MAGNETIC AND CRYSTALLOGRAPHIC CHARACTERISTICS OF Co-Cr LAYERS WITH Al ULTRA-THIN INTERLAYERS

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Abstracts--- $\text{Co}_{81}\text{Cr}_{19}$ /Al multilayered films with thicknesses of $\text{Co}_{81}\text{Cr}_{19}$ layers in the range of 46~170 Å and Al ones in the range of 7 Å~14 Å have been prepared on glass-slide substrate at room temperature by using the facing targets sputtering (FTS) apparatus. The dependence of the magnetic and crystallographic characteristics on the thicknesses of Co-Cr layers and Al ones have been investigated. The magnetoresistance effect of the specimen films have been also examined. The intrinsic $\text{Co}_{81}\text{Cr}_{19}$ layers were composed of hcp phase crystallites with well orientation of the c-axis normal to the film plane. Both the crystallinity of $\text{Co}_{81}\text{Cr}_{19}$ layers was improved and the d-spacing between the c-planes was expanded by using the Al interlayers. The saturation magnetization, the coercivity, and the in-plane squareness ratio depended strongly on the thicknesses of $\text{Co}_{81}\text{Cr}_{19}$ layers and Al ones. The magnetic anisotropy can be controlled by the thickness of Al layer. The magnetoresistivity ratio was negative and its absolute value was as small as 0.05% in 14Å-Al layer.

INTRODUCTION

The multilayered films composed of ferromagnetic layers and paramagnetic ones has developed rapidly and its achievements have become extremely attractive, since it is expected that the strong magnetic interactions at the interfaces between both of layers may occur.[1-4]

Co-Cr films have been extensively studied, in particular, for perpendicular magnetic recording media. However, the magnetic properties was not yet controlled in the films with single layer of Co-Cr alloy because the origin of magnetic anisotropy perpendicular to the film plane was not yet made enough clear. Therefore, it is necessary to propose a new type of medium in order to control the saturation magnetization, the coercivity and the magnetically anisotropic direction.

In this study, the Co-Cr/Al multilayered films composed of Co-Cr and Al layers have been prepared by using the facing targets sputtering (FTS) apparatus [1,5] with two pairs of targets. The dependence of the magnetic and crystallographic characteristics of the films on the thickness of Co-Cr and Al layers have been investigated in detail.

The magnetoresistance effect of the films have been also examined with high accuracy.

EXPERIMENTAL PROCEDURE

Figure 1 shows the schematic diagram of the FTS apparatus for preparing multilayered films. Multilayered films have been prepared by moving substrate alternately

Fig.1. FTS apparatus for preparing multilayered films.

Fig.2. Small angle X-ray diffraction diagrams of the films with modulation periods of 46Å-Co₈₁Cr₁₉/7Å-Al and 46Å-Co₈₁Cr₁₉/14Å-Al.

between two locations to deposit Co-Cr and Al layers. The rectangular targets of Co₈₁Cr₁₉ alloy and pure Al with the purity of 99.9 and 99.999 %, respectively, were used, of which the length, width and thickness were 16, 10, 0.5 cm, respectively. The background pressure was less than 1.2×10^{-6} Torr. Ar gas with the purity of 99.999% was introduced into the chamber at the pressure of 0.5mTorr. The Co₈₁Cr₁₉/Al multilayered films have been prepared by depositing alternately Co₈₁Cr₁₉ and Al layers on glass-slide substrates. Deposition rates of Co₈₁Cr₁₉ and Al layers at DC discharge current of 1A were 6.5 and 7 Å/sec at applied voltage of 520 and of 470V, respectively. The thickness of Co-Cr layers λ_{Co-Cr} was varied in the range of 46~170 Å, while, the thicknesses of Al layer λ_{Al} were 7 and 14Å. The total film thickness $\Sigma(\lambda_{Co-Cr} + \lambda_{Al})$ was about 1500Å. The first and last layers were Al ones so that every Co₈₁Cr₁₉ layer was sandwiched by Al ones.

For the purpose of investigating the effects of Al layers in detail, the two types of specimen films with λ_{Co-Cr} of 46 Å were prepared by intermittent sputtering method, where one was the films A composed of intermittently deposited Co₈₁Cr₁₉ multilayers and another was the films B with the Co₈₁Cr₁₉ multilayers sandwiched by only the first and last layers of Al.

Fig.3. Dependence of interplanar spacing of (002) d_{002} on thickness of Co₈₁Cr₁₉ layer λ_{Co-Cr} .

The crystal structure was analyzed by X-ray diffractometry. The saturation magnetization and the coercivity at room temperature were measured on the hysteresis loops by means of VSM. The anisotropy field H_k was estimated on the loops in the direction of the hard magnetization. Magnetoresistivity was measured with a four point probe at room temperature.

RESULTS AND DISCUSSION

The composition of the deposited Co-Cr layers was confirmed to be almost equal to Co₈₁Cr₁₉, that of target alloy by EPMA.

Figure 2 shows the typical small angle X-ray diffraction diagrams of two kinds of specimen films with modulation periods of 46Å-Co₈₁Cr₁₉/7Å-Al and 46Å-Co₈₁Cr₁₉/14Å-Al, respectively. The three peaks of the both of films were clearly observed. Their modulation lengths λ_M calculated from the angles at the position of these peaks were in good accordance with the expected ones. This may imply that the good periodic structure could be formed in the films deposited by using FTS apparatus. The Co₈₁Cr₁₉ layers in all specimen were composed intrinsically of the hcp phase crystallites with well orientation of c-axis normal to the film plane.

Figure 3 shows the dependence of the interplanar spacing between (002) planes d_{002} of hcp Co-Cr crystallites in multilayered films on λ_{Co-Cr} . Both of d_{002} were expanded gradually with decrease of

Fig.4. Dependence of c-axis dispersion $\Delta\theta_{50}$ on $\lambda_{\text{Co-Cr}}$.

$\lambda_{\text{Co-Cr}}$, and was about 2.056 Å at $\lambda_{\text{Co-Cr}}$ of 46 Å and λ_{Al} of 14 Å. These values of d_{002} were longer than that of $\text{Co}_{81}\text{Cr}_{19}$ single layer films (2.035 Å). [6] The specimen film A and B exhibited d_{002} of 2.038 and 2.037 Å, respectively. This may be due to the difference in Young's modulus between Co-Cr alloy and Al. Al is more easily expanded than Co-Cr. d_{002} in 14Å-Al layers are longer than that in 7Å-Al ones. This may be due to that the compressive stress depends on λ_{Al} .

Figure 4 shows the dependence of the dispersion of c-axis orientation $\Delta\theta_{50}$ in multilayered films on $\lambda_{\text{Co-Cr}}$. Both of $\Delta\theta_{50}$ decreased gradually with increasing $\lambda_{\text{Co-Cr}}$. The crystallinity was improved as $\lambda_{\text{Co-Cr}}$ increased. The specimen film A and B exhibited $\Delta\theta_{50}$ of 9.6 and 11°, respectively. $\Delta\theta_{50}$ in 7Å-Al layers was smaller than that in 14Å-Al ones. This may imply that Co-Cr crystallites may grow epitaxially in 7Å-Al layers. On the other hand, Co-Cr crystallites in 14Å-Al layers may not grow epitaxially but their grains may become fine by large compressive stress. It has been found from Figs.3 and 4 that the crystallinity was improved and the c-axis was expanded by using the Al interlayers.

The easy direction of magnetization in the films was perpendicular to the film plane in 7Å-Al layers.

Figure 5 shows the dependence of the saturation magnetization M_s on $\lambda_{\text{Co-Cr}}$. M_s were calculated for $\Sigma(\lambda_{\text{Co-Cr}} + \lambda_{\text{Al}})$. Both M_s depended significantly on $\lambda_{\text{Co-Cr}}$. M_s took maximum value of 610 emu/cc at $\lambda_{\text{Co-Cr}}$ of 84 Å

Fig.5. Dependence of saturation magnetization M_s on $\lambda_{\text{Co-Cr}}$.

in 7Å-Al layers. M_s of the specimen film A and B are 630, and 640 emu/cc, respectively, being larger than that of the $\text{Co}_{81}\text{Cr}_{19}/\text{Al}$ multilayered films with $\lambda_{\text{Co-Cr}}$ of 46 Å. The calculated M_s based on the experimental results of Co-Cr films by intermittent deposition, where λ_{Al} is taken account in. M_s in $\text{Co}_{81}\text{Cr}_{19}/\text{Al}$ multilayered films are strongly different from the calculated ones. This may be caused to the segregation of chromium by large compressive stress occurred in the plane of $\text{Co}_{81}\text{Cr}_{19}$ layers. This consideration may be supported by the significant extension of d_{002} as shown in Fig.3.

Figure 6 shows the dependence of the parallel coercivity $H_{c\parallel}$ and the perpendicular one $H_{c\perp}$ to the film plane on $\lambda_{\text{Co-Cr}}$. Both of $H_{c\parallel}$ and $H_{c\perp}$ also depended on $\lambda_{\text{Co-Cr}}$. $H_{c\perp}$ of the specimen film A and B are 400, and 350 Oe, respectively, being larger than that of the $\text{Co}_{81}\text{Cr}_{19}/\text{Al}$ multilayered films with $\lambda_{\text{Co-Cr}}$ of 46 Å. In 7Å-Al layers, $H_{c\perp}$ is higher in the range of 70~140 Å, where Co-Cr grains may become fine by compressive stress. On the other hand, in 14Å-Al layers, H_c increased gradually with increasing $\lambda_{\text{Co-Cr}}$. H_c also depend on λ_{Al} . This suggests that the multilayered films with 7Å-Al layers have some effect at the interface between Al and Co-Cr layers.

Figure 7 shows the dependence of the in-plane squareness ratio $(M_r/M_s)_{\parallel}$ on $\lambda_{\text{Co-Cr}}$. In 7Å-Al layers, $(M_r/M_s)_{\parallel}$ increased rapidly with increasing $\lambda_{\text{Co-Cr}}$ from 46 to

Fig.6. Dependence of coercivity H_{cII} and H_{cI} on $l_{\text{Co-Cr}}$.

100 Å. In this range, in-plane anisotropy become rather dominant. Co-Cr grains may become fine by compressive stress. And then $(Mr/Ms)_{II}$ decreased steeply with further increase of $l_{\text{Co-Cr}}$. In this range, the perpendicular magnetic anisotropy was rather remarkable. In 14Å-Al layers, $(Mr/Ms)_{II}$ is higher than that in 7Å-Al ones. The in-plane anisotropy is remarkable. The magnetic anisotropy can be controlled by l_{Al} . This is consistent to the relationship between $\Delta\theta_{50}$ and $l_{\text{Co-Cr}}$ as shown in Fig.4.

The dependence of the magnetoresistivity ratio $\Delta\rho$ on the external magnetic field H_E are investigated, where $l_{\text{Co-Cr}}$ is 46 Å. The absolute value of $\Delta\rho$ was 0.05% in 14Å-Al layers for H_E applied in the direction longitudinal to the current flow. This was smaller than that in 7Å-Al ones.

On the other hand, the change of $\Delta\rho$ with increase of H_E applied in the direction normal to the film plane was less than 0.035. This may imply that the interface between Co-Cr layers and Al ones in the films become sharp with increasing l_{Al} . This consideration may be also supported by the small angle X-ray diffraction diagrams as shown in Fig.2.

CONCLUSION

The $\text{Co}_{81}\text{Cr}_{19}/\text{Al}$ multilayered films have been prepared on glass-slide substrates by using FTS apparatus. $\Delta\theta_{50}$ decreased gradually with increasing $l_{\text{Co-Cr}}$ and d_{002} expanded gradually with the decrease of

Fig.7. Dependence of in-plane squareness ratio $(Mr/Ms)_{II}$ on $l_{\text{Co-Cr}}$.

$l_{\text{Co-Cr}}$, regardless of l_{Al} . Ms depended significantly on $l_{\text{Co-Cr}}$ and l_{Al} . Ms took maximum value of 610 emu/cc at $l_{\text{Co-Cr}}$ of 84 Å in 7Å-Al layers. Both of H_{cII} and H_{cI} also depended strongly on $l_{\text{Co-Cr}}$ and l_{Al} . In 7Å-Al layers, the perpendicular magnetic anisotropy was remarkable at $l_{\text{Co-Cr}}$ above 120 Å. In 14Å-Al layers, the in-plane magnetic anisotropy was remarkable. The changes in Ms and H_c may be due to that the internal stress in the films induced by the different Young's modulus between $\text{Co}_{81}\text{Cr}_{19}$ and Al. This may be caused due to the segregation of chromium by large compressive stress occurred in the plane of Co-Cr layers.

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