Institute of Physics Publishing | Nanotechnology

Nanotechnology **17** (2006) 2411–2414 | doi:10.1088/0957-4484/17/9/057

Magnetic properties of CoTb/FePt(001) nano-bilayer films

Y H Fang[1,3], P C Kuo[1], T H Yang[1], A C Sun[1], C Y Chou[1], S C Chen[2] and P L Lin[1]

[1] Institute of Materials Science and Engineering, National Taiwan University, Taipei 106, Taiwan

[2] Department of Materials Engineering, MingChi University of Technology, Taipei 243, Taiwan

E-mail: d93527014@ntu.edu.tw

Received 21 November 2005, in final form 13 March 2006

Published 19 April 2006

Online at stacks.iop.org/Nano/17/2411

Abstract

The magnetic properties and microstructure of CoTb/FePt bilayer films are investigated. The magnetic anisotropy of the $Co_{70}Tb_{30}$/FePt(001) film is perpendicular to the film plane. The saturated magnetization (M_s) and perpendicular coercivity ($H_{c\perp}$) of the $Co_{70}Tb_{30}$/FePt(001) bilayer films are higher than those of single-layered $Co_{70}Tb_{30}$ films. The $H_{c\perp}$ and M_s are 5450 Oe, and 403 emu cm^{-3}, respectively. As the temperature is increased to 200 °C, there is a rapid decrease in the $H_{c\perp}$ value.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The heat-assisted magnetic recording (HAMR) method, which is a combination of thermal magnetic writing and magnetic flux detection, has been suggested for increasing the recording density of magnetic disks [1, 2]. The medium used for HAMR must (i) provide satisfactory magneto-optical writing performance, (ii) have a large saturation magnetization to generate sufficient magnetic flux for giant magnetoresistive (GMR) head readout, and (iii) possess a large $H_{c\perp}$ to resist thermal agitation of the magnetic moments. CoTb is a rare-earth metal alloy possessing a large $H_{c\perp}$ value, perpendicular anisotropy ($K_{u\perp}$), and amorphous structure [3]. Moreover, the amorphous CoTb alloy has a short-range order without grain boundaries [3]. Therefore, it is a potential medium, which is expected to have low noise and high recording density, in HAMR.

Recently, the surface/interface roughness of magnetic thin films has been found to influence magnetic properties, such as magnetic anisotropy, coercivity, magnetoresistance, and magnetic domain structure [4, 5]. Various works on the relationship between the surface roughness and coercivity of thin films have been carried out [6–8]. In addition to the surface roughness, it is known that the thickness, composition, and crystalline structure of the magnetic film, as well as the preparation condition, also determine the magnetic properties of films. In this work, bilayer films of CoTb with an FePt(001) under-layer were fabricated. The magnetic properties of this bilayer system were investigated to assess its potential use as an HAMR medium.

2. Experimental procedure

$Fe_{50}Pt_{50}(001)/Pt(001)/Cr(200)$ films were fabricated on 7059 Corning glass substrates by conventional dc magnetron sputtering in an ultra-high vacuum sputtering chamber. The base pressure was better than 5×10^{-9} Torr before sputtering. The substrate was heated to 350 °C to prepare the Cr(200) under-layer and the Pt(001) buffer layer. The Cr and Pt layer thicknesses were 70 nm and 2 nm, respectively. The $Fe_{50}Pt_{50}$ (20 nm) magnetic layer was deposited at 420 °C in order to form the desired $L1_0$ FePt phase [9], followed by room-temperature deposition of 20–60 nm $Co_{70}Tb_{30}$ films by dc magnetron sputtering. To avoid the oxidation of the films, a protective layer of Si_3N_4 (20 nm) was deposited.

The film structure was examined by an x-ray diffractometer (XRD) and a field emission gun transmission electron microscope (FEG-TEM). Composition and homogeneity of the CoTb film were assessed from the energy dispersive spectrum (EDS). The film thickness was measured by an atomic force microscope (AFM). Magnetic properties of the films were

[3] Author to whom any correspondence should be addressed.

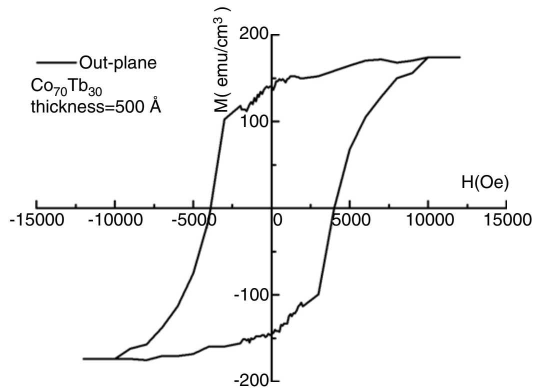

Figure 1. M–H loop of the $Co_{70}Tb_{30}$ film.

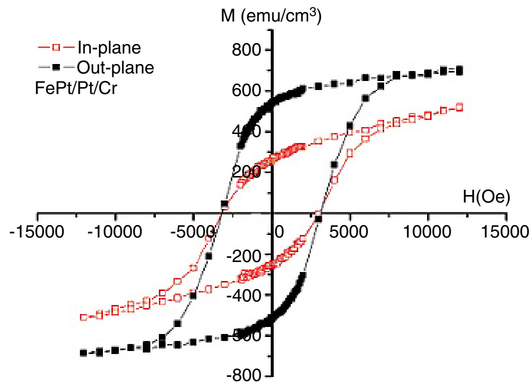

Figure 3. M–H loops of FePt/Pt/Cr tri-layer films.

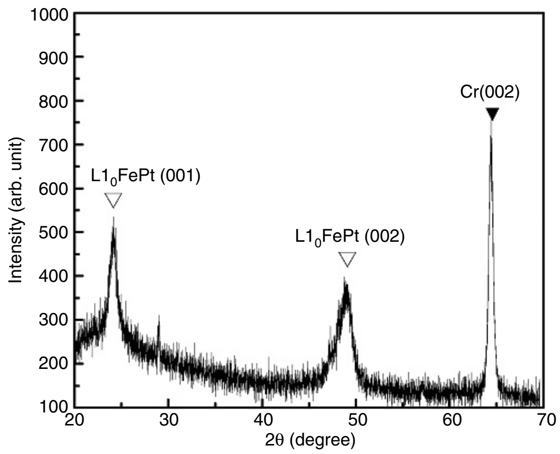

Figure 2. The x-ray diffraction pattern of FePt/Pt/Cr tri-layer films.

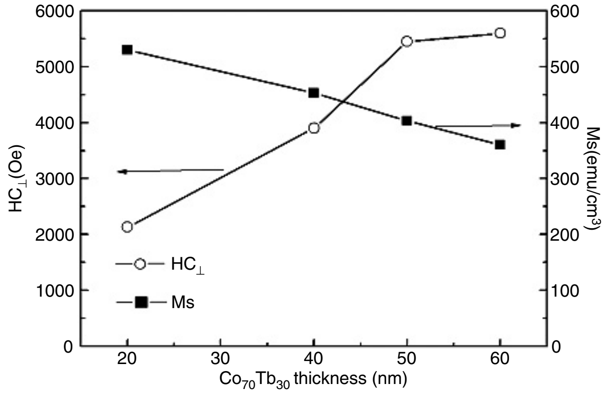

Figure 4. Variations of $H_{c\perp}$ and M_s values of $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films with the film thickness of $Co_{70}Tb_{30}$ in $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr.

measured by a vibrating sample magnetometer (VSM) with a maximum applied field of 12 kOe.

3. Results and discussion

If the Tb content was greater than 39 at.%, the CoTb films exhibit no magnetic properties because the Curie temperature (T_c) is lower than room temperature [10]. It was previously found that the T_c for a $Co_{70}Tb_{30}$ film was greater than 500 K [10–13], thus satisfying the criteria required for HAMR media. Figure 1 shows the M–H loop of the $Co_{70}Tb_{30}$ film at room temperature. The $H_{c\perp}$ and M_s values are approximately 3600 Oe and 176 emu cm^{-3}, respectively. This small M_s makes detection by a high-resolution giant magnetoresistive head (GMR) or a tunneling magnetoresistive (TMR) head difficult. Therefore, a FePt(001) film is introduced beneath the $Co_{70}Tb_{30}$ film in an attempt to increase the M_s value.

From a previous study [14], it was revealed that, in the absence of a Pt intermediate layer, the Cr atoms of the Cr(200) under-layer diffused directly into the FePt magnetic layer and prevented the formation of $L1_0$ FePt(001) orientation. However, by depositing Pt(001)/Cr(200) under-layers, the $L1_0$ FePt(001) and magnetic anisotropy was perpendicular to the surface [14]. In figure 2, peaks of Cr(002), along with (001) and (002)FePt are observed. This would suggest that the FePt/Pt/Cr trilayer films have perpendicular magnetic anisotropy. Indeed, figure 3 shows that the magnetic FePt(001) film exhibits perpendicular magnetic anisotropy with an out-of-plane squareness ($S_\perp$) of around 0.8. The M_s and $H_{c\perp}$ values are about 691 emu cm^{-3} and 3100 Oe, respectively.

The variation of $H_{c\perp}$ and M_s with $Co_{70}Tb_{30}$ film thickness at room temperature in the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr system is shown in figure 4. It is noticed that, as the thickness of the $Co_{70}Tb_{30}$ film ranges between 20 nm and 60 nm, the $H_{c\perp}$ value of the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films increases from about 2100 Oe to 5700 Oe and the M_s value decreases from 530 emu cm^{-3} to 365 emu cm^{-3}. According to the study of Wan *et al* [15], the interaction of the domain wall increases with film thickness. This is considered to be the explanation behind the increased $H_{c\perp}$ value of the $Co_{70}Tb_{30}$ films with increasing thickness. As an HAMR medium is required to have large values of $H_{c\perp}$ and M_s at room temperature, the $Co_{70}Tb_{30}$ film with a thickness of 50 nm is examined further.

After introducing the under-layer of $L1_0$ FePt(001) film into the $Co_{70}Tb_{30}$ (50 nm) film, the M–H loops of the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films are shown in figure 5. It can be seen that the $H_{c_\perp}$, M_s, $S_\perp$ and in-plane squareness ($S_\parallel$) are 5450 Oe, 403 emu cm^{-3}, 0.82 and 0.38, respectively. Figure 6 shows the M–H loops of the $Co_{70}Tb_{30}$, FePt(001) and $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films alone. It is seen that

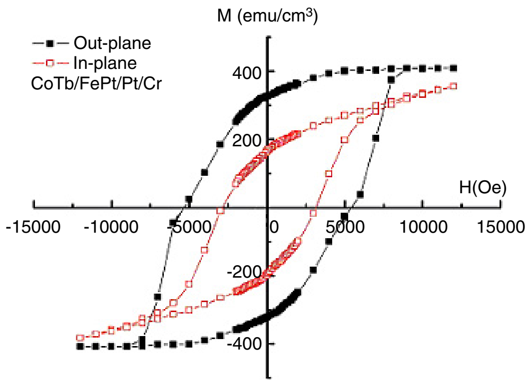

Figure 5. M–H loops of the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films.

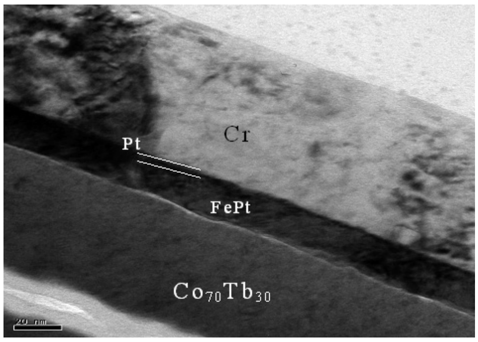

Figure 7. The cross-sectional TEM image of the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr film.

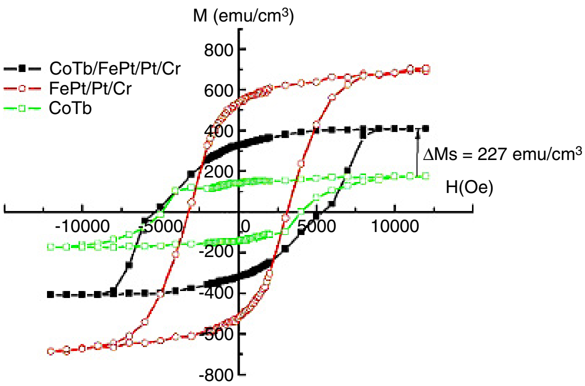

Figure 6. Different M–H loop of $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr, $Co_{70}Tb_{30}$ and FePt(001)/Pt/Cr film.

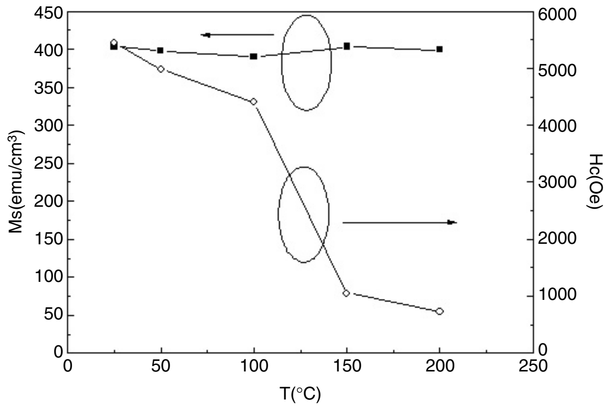

Figure 8. The relationship of the M_s value, $H_{c\perp}$ value, and the temperature of the $Co_{70}Tb_{30}$/FePt(001) bilayer films.

the M_s value of the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr film (M_s = 403 emu cm^{-3}) lies between those of the $Co_{70}Tb_{30}$ (M_s = 176 emu cm^{-3}) and the FePt (M_s = 691 emu cm^{-3}) single-layered films. This is attributed to the fact that M_s is related to the moments of the domain per unit volume of the material. On the other hand, the $H_{c\perp}$ value of $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films is larger than that of either single-layered $Co_{70}Tb_{30}$ or FePt(001) films. This is due to the roughness of the interface. The roughness of the interface is inferred from the cross-sectional transmission electron microscope (TEM) image of the $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr film, shown in figure 7. The surface roughness between the $Co_{70}Tb_{30}$ and FePt(001) films is found to be quite high. The magnetic properties are very sensitive to surface roughness. This roughness could create areas of different domain orientation. Thus the uncompensated surfaces are increased and this causes the total number of spins in one direction to be reduced [16]. Moreover, the rough surface provides more pinning sites and impedes the motion of domain walls at the interface between the $Co_{70}Tb_{30}$ and FePt(001) films [17–22]. It indicates that the magnetic moment needs a larger magnetic field to reverse, so the $H_{c\perp}$ value is increased due to high surface roughness.

The $H_{c\perp}$ and M_s values of the $Co_{70}Tb_{30}$/FePt(001) bilayer films at various temperatures are plotted in figure 8. It can be seen that M_s remains at an almost constant value of around 400 emu cm^{-3} across the temperature range studied. However, the $H_{c\perp}$ value decreases from 5450 Oe to 730 Oe as the temperature increases from 25 °C to 200 °C. The rapid decrease in the $H_{c\perp}$ value with temperature satisfies the writing requirements of the HAMR medium.

4. Conclusions

It has been shown that $Co_{70}Tb_{30}$/FePt(001) films have a high M_s value at room temperature. On the other hand, due to a high interface roughness between the $Co_{70}Tb_{30}$ and FePt(001) films, the $Co_{70}Tb_{30}$/FePt(001) bilayers also have a large $H_{c\perp}$ value at room temperature. The $Co_{70}Tb_{30}$/FePt(001)/Pt/Cr films thus appear to be a promising material as a HAMR medium.

Acknowledgments

This work was supported by the National Science Council and Ministry of Economic Affairs of Taiwan through the NSC grants 94-2216-E-002-009 and 94-EC-17-A-08-S1-0006, respectively.

References

[1] Saga H, Nemoto H, Sukeda H and Kesteren H W 1999 *Japan. J. Appl. Phys.* 1 **38** 1839
[2] Ruigrok J J M, Coehoorn R, Cumpson S R and Kesteren H W 2000 *J. Appl. Phys.* **87** 5398

[3] Kuo P C and Kuo C H 1998 *J. Appl. Phys.* **84** 3317
[4] Chang C H and Kryder M H 1994 *J. Appl. Phys.* **75** 6864
[5] Bruno P, Bayureuther G, Beauvillain P, Chappert C, Lugert G, Renard D, Renard J P and Seiden J 1990 *J. Appl. Phys.* **68** 5759
[6] Malyutin V I, Osukhovskii V E, Vorobiev Yu D, Shishkov A G and Yudin V V 1981 *Phys. Status Solidi* a **65** 45
[7] Vilain S, Ebothe J and Troyon M 1996 *J. Magn. Magn. Mater.* **157** 274
[8] Jiang Q, Yang H N and Wang G C 1997 *Surf. Sci.* **373** 181
[9] Sun A C, Kuo P C, Chen S C, Chou C Y, Huang H L and Hsu J H 2004 *J. Appl. Phys.* **95** 7624
[10] Betz J, Mackay K and Givord D 1999 *J. Magn. Magn. Mater.* **207** 180
[11] Hansen P, Raasch D and Mergel D 1994 *J. Appl. Phys.* **75** 5267
[12] Hansen P, Clausen C, Much G, Rosenkranz M and Witter K 1989 *J. Appl. Phys.* **66** 756
[13] Hansen P, Klahn S, Clausen C, Much G and Witter K 1991 *J. Appl. Phys.* **69** 3194
[14] Sun A-C, Kuo P C, Hsu J-H, Huang H L and Sun J-M 2005 *J. Appl. Phys.* **98** 076109
[15] Wan H, Tsoukatos A and Hadjipanayis G C 1993 *J. Magn. Magn. Mater.* **125** 157
[16] Nogues J and Schuller I K 1999 *J. Magn. Magn. Mater.* **192** 203
[17] Yang W, Lambeth D N, Tang L and Laughlin D E 1997 *J. Appl. Phys.* **81** 4370
[18] Matsumoto K, Ozaki K and Chekanov A 2000 *Japan. J. Appl. Phys.* **39** 1161
[19] Katayama H, Watanabe K, Takayama K, Sato J-I, Miyanishi S and Ohta K 2002 *Appl. Phys. Lett.* **81** 4994
[20] Li M, Zhao Y P and Wang G C 1998 *J. Appl. Phys.* **83** 6287
[21] Ng V, Hu J F, Adeyeye A O and Wang J P 2002 *J. Appl. Phys.* **91** 7206
[22] Chang C-H and Kryder M H 1994 *J. Appl. Phys.* **75** 6864