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Soft Magnetic Fe-Co-B/Ni-Fe Double Layer with High Magnetic Anisotropy Field

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It is well known that the combination of a single pole head and a soft magnetic underlayer increases the signal to noise ratio(SNR) of perpendicular magnetic recording media. The large in-plane uniaxial magnetic anisotropy field H_k in soft magnetic underlayer is essentially required to increases the SNR. Fe-Co-B films with saturation magnetization of 23 kG deposited on Ni-Fe seedlayer exhibited low H_c of 0.6 Oe along hard axis and very high H_k of about 300 Oe[1]. In this study, the magnitude of H_k of Fe-Co-B/Ni-Fe double layer were controlled by adjusting various preparation conditions. All specimens were prepared by facing targets sputtering apparatus. The direction of easy axis of the film prepared at Ar gas pressure of 1mTorr was lying along the magnetic field direction, however, the easy axis direction turned at 90 degrees in in-plane for the film prepared at 5mTorr. Moreover taking into account of the incident direction of sputtered particles the H_k has increased. These films are hopeful candidates for the underlayer of the perpendicular magnetic recording media with high SNR.

Keywords : Soft magnetic underlayer, uniaxial magnetic anisotropy field, Fe-Co-B/Ni-Fe double layer

1. INTRODUCTION

It is well known that perpendicular magnetic recording media with soft magnetic underlayer has been demonstrated by their proven high density response [2]. Furthermore, it was reported that the large in-plane uniaxial magnetic anisotropy field H_k in soft magnetic underlayer has an important role to increase signal to noise ratio(SNR) by setting the easy axis orientation to the cross track direction [3]. Thus, the control of direction and magnitude of magnetic anisotropy field in soft magnetic underlayer is important to increase the recording density and reduce the media noise. Soft magnetic underlayer is required the characteristics of high saturation magnetization (M_s), low in-plane corcivity (H_c) and H_k. From the Slater-Poling curves $Fe_{70}Co_{30}$ is selected because the atom moment of saturation magnetization is maximum in the case of composition ratio Fe:Co=7:3. Moreover $Fe_{70}Co_{30}$ has high saturation magnetostriction constant (λ_s) such as $6.5*10^{-5}$. Therefore it is expectable to make high H_k. Fe-Co-B films with saturation magnetization of 23 kG which were deposited on Ni-Fe seedlayer exhibited low H_c of 0.6 Oe in hard axis direction and very high H_k of about 300 Oe [1]. In this study, we investigated that the origin of the high H_k in the double layers. The dependence of H_k of the double layer on post-annealing temperature and on Ar pressure were also investigated in order to proove that the difference of lattice constant between hard axis and easy axis occurs the high H_k.

2. EXPERIMENTAL

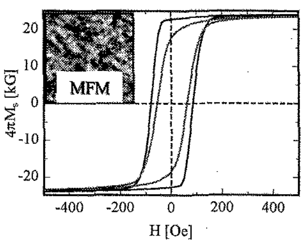
$Fe_{64.6}Co_{30.8}B_{4.6}$ single layer and $Fe_{64.6}Co_{30.8}B_{4.6}/Ni_{79}Fe_{21}$ double layer films were prepared on Si wafers using facing targets sputtering apparatus at room temperature. A post-deposition thermal annealing was performed at the annealing temperature of 300, 400 and 500 °C for 1 hour in vacuum below 3×10^{-6} Torr. The crystallographic structure was examined by X-ray diffraction (XRD) of in-plane $2\theta_\chi$ method and conventional out-of-plane θ-2θ method using Cu K_α radiation. The values of coercivity H_c, H_k and saturation magnetization $4\pi M_s$ were measured using a vibrating sample magnetometer (VSM) respectively.

3. RESULTS AND DISSCUSSION

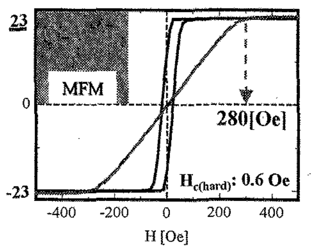
3.1 The effect of adding Boron and inserting Ni-Fe underlayer

Figure 1 shows the M-H loops and MFM images of Fe-Co-B layer and Fe-Co-B/Ni-Fe double layer. As shown in MFM image, the cluster which remains magnetic constant has dissapeared. Moreover H_k increased to 280 Oe and H_c on hard axis decreased to 0.6 Oe maintaining high M_s of 23 kG by inserting the Ni-Fe underlayer.

Figure 2 shows the in-plane XRD diagrams of (a) Fe-Co-B single layer and (b) Fe-Co-B/Ni-Fe double layer. In-plane XRD study clarified that the lattice spacing of the planes along the easy axis direction is expanded than that along the hard axis direction in the Fe-Co-B/Ni-Fe double layer. The lattice spacing of (110) planes along the easy axis was 2.028 Å, while that of the planes along hard axis direction exhibited 2.020 Å. Thus, in-plane and out-of-plane XRD results indicate that the lattice spacing of planes along the hard axis was shrunk, while that of planes along the easy axis and perpendicular direction of film were expanded. On the other hand, no change in lattice spacing was observed in Fe-Co-B single layer with low H_k. These results mean that a compressive stress along the hard axis direction of the film plays an important role to induce such a high magnetic anisotropy field in the double layer. In-plane magnetic anisotropy field H_k of Fe-Co-B/Ni-Fe double layer was estimated using the change of lattice spacing of planes along the easy axis and saturation magnetostriction λ_s of 1.7×10^{-5}. The estimated H_k was about 250 Oe. This value is in almost good agreement with that of about 280 Oe of the measured value.



(a) M-H loop and MFM image of Fe-Co-B layer



(b) M-H loop and MFM image of Fe-Co-B/Ni-Fe layer

Fig. 1. M-H loop and MFM image of Fe-Co-B layer and Fe-Co-B/Ni-Fe double layer

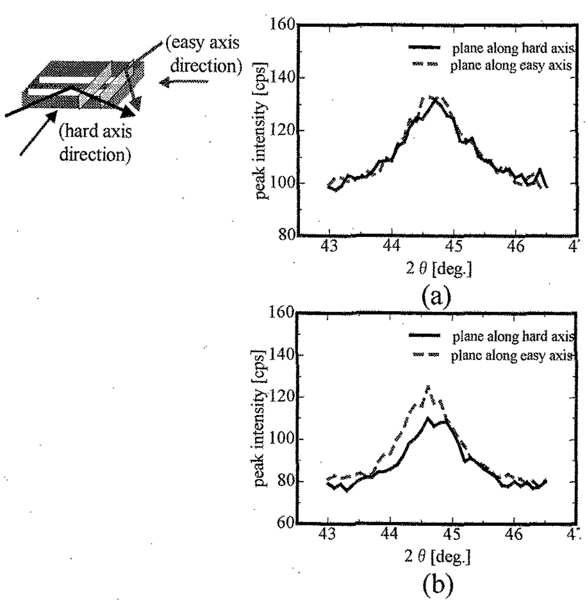
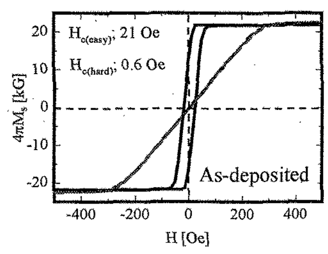


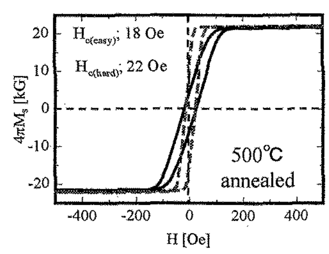
Fig. 2. In-plane XRD profiles for (a) Fe-Co-B(160 nm) single layer and (b) Fe-Co-B(200 nm)/Ni-Fe(10 nm) double layer.

3.2 Releasing the stress by annealing

Fig 3 shows the M-H loops for Fe-Co-B/Ni-Fe films (a) as-deposited and (b) post-annealed at 500 ℃, respectively. The as-deposited film possess high H_k,



(a) As-deposited in Fe-Co-B/Ni-Fe double layer



(b) 500°C annealed in Fe-Co-B/Ni-Fe double layer

Fig. 3. M-H loop of Fe-Co-B/Ni-Fe double layer on the characteristics of annealing

however this H_k was decreased by post-annealing. The phenomenon occurs because the stress has released. From in-plane XRD diagrams (a) and (b), it was proved that the compressive stress along the hard axis direction of the film plays an important role to induce such a high magnetic anisotropy field in the double layer.

Figure 4 shows the in-plane XRD diagrams for as deposited and 500°C annealed films, respectively. No change in lattice spacing was observed in the case of 500°C annealing where H_k is decreased. This implies that the difference of lattice spacing causes such a high H_k.

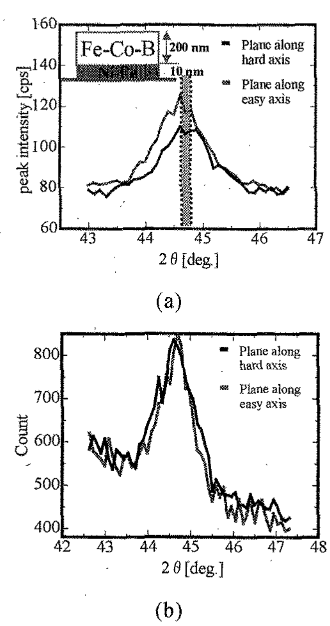
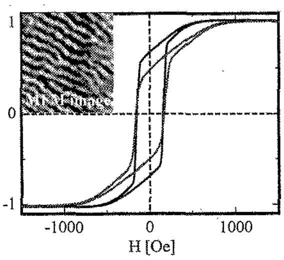


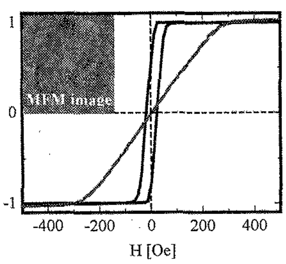
Fig 4. In-plane XRD profiles for (a) Fe-Co-B(200 nm)/Ni-Fe(10 nm) double layer as deposited and (b) Fe-Co-B(200 nm)/Ni-Fe(10 nm) double layer

3.3 The change of magnetic anisotropy field on Ar gas pressure

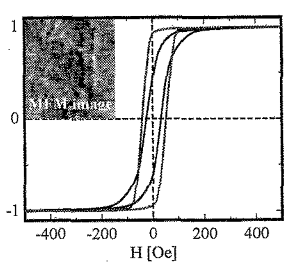
Figure 5 shows the M-H loops and MFM images of Fe-Co-B/Ni-Fe double layers for different deposition conditions of Ar gas pressure. At 0.5 mTorr the M-H loop shows the characteristics of rotation curve and stripe domain was observed from MFM image. We anticipate that this case occurs that the energy of sputtered particles that reach substrate directly is too high. At 5 mTorr the H_k decreased. In this case we anticipate that the sputtered particles don't reach directly because of high Ar gas pressure. From this results, at 1 mTorr showed the best magnetic characteristics. Moreover the approximate energy and the incident direction of the sputtered particles seemed to cause high H_k.



(a) M-H loop and MFM image on 0.5mTorr



(b) M-H loop and MFM image on 1mTorr

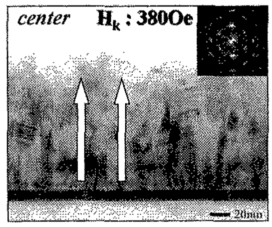


(c) M-H loop and MFM image on 5mTorr

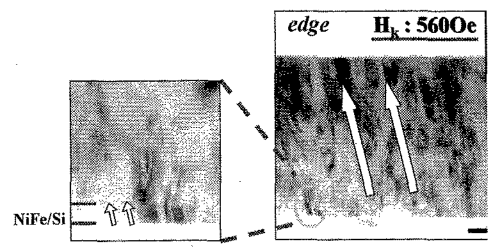
Fig 5 M-H loops and MFM images of Fe-Co-B/Ni-Fe double layers for different deposition conditions of Ar gas pressure

3.4 The influence of the direction of sputtered particles

Figure 6 shows the cross TEM images of (a) center part of the substrate and (b) edge part of the substrate, respectively. We set an angle between substrate and the incident direction of sputtered particles in order to prove the influence of the direction of sputtered particles. As shown in (a), the crystalline grows normal to the substrate, while the crystalline growth is slanting for (b) with H_k of 560 Oe. We anticipate that such a high H_k occurs because the difference of in-plane lattice spacing has broadened. To prove this thought we are ready to measure in-plane XRD.



(a)



(b)

Fig 6. The cross TEM image of (a) center part of the substrate and (b) edge part of the substrate

3.5 Noise characteristics of the magnetude of H_k

Figure 7 shows the noise characteristics of the magnitude of H_k using two kinds of soft magnetic underlayer, low H_k and high H_k with Co-Cr-Pt recording layer. Using high H_k of soft magnetic underlayer the noise decreased in low frequency than using low H_k of soft magnetic underlayer. It implies that high H_k of soft magnetic underlayer is effective to reduce the noise.

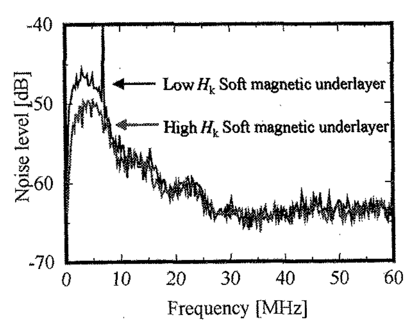


Fig 7. The noise characteristics of Co-Cr-Pt/Fe-Co-B/Ni-Fe/Si films with low H_k and high H_k soft magnetic underlayer

4. CONCLUSION

Measuring in-plane XRD it is proved that high H_k is derived from the difference of lattice spacing. Moreover a compressive stress along the hard axis direction of the film plays an important role to induce such a high magnetic anisotropy field in the double layer.

Taking account of the direction of the sputter paticles we are able to make very high H_k thin film such as 560 Oe. This film is also brought into the limelight from other fields because of very high H_k.

It has proved that high H_k of soft magnetic underlayer is effective to reduce the low frequency noise.

5. REFERENCE

[1] S. H. Kong, T. Okamoto, and S. Nakagawa, "Microstructure and magnetic properties in Fe-Co-B/Ni-Fe double layer," J. Magn. Magn. Mat., to be published.
[2] S. Yamamoto, Y. Nakamura, and S. Iwasaki, IEEE Trans. on Magn., 23 (5) 2070 (1987).
[3] Y. Nakatani, N. Hayashi, Y. Uesaka, and H. Fukushima, J. Appl. Phys., 93 (10) 7744 (2003).

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