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Composition Dependent Formation of Sputtered Co-Cu Film on Cr Under-Layer

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***Abstract*—**Sputtered Co_xCu_{100-x} films with the different compositions of x = 57.7, 45.8, 25.5, 13.8, 8.8, 7.5 and 1.8 were deposited on Cr under-layer by RF-sputtering. SEM result reveals that the averaged thickness of Co-Cu film and Cr under-layer are 92 nm and 22nm, respectively. All Co-Cu films are composed of Co (FCC) and Cu (FCC) phases in (111) directions on BCC-Cr (110) under-layers. Magnetic properties, surface roughness and morphology of Co-Cu films are dependent on the film composition. The maximum and minimum surface roughness of 3.24 and 1.16nm are observed on the $Co_{7.5}Cu_{92.5}$ and $Co_{45.8}Cu_{54.2}$films, respectively. It can be described that the variance of surface roughness of the film because of the difference of the agglomeration rate of Co and Cu atoms on Cr under-layer. The $Co_{57.5}Cu_{42.3}$, $Co_{45.8}Cu_{54.2}$ and $Co_{25.5}Cu_{74.5}$ films shows the ferromagnetic phase whereas the rest of the film exhibits the paramagnetic phase at room temperature. The saturation magnetization, remnant magnetization and coercive field of Co-Cu films on Cr under-layer are slightly increased with increasing the Co composition. It can be concluded that the required magnetic properties and surface roughness of the Co-Cu film can be adapted by the adjustment of the film composition.

***Keywords*—**Co-Cu films, Under-layers, Sputtering, Surface roughness, Magnetic properties, Atomic force microscopy (AFM).

I. Introduction

MAGNETIC granular films consisted of the ferromagnetic granules embedded in non-magnetic metal matrixes have attracted much interest because of their applications such as giant magnetoresistance (GMR) sensor and perpendicular magnetic recording media in hard disk drives (HDDs) technology. The granular film for recording media requires small magnetic particles dispersed in metal metrics with a high coercive field and perpendicular magnetic anisotropy. The sputtered Co-Cu granular films have been widely studied by many research groups [1]-[4] because of their immiscible alloying elements and numerous applications. The coercive field of sputtered Co-Cu films deposited on Si (100) substrates was meaningfully as a function of annealing temperature and perpendicular magnetic anisotropy was found in Co-rich films [4]. The effects of film thickness on magnetic parameter such as coercivity and magnetization of the magnetic films on different substrate have been investigated [5]-[7].

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In this work, structural, magnetic and morphological properties of sputtered Co-Cu granular films with different compositions on Cr under-layer prepared by RF-sputtering using Co target with Cu sheets were investigated to study the effects of film composition on the surface roughness, structural and magnetic properties.

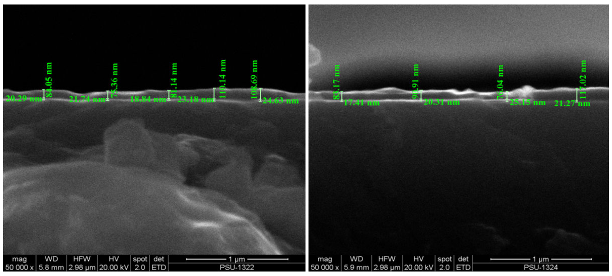
II. Materials and Methods

Co-Cu granular films with various compositions were deposited on the sputtered Cr under-layer in Ar atmosphere. The composite target was prepared from Co (99.99%) target and Cu (99.95%) sheets then installed at a distance of ~4.5 cm away from the Cr under-layer on glass substrate. The base pressure in the chamber and the argon pressure during the deposition were around 10^{-5} mbar and 10^{-3} mbar, respectively. The composite target was cleaned before coating by glow discharge process. Difference of the composition of sputtered Co-Cu films on Cr under-layer was controlled by a number of Cu pieces placed on the Co target. The deposition process was performed with constant sputtering power of 200 W at sputtering time of 1 hour. The chemical composition of sputtered Co-Cu films was identified by an energy-dispersive (EDS) detector using line-scan profiles. Structural and magnetic properties of the sputtered films were studied by X-raydiffraction (XRD) with CuK_α radiation and vibrating sample magnetometer (VSM) under an applied magnetic field of 10 kG, respectively. Surface morphology of the film was characterized by atomic force microscopy (AFM). Scanning electron microscopy (SEM) was used to investigate the thickness of Co-Cu granular films.

III. Results and Discussion

Side view SEM micrographs of $Co_{57.7}Cu_{42.3}$ and $Co_{45.8}Cu_{54.2}$ films on Cr under-layer are shown in Fig. 1. SEM measurement reveals that the averaged thickness of sputtered Co-Cu films and Cr under-layer is 92nm and 22nm, respectively.

Fig. 2 shows XRD patterns of Co film and Co-Cu films with different compositions on Cr under-layer. Sputtered Co film is composed of FCC-Co phase in (111) direction on BCC (110)-Cr under-layer. Two major peaks of FCC-Co (111) and FCC-Cu (111) phases are observed in all Co-Cu films on Cr under-layer. Intensity of Cu (111) peak is clearly increased with Cu fraction and slightly shifted to the lower diffraction angle. The XRD result confirms that sputtered Co-Cu films on Cr under-layer are consisted of Co granules regularly imbedded in Cu matrix. With increasing of Cu fraction, the Cu peak is slightly shifted to the lower 2θ angle. It signifies that Cu lattice parameter is decreased and the strain effect is occurred during the dispersion of fine Co clusters into Cu matrix.



(a) (b)

Fig. 1 SEM micrographs of sputtered (a) $Co_{57.7}Cu_{42.3}$ and (b) $Co_{45.8}Cu_{54.2}$ films on Cr under-layer

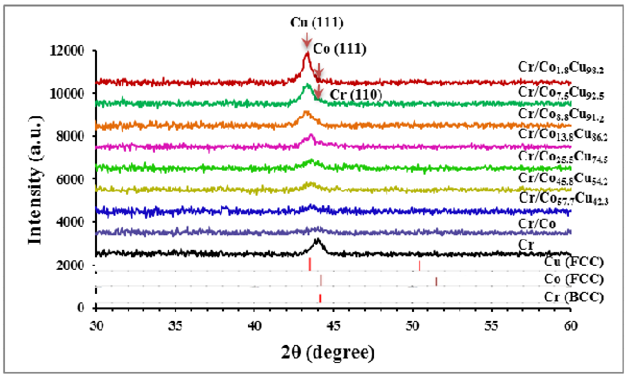
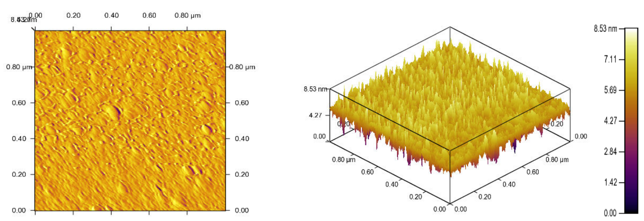
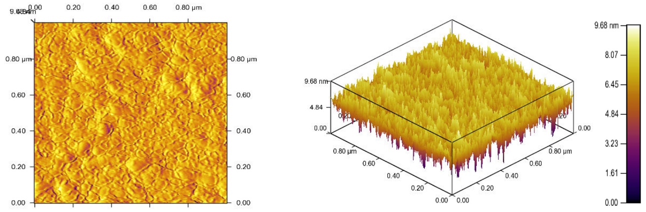


Fig. 2 X-ray diffraction patterns of sputtered Co and Co-Cu films with various compositions on Cr under-layer

2D and 3D-AFM images of sputtered Co and Co-Cu films with different compositions on Cr under-layer over scan area of 1μm×1μm are shown in Fig. 3. The surface morphology reveals granular structure with different grain size, distribution and shape depending on film composition. Tendency of island formation is slightly increased with Cu fraction increasing from 42.3 to 91.2%. Island cluster is clearly observed on $Cr/Co_{8.8}Cu_{91.2}$ film as shown in Fig. 3 (f). For Co-Cu films on Cr under-layer, $Cr/Co_{45.8}Cu_{54.2}$ film shows the lowest surface of 1.16nm with fine grain size and regular distribution and $Cr/Co_{7.5}Cu_{92.5}$ films exhibits the highest surface roughness of 3.24 nm with irregular grain size and distribution. From these AFM results, it can be confirmed that grain size, shape and distribution are composition dependent.



(a)



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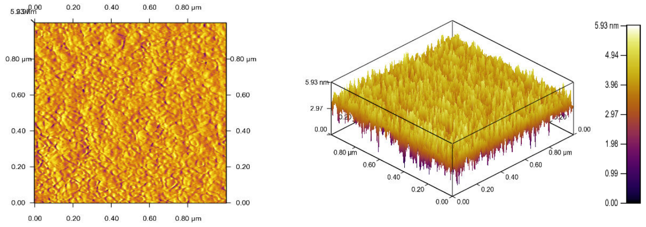

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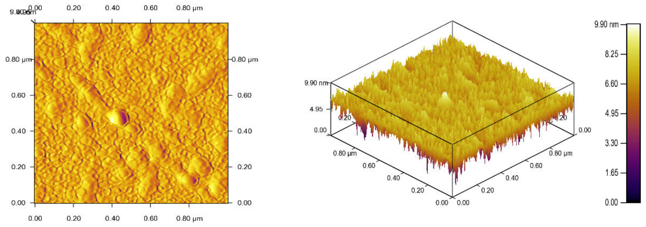

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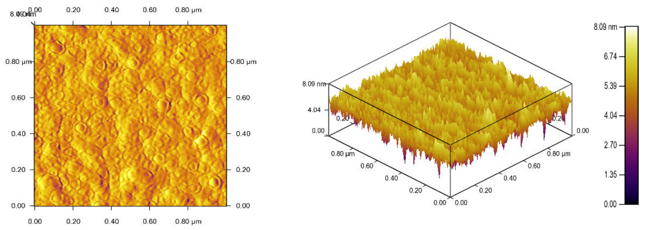
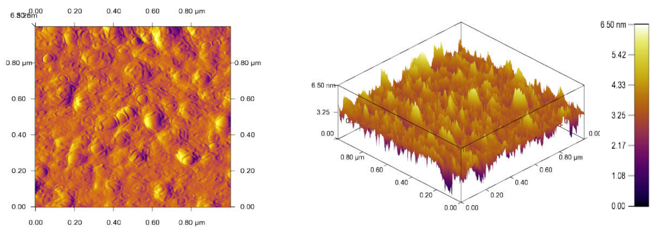
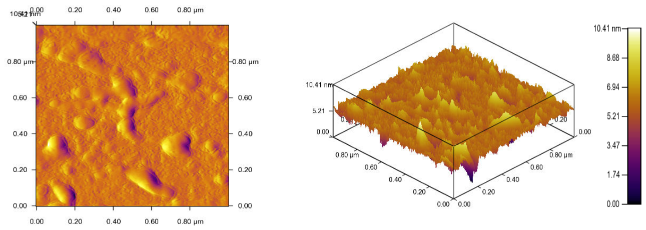


(e)



(f)



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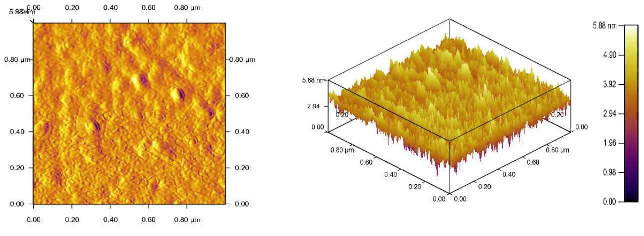

(h)

Fig. 3 AFM images of sputtered (a) Co, (b) $Co_{57.7}Cu_{42.3}$, (c) $Co_{45.8}Cu_{54.2}$, (d) $Co_{25.5}Cu_{74.5}$, (e) $Co_{13.8}Cu_{86.2}$, (f) $Co_{8.8}Cu_{91.2}$ (g) $Co_{7.5}Cu_{92.5}$ and $Co_{1.8}Cu_{98.2}$ films on Cr under-layer

Fig. 4 displays the surface roughness of Co-Cu films with various compositions on Cr under-layer. Roughness of the Co-Cu film on Cr under-layer tends to decrease with increasing Co fraction. It can be described that the dependence of surface roughness on the film composition because of the difference of the accumulative rate on Cr under-layer of Cu atoms and Co atoms during the sputtering process. In comparison to Co-Cu film on Cr under-layer, the Co and Cu-rich film on Cr under-layer also possess the low surface roughness. It can be understood that one atom deposition results in the lower surface roughness compared to the composite atom deposition.

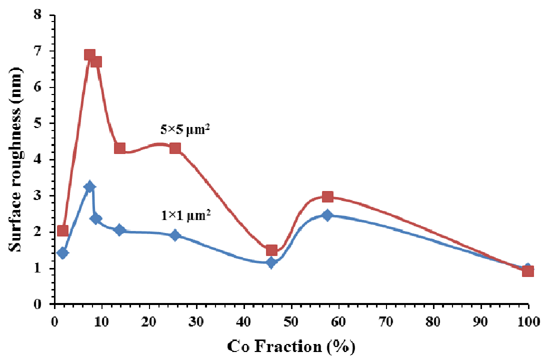

Fig. 4 Surface roughness of Co-Cu films with different composition on Cr under-layer as a function of Co fraction

For Co fraction < 8%, the surface roughness of Co-Cu films on Cr under-layer is tightly enhanced with increasing Co fraction and then reaches the maximum value at Co fraction of 7.5%. It can be described that the initial state of Co atom diffusion agglomeration is originated into Cu matrix give rise to the irregular big island on the surface of $Cr/Co_{7.5}Cu_{92.5}$ film. For Co fraction > 8%, surface roughness is decreased with increasing Co fraction and then approaches the minimum surface roughness on $Cr/Co_{45.8}Cu_{54.2}$ film. The homogeneous surface morphology of $Co_{54.5}Cu_{45.5}$ film is originated from an appropriation of Cu- and Co-atom agglomeration on Cr under-layer. From AFM result confirms that the surface morphology of Co-Cu granular films on Cr under-layer is film composition dependent.

Fig. 5 shows magnetization curve from VSM of Co-Cu films on Cr under-layer at room temperature in comparison to the Co film when an applied magnetic field is parallel to the film plane. From VSM result, the Cr/Co-Cu films with Co content >7.5% exhibit the ferromagnetic phase at room temperature and with Co content ≤7.5% display the diamagnetic phase. It can be defined that Co content at 7.5% is an initial stage of the homogeneous dispersion of the small grain sizes of Co granules in a Cu matrix. From hysteresis loops, the magnetic parameters of Cr/Co-Cu granular films are summarized in Table I. It is clearly shown that saturation magnetization, remanent magnetization and coercive field are increased with increasing Co content.

It is reliable that ferromagnetic phase of Cr/Co-Cu films is originated from Co atoms and their cluster gran size, shape and distribution. It has known that that the saturation and remanent magnetization are obviously dependent on Co fraction in the films, while the coercive field is strongly dependent on the magnetic grain size, shape and distribution. The coercive field is increased with increasing Co fraction. It implies small cluster of Co atoms start to agglomerate into larger cluster. It can be confirmed from AFM results that the ferromagnetic phase is initially found in $Cr/Co_{8.8}Cu_{91.2}$ film. Moreover, the coercive field of $Cr/Co_{57.7}Cu_{42.3}$ film is nearly as high as of Cr/Co film. This result also confirms that the ferromagnetic phase is strongly depended on magnetic grain size and distribution. It can be concluded that magnetic phase of the Co-Cu film on Cr under-layer are started at Co content of 8.8%.

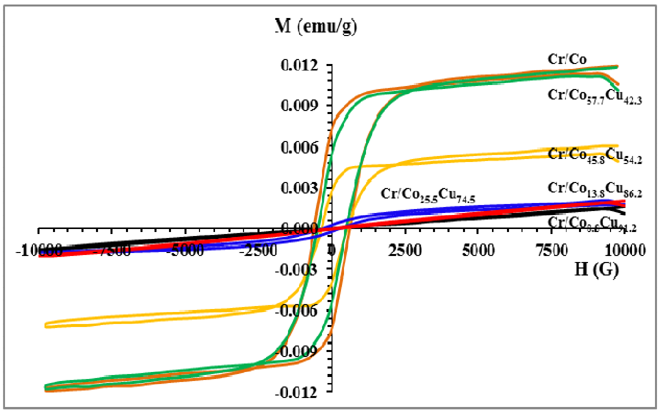

Fig. 5 Hysteresis loops of sputtered Co-Cu films with different compositions on Cr under-layer when magnetic field is applied in the parallel direction to the film plane

TABLE I
SATURATION MAGNETIZATION (M_S), REMANENT MAGNETIZATION (M_R) AND COERCIVE FIELD (H_C) OF CR/CO-CU GRANULAR FILMS WITH DIFFERENT COMPOSITIONS

Film	M_s (arb. unit)	M_r (arb. unit)	H_c (G)
Cr/Co	0.01191	0.00730	610.0
$Cr/Co_{57.5}Cu_{42.3}$	0.01179	0.00545	486.0
$Cr/Co_{45.8}Cu_{54.2}$	0.00663	0.00335	442.0
$Cr/Co_{25.5}Cu_{74.5}$	0.00202	0.00024	302.5
$Cr/Co_{13.8}Cu_{86.2}$	0.00201	0.00003	120.0
$Cr/Co_{8.8}Cu_{91.2}$	0.00157	0.00001	58.0

IV. CONCLUSION

The homogeneous Co-Cu magnetic films on Cr under-layer with FCC-Co (111) phase can be prepared by sputtering process for Co fraction >8.8%. Structure, morphology, surface roughness and magnetic properties of Cr/Co-Cu films are found strongly depend on film composition because of the difference of cluster grain size and distribution of deposited atoms. Increase of Co fraction in Cr/Co-Cu films gives rise to the lower surface roughness and the higher coercive field because of Co- atoms accumulation and distribution in Cu matrix.

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