Effects of Ag buffer layer on the microstructure and magnetic properties of nanocomposite FePt/Ag multilayer films

S. C. Chen[a)]

Department of Mechanical Engineering, De Lin Institute of Technology, Taipei 236, Taiwan and Center for Nanostorage Research, National Taiwan University, No.1, Sec. 4, Roosevelt Road, Taipei 106, Taiwan

P. C. Kuo, C. Y. Chou, and A. C. Sun

Institute of Materials Science and Engineering and Center for Nanostorage Research, National Taiwan University, Taipei 106, Taiwan

The face-centered-tetragonal $L1_0$ FePt films with (001) preferred orientation has perpendicular coercivity ($Hc_\perp$) of about 2462 Oe that can be achieved by stacking a structure of (FePt 4 nm/Ag 2 nm)$_5$ multilayer films on the 5 nm thick MgO underlayer and annealing at 600 °C for 30 min. It is found that both the perpendicular anisotropy and coercivity of (FePt 4 nm/Ag 2 nm)$_5$ multilayer films are enhanced by introducing an Ag buffer layer ($\leqq 20$ nm) between the (FePt 4 nm/Ag 2 nm)$_5$ films and the MgO underlayer. When introducing an Ag buffer layer of 20 nm thickness, the $Hc_\perp$ value of the MgO 5 nm/Ag 20 nm/ (FePt 4 nm/Ag 2 nm)$_5$ multilayer films is observed to increase from 2462 to 4731 Oe, which has significant potential as perpendicular magnetic recording media for high-density recording. © *2005 American Institute of Physics.* [DOI: 10.1063/1.1850386]

I. INTRODUCTION

Due to the large magnetocrystalline anisotropy ($Ku \sim 7 \times 10^7$ erg/cm^3)[1] of the ordered $L1_0$ FePt phase, a small face-centered-tetragonal (fct) FePt grain about 3 nm can overcome thermal instability that results in superparamagnetism.[2] On the other hand, perpendicular magnetic recording media has a narrow transition region between recording bits,[3] which leads to a higher recording density than that of longitudinal recording. Therefore, the $L1_0$ FePt film has attracted much attention to be applied as perpendicular magnetic recording media for ultra high-density recording.[4]

Because the highest atom density plane (close-packed plane) of the FePt alloy is the (111) plane, the $L1_0$ FePt film normally has (111) preferred orientation, which means the easy axis [001] is tilted 35° away from the film plane. In order to obtain (001) preferred orientation, i.e., the easy axis [001] is perpendicular to the film plane, FePt films grown on single crystal MgO (100) substrate has been used.[5,6] However, large lattice misfit at the interface between the MgO (100) and FePt (001) planes is about 9%, the introduction of an Au buffer layer between the MgO (100) and FePt (001) planes is observed to decrease the lattice misfit, leading to the enhancement of the perpendicular anisotropy of FePt layer.[7]

An Ag underlayer is found not only to induce epitaxial growth of FePt films but also to decrease the FePt ordering temperature.[8] Furthermore, the Ag is immiscible with either Fe or Pt. Instead, it tends to segregate at a grain boundary of FePt,[9,10] and increases the grain boundary energy, which can change the preferred orientation of FePt film.[11] In this study, the effects of an Ag buffer layer on the microstructures, mag-

netic properties, and orientation of the FePt easy axis of the nanocomposite MgO/(FePt/Ag)$_5$ multilayer films are investigated.

II. EXPERIMENT

In order to obtain maximum intensity of the MgO (200) peak, the MgO underlayer of 5 nm thickness is deposited onto naturally oxidized Si (100) substrates by rf magnetron sputtering at ambient temperature under an (Ar+N$_2$) pressure of 10 mTorr.[12] The flow rate ratio of N$_2$ to Ar is 2:5. An Ag buffer layer with thickness of 0–30 nm and (FePt 4 nm/Ag 2 nm)$_5$ multilayer films are deposited subsequently by dc magnetron sputtering onto the MgO underlayer. The as-deposited films are annealed at 600 °C for 30 min in vacuum better than 5×10^{-7} Torr. The composition of the FePt film determined by x-ray energy disperse spectrum (EDS) is Fe$_{50.2}$Pt$_{49.8}$.

The microstructures of the film are investigated by a Philips Tecnai F30 field emission gun transmission electron microscopy (TEM) and by x-ray diffractometer (XRD) with Cu-K$_\alpha$ radiation. Compositions of the films are determined by EDS. The magnetic properties of the films are measured using a vibrating sample magnetometer.

III. RESULTS AND DISCUSSION

Figure 1 shows the x-ray diffraction patterns of various MgO 5 nm/Ag t nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films (where t=0–30 nm) after annealing at 600 °C for 30 min. It is found that the (001) and (002) peaks of the FePt films are enhanced by introducing an Ag buffer layer ($\leqq 20$ nm) between the (FePt 4 nm/Ag 2 nm)$_5$ films and the MgO underlayer. This implies that introducing an Ag buffer

---

[a)]Electronic mail: sscchh@ms28.hinet.net
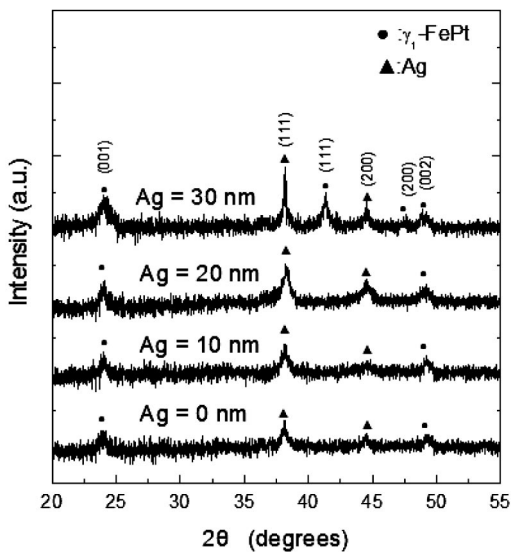
97, 10N107-1

FIG. 1. The x-ray diffraction patterns of various MgO 5 nm/Ag t nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films (where t = 0–30 nm) after annealing at 600 °C for 30 min.

FIG. 3. The high-resolution cross-sectional lattice image of Si/MgO 5 nm/Ag 20 nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films after annealing at 600 °C for 30 min.

layer ($\leqq$20 nm) is beneficial for increasing the perpendicular anisotropy of the FePt films. However, as the Ag buffer layer is increased to 30 nm, the fct FePt (111) and (200) peaks appeared, indicating the preferred orientation of the FePt films is changed from (001) plane to random. The worse (001)$_{FePt}$ texture when the Ag layer increases to 30 nm may be attributed to the epitaxial growth of the (200)$_{Ag}$ plane on the (200)$_{MgO}$ plane which cannot keep as the Ag layer thickness is larger than 20 nm. This results in the (001)$_{FePt}$ plane not stacking well on the (200)$_{Ag}$ plane.

Figure 2 shows the high-resolution TEM cross-sectional lattice image of Si/MgO 5 nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films after annealing at 600 °C for 30 min. The enclosed area clearly shows a misfit dislocation at the MgO/FePt interface due to a large lattice misfit (~9%) at the interface. Therefore, the interface between the FePt mag-
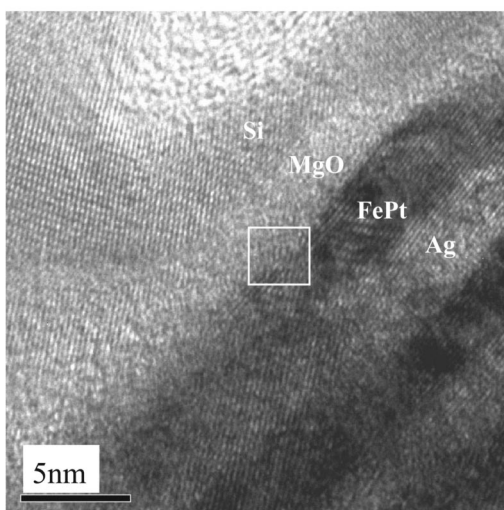
netic layer and the MgO underlayer is a semicoherent interface, which has low strain energy. However, the lattice misfit will be decreased to about 4.5% as introducing an Ag buffer layer between the FePt magnetic layer and the MgO underlayer, and a coherent interface associated with high strain energy is obtained at the interface between the FePt magnetic layer and the Ag buffer layer, as shown in the enclosed area of Fig. 3.

Figure 4 shows the variations of the in-plane coercivity (Hc$_\parallel$) and perpendicular coercivity (Hc$_\perp$) with Ag buffer layer thickness of various MgO 5 nm/Ag t nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films (where t = 0–30 nm) after annealing at 600 °C for 30 min. It is found that both Hc$_\parallel$ and Hc$_\perp$ of the film increase with increasing the thickness of the Ag buffer layer. For the MgO 5 nm/ (FePt 4 nm/Ag 2 nm)$_5$ multilayer films without an Ag buffer layer, the Hc$_\parallel$ and Hc$_\perp$ are 2190 and 2460 Oe, respectively. When introducing an Ag buffer layer of 20 nm thick-

FIG. 2. The high-resolution cross-sectional lattice image of Si/MgO 5 nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films after annealing at 600 °C for 30 min.
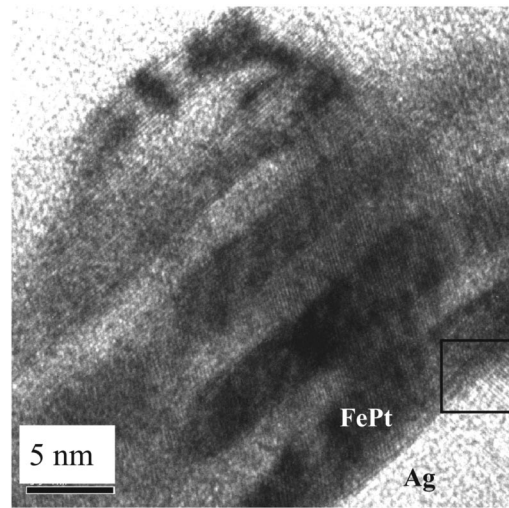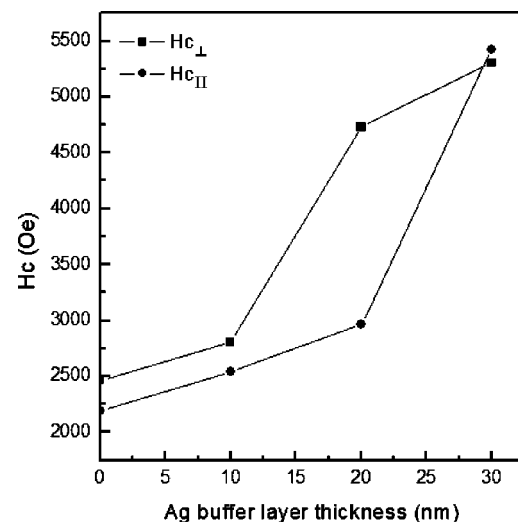

FIG. 4. Variations of the Hc$_\parallel$ and Hc$_\perp$ with an Ag buffer layer thickness of various MgO 5 nm/Ag t nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films (where t = 0–30 nm) after annealing at 600 °C for 30 min.
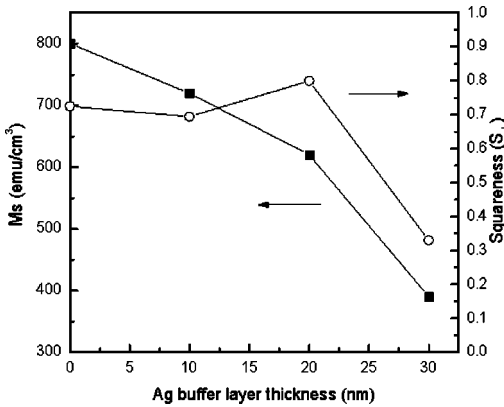
FIG. 5. Variations of the Ms and $S_\perp$ with an Ag buffer layer thickness of various MgO 5 nm/Ag t nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films (where $t=0-30$ nm) after annealing at 600 °C for 30 min.

ness, the Hc$_\parallel$ and Hc$_\perp$ are observed to increase to 2960 and 4730 Oe, respectively. When the thickness of the Ag buffer layer is further increased to 30 nm, although the Hc$_\parallel$ and Hc$_\perp$ both increase to 5420 and 5300 Oe, respectively, the Hc$_\perp$ value is almost the same as the Hc$_\parallel$. This indicates that both the perpendicular anisotropy and coercivity of the FePt films are enhanced by introducing an Ag buffer layer ($\leqq$20 nm) between the (FePt 4 nm/Ag 2 nm)$_5$ films and the MgO underlayer. However, the preferred orientation of the FePt films will be changed from the (001) plane to random as introducing an Ag buffer layer of 30 nm thickness. This is consistent with the XRD observed (see Fig. 1).

The gain in Hc$_\parallel$ and Hc$_\perp$ of the FePt films expands with increasing the thickness of the Ag buffer layer may be ascribed to the following reasons: (1) In the film with the Ag buffer layer, a coherent interface associated with high strain energy is obtained at the interface between the FePt magnetic layer and the Ag buffer layer. During annealing, the higher strain energy is stored in the film, and decreases the energy barrier of phase transformation of FePt from fcc disordered phase to fct ordered phase, resulting in an increase in the coercivity; (2) introduction of the Ag buffer layer will prevent the interdiffusion of the MgO underlayer and (FePt 4 nm/Ag 2 nm)$_5$ multilayer films; and (3) the Ag is immiscible with either Fe or Pt. Instead, Ag tends to segregate at the grain boundary of FePt, and increases the grain boundary energy, which results in the enhancement of the coercivity and changes the preferred orientation of the FePt film.

Figure 5 shows the variations of the saturation magnetization (Ms) and perpendicular squareness ($S_\perp$) with the Ag buffer layer thickness of various MgO 5 nm/Ag t nm/ (FePt 4 nm/Ag 2 nm)$_5$ multilayer films (where $t=0-30$ nm) after annealing at 600 °C for 30 min. The results show that the Ms value of the film decreases with increasing the thickness of the Ag buffer layer. For

MgO 5 nm/(FePt 4 nm/Ag 2 nm)$_5$ multilayer films without the Ag buffer layer, the Ms values is 800 emu/cm^3, and it will decrease to 620 emu/cm^3 as the Ag buffer layer of 20 nm thickness is introduced. The decrease in magnetization of the FePt layer with an increasing Ag buffer layer thickness is mainly due to the increase of ordered $L1_0$ FePt phase content in the film[13] and the dilution of no-magnetic element Ag. On the other hand, the $S_\perp$ value is in the range of 0.7–0.8, when introducing an Ag buffer layer thickness less than 20 nm, where $S_\perp$ is defined as the ratio of perpendicular remnant magnetization (Mr$_\perp$) to Ms. However, as the Ag buffer layer thickness increases to 30 nm, the $S_\perp$ value is decreased dramatically to about 0.33. The result is also consistent with the observation of XRD (see Fig. 1) and the coercivity measurement (see Fig. 4).

IV. CONCLUSION

Both the perpendicular anisotropy and coercivity of FePt films are enhanced by introducing an Ag buffer layer ($\leqq$20 nm) between the (FePt 4 nm/Ag 2 nm)$_5$ films and the MgO underlayer. When introducing a 20 nm thick Ag buffer layer, the Hc$_\perp$ value of the MgO 5 nm/Ag 20 nm/ (FePt 4 nm/Ag 2 nm)$_5$ multilayer films can be increased from 2462 to 4731 Oe, which reveals that it is a promising candidate for high-density perpendicular magnetic recording media application.

[1] S. C. Chen, P. C. Kuo, A. C. Sun, C. T. Lie, and C. C. Chiang, IEEE Trans. Magn. **39**, 584 (2003).
[2] D. Weller, A. Moser, L. Folks, M. E. Best, W. Lee, M. F. Toney, M. Schwickert, J.-U. Thiele, and M. F. Doerner, IEEE Trans. Magn. **36**, 10 (2000).
[3] T. Suzuki, IEEE Trans. Magn. **20**, 675 (1984).
[4] K. Kang, Z. Zhang, and T. Suzuki, IEEE Trans. Magn. **39**, 2317 (2003).
[5] M. H. Hong, K. Hono, and M. Watanabe, J. Appl. Phys. **84**, 4403 (1998).
[6] J.-U. Thiele, L. Folks, M. F. Toney, and D. K. Weller, J. Appl. Phys. **84**, 5686 (1998).
[7] T. Seki, T. Shima, K. Takanashi, Y. Takahashi, E. Matsubara, Y. K. Takahashi, and K. Hono, J. Appl. Phys. **96**, 1127 (2004).
[8] Y. N. Hsu, S. Jeong, D. E. Laughlin, and D. N. Lambeth, J. Appl. Phys. **89**, 7068 (2001).
[9] Z. L. Zhao, J. Ding, K. Inaba, J. S. Chen, and J. P. Wang, Appl. Phys. Lett. **83**, 2196 (2003).
[10] S. S. Kang, D. E. Nikles, and J. W. Harrell, J. Appl. Phys. **93**, 7178 (2003).
[11] Y. Z. Zhou, J. S. Chen, G. M. Chow, and J. P. Wang, J. Appl. Phys. **93**, 7577 (2003).
[12] Y. Misaki, M. Mikawa, T. Ishiguro, and K. Hamasaki, J. Vac. Sci. Technol. A **15**, 48 (1997).
[13] T. Katayama, T. Sugimoto, Y. Suzuki, M. Hashimoto, P. dc Haan, and J. C. Lodder, J. Magn. Magn. Mater. **104–107**, 1002 (1992).