Perpendicular Magnetic Anisotropy in TbFeCo Magneto-Optic Recording Thin Films

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ABSTRACT

In order to clarify the origin of perpendicular anisotropy in thermally evaporated TbFeCo amorphous thin films, we have investigated the effects of deposition angle on magnetic Kerr hysteresis loops, perpendicular magnetic anisotropy and internal stress. It is found that the perpendicular anisotropy and the internal stress depend strongly on the deposition angle and above a threshold value(3O°), the perpendicular anisotropy disappears and the in-plane anisotropy appears. The measurement of internal stress, which is due to the substrate constraint, reveals that the compressive stress is the major contribution to the perpendicular anisotropy. The measurements of Kerr hysteresis loops in the polar and the longitudinal directions show that as the deposition angle increases the polar Kerr hysteresis loop deteriorates while the longitudinal Kerr hysteresis loop becomes prominent.

INTRODUCTION

Amorphous films of rare-earth transition-metal alloy, such as TbFeCo, NdDyFeCo etc, with perpendicular magnetic anisotropy are of great interest because of their application in magneto-optical recording.[1] Although several mechanisms such as pair- ordering,[2] columnar structure[3] and magnetostrictive effect[4] were proposed, the origin of the perpendicular magnetic anisotropy is not fully explained yet. Perpendicular magnetic anisotropy is known to be sensitive to the film preparation conditions and the relative magnitudes of the contributions of these mechanisms seem to be different for different materials.[5] Deliberate creation and control of perpendicular anisotropy in films require a further understanding of the origin and the controlling factors of the anisotropy.

In this study, in order to clarify the origin of perpendicular anisotropy in thermally evaporated TbFeCo thin films, we investigate the effects of deposition angle on perpendicular magnetic anisotropy, internal stress and magnetic Kerr hysteresis loops.

EXPERIMENT

Amorphous TbFeCo films are prepared by resistive thermal evaporation of an arc melted alloy onto the slide glass, Si and polyimide substrates. The pressure during evaporation is maintained at about 5×10^{-6} torr and the substrates are at room temperature. The typical deposition rate is about 15nm/sec. To achieve oblique deposition, substrates are mounted on a tilted substrate holder so as to make the angles of incidence of the vapor beam $\alpha=0^\circ$ - 60° with respect to the normal of the substrate. The films are cut into small pieces of 4mm in width. The spread of the deposition angle in each piece is within $\pm$ 3°. The film thickness is in the range of 100 - 200nm, as measured by the Tolansky interferometry. X-ray diffraction and high resolution scanning electron microscope measurements have shown that the films have amorphous structure.

The magnetic Kerr rotation angle Θ_K and hysteresis loops of the films in the polar and longitudinal directions are measured with He-Ne laser(632.8nm) with an accuracy of better than $\pm0.001^\circ$. Polarization modulation and phase-sensitive detection methods are used.

The perpendicular anisotropy constant K_u and the saturation magnetization M_s are measured by using a torque magnetometer with the method developed by Miyajima *et al.* [6]

The internal stress σ between the film and the substrate is measured by measuring the deflection of a laser beam reflected from the substrate before and after chemical etching of the alloy film.[4] The magnetostriction constant λ is measured by an optical interferometric method in which the specimen held by a cantilever acts as one of the two facing mirrors of the Fizeau interferometer.

RESULTS AND DISCUSSIONS

Figure 1 shows the observed magnetic Kerr hysteresis loops for the films with several deposition angles. It compares the polar and longitudinal Kerr effects. As the

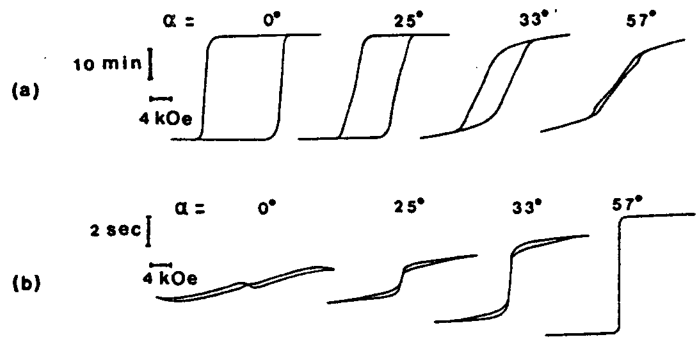

Fig.1. Kerr hysteresis loops for several deposition angles: (a)polar direction and (b) longitudinal direction.

incidence angle of the laser beam is limited to 10° by the electromagnet pole pieces, the magnitude of Θ_K, as shown in Fig.1(b), is necessarily small in the longitudinal direction. As seen in the figure, at the normal incidence deposition, square hysteresis loop appears in the polar direction while in the longitudinal direction the hysteresis is very small, which is a typical behavior of the hysteresis loop of the thin film with perpendicular anisotropy. As α increases, the polar Kerr hysteresis loop deteriorates while the longitudinal Kerr hysteresis loop becomes gradully prominent and at a deposition angle of 57°, the squareness disappears in the polar direction while in the longitudinal direction, square hysteresis loop is observed with a coercivity of 0.12kOe much smaller than that of the polar direction(7kOe) for α=0°. Figure 2 shows the relative changes of the coercivity H_c and the remanent Kerr rotation angle Θ_K with deposition angle for the polar Kerr hysteresis loops.

Figure 3 shows the dependence of perpendicular anisotropy constant K_u and saturation magnetization M_s on the deposition angle α. As shown in the figure, K_u is positive at low deposition angle(α<30°) where positive K_u means that the easy direction of magnetization is perpendicular to the film plane. As α increases, K_u becomes zero and then becomes negative, namely, the film has in-plane easy axis. M_s increases gradually with α. The deterioration of the polar Kerr hysteresis loop with deposition angle can be understood from the change of perpendicular anisotropy constant.

The internal planar stress σ and the magnetostriction constant λ are shown in Fig.4. The stress is compressive(σ<0) for α<30°, while it is tensile(σ>0) for α>30°. λ is decreasing gradually with deposition angle and is always positive. In the calculation of λ, Young's modulus of TbFeCo films is taken as 9.3×10^{11} dynes/cm^2[7] and the change of Young's modulus with deposition angle is neglected.

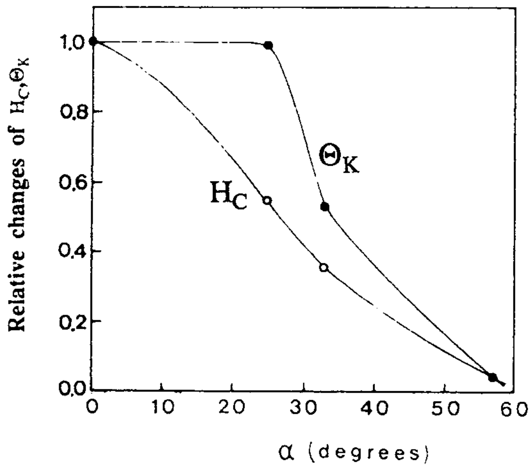

Fig.2. Relative changes of coercivity $H_C(\alpha)/H_C(0)$ and remanent Kerr rotation angle $\Theta_K(\alpha)/\Theta_K(0)$ with deposition angle α for the polar Kerr hysteresis loops.

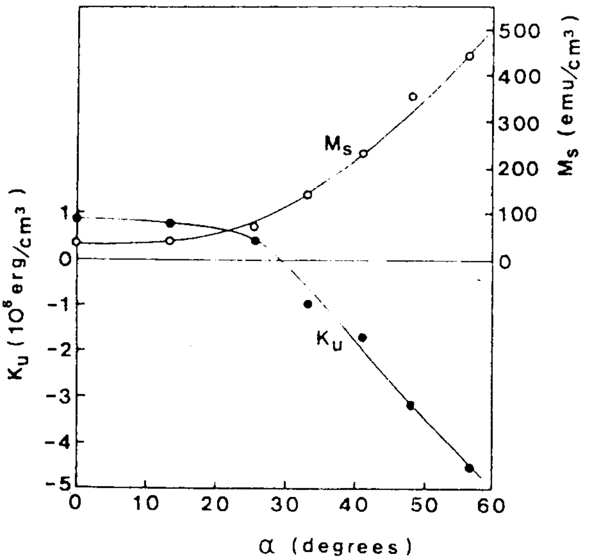

Fig.3. Perpendicular anisotropy constant K_u and saturation magnetization M_s as a function of deposition angle α.

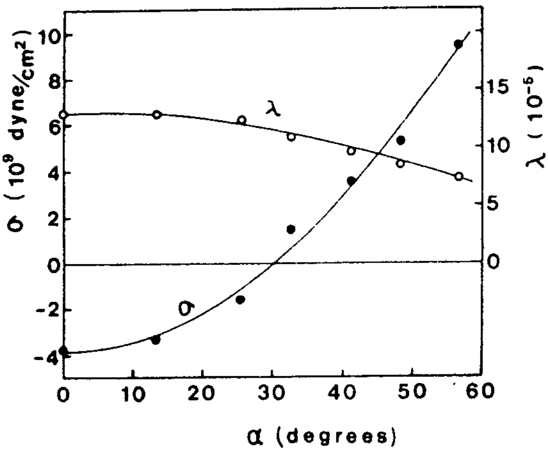

Fig.4. Internal planar stress σ and magneto striction constant λ as a function of deposition angle α.

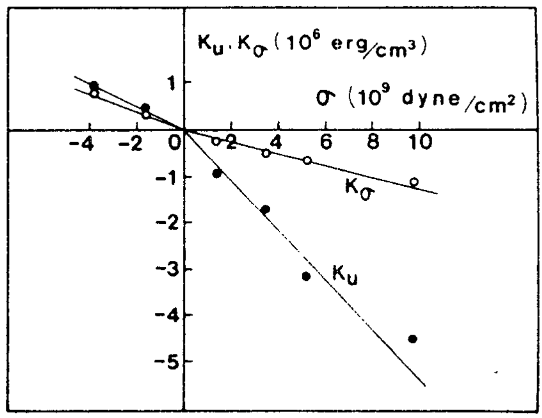

Fig.5. Anisotropy constants K_u, K_σ versus stress σ for various internal stress. Variation of σ corresponds to the variation of the deposition angle α.

From Fig.3 and Fig.4, we see that K_u and σ change their polarities at the same point of α=30°. Both dependences on deposition angle suggests that K_u and σ are strongly correlated. Stress-induced anisotropy constant K_σ is equal to $K_\sigma = -3\lambda\sigma/2$, so that the internal compressive stress can induce perpendicular anisotropy($K_\sigma>0$) through the positive magnetostrictive effect. In order to investigate the contribution of stress to K_u in TbFeCo films, we have plotted K_u and K_σ versus stress for all of our films with various deposition angles in Fig.5. From the figure, it is clear that the internal compressive stress due to the substrate constraint contributes dominantly to the perpendicular anisotropy. Further, the normal incidence deposition is essestial to obtain magnetic thin film with large perpendicular anisotropy and square hysteresis loop.

CONCLUSIONS

It is found that the deposition angle during evaporation effects greatly the perpendicular anisotropy and the internal stress in evaporated TbFeCo films. Above 30° of deposition angle, the film loses the perpendicular anisotropy because the internal stress shifts from compression to tension. The internal compressive stress contributes mainly to the perpendicular anisotropy. The change in the state of the internal stress for increasing deposition angle is the cause of deterioration in the polar Kerr hysteresis loop.

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