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Effects of Substrate Temperature on Crystal Structure and Magnetic Properties of Sm-Co/Cu Films with Perpendicular Anisotropy

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Sm-Co/Cu films with perpendicular anisotropy were prepared and effects of the substrate temperatures during the preparations of the Cu underlayer and the Sm-Co layer were studied. When the Cu underlayer was prepared without heating and the Sm-Co layer were prepared at 300 ℃, it was found that the Sm-Co layer with $SmCo_5$ (002) plane grew onto the (111) preferred-oriented Cu underlayer and the magnetic easy axis was in the perpendicular direction. The dependence of the thickness of Sm-Co layer was also studied. The coercivity in the perpendicular direction was about 6.2 kOe and that in the in-plane direction was about 0.9 kOe even though the Sm-Co layer thickness was 10 nm.

Key words: Sm-Co/Cu film, perpendicular anisotropy, crystal structure, high coercivity, substrate temperature, Sm-Co layer thickness

1. INTRODUCTION

At such high density as recently reported 146 Gbits/in^2 in hard disk storage [1], the control of the media microstructures such as grain size and its dispersion are necessary in order to increase the recording density and keep the media noise within acceptable bounds [2]. Reducing the grain size, however, causes the thermal decay problem simultaneously. To overcome this problem, materials with larger magnetocrystalline anisotropy must be selected [3]. Therefore we have paid attention to SmCo alloys, especially $SmCo_5$ alloy with the anisotropy above 10^8 erg/cm^3, as a candidate of the recording medium in the next generation.

The Sm-Co/Cr films prepared without heating have attracted many researchers to date. It was found that the Sm-Co layer consisted of nano-crystallites with the size of about 5 nm surrounded by amorphous matrix [4] and the coercivity in the in-plane direction decreased to about 1kOe when the thickness of the Sm-Co layer was 10 nm [5]. To increase the coercivity at thinner Sm-Co layer, the Sm-Co/Cr films were prepared with substrate heating [6]. When the Sm-Co/Cr film was prepared at 250 ℃, it was found that the Sm-Co layer with $SmCo_5$ (110) plane grew epitaxially onto the Cr underlayer with (200) plane and the coercivity in the in-plane direction was about 3kOe even though the thickness of the Sm-Co layer was 5 nm. These results indicated that the film is expected to be a longitudinal medium.

In general, the recording density limit of the perpendicular medium is theoretically much higher than that of the longitudinal medium, so that many researchers have headed toward the perpendicular recording medium. Therefore we attempted to prepare the Sm-Co film with perpendicular anisotropy and focused on *fcc*-Cu as an underlayer. It was because that the misfit ratio between $SmCo_5$ (001) plane and Cu (111) plane has to be about 2 % in the ideal case. In this study, effects of the substrate temperature during the preparations of both the Cu underlayer and the Sm-Co layer on the crystal structures and the magnetic properties were studied. And the dependence of Sm-Co layer thickness on the magnetic properties was also studied.

2. EXPERIMENTAL PROCEDURE

The Sm-Co/Cu films were prepared continuously in the same sputtering chamber without exposure to air. The base pressure was below 2×10^{-6} Torr. Corning #7059 glass was used as the substrate. The Cu underlayer was prepared by a facing targets sputtering (FTS) system at various substrate temperature. The sputtering gas pressure was 1 mTorr and the power was about 60 W. The thickness of the Cu underlayer was 200nm. The Sm-Co layer was prepared by a conventional DC magnetron sputtering system. The substrate temperature was increased or decreased to the designated temperature at the time of about 10 min. The SmCo target was a composite type with Sm plates of 5 mm square placed on a thin Co disk. The number of Sm plates were adjusted to be the Sm concentration in films of about 17 at. %, which was checked with an EPMA. The sputtering gas pressure was 1 mTorr and the power was about 30 W.

3. RESULTS AND DISCUSSIONS

3. 1 Effect of substrate temperature during Cu underlayer preparation

To study the effect of the substrate temperature during the preparation of the Cu underlayer on the crystal structure and the magnetic properties, the Cu underlayers were prepared at various temperature $T_{s\,Cu}$. The Sm-Co layer with the thickness of 40 nm was prepared consecutively at 300 ℃. Figure 1 shows the XRD diagrams of the Sm-Co/Cu films. Only diffraction lines from both Cu (111) plane and (200) plane were

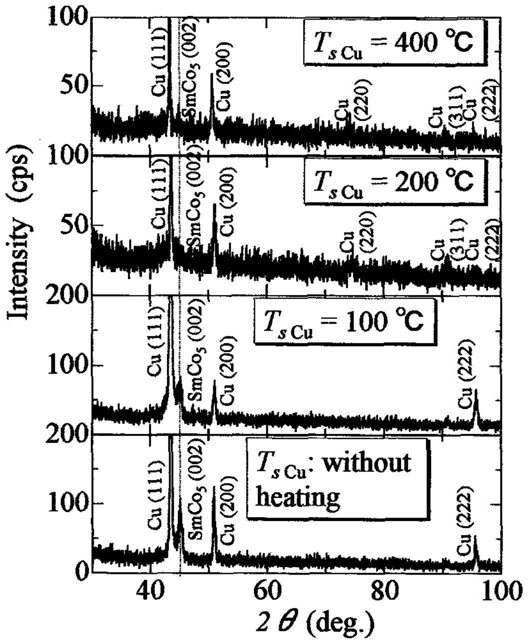

Fig. 1 XRD diagrams of Sm-Co/Cu films prepared at various $T_{S\,Cu}$.

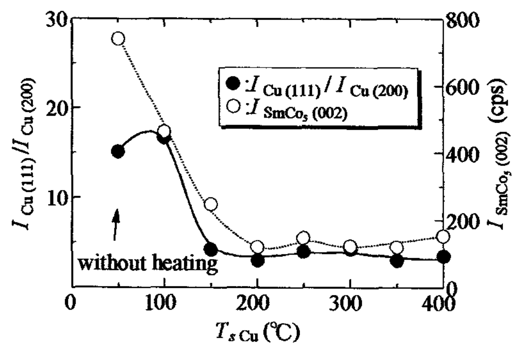

Fig. 2 Dependence of intensity of Cu (111) diffraction line on $T_{S\,Cu}$.

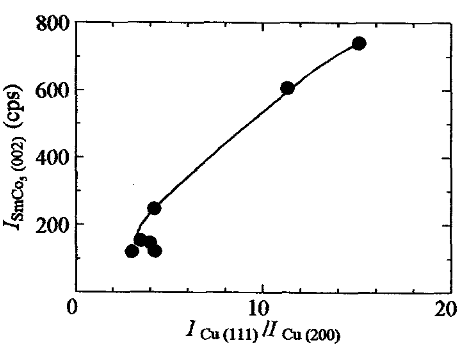

Fig. 3 Intensity of Cu (111) diffraction line *vs.* intensity of $SmCo_5$ (002) line.

observed when the $T_{S\,Cu}$ was lower than 100 ℃, although various lines from the underlayer were observed when the $T_{S\,Cu}$ was higher than 150 ℃. As shown in Figure 2, the intensity of the Cu (111) line was about 15-20 times higher than that of the (200) line when the $T_{S\,Cu}$ was lower than 100 ℃. In case of

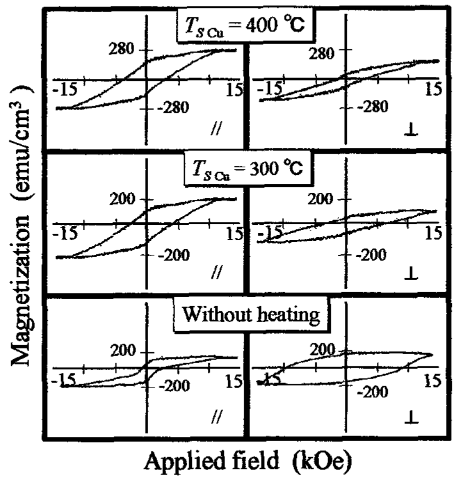

Fig. 4 Hysteresis loops of Sm-Co/Cu films prepared at various $T_{S\,Cu}$.

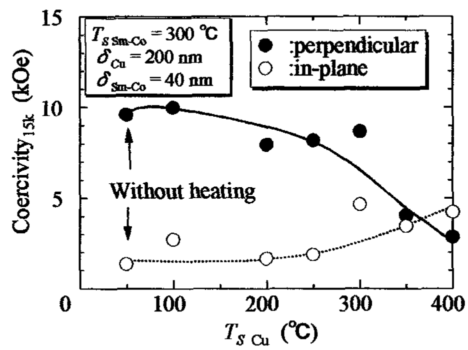

Fig. 5 Dependence of coercivity on $T_{S\,Cu}$.

powdered Cu, the intensity of the (111) line is about 2 times higher than that of the (200) line. Therefore this result indicated that the Cu underlayer was (111) preferred-oriented structure. The diffraction line from $SmCo_5$ (002) plane was also observed in each XRD diagram. The intensity in the $SmCo_5$ (002) line decreased with the increase of the $T_{S\,Cu}$. Figure 3 shows the relation between the relative intensity of the Cu (111) line and the intensity of the $SmCo_5$ (002) line. The intensity of the $SmCo_5$ (002) line increased with the increase of that of the Cu (111) line. Therefore it was believed that the Sm-Co layer with (002) plane grew epitaxially onto the (111) preferred-oriented Cu underlayer. To clarify the relation, the cross-section of the film needs to be observed by a TEM.

The magnetic properties were measured using a VSM with the maximum field of 15 kOe. Figure 4 shows the hysteresis loops of the film in the in-plane direction and the perpendicular direction. The maximum field of the VSM was not enough to saturate the magnetizations of the films. From the shapes of these loops, it was found that the perpendicular anisotropic Sm-Co/Cu film was formed when the $T_{S\,Cu}$ was below 100 ℃. It coincided with the result of XRD measurements. Figure 5 shows the dependence of the coercivity on the $T_{S\,Cu}$. At lower $T_{S\,Cu}$, the OR ratio (the ratio of the coercivity in the perpendicular to the coericivity in the in-plane) was large, which indicates the Cu underlayer should be prepared without heating.

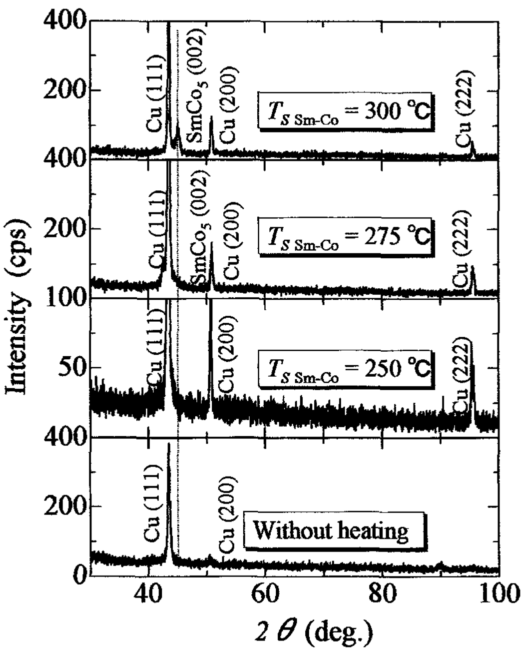

Fig. 6 XRD diagrams of Sm-Co/Cu films prepared at various $T_{S\,\mathrm{Sm\text{-}Co}}$.

3. 2 Effect of substrate temperatures during Sm-Co layers preparation

Secondly, the Cu underlayer was prepared without heating and effects of the substrate temperature during the Sm-Co layer preparation $T_{S\,\mathrm{Sm\text{-}Co}}$ were studied. The Sm-Co layer thickness was 40 nm. Figure 6 shows XRD diagrams of Sm-Co/Cu films. The relative intensity of the Cu (111) line indicated the Cu underlayer was (111) preferred-oriented structure. When the $T_{S\,\mathrm{Sm\text{-}Co}}$ was 300 ℃, the $SmCo_5$ (002) line was observed clearly. The position of the line was 45.2 degree. It was corresponding to the lattice constant c of about 0.401 nm, which was slightly wider than that of powdered $SmCo_5$ alloy of 0.398 nm. At the $T_{S\,\mathrm{Sm\text{-}Co}}$ of 275 ℃, there was a shoulder on the right side of the Cu (111) diffraction line, which was very close to the position of the $SmCo_5$ (002) diffraction line. Therefore it was believed the crystallization temperature of the Sm-Co layer was around 275 ℃.

Figure 7 shows the hysteresis loops of the films. The hysteresis loops indicated that magnetic easy axis of the film prepared at $T_{S\,\mathrm{Sm\text{-}Co}}$ below 275 ℃ was in the in-plane direction. However, when the $T_{S\,\mathrm{Sm\text{-}Co}}$ was above 300 ℃, the magnetic easy axis was in the perpendicular direction. The hysteresis loops in the in-plane direction indicated that the structure with (002) plane in the Sm-Co layer was imperfect, therefore the Cu underlayer should be more oriented. Figure 8 shows the dependence of the coercivity on the $T_{S\,\mathrm{Sm\text{-}Co}}$. The coercivity in both directions were almost same values at the $T_{S\,\mathrm{Sm\text{-}Co}}$ below 275 ℃. When the $T_{S\,\mathrm{Sm\text{-}Co}}$ was 300 ℃, the coercivity in the perpendicular direction became a maximum value of 9.6 kOe and that in the in-plane direction was about 0.9 kOe. Therefore it was found that the Sm-Co layer should be prepared at 300 ℃.

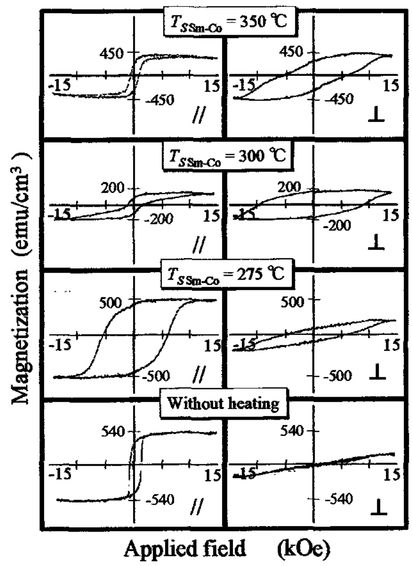

Fig. 7 Hysteresis loops of Sm-Co/Cu films prepared at various $T_{S\,\mathrm{Sm\text{-}Co}}$.

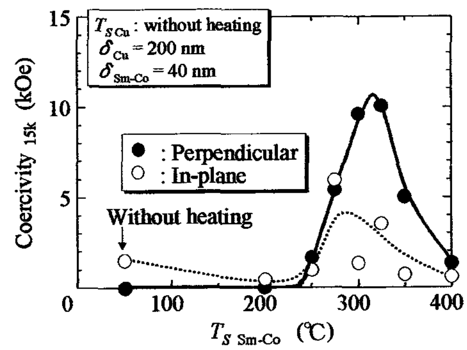

Fig. 8 Dependence of coercivity on $T_{S\,\mathrm{Sm\text{-}Co}}$.

3. 3 Dependence of Sm-Co layer thickness

From the results above, the dependence of Sm-Co layer thickness on magnetic properties was studied. The diffraction line from $SmCo_5$ (002) plane was observed in each XRD diagram when the thickness was thicker than 10 nm.

Fig. 9 shows the surface of the Sm-Co/Cu films and the Cu underlayer film that was annealed at 300℃ for 10 min. It was observed that the grain size of the Cu film increased due to the annealing. The grain size of annealed Cu film was about 270 nm and the roughness *Ra* was about 12 nm. The structure of the Sm-Co/Cu film was so-called island structure when the thickness was 5 nm, and the continuous-film was formed when the thickness was thicker than 10 nm. The grain size of the Sm-Co/Cu film increased from about 35 nm to 60 nm when the thickness was increased from 10 nm to 100 nm.

From the shape of the hysteresis loops, it was found that the magnetic easy axis of the film was in the perpendicular direction when the thickness was thinner than 40 nm. Fig. 10 shows the dependence of the coercivity on Sm-Co layer thickness. The coercivity in the perpendicular direction was about 6.2 kOe and that in the in-plane direction was about 0.9 kOe when the

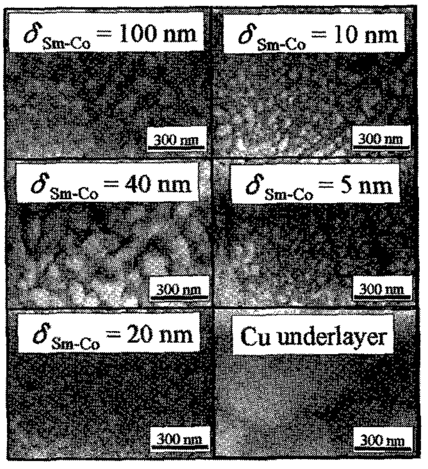

Fig. 9 SEM images of Cu underlayer and Sm-Co/Cu films with various Sm-Co layer thicknesses $\delta_{Sm\text{-}Co}$.

thickness was 10 nm. The coercivity in the perpendicular direction increased with the Sm-Co layer thickness and became a maximum value when the thickness was 40 nm. On the other hand, from the hysteresis loops, it was found the magnetic easy axis was in the in-plane direction when the thickness was higher than 70 nm. These results seemed that the structure of the Sm-Co layer was not fully oriented, especially at the initial growth region.

4. SUMMARY

In this study, the Sm-Co film with the perpendicular anisotropy was successfully prepared when the Cu underlayer prepared without heating and the Sm-Co layer was prepared at 300 ℃. It was indicated that the Sm-Co layer with $SmCo_5$ (002) plane grew on the Cu with (111) plane. The coercivity in the perpendicular direction was about 6.2 kOe even though the Sm-Co layer thickness was 10 nm.

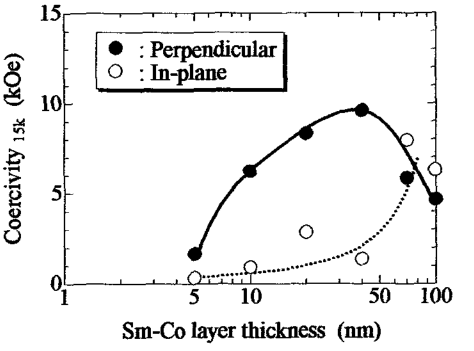

Fig. 10 Dependence of coercivity on Sm-Co layer thickness.

5. ACKNOWLEDGEMENT

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