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A new TiW seed layer for $SmCo_5$ films with perpendicular magnetic anisotropy

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ABSTRACT

A new seed layer TiW is proposed for $SmCo_5$ films with perpendicular magnetic anisotropy. The influence of a TiW seed layer on the microstructure and the surface morphology of Cu underlayer are studied. The grain size and surface roughness dependence of Cu underlayer on the thickness and the annealing of the TiW seed layer are also investigated. The improvement in the perpendicular magnetic properties of $SmCo_5$ film from the TiW seed layer is approved. The results show that a 5 nm Ti_3W_7 seed layer improves the microstructure and surface morphology of Cu underlayer, and significantly improves the perpendicular magnetic properties of $SmCo_5$ film. The diffusion barrier and a high melting point of the TiW seed layer are regarded as the physical mechanism of the improvement for $SmCo_5$ film with perpendicular magnetic anisotropy.

1. Introduction

$SmCo_5$ alloy is a promising candidate for future ultrahigh density magnetic recording because of its huge uniaxial magneto-crystalline anisotropy [1,2]. The magnetic anisotropy constant, K_u, reaches $1.1–2.0 \times 10^8$ erg/cm^3 which is the highest among all the hard magnetic materials. The estimated minimal stable grain size of $SmCo_5$ is 2.4 nm which enables a high recording density of 10 Tbit/in^2 [3]. Cu underlayer plays an essential role to successfully fabricate $SmCo_5$ film with large perpendicular magnetic anisotropy since the close packed plane Cu(111) matches well with $SmCo_5$(0001) [4]. The microstructure and surface morphology of Cu underlayer significantly influence the texture and magnetic property of $SmCo_5$ film [5]. Adding a Ta or Ru seed layer beneath Cu underlayer could decrease the surface roughness(R_a) of Cu underlayer and it also improved the Cu(111) orientation, then benefits the texture and perpendicular magnetic anisotropy of $SmCo_5$ layer [6,7].

TiW is known as a good diffusion-barrier material [8]. TiW is proposed to be a new seed layer because it can prevent Cu diffusion from Cu underlayer into glass substrate and improve the microstructure of Cu layer. At the same time, TiW has a higher melting point thus have a larger surface energy than Cu. It is known that Cu has a smoother surface, a higher crystallinity and a better texture deposited on a material with higher surface energy [6]. In this paper, a TiW seed layer is proposed to improve the microstructure and surface morphology of Cu underlayer and the magnetic properties of $SmCo_5$ films with perpendicular magnetic anisotropy. The influence of the film thickness and the annealing process of TiW seed layer on Cu underlayer and $SmCo_5$ films with perpendicular magnetic anisotropy are studied.

2. Experimental

$SmCo_5$/Cu/TiW film samples were fabricated by JZCK-640S RF magnetron sputtering system at the sputtering power of 100 W and the Ar pressure of 0.48 Pa. The base pressure of the sputtering chamber was 7.2×10^{-5} Pa. The TiW seed layer was firstly deposited onto quartz glass substrate using an alloy target of Ti_3W_7 at room temperature. Subsequently, the Cu underlayer and $SmCo_5$ magnetic layer were deposited in order. And $SmCo_5$ thin films were sputtered utilizing a composite SmCo target with Co plates on a Sm disk with 4 in. in diameter. The deposited film thickness was measured by a Tencor P16+ surface profile measuring system. The sputtering rates of Ti_3W_7 and Cu films were 12 nm/min and 22 nm/min respectively. The crystal structure of the film was analyzed by a Philips PANalytical PW3040/60 X-ray diffraction (XRD) with CuKα radiation. Based on the Scherrer Formula, the grain size of the Cu film was calculated through the full width of half maximum (FWHM) of XRD results. The surface morphology of the film was observed by a Veeco

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NanoScope SPM atomic force microscope (AFM). The out-of-plane perpendicular magnetic property of the film was measured by a Lakeshore 7404 vibrating sample magnetometer (VSM).

3. Results and discussion

Ti_3W_7 films with different thicknesses of 5, 10 and 30 nm were deposited on glass substrates at room temperature. Then 100 nm Cu underlayers and 60 nm $SmCo_5$ films were grown on the TiW seed layer subsequently. Fig. 1 shows the XRD patterns of Cu/TiW double-layer films. The XRD patterns indicate that the insert of TiW seed layer with 5, 10 and 30 nm thickness increases the intensity of Cu(111) peak while remains the intensity of Cu(200) peak at a very low height.

The close packed plane of Cu film is (111) which has the lowest surface energy. That is the reason why Cu(111) peak is much higher than Cu(200) and Cu(220) peaks in XRD patterns of Cu underlayer. The intensity of Cu(111) and Cu(200) peaks and the FWHM of Cu(111) peak in Fig. 1 are obtained using X'Pert Highscore software and listed in Table 1. Noted that the ratio of the intensity of Cu(111) peak to Cu(200) peak $I_{Cu(111)}/I_{Cu(200)}$ is used to represent the (111) texture of Cu film. The larger the ratio is, the better (111) texture the Cu film possesses [9,10]. Meanwhile, the low ratio of $I_{Cu(111)}/I_{Cu(200)}$ of Cu film illustrate that there is a relatively higher share of (200) texture which will lead to the disorder of surface morphology of Cu underlayer.

Table 1 exhibits that $I_{Cu(111)}/I_{Cu(200)}$ increases from 5.7 to 9 when the Cu films are deposited on the TiW seed layer. The significant enhancement of Cu(111) peak intensity and $I_{Cu(111)}/I_{Cu(200)}$ illustrates that TiW seed layer improves the crystallization and (111) texture of Cu film at the same time.

When the film thickness of the TiW seed layer is not more than 10 nm, there is no TiW peak appeared in XRD patterns which implies that the TiW with thickness of 10 nm or less may be in amorphous state. The TiW(110) peak appears in the sample with 30 nm TiW. The effect of TiW thickness on the surface morphology of Cu film is further studied. The grain size and the surface roughness of Cu films deposited on the TiW seed layer with 0, 5, 10 and 30 nm thickness. Fig. 2 is the AFM images of Cu surface grown on the TiW seed layer. It is easy to find that the surface of the Cu film with100 nm thickness grown on 5 nm and 30 nm seed layer are smoother among the four samples, while the Cu film grown on 10 nm TiW seed layer has the roughest surface.

The Cu underlayer surface with a large Cu grain will induce $SmCo_5$ film with a larger grain and a rougher surface and deteriorate the magnetic properties of $SmCo_5$ film [11]. The changes of the grain sizes and the surface roughness of Cu films deposited on the TiW seed layers with 0, 5, 10, 30 nm thickness are shown in Fig. 3. The results show that 100 nm Cu film grown on the 5 nm TiW seed layer has the smallest grain size of 11.7 nm and surface roughness of 0.96 nm compared with another three samples.

The improvement of Cu crystallization, texture, grain size and surface roughness when deposited on the TiW seed layer might be explained by the diffusion barrier effect and surface energy. During the sputtering process of Cu film, Cu atoms will partly

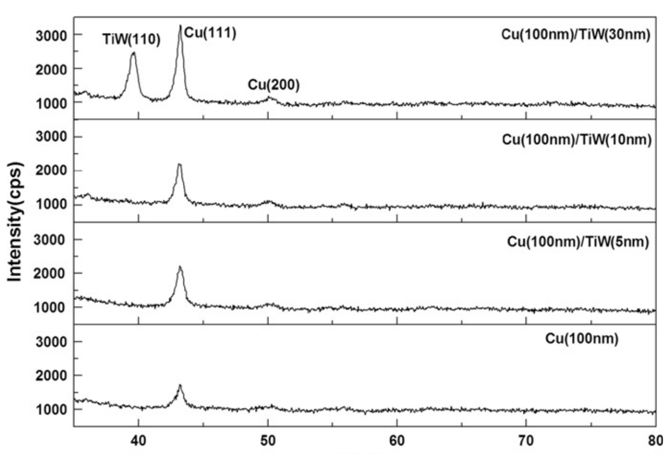

Fig. 1. XRD patterns of Cu films on TiW seed layers.

Table 1
$I_{Cu(111)}/I_{Cu(200)}$ and FWHM of Cu films grown on TiW seed layers.

Film structure	FWHM	$I_{Cu(111)}/I_{Cu(200)}$
Cu/glass	0.62	5.7
Cu/TiW (5 nm)/glass	0.73	9.0
Cu/TiW (10 nm)/glass	0.65	9.1
Cu/TiW (30 nm)/glass	0.58	9.2

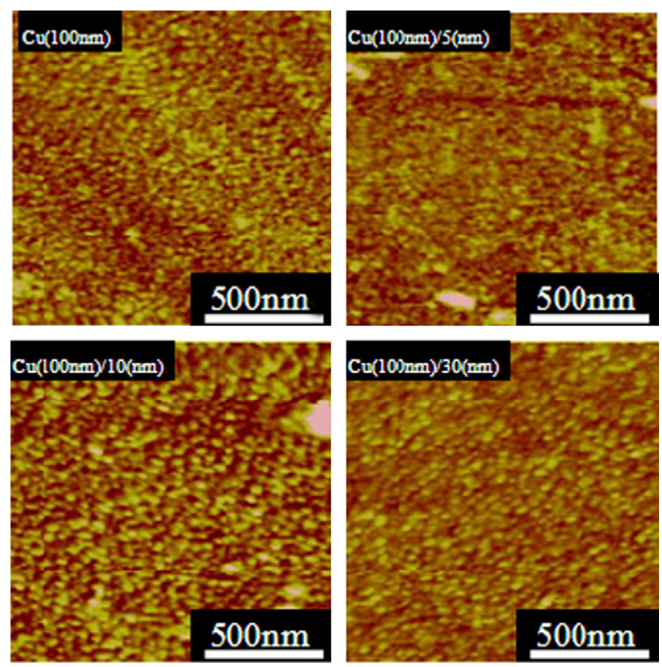

Fig. 2. AFM images of Cu film (100 nm) with 0, 5, 10 and 30 nm TiW seed layers.

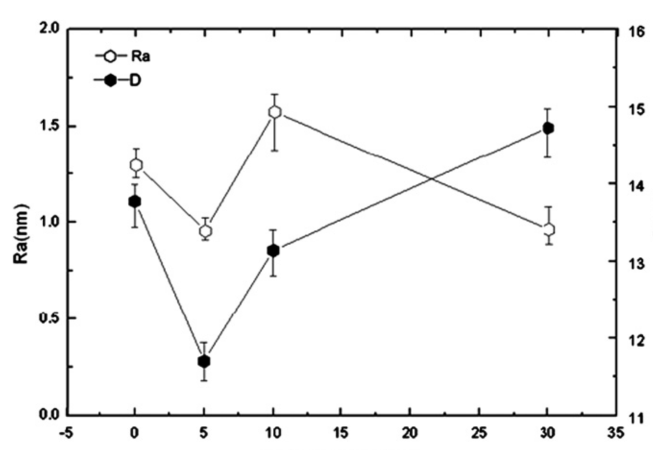

Fig. 3. Grain size D and roughness R_a of Cu film on TiW seed layer thickness.

diffuse into the glass substrate due to the thermal diffusion which might cause a disorder of Cu without good (111) texture. Cu is known to readily react with Si below 200 °C in the $Si(SiO_2)/Cu$ structure [12], but no Si–Cu compound and Cu–Ti–W ternary phases are detected in $Si(SiO_2)/TiW/Cu$ structures below 800 °C [8]. The TiW seed layer acts as an important role of diffusion barrier which prevents Cu atoms from diffusing into glass substrate. Therefore, Cu film will maintain its microstructure when deposited on TiW seed layer. Furthermore, the melting point of Ti_3W_7 is about 2523 K according to TiW phase diagram which is much higher than 1358 K of Cu. TiW with higher melting point has a larger binding energy which leads to a higher surface energy than Cu. Therefore, Cu is very easy to adhere on TiW seed layer forming a smooth and constant (111) close packed plane at the very beginning, which benefits the further growth of ordered-(111) texture of Cu film [13]. The results in Fig. 1 show that TiW film may be in amorphous state when the thickness is not more than 10 nm. It suggests that TiW film begins to be crystallized and the grain size of TiW becomes larger as the thickness of TiW increases. TiW seed layer with a large grain size and a rough surface will cause the increase of Cu grain size deposited on it. Therefore, amorphous TiW seed layer with 5 nm thickness brings the most significant improvement of the microstructure and the surface morphology of Cu film.

When the $SmCo_5$ film with perpendicular magnetic anisotropy is sputtered on the substrate, the substrate must be heated to at least 300 °C to ensure the crystallization of $SmCo_5$ [4]. Both TiW seed layer and Cu underlayer are inevitably heated at the same time. Two Cu samples of 100 nm thickness with/without a 5 nm TiW seed layer were fabricated to study the influence of the annealing process on the microstructures and the surface morphology. Sample was post-annealed at 350 °C in the chamber for 1 h. Fig. 4 shows the XRD patterns of the Cu films with/without a TiW seed layer. XRD patterns of samples exhibit a higher Cu(111) and Cu(200) peaks than the as-deposited samples. It indicates that annealing process enhances the crystallization of Cu film and improves the texture of Cu film. The Cu(111) texture has already been proved to induce the $SmCo_5$(0001) texture effectively and improve the magnetic properties of $SmCo_5$ film. Moreover, the (111) peak of the Cu film with a TiW seed layer has a higher intensity because the TiW seed layer with a high melting point can improve the crystallinity and texture of Cu(111) underlayer. However, the annealing process can worsen of the Cu surface morphology which will deteriorate the perpendicular magnetic properties of $SmCo_5$ deposited on it.

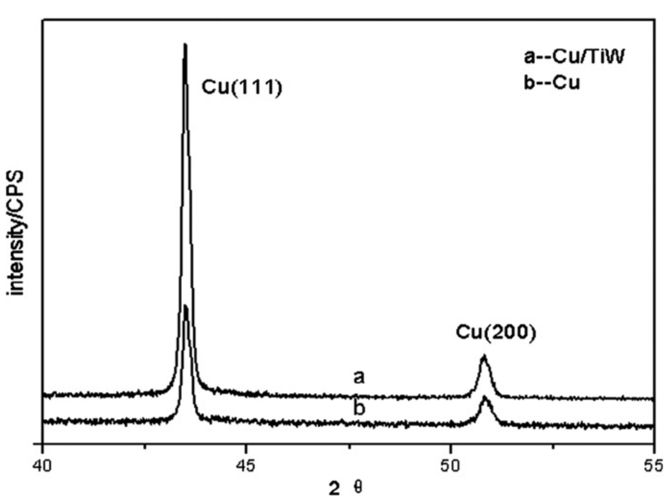

Fig. 4. XRD Patterns of Cu underlayers with and without a TiW seed layer annealed at 350 °C for 1 h.

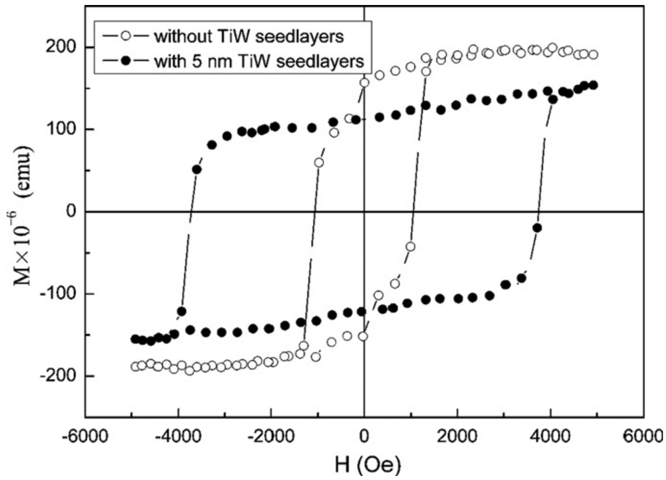

Fig. 5. Out-of-plane hysteresis loops of $SmCo_5$/Cu underlayers (●) with and (○) without a TiW seed layer.

In order to confirm the improvement of a TiW seed layer on the magnetic properties of $SmCo_5$ films, the $SmCo_5$ films with perpendicular magnetic anisotropy were sputtered on the Cu underlayer with and without a TiW seed layer. Fig. 5 shows the out-of-plane hysteresis loops of the two films. The squareness ratio of the two films in the perpendicular direction are the same value about 0.80, however, the perpendicular coercivity of the two films display large differences. $SmCo_5$ film with a 5 nm TiW seed layer shows a higher coercivity of 3719 Oe, while $SmCo_5$ film without a TiW seed layer has a lower coercivity of 1041 Oe, which indicates $SmCo_5$ film with TiW seed layer has a better perpendicular magnetic anisotropy [4]. The perpendicular magnetic property of $SmCo_5$ film can be significantly improved by a TiW seed layer, which should be related to the improvement of the morphology and texture of Cu underlayer. Notably, the magnetization of $SmCo_5$ films with a TiW seed layer is lower because TiW seed layer prevents Cu diffusion into the glass substrate, which gives rise to the more Cu diffusion into the $SmCo_5$ films and induces a larger decrease of magnetization of $SmCo_5$ films [14].

4. Conclusions

A new seed layer TiW is proposed for $SmCo_5$ films with perpendicular magnetic anisotropy. The TiW seed layer is fabricated on the glass substrates by RF magnetron sputtering. X-ray diffraction and atom force microscope are used to characterize the preferred orientation, grain size and surface roughness of the TiW seed layer and the Cu underlayer. The results show that the microstructure and the surface morphology of Cu depends strongly on the thickness of TiW seed layer, a 5 nm Ti_3W_7 seed layer obviously enhances the Cu(111) texture and reduces the grain size to 11.7 nm and the surface roughness to 0.9 nm. The TiW seed layer will benefit the perpendicular magnetic properties of $SmCo_5$ films, and improve effectively the perpendicular coercivity of $SmCo_5$ films from 1041 Oe to 3719 Oe. The results show TiW film is a good seed layer for $SmCo_5$ films with perpendicular magnetic anisotropy because of the physical mechanism on its diffusion barrier and high melting point.

Acknowledgments

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