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Influence of antiferromagnetic FeMn on magnetic properties of perpendicular magnetic thin films

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ABSTRACT

We studied the influence of an anitferromagnetic FeMn layer on perpendicular magnetic anisotropy (PMA) and perpendicular coercivity ($H_C\perp$) of the CoCr/Pt multilayers and found that both PMA and $H_C\perp$ can be enhanced by the FeMn layer. We observed an obvious exchange coupling between FeMn and CoCr/Pt multilayers which enhances PMA and may increase the density of pinning sites that can pin the domain wall of ferromagnetic layers and lifts up energy barrier during the propagation of domain walls. This leads to the enhancement of $H_C\perp$. Moreover, X-ray diffraction results shows that the (111) texture of the FeMn layer enhances that of the CoCr/Pt multilayers, leading to the increase of PMA and $H_C\perp$ as well. This result is of great significance on improving magnetic properties of perpendicular magnetic recording media by using an antiferromagnetic manganese alloy.

1. Introduction

Meiklejohn and Pean discovered exchange coupling between a ferromagnet (FM) and an anitferromagnet (AFM) in 1956 [1]. After that, exchange coupling has been extensively studied because of its application in reading head and magnetoresistive sensors. Many reports indicate exchange coupling between AFM and soft magnetic materials commonly accompanies with an enhancement of coercivity [1–3]. Sort et al. found that the temperature range of square loop behavior in Co/Pt mutilayers can be extended by introducing exchange coupling between IrMn and the mutilayers [4]. Skumryev et al. embedded FM Co nanoparticles into an AFM CoO matrix and found the enhancement of the anisotropy of Co nanoparticles due to exchange coupling, which leads to a remarkable improvement in thermal stability and superparamagnetic critical temperature of FM particles [5]. However, these works focus on the effect of an AFM on magnetic properties of soft magnetic materials. Whether an AFM has influence on hard magnetic materials such as magnetic recording media? Chiang et al. found an increase of H_C in FePt films by depositing PtMn on a FePt layer [6]. Sort et al. ball milled $SmCo_5$ and NiO powders and found an enhancement of H_C and squareness of $SmCo_5$ powders [7]. The emphasis of above work is studying the impact of an AFM on magnetic properties of magnetic recording materials with parallel magnetic anisotropy. The mechanism is not clear and needs to be further investigated. On the other hand, how an AFM influences magnetic properties of magnetic recording materials with perpendicular magnetic anisotropy (PMA) is still unknown. Based on the important application of the materials with PMA on ultrahigh density magnetic recording media, it is of more importance to explore the effect of an AFM on perpendicular magnetic recording materials and its mechanism.

CoCr based alloy is already widely used in hard disk drives. Recently, CoCr/Pt multilayers with a Pt buffer layer were reported to possess strong PMA [8]. In this paper, we deposited a FeMn layer on the CoCr/Pt multilayers and investigated the impact of AFM on magnetic properties of perpendicular magnetic recording materials and the underlying mechanism. We find that both PMA and perpendicular coercivity ($H_C\perp$) are remarkably increased due to interactions between FeMn and CoCr/Pt multilayers including exchange coupling. This result is of great significance on improving magnetic properties of perpendicular magnetic recording media by using an AFM manganese alloy.

2. Experimental details

The films with the structure of Pt(20 nm)/[CoCr(0.5 nm)/Pt (1.5 nm)]$_5$ and Pt(5–30 nm)/[CoCr(0.3–1.3 nm)/Pt(1.5 nm)]$_5$/FeMn (2–20 nm)/Pt(2.5 nm) were deposited on 220 °C glass substrates by magnetron sputtering. The base pressure of sputtering system was better than 5×10^{-5} Pa and the Ar pressure was kept at 0.9 Pa during sputtering. A field 55.7 kA/m was applied perpendicular to the films during sputtering. The atomic ratio of Co to Cr in the films was measured to be about $Co_{85}Cr_{15}$ by inductively coupled plasma atomic emission spectrometer. Magnetic properties were measured using an alternating gradient field magnetometer (AGFM Micromag2900) with applied in-plane or out-of-plane field up to 1432 kA/m at room temperature. Some samples were measured with vibrating sample Magnetometer (VSM) at a temperature of 120 K with a maximal filed

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of 1194 kA/m. The crystal structures of all films were identified by a MXT21VAHF X-ray diffractometer (XRD) using Cu-Kα radiation (40 kV × 200 mA) and a graphite monochromator using a continuous scanning mode with rate of 8° (2θ)/min.

3. Results and discussion

Fig. 1 shows the in-plane and out-of-plane hysteresis loops of Pt (20 nm)/[CoCr(0.5 nm)/Pt(1.5 nm)]$_5$ (sample 1) and Pt(20 nm)/[CoCr (0.5 nm)/Pt(1.5 nm)]$_5$/FeMn(7 nm)/Pt(2.5 nm) (sample 2). Both of films show excellent PMA due to the interfacial anisotropy energy of CoCr/Pt mutilayers [9]. However, we can clearly see that PMA of sample 2 is obviously better than that of sample 1 and $H_C\perp$ is also larger than that of sample 1. To systematically study the effect of FeMn on PMA and $H_C\perp$ of CoCr/Pt mutilayers, we prepared the Pt(20 nm)/[CoCr(0.5 nm)/Pt(1.5 nm)]$_5$/FeMn (0–20 nm)/Pt(2.5 nm) films. The effective anisotropy constant (K_{eff}), defined as the energy change when a film is magnetized along in-plane and out-of-plane direction, can be cited to describe PMA. K_{eff} K_{eff} is equal to the difference of areas surrounded by the vertical axis and the initial magnetization curve of the in-plane and out-of-plane direction respectively. When $K_{\mathrm{eff}}>0$, the film possesses PMA. The variation of $H_C\perp$ and K_{eff} of films with the thickness of FeMn (d) are shown in Fig. 2 (a) and (b). We can only realize relatively low $H_C\perp$ of 59.7 kA/m and K_{eff} of 3.0×10^5 J/m^3 without a FeMn layer. After depositing the FeMn layer, $H_C\perp$ gradually rises up as d increases. When d = 7 nm, $H_C\perp$ and K_{eff} of the film increase to 86.9 kA/m and 4.13×10^5 J/m^3, respectively. $H_C\perp$ and K_{eff} are saturated with further increase of d. This implies that $H_C\perp$ and K_{eff} of CoCr/Pt mutilayers can be effectively enhanced by introduction of a FeMn layer.

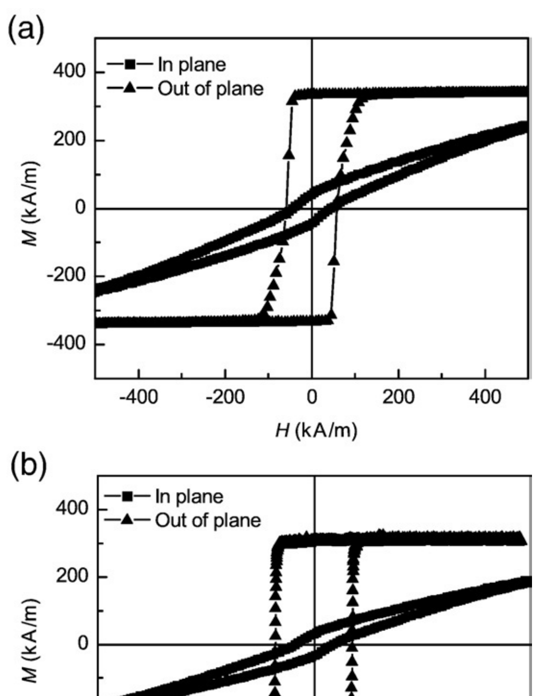

Fig. 1. In-plane and out-of-plane hysteresis loops of the Pt(20 nm)/[CoCr(0.5 nm)/Pt (1.5 nm)]$_5$ (a) and Pt(20 nm)/[CoCr(0.5 nm)/Pt(1.5 nm)]$_5$/FeMn(7 nm)/Pt(2.5 nm) (b).

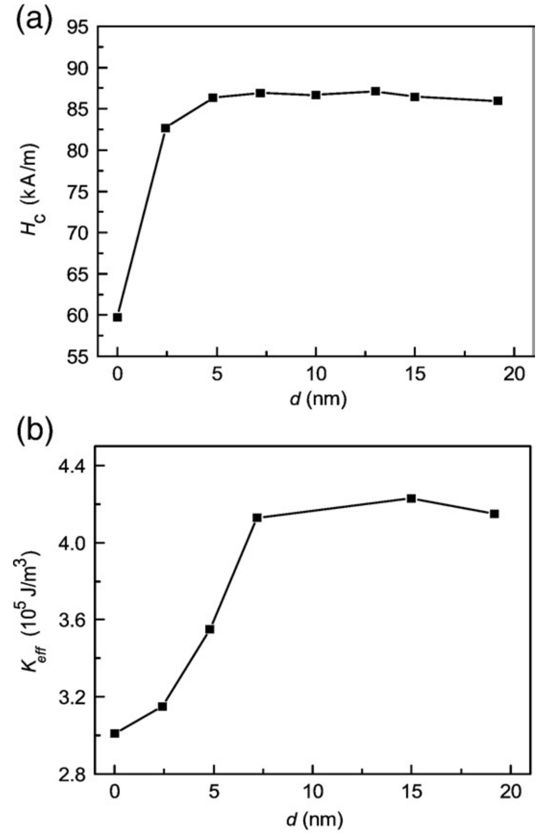

Fig. 2. Variation of $H_C\perp$ (a) and K_{eff} (b) of Pt(20 nm)/[CoCr(0.5 nm)/Pt(1.5 nm)]$_5$/FeMn (d nm)/Pt(2.5 nm) films with d.

To explore the underlying physics for the enhancement of K_{eff} and $H_C\perp$ of CoCr/Pt mutilayers by the FeMn layer, we studied the crystal structure of Pt(20 nm)/[CoCr(0.5 nm)/Pt(1.5 nm)]$_5$/FeMn films with different FeMn thickness d. The XRD patterns are shown in Fig. 3. For all samples, very strong peaks appear at $2\theta\approx4.9°$ and 9.9° corresponding respectively to the first and second small angle diffraction of mutilayers. The calculated periodic thickness of mutilayers is 1.81 nm. Obviously, the films have very good multilayer structure. Pt (111) and (200) peaks come from the Pt buffer layer, whereas Pt (111) and CoCr (002) peaks of CoCr/Pt mutilayers structure merge into a CoCr/Pt (111) peak. This is because Pt has a face-centered cubic structure (a = 0.3931 nm) and CoCr has a hexagonal cubic pyramidal structure

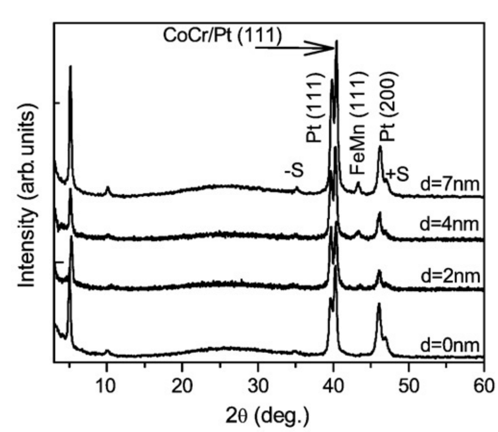

Fig. 3. XRD patterns of Pt(20 nm)/[CoCr(0.5 nm)/Pt(1.5 nm)]$_5$/FeMn (d nm)/ Pt(2.5 nm) films. The curves are offset vertically for clarity.