Effects of Under-layers on Surface Morphology of Sputtered Co Film

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ABSTRACT

The structure, electrical resistance and surface morphology of 85 nm Co films sputtered on Cr, Co, Cu Ag and Al under-layers were studied. The average thickness and electrical resistance of the Co films were significantly altered, depending on the under-layer thickness and material. The Co film on various under-layers consisted of a Co (HCP) phase in the (101) direction. The surface morphology of the Co film was strongly dependent on the surface roughness and morphology of the under-layers. The Co film showed a maximum surface roughness of 1.69 nm and a minimum roughness of 0.720 nm over a scan area of 1 µm2 on the Ag and Cr under-layers, respectively. The grain size and distribution of the Co films were affected by the grain size and distribution of the under-layer film. The average grain size of the Co films ranged from 13.3 nm on a Co under-layer to 26.2 nm on a Cu under-layer. AFM results indicated that a small grain size on the surface area of the under-layer film gave rise to a bigger grain size of the Co film, whereas a big grain size of the under-layer film produced a smaller grain size of the Co film. The under-layer thickness and material had a secondary effect on the surface morphology of Co films, because both the thickness and material were surface morphology dependent. All results confirmed that the morphology of an under-layer film plays an important role in the surface roughness of a Co film. It can be concluded that the surface roughness and morphology of a Co film can be modified by the under-layer roughness and material.

Keywords: Co films, Under-layers, Sputtering, Surface roughness, Thickness

INTRODUCTION

Thin films prepared on various under-layers and substrates have attracted great interest, because of their sensor and recording media applications. The effects of different metallic under-layers on the structural, magnetic and morphological aspects of magnetic thin films have been studied by many groups of researchers. Lee et al. (1998) reported that a CrMn alloy improves the magnetic properties of sputtered CoCrPt film compared to the conventional Cr under-layer. Nguyen et al. (2002) revealed the effects of a metallic Al under-layer and polymer substrate

(PET) on the morphology of the magnetic properties of Co film prepared by s puttering. Moreover, Nguyen and Lodder (2004) investigated the morphology and structure of the Co film on Cu and Cr under-layers and found that the different microstructure and morphology of the under-layers strongly affected the properties of sputtered Co film, and the differences in the morphology of the under-layers resulted in different structures of 20 nm Co film. Yang et al. (2011) studied the properties of Fe/Pt multilayer films with and without an Al under-layer prepared by magnetron sputtering on SiO_2 substrate. They found that the Al under-layer could reduce the ordering temperature of Fe/Pt film and increase its coercive field. Fu et al. (2007) investigated the morphology, structure and magnetic properties of a FeCo thin film on a Co under-layer with different thicknesses. They reported that the Co under-layer changed the preferred orientation and reduced the average grain size and surface roughness of the FeCo films.

In this study, the surface morphology, structure and electrical resistance of Co film on different under-layers (Cr, Co, Cu, Ag and Al) prepared by RF-sputtering were investigated to study the effects of under-layers on the properties of sputtered Co film.

MATERIALS AND METHODS

Co film was deposited on different under-layers (Cr, Co, Cu, Ag and Al) by RF-sputtering in an argon atmosphere. The targets with a diameter of 3.00 inches and thickness of 0.250 inches were installed at a distance of about 4.5 cm away from the substrate in a vacuum chamber under a base pressure of about $1x10^{-5}$ mbar. The argon pressure during the deposition process was $1x10^{-3}$ mbar. The glow discharge process was performed before the sputtering process to clean the target. The Co film was prepared at a constant sputtering power of 250 W for 1 hour. The under-layers of Cr, Cu, Ag, Al and Co films were sputtered at a power of 200 W for 10 min and 1 hour, respectively. The thickness of the sputtered films was measured by scanning electron microscopy (SEM). The morphology and surface roughness of each film were investigated by atomic force microscopy (AFM). The crystal structure of the film was obtained using X-ray diffraction (XRD) with CuK_α radiation being used to identify the film crystal structure. The electrical resistance of films was measured by a four-point-probe technique.

RESULTS AND DISCUSSION

The SEM images revealed the thickness and cross section of Co film on Cr, Co, Cu, Ag and Al under-layers as shown in Figure 1. The SEM images show a smooth interface between the Co film and the different under-layers. The average thickness of the Co films on the different under-layers and on a glass substrate was estimated from SEM to be between 72-93 nm and 85 nm, respectively. The thickness, electrical resistance and crystal structure of Co films on various under-layers are summarized in Table 1. The thickness of the Cr, Co, Cu Ag and Al under-layers was about 137, 69, 149, 317 and 108 nm, respectively. The maximum and minimum thicknesses of Co film were observed on Cu and Cr under-layers, respectively. The differences in the Co film thickness may have been due to the variance of the atomic interactions at the interface surface between the Co film and the under-layers.

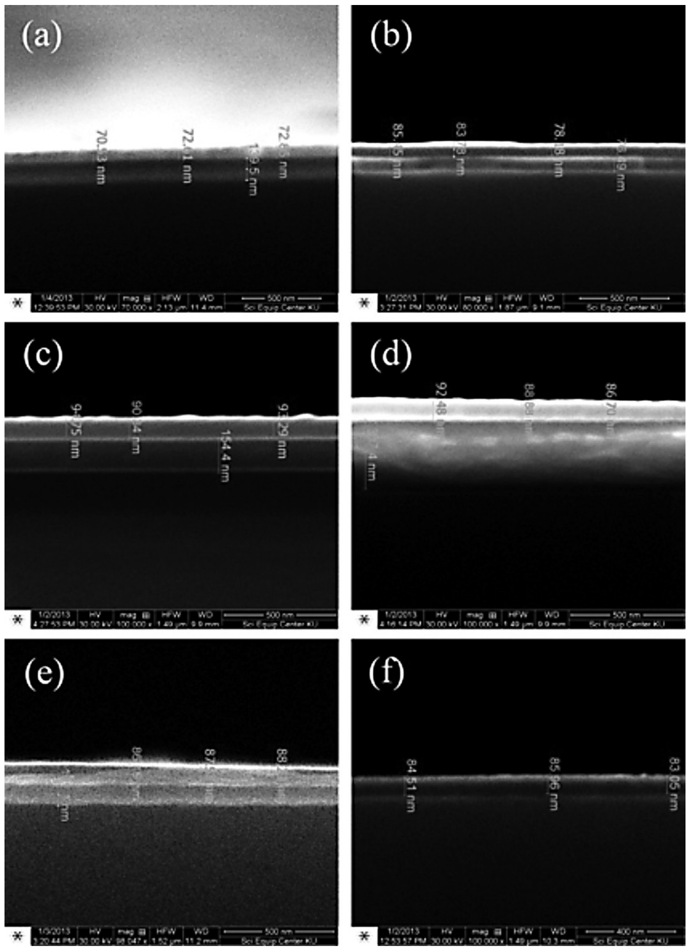

Figure 1. Cross section and thickness from SEM of Co film on (a) Cr, (b) Co, (c) Cu, (d) Ag, (e) Al under-layers and (f) glass substrate.

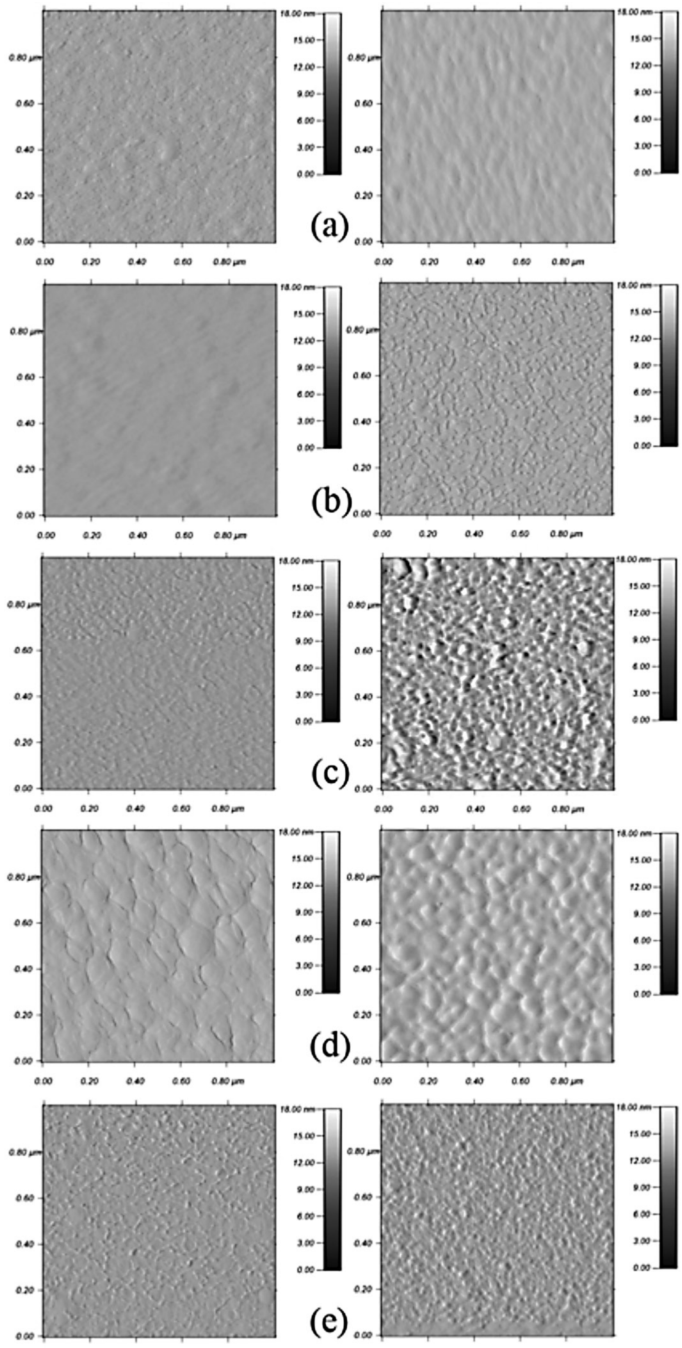

Figure 2. AFM images of under-layer (left) and Co film (right) on (a) Cr, (b) Co, (c) Cu, (d) Ag and (e) Al under-layers.

The AFM results in Figure 2 show the surface morphology of the Co films on different under-layers over a scan area of 1 μm^2. The surface morphology of the Co film revealed a granular structure with a different grain size, distribution and shape, depending on the under-layer material. A fine granular size with a regular size distribution was found in the Co film on the Al under-layer, whereas the biggest granular size with a regular distribution was observed in the Co film on the Ag under-layer. These results clearly showed that the surface morphology of the Co film was affected by the under-layer morphology. It appeared that a small grain size of the under-layer produced a bigger grain size of the Co film, as shown in Figures 2 (a), (c) and (e). On the other hand, a big grain size of the under-layer gave rise to a smaller grain size of the Co film as shown in Figures 2 (b) and (d). The average grain size of the Co film on the Cr, Co, Cu, Ag and Al under-layers calculated from AFM images was 14.3, 13.3, 26.2, 25.7 and 22.7 nm, respectively, while the average grain size of the under-layer films was 9.4, 27.2, 12.8, 41.3 and 11.7 nm, respectively. The Cr, Cu and Al under-layers with a layer thickness of 137, 143 and 108 nm, respectively, had a small grain size on the surface, but the Co and Ag under-layers with a layer thickness of 69 and 319 nm, respectively, exhibited a bigger grain size. Nguyen et al. (2002) reported that Al could induce a microstructure change by isolating the nuclei and reducing their sizes. A similar effect was observed for Cu under-layer on the sputtered Co film grown on a polymer substrate (Nguyen et al., 2002). Besides this, a Cu under-layer and Au under-layer could also reduce the ordering temperature of sputtered FePt film (Yang et al., 2011) and FePd film (Li et al., 2013), respectively.

These results indicated the dependence of the surface morphology on the thickness of the films, as the under-layer thickness directly affected the surface morphology of the under-layer film and, consequently, it had an indirect effect on the surface morphology and roughness of the Co film. Moreover, the cross sections in 3D of under-layers (Figure 3) show the different surface roughness of the Co film on the different under-layers. These cross sections clearly reveal that all the Co films on the various under-layers show a columnar structure with different sizes and distributions. The under-layer films had a different structure at the surface, depending on their material type. The smoothest surface was observed in the Co/Cr film with a minimum surface roughness (R_a) of 0.72 nm. The maximum roughness of 1.69 nm was found in the Co/Ag film. The correlation of under-layer material and roughness as a function of the surface roughness of sputtered Co film is shown as a column chart in Figure 4, which indicates that the Co, Cu, Ag and Al under-layers and the glass substrate gave rise to a higher surface roughness of the Co film than did the Cr under-layer for a Co film.

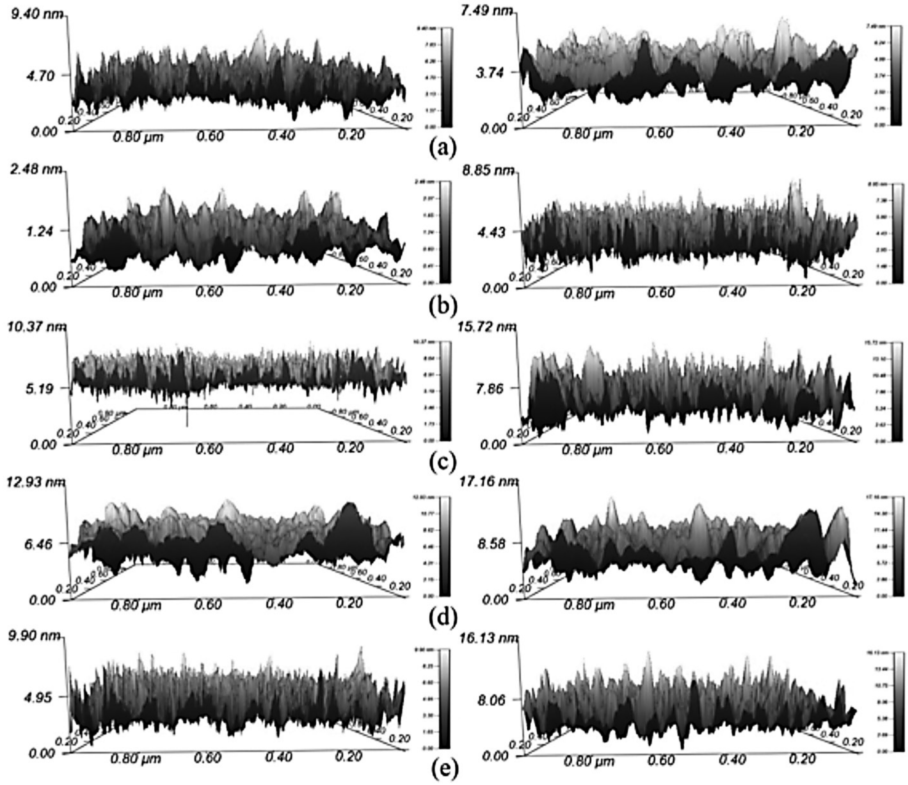

Figure 3. Cross sections in 3D of under-layers (left) and Co film (right) on (a) Cr, (b) Co, (c) Cu, (d) Ag and (e) Al under-layers.

The crystal structures of the sputtered Co films from XRD characterization are summarized in Table 1. All sputtered Co films on the various under-layer materials exhibited the Co (HCP) phase in the (101) preferred direction corresponding to 2-theta of 47.30 degree. The Cr under-layer showed the Cr (BCC) phase with the (110) direction. The Cu, Ag and Al under-layers were similar and showed the FCC phase in the (111) direction. These results suggested that the Co/Cr film possessed the smoothest surface and a regular grain size and distribution, because the BCC lattice of the Cr under-layer and the FCC-under-layers increased the roughness of the Co film. It appears that the roughness of the Co film is substantially affected by the under-layer crystal structure. These results are consistent with the previous studies that the Cr under-layers changed the crystallite size of FePt film prepared on MgO substrate (Ding et al., 2006) and modified the columnar structure of Nd-Fe-B thin film (Shima et al., 1998).

Table 1. Thickness, electrical resistance and crystal structures of Co film on different under-layers.

Sample	Thickness (nm)	Resistance (Ω)	Structure
Co/Cr	72/138	16.917	Cr: BCC (110), Co: HCP (101)
Co/Co	83/69	0.9966	Co: HCP (101), Co: HCP (101)
Co/Cu	93/150	0.3794	Cu: FCC (111), Co: HCP (101)
Co/Ag	89/317	0.0327	Ag: FCC (111), Co: HCP (101)
Co/Al	87/108	25.695	Al: FCC (111), Co: HCP (101)
Co/Glass	85	46.363	Co: HCP (101)

The electrical resistance of all samples is presented in Table 1, which shows that the Co/Ag film had minimum resistance because of the high conductivity of the Ag elements, while the highest resistance was the Co film on the glass substrate. The electrical resistance of sample films was strongly dependent on the under-layer resistance, under-layer thickness and the interaction between the different substrates and the Co film. All results confirmed that the under-layer film plays an important role in the surface roughness of the Co film, because of the under-layer grain size, roughness and crystal structure. It can be concluded that the desirable surface roughness of a Co film prepared by the sputtering process can be strongly modified by the material used for the under-layer and its roughness. Additionally, the BCC phase structure of the under-layer substantially reduced the surface roughness of the HCP-Co film.

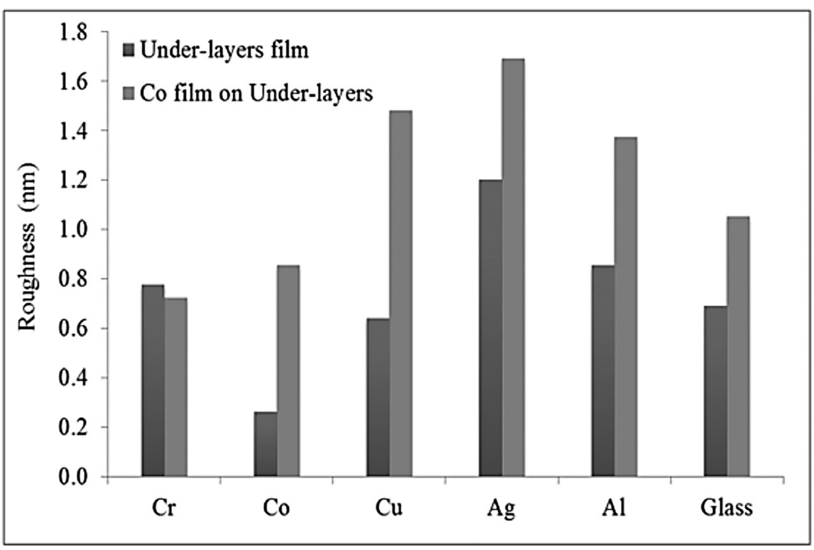

Figure 4. Correlation between surface roughness of under-layers and Co films.

CONCLUSION

Co film was deposited on different under-layers (Cr, Co, Cu, Ag and Al) by RF-sputtering. Co/Cr and Co/Ag films had the minimum and maximum surface roughness of 0.72 and 1.69 nm, respectively. The smaller grain size of the Cr, Cu and Al under-layers gave rise to a bigger grain size of the Co film, whereas the bigger grain size of the Co and Ag under-layers gave rise to a smaller grain size of the Co film. The surface morphology and roughness of the sputtered Co films on various under-layer materials were strongly affected by the under-layer thickness, roughness, crystal structure and material, because of the atomic match and the interaction between the different under-layers and the Co film.

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