Journal of Magnetism and Magnetic Materials 322 (2010) 2027–2030

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Ordering temperature of $L1_0$-type FePt films reduced by CuO addition

W.B. Cui, X.H. Liu, F. Yang, X.K. Lv, S. Guo, W.J. Gong, W. Liu*, Z.D. Zhang

Shenyang National Laboratory for Materials Science, Institute of Metal Research and International Center for Materials Physics, Chinese Academy of Sciences, Shenyang 110016, People's Republic of China

ARTICLE INFO

Article history:
Received 12 November 2009
Received in revised form
15 January 2010
Available online 28 January 2010

Keywords:
Magnetic film
Thin film
Magnetron-sputtering
Ordering

ABSTRACT

Effects of addition of CuO layers in $L1_0$-type FePt thin films are investigated. The ordering temperature of $L1_0$-type FePt films can be reduced by CuO addition. The coercivities of 0.78 and 0.82 T are achieved in $[Pt(10\,Å)/Fe(14\,Å)/CuO(2\,Å)]_{10}$ film annealed at 550 °C for 20 min and $[Pt(10\,Å)/Fe(15\,Å)/CuO(3\,Å)]_{10}$ film annealed at 600 °C for 20 min, respectively, and these values are compared to the coercivity of 0.8 T in $[Pt(10\,Å)/Fe(13\,Å)]_{10}$ film annealed at 650 °C. The thickness of Fe and CuO layers strongly influences the ordering temperature of $L1_0$-type FePt and the magnetic properties of the films. The addition of CuO not only brings microstructure and surface morphology changes of FePt film, but also lowers the ordering temperature.

1. Introduction

The $L1_0$-type FePt ordered alloy, with high magnetic anisotropic energy ($\geq 7\times10^6$ J/m^3), is considered to be a promising candidate for magnetic recording media [1]. To realize the magnetic recording densities over 1 T/in^2, the recording media are required to possess high coercivity, good corrosion resistance and small but magnetically isolated grains with diameter less than 11–12 nm. From the viewpoint of the material fabrication, there are three main challenges: (i) isolated PtFe nanograins with narrow size distribution, (ii) textured microstructure with *c*-axis perpendicular to the film planes and (iii) the low ordering temperature [2]. In order to achieve the isolated FePt nanograins, magnetic films with particulate or layered microstructure were prepared by alternatively sputtering or co-sputtering FePt and additives [3,4]. Textured structure can be induced by sputtering on heated substrates [5], underlayers [6] or capping layers [7]. Apart from the above studies, few investigations have also been reported on low-temperature synthesis. Pure metals Cu and Zr have been reported to reduce the ordering temperature of FePt [8,9]. Most of the investigations on the role of related oxide in FePt films were focusing only on the refinement of grain size rather than the ordering temperature. Hence, in the present study, we concentrate to see the effect of CuO addition on the ordering temperature. The accompanied microstructure change and magnetic properties are also discussed.

* Corresponding author. Fax: +86 24 23891320.
E-mail address: wliu@imr.ac.cn (W. Liu).

0304-8853/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2010.01.028

2. Experiments

FePt films with CuO addition were deposited directly onto Si substrate at room temperature under a base pressure better than 4×10^{-5} Pa and sputtering pressure of 0.7 Pa by alternatively dc or rf sputtering the Pt(99.9%), Fe(99.5%) and CuO (99.5%) targets. Two series of films with different thickness of the CuO layer, $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($13\leq x\leq 17$) and $[Pt(10\,Å)/Fe(y\,Å)/CuO(3\,Å)]_{10}$ ($14\leq y\leq 18$), with $[Pt(10\,Å)/Fe(13\,Å)]_{10}$ film, were deposited onto Si (1 0 0) substrate with Mo underlayer and coverlayer for protection of oxidation. After deposition, the films were annealed at temperatures from 500 to 650 °C for 20 min in vacuum better than 2×10^{-5} Pa. All magnetic hysteresis loops were measured at room temperature along the in-plane direction with a superconducting quantum interference device (SQUID, Quantum Design MPMS-7S). The cross-sectional view of the films was studied by a transmission electron microscopy (TEM, JEOL 2010) and the surface morphology was studied by a field-emission scanning electron microscopy (FESEM, Zeiss Supra 35).

3. Results and discussions

Fig. 1(a) and (b) shows the dependences of the coercivities of $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($13\leq x\leq 17$) and $[Pt(10\,Å)/Fe(y\,Å)/CuO(3\,Å)]_{10}$ ($14\leq y\leq 18$) films annealed from 500 to 650 °C, in comparison with those of FePt film. It can be seen that the coercivity of the FePt film is enhanced to 0.8 T by increasing the annealing temperature up to 650 °C. It means that the ordering temperature in the FePt film without any additives is about 650 °C. A significant difference in coercivities can be seen between

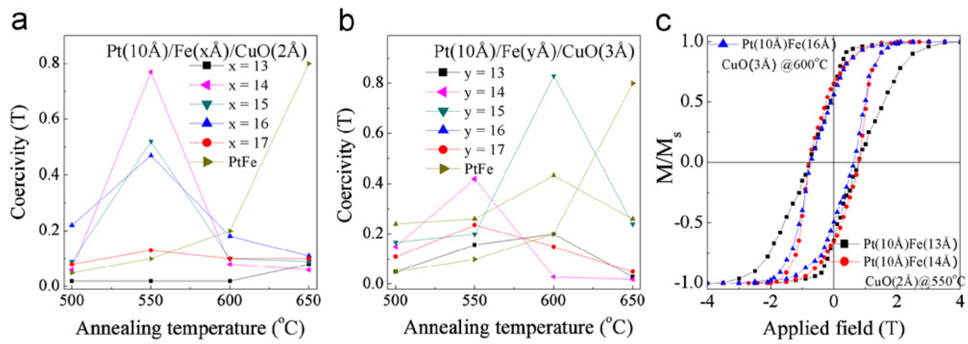

Fig. 1. . Dependence of coercivities in (a) $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($14 \le x \le 16$) films, (b) $[Pt(10\,Å)/Fe(y\,Å)/CuO(3\,Å)]_{10}$ ($14 \le y \le 18$) films on the annealing temperature from 500 to 650 °C and (c) in-plane magnetic hysteresis loops of $[Pt(10\,Å)Fe(14\,Å)/CuO(2\,Å)]_{10}$ film annealed at 550 °C, $[Pt(10\,Å)/Fe(16\,Å)/CuO(3\,Å)]_{10}$ film annealed at 600 °C and $[Pt(10\,Å)/Fe(13\,Å)]_{10}$ film annealed at 650 °C.

FePt film and $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($13 \le x \le 17$) films annealed at the same temperature. At 500 °C, both the FePt and $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($13 \le x \le 17$) films show soft magnetic performance with small coercivities. But annealing at 550 °C appears to be high enough to obtain a large coercivity for $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($14 \le x \le 16$) films. A maximum coercivity of 0.78 T is obtained in annealed $[Pt(10\,Å)Fe(14\,Å)/CuO(2\,Å)]_{10}$ film, which is comparable to that of FePt films annealed at 650 °C. This implies that the ordering temperature in the film with addition of CuO(2 Å) layer is 100 °C lower than that of FePt. Too thin or too thick Fe layer would lead to a low coercivity, as seen in Fig. 1(a), which is due to the composition deviation in FePt layer. Similar results can also be observed in Fig. 1(b). With increase of the annealing temperature, the coercivities of $[Pt(10\,Å)/Fe(y\,Å)/CuO(3\,Å)]_{10}$ ($14 \le y \le 18$) films also increase and reach a maximum at 550 or 600 °C, depending on the thickness of the Fe layer. The maximum coercivity of 0.83 T is obtained in $[Pt(10\,Å)/Fe(16\,Å)/CuO(3\,Å)]_{10}$ film annealed at 600 °C, with the ordering temperature reduced by 50 °C due to the addition of CuO(3 Å) layer. From Fig. 1(a), it can be seen that thinner the CuO layer, more is the effect in the reduction of the temperature. Fig. 1(c) shows the in-plane magnetic hysteresis loops of $[Pt(10\,Å)/Fe(14\,Å)/CuO(2\,Å)]_{10}$ film annealed at 550 °C, $[Pt(10\,Å)/Fe(16\,Å)/CuO(3\,Å)]_{10}$ film annealed at 600 °C and $[Pt(10\,Å)/Fe(13\,Å)]_{10}$ film annealed at 650 °C. One can see that the coercivity and reduced remanence magnetization are similar in all these three films. Additionally, with increasing demagnetization field, the magnetization drops more sharply in the first two films than in the annealed $[Pt(10\,Å)Fe(13\,Å)]_{10}$ film. It means that the grains are more strongly decoupled and a narrow distribution of the reversal nucleation field is obtained in the first two films with the addition of CuO, indicating its beneficial effects.

In order to understand the magnetic properties–microstructure correlation, we carried out further XRD and TEM studies. Fig. 2(a) shows the XRD patterns of the $[Pt(10\,Å)Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($13 \le x \le 16$) annealed at 550 °C with different thickness of the Fe layer. When the thickness of the Fe layer is low (x=13 Å), only (1 1 1) peaks of the disordered phase can be seen, as the annealing temperature is not high enough to form ordered structure. However, with increasing thickness of Fe layer, diffraction peaks of an ordered structure, such as (0 0 1), (0 0 2) and (1 0 2) peaks, show prominently, indicating the formation of the ordered phase. With thicker Fe layer, the intensities of ordered phases gradually decrease and some peaks even disappear again. The change of the XRD patterns suggests that the ordering temperature decreases first and then increases with thicker Fe layer, strongly dependent on the Fe content rather than only on CuO content. Fig. 2(b) gives the XRD patterns of

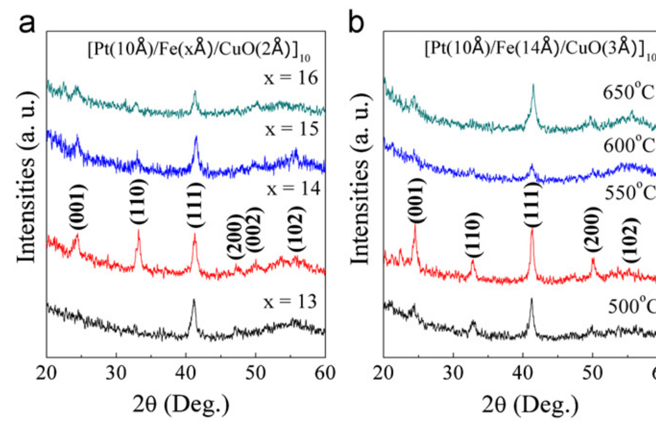

Fig. 2. . XRD patterns of (a) $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($14 \le x \le 16$) films annealed at 550 °C and (b) $[Pt(10\,Å)/Fe(14\,Å)/CuO(3\,Å)]_{10}$ film annealed at temperatures from 500 to 650 °C.

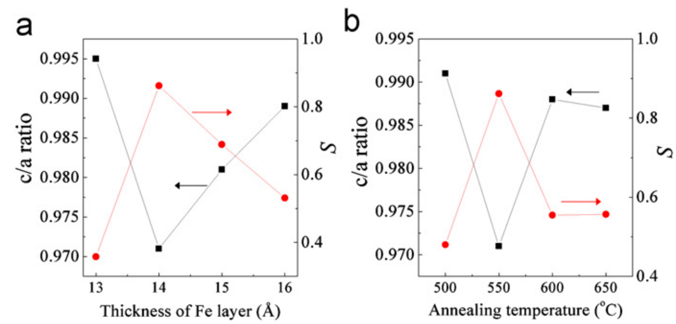

Fig. 3. . Dependence of axial ratio (c/a) and ordering degree (S) on (a) the thickness of Fe layer in $[Pt(10\,Å)/Fe(x\,Å)/CuO(2\,Å)]_{10}$ ($14 \le x \le 16$) films annealed at 550 °C and (b) the annealing temperature of $[Pt(10\,Å)/Fe(14\,Å)/CuO(3\,Å)]_{10}$ film annealed at temperatures from 500 to 650 °C.

$[Pt(10\,Å)/Fe(14\,Å)/CuO(2\,Å)]_{10}$ film annealed at different temperatures (500, 550, 600 and 650 °C). It can be observed that at 500 °C, only (1 1 1) and (1 0 2) peaks are observed, indicating that ordered $L1_0$-type FePt phase has not been well formed. With increase of the annealing temperature to 550 °C, the superlattice reflection of the ordered $L1_0$-type FePt phase appears. Higher annealing temperature (600–650 °C) leads to the formation of the disordered structure again. To describe the ordering process quantitatively, the ordering parameter S is proposed and defined as: $S=[1-(c/a)]/[1-(c/a)_{Sf}]$, where $(c/a)_{Sf}$ is the axial ratio of the