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Investigation of fabrication and hetero-epitaxy relationship of CoCrPt thin films grown on CrW underlayer*

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This paper reports that longitudinally oriented CoCrPt thin films with $Cr_{85}W_{15}$ underlayer and CoCr intermediate layer for use of giant magnetoresistance heads were fabricated by magnetron sputtering. Without CoCr intermediate layer, CoCrPt layer deposited directly on $Cr_{85}W_{15}$ underlayer which has a dominant (200) texture exhibits unexpected $(10\bar{1}1)$ texture. After introducing CoCr intermediate layer, the CoCrPt layer shifts into $(11\bar{2}0)$ texture. This article studies the crystallographic hetero-epitaxy relationship between magnetic layer and underlayer in order to understand the appearance of CoCrPt $(10\bar{1}1)$ texture on (200) textured Cr underlayer and the influence of CoCr intermediate layer on the inducement of CoCrPt $(11\bar{2}0)$ texture. The CoCr intermediate layer plays a crucial role in controlling the microstructure and consequently the magnetic properties of the overlying magnetic layer.

Keywords: CoCrPt thin films, hetero-epitaxy, texture
PACC: 7550S, 8115C

1. Introduction

In past years, Co-based alloy thin films especially CoCrPt alloy thin films have attracted considerable interest for their remarkable magnetic properties, such as strong magnetic crystalline anisotropy and low media noise.[1,2] They can be used as high density magnetic recording media, such as longitudinal magnetic recording media,[3,4] or bias layer in spin valve giant magnetoresistance (GMR) read heads to provide longitudinal field.[5,6] For both applications, it is desirable to have grains with their easy magnetization *c*-axis lying in the plane of the films as many as possible.[7]

In order to obtain CoCrPt films with *c*-axis lying in the plane of the film, different schemes have been devised to optimize the crystallographic texture, including the use of underlayers. The advance in construction of the longitudinal Co-based alloy films is to deposit the Cr underlayer by sputtering at an elevated temperature so as to get Cr underlayer with (200) crystallographic texture. By means of hetero-epitaxial growth, it is possible to obtain $(11\bar{2}0)$ textured Co-based alloy films on (200) textured Cr underlayer, and hence, make the easy magnetization c-axis lie in the plane of the film.

In CoCrPt films, Cr exists in the grain boundary and Pt is soluble into the Co lattice. The addition of Pt has proved to expand the lattice and increase the mismatch between the CoCrPt layer and the underlayer. Therefore, the addition of larger atomic size elements such as Mo, V, Ti and W to Cr lattice can make a better lattice match between the overlying magnetic layer and underlayer.[8−11] In addition, to improve the magnetic properties of Co-based films, the introduction of nonmagnetic intermediate layers has been proposed.[12,13]

In this work, longitudinally oriented CoCrPt films with $Cr_{85}W_{15}$ underlayer and CoCr intermediate layer were fabricated. The influence of W, Mo and Ti doping to Cr underlayer on the Cr (200) texture was studied. From the view point of crystallographic hetero-epitaxy, we investigated the reason why the CoCrPt films deposited on $Cr_{85}W_{15}$ underlayer growing two distinct $(11\bar{2}0)$ and $(10\bar{1}1)$ textures with and without CoCr intermediate layer.

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2. Experiment

All films in our work were deposited on SiO_2 substrates or Corning-7059 glass substrates using direct current and radio frequency co-sputtering method in the CM-18 magnetron sputtering system. The base pressure was better than 3×10^{-7} Torr (1 Torr=133 Pa) and the sputtering Ar gas pressure fixed at 6 mTorr. The deposition temperature and thickness of Cr and CrX (X=Ti, Mo, W) underlayer were 300 °C and 50 nm respectively. The CoCrPt (50 nm) magnetic layer and CoCr (3 nm) intermediate layer were deposited at ambient temperature. The crystallographic structure and lattice constants of the films were characterized by x-ray diffractometry using Cu K_α radiation. The magnetic properties of the films were measured by vibrating-sample magnetometer with a maximum applied field of 16 kOe (1 Oe=80 A/m).

3. Results and discussion

Figure 1 shows the typical x-ray diffraction (XRD) patterns for Cr and $Cr_{85}X_{15}$ (X=W, Mo, Ti) underlayers. The concentration of X fixed at 15% in order to get optimized lattice match. Compared with the others, we find that the $Cr_{85}W_{15}$ underlayer shows a prominent (200) texture. In the process of our experiments, we had predicted to obtain $(11\bar{2}0)$ textured CoCrPt magnetic layer by hetero-epitaxial growth on (200) textured $Cr_{85}W_{15}$ underlayer.

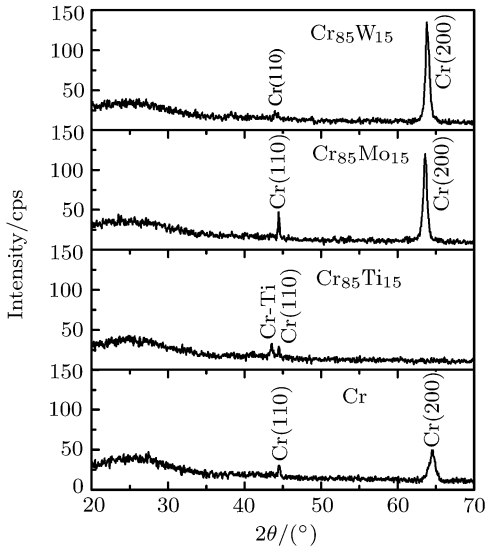


Fig.1. X-ray diffraction patterns of Cr and CrX underlayers.

Figure 2 shows the XRD patterns of CoCrPt thin films with and without CoCr intermediate layer deposited on $Cr_{85}W_{15}$ underlayer respectively. From the XRD patterns, we can see that CoCrPt films depositing on $Cr_{85}W_{15}$ underlayer directly did not show a prospective $(11\bar{2}0)$ texture but a $(10\bar{1}1)$ texture. This means that although the $Cr_{85}W_{15}$ underlayer shows a prominent (200) texture, it cannot hetero-epitaxially grow a $(11\bar{2}0)$ textured CoCrPt films. After introducing CoCr intermediate layer, CoCrPt magnetic layer exhibits a desirable $(11\bar{2}0)$ texture, which implies that the easy magnetization c-axis lies in the plane of the film.

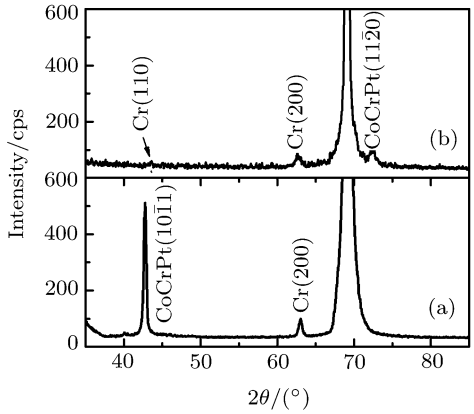


Fig.2. X-ray diffraction patterns of (a) CoCrPt/$Cr_{85}W_{15}$ and (b) CoCrPt/CoCr/$Cr_{85}W_{15}$ films.

The hysteresis loops of CoCrPt/$Cr_{85}W_{15}$ and CoCrPt/CoCr/$Cr_{85}W_{15}$ films are shown in Fig.3 respectively. For $(10\bar{1}1)$ textured CoCrPt thin films, the c-axis is not in the plane of the film, the angle between the $(10\bar{1}1)$ plane and the c-axis is calculated to be 28°, which is not ideal for in-plane magnetization. The employment of CoCr intermediate induces the appearance of CoCrPt $(11\bar{2}0)$ texture and therefore

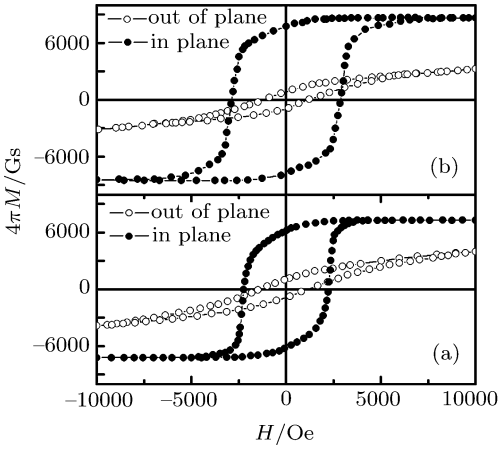


Fig.3. Hysteresis loops of (a) CoCrPt/$Cr_{85}W_{15}$ and (b) CoCrPt/CoCr/$Cr_{85}W_{15}$ films (1 Gs=10^{-4} T).

improves the magnetic properties. With the appearance of CoCrPt $(11\bar{2}0)$ texture, the out-of-plane coercivity decreases and the in-plane coercivity increases from 2.2 kOe to 3.0 kOe correspondingly. The squareness of in-plane hysteresis loop has slight improvement from 0.86 to 0.91.

In order to understand the appearance of CoCrPt $(10\bar{1}1)$ texture on (200) textured Cr underlayer and the influence of CoCr intermediate layer on the inducement of CoCrPt $(11\bar{2}0)$ texture, we studied the crystallographic hetero-epitaxy relationship between overlying magnetic layer and underlayer.

Figure 4 schematically shows the $(10\bar{1}1)$ and $(11\bar{2}0)$ crystal planes of Co-based alloy and the (110) and (200) crystal planes of Cr metal. The Co $(10\bar{1}1)$ crystal plane cannot hetero-epitaxially grow on Cr (200) crystal plane, because there is no hetero-epitaxial relationship between the two planes. Carefully examining the foregoing XRD patterns, we found that there were Cr (110) peaks in $Cr_{85}W_{15}$ underlayers, although they are so weak and toilful to distinguish. The evidence of weak Cr (110) peak implies the existence of Cr (110) texture in $Cr_{85}W_{15}$ underlayer. Combining the analysis of magnetic properties in Fig.3, we find that the hetero-epitaxial relationship of Co $(10\bar{1}1)$ // Cr (110) has actually developed in the CoCrPt films deposited on CrW underlayer directly.

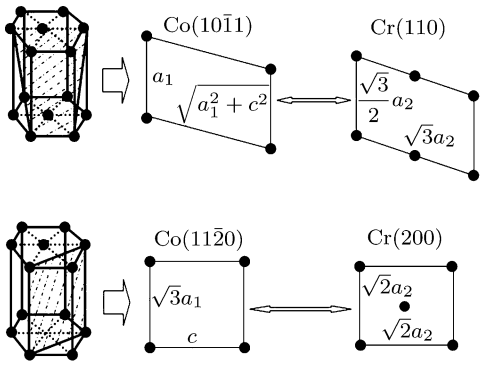


Fig.4. Schematic diagram of hetero-epitaxial relationship of Co $(10\bar{1}1)$//Cr(110) and Co $(11\bar{2}0)$//Cr(200).

In the CrW underlayer with a dominating (200) texture, the hetero-epitaxial relationship of Co$(10\bar{1}1)$//Cr(110) can take precedence in this system which may be due to their good lattice match between Co $(10\bar{1}1)$ crystal plane and Cr(110) crystal plane. Lattice constants of the $Cr_{85}W_{15}$ underlayer and CoCrPt magnetic layer have been analysed by using x-ray diffraction. The XRD data is listed in Table 1. As Table 1 shows, the lattice expands because of doping of W and Pt elements.

Table 1. X-ray diffraction data: d spacing and lattice constant for CoCrPt/$Cr_{85}W_{15}$ films (1 Å=0.1 nm).

	CoCrPt		$Cr_{85}W_{15}$	
Crystal plane	$(10\bar{1}1)$	$(11\bar{2}0)$	(110)	(200)
d spacing/Å	2.080	1.305	2.081	1.471
Lattice constant/Å	$a_1 = 2.610,\ c = 4.245$		$a_2 = 2.942$	

Table 2 lists the lattice mismatch for CoCrPt $(10\bar{1}1)$ // $Cr_{85}W_{15}$(110) and CoCrPt $(11\bar{2}0)$ // $Cr_{85}W_{15}$(200). Two dimensional lattice mismatch of CoCrPt $(10\bar{1}1)$ // $Cr_{85}W_{15}$(110) is 1.0% and 2.2% respectively. This is much smaller than that of CoCrPt $(11\bar{2}0)$ // $Cr_{85}W_{15}$(200), which has two dimensional lattice mismatch of 8.3% and 2.0% respectively. It implies that the hetero-epitaxial growth between CoCrPt $(10\bar{1}1)$ and $Cr_{85}W_{15}$ (110) can establish more easily. For this reason, the fact that CoCrPt films deposited on $Cr_{85}W_{15}$ underlayer directly did not exhibit a $(11\bar{2}0)$ texture but a $(10\bar{1}1)$ texture can be understood.

Table 2. Two dimensional lattice mismatch for CoCrPt $(10\bar{1}1)$//$Cr_{85}W_{15}$(110) and CoCrPt $(11\bar{2}0)$//$Cr_{85}W_{15}$ (200).

	CoCrPt $(10\bar{1}1)$ // $Cr_{85}W_{15}$(110)		CoCrPt $(11\bar{2}0)$ // $Cr_{85}W_{15}$(200)	
CoCrPt/Å	$a_1 = 2.610$	$\sqrt{a_1^2+c^2} = 4.983$	$\sqrt{3}a_1 = 4.521$	$c = 4.245$
$Cr_{85}W_{15}$/Å	$(\sqrt{3}/2)a_2 = 2.584$	$\sqrt{3}a_2 = 5.096$	$\sqrt{2}a_2 = 4.161$	$\sqrt{2}a_2 = 4.161$
Lattice mismatch	1.0%	2.2%	8.3%	2.0%

After introducing a very thin CoCr intermediate layer, CoCrPt $(11\bar{2}0)$ peak is observed, indicating that the c-axis of the CoCrPt layer is effectively in-plane oriented. The thin CoCr intermediate layer spaces out the CrW underlayer and the CoCrPt layer and weakens the hetero-epitaxial growth of CoCrPt $(10\bar{1}1)$ // $Cr_{85}W_{15}(110)$. The CoCr intermediate layer with a hexagonal closest packed (HCP) texture was thought to provide an HCP-texture template for hetero-epitaxial growth of CoCrPt layer and play a key role to modulate the misfits of both underlayer and overlying magnetic layer.

4. Conclusion

The crystallographic hetero-epitaxy relationship between underlayer and magnetic layer was studied. Introducing CoCr intermediate layer, we find that the CoCrPt layer deposited on $Cr_{85}W_{15}$ underlayer with dominant (200) texture shifts from $(10\bar{1}1)$ texture to $(11\bar{2}0)$ texture, indicating that the c-axis of the CoCrPt layer is effectively in-plane oriented. The CoCr intermediate layer plays a crucial role in controlling the microstructure and consequently the magnetic properties of the overlying magnetic layer.

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