnetic anisotropy in Fe–Co–B soft magnetic underlayer for perpendicular magnetic recording media

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Abstract Anisotropic residual stress induced in the Fe–Co–B/Ni–Fe layers causes high anisotropy field H_k in the films induced by magnetoelastic effect. The origin of residual stress in Fe–Co–B/Ni–Fe layers was investigated. The direction of magnetic anisotropy of Fe–Co–B/Ni–Fe layers was formed in the direction corresponding to the incident direction of sputtered particles reached substrate. The magnitude of the H_k depended strongly on the condition of argon gas pressure. An incident direction of sputtered particles, which has an important effect on the direction of H_k, seemed to be dispersed under high Ar gas pressure condition because of the increase of collision number between sputtered particles and Ar particles. However, a low gas pressure condition of 1 mTorr in which sputtered particles have a long mean free path led to restrain the dispersion of H_k direction. As a soft magnetic underlayer of high H_k, the noise level of the media with Fe–Co–B/Ni–Fe decreased about 4 dB compared to that with the layer of low H_k in low frequency.

Keywords Fe–Co–B/Ni–Fe layer · High H_k · Incident direction of sputtered particles · Low gas pressure · Residual stress

1 Introduction

Domain stability in soft magnetic underlayer for perpendicular magnetic recording media is required to decrease the media noise. It was reported that spike noise was originated from the domain wall and magnetic fluctuations caused by magnetic interaction with the recording layer in soft magnetic underlayer [1, 2]. For suppression of the magnetic fluctuations and domain wall in soft magnetic underlayer, it is necessary to induce strong in-plane uniaxial magnetic anisotropy in the layer. It was also reported that the high in-plane magnetic anisotropy in soft magnetic underlayer played an important role to increase a signal to noise ratio by setting the easy axis to the cross track direction [3]. We found that Fe–Co–B layer with high $4\pi M_s$ of about 23 kG deposited on Ni–Fe layer exhibited very high in-plane magnetic anisotropy field H_k induced by magnetoelastic anisotropy owing to a residual stress [4].

In this study, the origin of the residual stress which causes high H_k in Fe–Co–B layer was investigated. Furthermore, the noise property of media with soft magnetic underlayer of high H_k was compared to media with the layer of low H_k.

2 Experimental

Fe–Co–B(200 nm)/Ni–Fe(3 nm) and Fe–Co–B(200 nm)/[Ni–Fe–(10 nm)/Si(2 nm)] layers were prepared on Si wafers by facing targets sputtering apparatus. Sputtering

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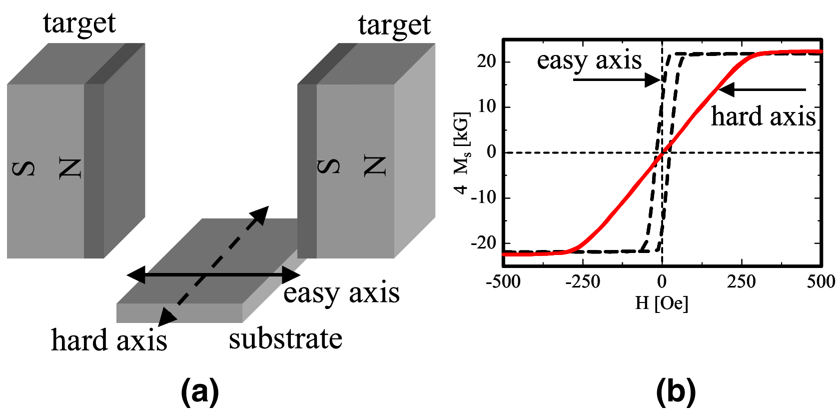


Fig. 1 (**a**) A schematic configuration of facing targets sputtering apparatus and (**b**) M–H loop of Fe–Co–B(200 nm)/Ni–Fe (3 nm) layer prepared by the FTS apparatus

targets of square type (115×115 mm) with composition of $Fe_{67}Co_{29}B_4$ and $Ni_{79}Fe_{21}$ were used. The distance between the center of target and the substrate was about 175 mm. All of specimens were deposited at room temperature. An Ar gas pressure was varied from 0.5 to 5 mTorr. The crystallographic structure was examined by X-ray diffraction (XRD) of in-plane 2_{χ} method and transmission electron microscopy (TEM). Vibrating sample magnetometer (VSM) and magnetic force microscopy (MFM) were used to determine magnetic properties. The noise characteristic was direction performed using media with configuration of Co–Cr–Pt(50 nm)/Si(10 nm)/[Fe–Co–B (200 nm)/Ni–Fe(3 nm)]. A 5 nm-thick carbon layer was deposited to protect the media surface.

3 Results and discussion

Figure 1 shows (a) the configuration of facing targets sputtering (FTS) apparatus and (b) the M–H loop of Fe–Co–B/Ni–Fe layer prepared by the apparatus. The Fe–Co–B(200 nm)/Ni–Fe(3 nm) layer exhibited $4\pi M_s$ of 23 kG, easy and hard axis coercivity of 21 and 0.6 Oe, respectively, and H_k of 280 Oe. The direction of H_k in Fe–Co–B/Ni–Fe layers prepared by FTS apparatus depended strongly on the only incident direction of sputtered particles with oblique angle. Figure 2 shows the changes of value of M_r/M_s for samples taken from center position in which the incident angle α, which indicates the mean direction of sputtered particles to the substrates as shown in the inset, is 90° and edge position with the angle α of about 70°, as a function of applied magnetic field direction. In this case, only one target was sputtered for deposition, while the other one was blocked with a shutter so that no sputtered particles could reach the substrate from the later target. An angle in horizontal axis represents the angle between applied magnetic field direction and easy axis of H_k in sample taken from center position. The easy axis in the sample taken from center position was formed in incident direction of sputtered particles with $\alpha=90°$. It was observed that easy axis and hard axis of the sample taken from edge position shift to higher angle of about 20° which correspond to $90-\alpha°$ in this case. This result indicates that the direction of H_k in Fe–Co–B/Ni–Fe layer is formed in the direction corresponding to the incident direction of sputtered particles. For confirming the effect of incident angle of sputtered particles for H_k, the dependence of H_k on Ar gas pressure was investigated. Figure 3 shows the M–H loops of Fe–Co–B/Ni–Fe layers prepared under Ar gas pressure of (a) 0.5, (b) 1 and (c) 5 mTorr. The layer prepared under 0.5 mTorr pressure exhibited deteriorated soft magnetic property. This seems to be attributed to the perpendicular magnetic anisotropy induced by a high compressive stress owing to peening effect of the recoiled particles with high kinetic energy. On the other hand, the H_k of the layer prepared under Ar gas pressure of 1 mTorr was as high as 280 Oe, while that of the layer prepared under 5 mTorr pressure exhibited below

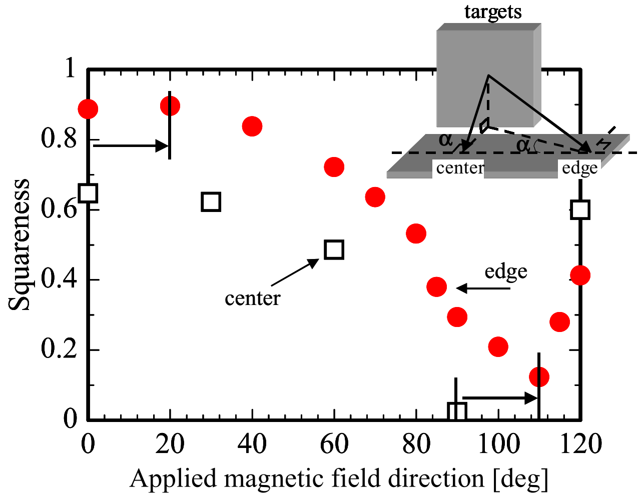
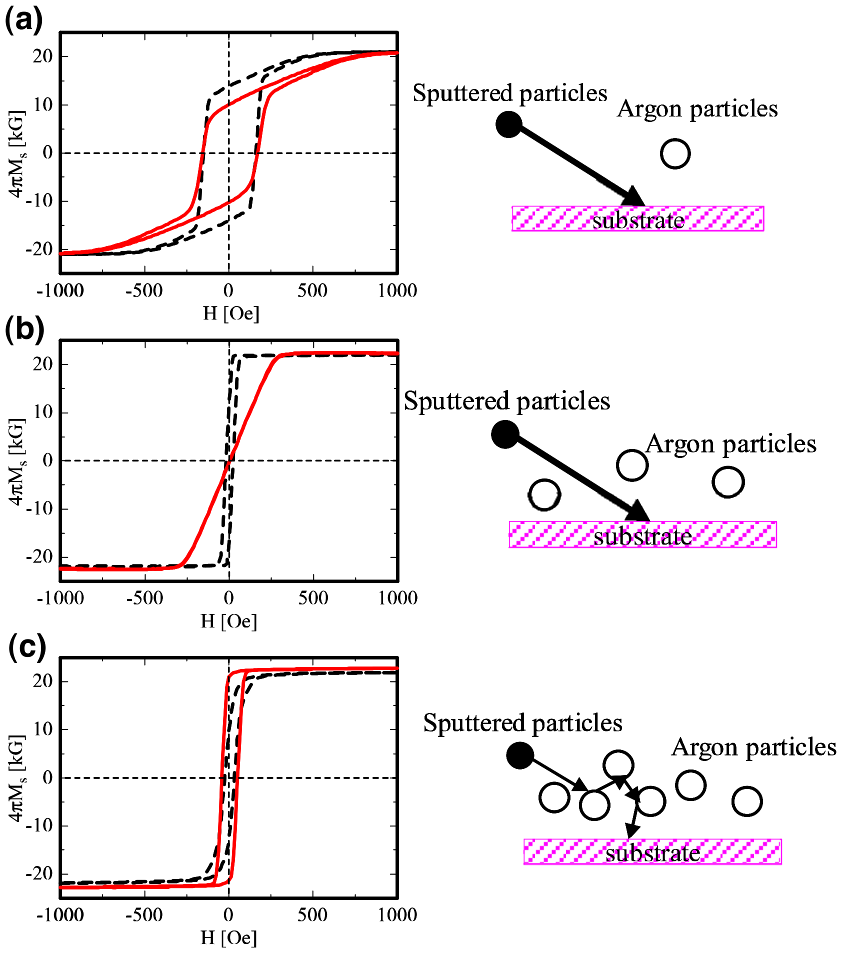


Fig. 2 Dependence of Mr/Ms for Fe–Co–B(200 nm)/Ni–Fe(3 nm) layer taken from center position (*square mark*) and edge position (*circle mark*) on applied magnetic field

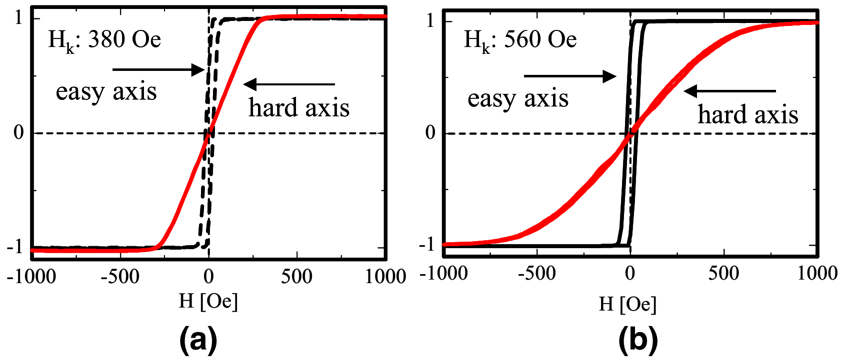
Fig. 3 M–H loops of Fe–Co–B (200 nm)/Ni–Fe(3 nm) layers prepared under argon gas pressure of (**a**) 0.5 mTorr, (**b**) 1 mTorr and (**c**) 5 mTorr



100 Oe. Furthermore, the dispersion of magnetic anisotropy was observed from the M–H loop for the layer prepared at 5 mTorr. An incident angle of sputtered particles, which has an important effect on direction of H_k, seemed to be dispersed in 5 mTorr condition because of increased collision number of about nine times between sputtered particles and Ar particles. However, the 1 mTorr condition in which sputtered particles have a long mean free path seemed to reduce the dispersion in incident angle.

The magnitude as well as direction of H_k depended on the incident angle of sputtered particles. Figure 4 shows the M–H loops of Fe–Co–B layer deposited on [Ni–Fe/Si] seedlayer [5] taken from (a) center and (b) edge position. The H_k of the layer deposited on center position was 380 Oe, while the layer deposited on edge position exhibited higher H_k of 560 Oe. Cross-sectional TEM images revealed that the Fe–Co–B layer taken from edge position exhibited clear columnar structure and grew with

Fig. 4 M–H loops of Fe–Co–B (200 nm)/[Ni–Fe(10 nm)/Si (2 nm)] layers taken from (**a**) center position and (**b**) edge position



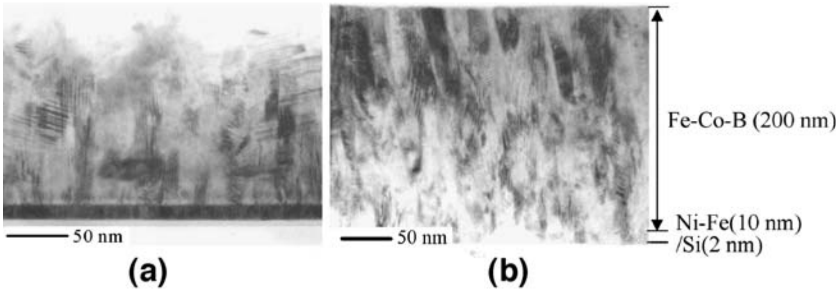


Fig. 5 Cross-sectional TEM images of Fe–Co–B(200 nm)/[Ni–Fe(10 nm)/Si(2 nm)] layers taken from (**a**) center position and (**b**) edge position

inclination from the normal direction to the film plane, as shown in Fig. 5. Such inclined columnar structure seems to change the lattice spacing of normal planes to the film plane.

Figure 6 shows in-plane XRD diagrams of (110) plane along easy axis in Fe–Co–B/[Ni–Fe/Si] layers taken from (a) center and (b) edge position. The in-plane XRD diagrams imply that the layer taken from edge position exhibits a fine structure as indicated by its diffraction pattern with broad peak. Furthermore, the lattice spacing of (110) planes along the easy axis direction in the layer taken from edge position was 2.038 Å, while that of the planes in the layer from center position exhibited 2.034 Å. These values are quite larger than that of ordinary Fe–Co–B (2.020 Å) which did not indicate significant H_k. An estimated value of H_k in the layer taken from edge region was 560 Oe supposing the anisotropic stress evaluated from the change of lattice spacing along the easy and hard axes direction and saturation magnetostriction constant λ_s of 1.7×10^{-5}. This value is in agreement with that of measured H_k from M–H loop. These results indicate that the magnitude as well as direction of H_k depends strongly on the incident angle of sputtered particles in Fe–Co–B layers.

Figure 7 shows the MFM images for Fe–Co–B/Ni–Fe layers with (a) low H_k of 100 Oe and (b) high H_k of 280 Oe and the changes of noise coming from double layered media with the (a) and (b) layers as soft magnetic underlayer, as a function of recording frequency. The layer with high H_k exhibited a single domain like pattern, while that with low H_k revealed domain wall which may cause media noise, as shown in MFM images. Moreover, the noise level of the media with the soft magnetic underlayer of high H_k (media b) decreased about 4 dB compared to that of that with the layer of low H_k (media a) in low frequency region.

4 Conclusions

It was found that the residual stress, which induced high H_k in Fe–Co–B/Ni–Fe layers, is originated from oblique incident angle of sputtered particles reached substrate. A low gas pressure condition of 1 mTorr in which sputtered particles have a long mean free path led to restrain the dispersion of H_k direction. Thus, the layer prepared under 1 mTorr pressure exhibited a strong uniaxial in-plane magnetic anisotropy. Furthermore, as a soft magnetic underlayer of high H_k, the noise level of the media with

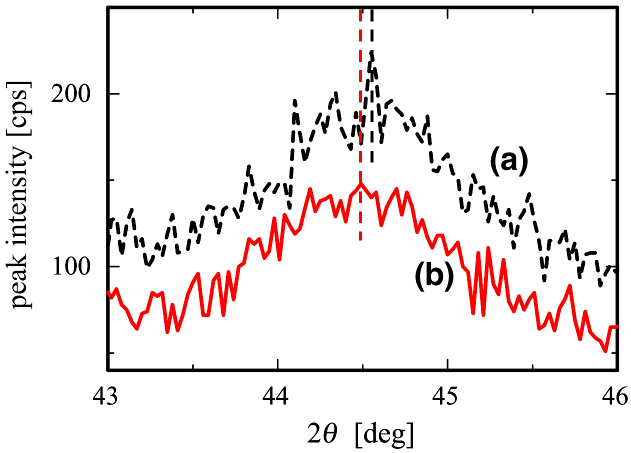


Fig. 6 In-plane XRD diagrams of Fe–Co–B(200 nm)/[Ni–Fe(10 nm)/Si(2 nm)] layers taken from (*a*) center position and (*b*) edge position

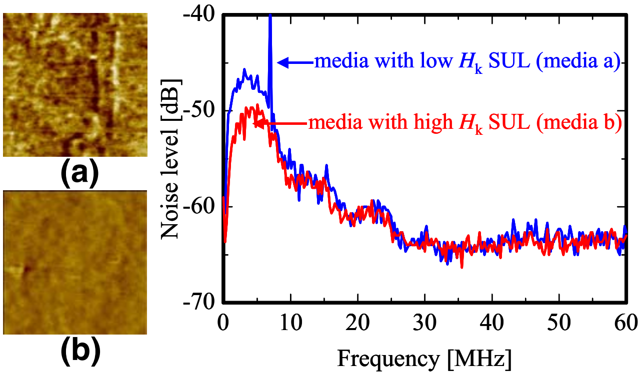


Fig. 7 MFM images of Fe–Co–B(200 nm)/Ni–Fe(3 nm) layers with (**a**) low H_k and (**b**) high H_k and dependence of noise level on frequency in media with the Fe–Co–B(200 nm)/Ni–Fe(3 nm) soft magnetic underlayer of low H_k (media a) and high H_k (media b)

Fe–Co–B/Ni–Fe decreased about 4 dB compared to that with the layer of low H_k in low frequency region.

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