Effects of Pt content on the microstructure and magnetic properties of CoTbPt thin films

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This work presents a single-layer CoTbPt film for use as a hybrid-recording medium. Co_{77.5-x}Tb_{22.5}Pt_x films with $x=0-14$ at. % are fabricated on glass and naturally oxidized silicon wafer substrates by dc magnetron sputtering. The magnetic film is sandwiched between SiN_x protective layers to prevent oxidization. The effects of Pt content on the magnetic properties and microstructure of the film are investigated. X-ray diffraction and transmission electron microscope diffraction patterns revealed that all the films are amorphous. It shows that substituting a small amount of Co for the nonmagnetic element Pt will increase the saturation magnetization, the perpendicular remanence, and the perpendicular coercivity of the Co_{77.5}Tb_{22.5} film. It is found that the saturation magnetization of the Co_{75.3}Tb_{22.5}Pt_{2.2} film is about 245 emu/cm³, the perpendicular squareness is about 0.8, perpendicular coercivity is about 2100 Oe at room temperature and the coercivity decreases rapidly with increasing temperature. The coercivity is decreased to about 50 Oe when temperature is increased to 200 °C. © 2003 American Institute of Physics.

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I. INTRODUCTION

The hybrid-recording method, which combines thermally assisted writing and magnetic flux detection, has been suggested to increase the recording density of magnetic disks.¹⁻³ In this method, the small perpendicular domains are formed by thermomagnetic writing and detected by a high-resolution giant magnetoresistive (GMR) head or a tunneling magnetoresistive (TMR) head.

The recording media for hybrid recording must satisfy three requirements: (1) they must provide satisfactory magneto-optical writing performance; (2) they must have a large saturation magnetization, M_s , that generates sufficient magnetic flux for the GMR head or the TMR head readout, and (3) they must have a large perpendicular coercivity, H_c , to resist self-demagnetization. The traditional magneto-optical (MO) recording medium has been considered for use as a hybrid recording medium because of its writing principle is the same as that of hybrid recording. However, the M_s value of the MO medium at room temperature is too small to generate sufficient magnetic flux for GMR or TMR head readout. The bilayer structure, including a readout layer and a recording layer, is proposed to solve this problem.^{4,5} The recording layer has good thermomagnetic writing characteristics and a high H_c at room temperature. The readout layer has a large M_s at room temperature, and thus generates sufficient flux density for GMR or TMR head sensing.

This study aims to find a single-layer recording medium which is suitable for a hybrid-recording medium application.

Previously, we showed that the magnetic properties of amorphous CoTb film are sensitive to the composition of the film and the process parameters.⁶ The perpendicular coercivities of some amorphous CoTb films are very large, but their M_s values are small at room temperature. This work incorporates Pt in the CoTb alloy film to increase its M_s value. The effects of Pt content on the structure and magnetic properties of the CoTbPt film are also investigated.

II. EXPERIMENT

Co_{77.5-x}Tb_{22.5}Pt_x films with $x=0-14$ at. %, were deposited on glass and on naturally oxidized Si(100) substrates by dc magnetron sputtering at room temperature. The target was a Co disk overlaid with Tb and Pt pieces to obtain a desired film composition. The base pressure was 5×10^{-7} Torr and the sputtering pressure of Ar gas was maintained at 4 mTorr. The magnetic film was sandwiched between SiN_x protective layers to prevent oxidization. The SiN_x protective layers were produced by rf magnetron sputtering of an Si₃N₄ target. The thicknesses of the Co_{77.5-x}Tb_{22.5}Pt_x layer and the SiN_x layer were 75 nm and 30 nm, respectively.

The microstructures of the films were examined by x-ray diffraction (XRD) with Cu $K\alpha$ radiation, and by transmission electron microscopy (TEM). Depth profiles of the elements in the films were analyzed by Auger electron spectroscopy (AES). Compositions of the films were determined by x-ray energy dispersive spectroscopy. The magnetic properties of the films were measured using a vibrating sample magnetometer.

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FIG. 1. θ - 2θ XRD patterns of various $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ films.

III. RESULTS AND DISCUSSION

Figure 1 shows the θ - 2θ XRD patterns of various $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ films with different Pt contents. No film presents a diffraction peak. This implies that all $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ films are amorphous. Figure 2(a) is a typical TEM image of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ film, in which $x = 13.5$. The film includes no crystal grains. When the specimen is examined in detail, a lemon peel-like microstructure is observed.⁶ Figure 2(b) is the electron diffraction pattern of the film; the broad diffusive diffraction rings indicate that this film has an amorphous structure.

The rare earth-transition metal (RE-TM) magnetic films are easily oxidized. Figure 3 shows the depth profiles of elements in the $\text{Co}_{74.5}\text{Tb}_{23}\text{Pt}_{2.5}$ film. We can see that 30 nm SiN_x protective layer is effective to prevent the oxidation of this magnetic film. Some oxygen is present in the two SiN_x protective layers and in the surface of the naturally oxidized Si substrate but not in the magnetic layer.

Figure 4(a) shows the variations of saturation magnetization, M_s , and perpendicular remanence, M_r , with Pt content of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ films at room temperature. The M_s and M_r values of the $\text{Co}_{77.5}\text{Tb}_{22.5}$ film ($x = 0$ at. %) are about 135 emu/cm^3 and 85 emu/cm^3 , respectively. M_s and M_r increase rapidly with Pt content $x < 2.2$ at. %. Then, they increase slowly with Pt content when $x > 2.2$ at. % M_s exceeds 230 emu/cm^3 and M_r exceeds 175 emu/cm^3 when x

FIG. 2. (a) TEM bright-field image and (b) electron diffraction pattern of the $\text{Co}_{64}\text{Tb}_{22.5}\text{Pt}_{13.5}$ film. FIG. 3. AES depth profiles of the elements in the $\text{Co}_{75}\text{Tb}_{22.5}\text{Pt}_{2.5}$ film.

> 2 at. %. The variation of the squareness, M_r/M_s , with Pt content is very small: The squareness of the film exceeds 0.75 when $x > 2$ at. %.

CoTb alloy is sperimagnetic.⁷ The magnetization of the Co subnetwork is antiparallel to that of the Tb subnetwork. The compensation temperature, T_{comp} , of the RE-TM alloy is very sensitive to the composition of the alloy. $\text{Co}_{77.5}\text{Tb}_{22.5}$ is TM rich because its T_{comp} is lower than room temperature.^{8,9} The magnetization of the $\text{Co}_{77.5}\text{Tb}_{22.5}$ alloy is parallel to the direction of Co magnetization. When some Co atoms are substituted for the nonmagnetic Pt atoms, the magnetization of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ alloy system declines. So, the M_s of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ film decreases as the Pt content, x , is increased. However, the M_s of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ film increases with Pt content, as shown in Fig. 4(a), owing to the effect of the Co-Pt interface on the

FIG. 4. (a) Variation of M_s and M_r with Pt content in the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ film and (b) M_s values calculated from Eq. (1).

FIG. 5. Variation of H_c with Pt content of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ film.

magnetization.^{10–12} The magnetization of Co is increased due to the polarization of the Pt atoms. The relationship between M_s and x of this $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ alloy film can be expressed as

$$M_s = M_{s(\text{Co}_{77.5}\text{Tb}_{22.5})} + \alpha \ln(1 + xM_{\text{Co-Pt}}/M_{s(\text{CoTb})}), \quad (1)$$

where $M_{s(\text{Co}_{77.5}\text{Tb}_{22.5})}$ is the saturation magnetization of the $\text{Co}_{77.5}\text{Tb}_{22.5}$ film ($x=0$) and $M_{\text{Co-Pt}}$ is the induced magnetization due to the effect of the Co–Pt interface. $M_{s(\text{CoTb})}$ is the saturation magnetization of CoTb for the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ alloy except Pt. α is a constant. Figure 4(b) plots Eq. (1) with the values of the constants chosen to give the best fit to the experimental M_s values in Fig. 4(a). The best fit is obtained with $\alpha=30.5 \text{ emu/cm}^3$ and $M_{\text{Co-Pt}}/M_{s(\text{CoTb})}=5.8$. Clearly, $M_{\text{Co-Pt}}$ can be determined if $M_{s(\text{CoTb})}$ is known.

Figure 5 plots the relationship between perpendicular coercivity H_c and the Pt content of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ film at room temperature. The H_c value increases from about 1000 Oe to 2100 Oe as Pt content increases from 0 at. % to 2.2 at. %, and H_c decreases rapidly as $x>2.5$ at. %. The increase of H_c with Pt content may be owing to that some Pt atoms close together into Pt clusters in the CoTbPt film. These clusters are like defects that cling to the domain wall to reduce the domain-wall energy,¹³ pinning the movement of the domain wall, and increasing the coercivity of the film.¹⁴ This pinning effect depends on the thickness of the domain wall and the size of the defects. Maximum pinning effect occurs when the size of the defect is about equal to the thickness of the domain wall.¹³ When the Pt content of the film exceeds 2.5 at. %, the diameter of some Pt clusters may exceed the thickness of the domain wall, reducing the pinning effect. Therefore, the H_c value decreases as the Pt content increases as $x>2.5$ at. %.

Figure 6 plots the relationship between the H_c value and the temperature of the $\text{Co}_{75.3}\text{Tb}_{22.5}\text{Pt}_{2.2}$ film, showing that the H_c value decreases rapidly from 2100 Oe to about 50 Oe as the temperature increases from 25 °C to 200 °C. The M_s

FIG. 6. Relationship between H_c and temperature of the $\text{Co}_{75.3}\text{Tb}_{22.5}\text{Pt}_{2.2}$ film.

value of the $\text{Co}_{75.3}\text{Tb}_{22.5}\text{Pt}_{2.2}$ film is about 245 emu/cm^3 , the squareness is about 0.8, and the H_c is about 2100 Oe at room temperature. The rapid decrease in H_c with an increase in temperature is shown in Figs. 5 and 6.

IV. CONCLUSION

The effects of Pt content on the microstructure and magnetic properties of the $\text{Co}_{77.5-x}\text{Tb}_{22.5}\text{Pt}_x$ films with $x=0-14$ at. % were investigated. The XRD and TEM analysis indicated that all these films are amorphous. Substituting a small amount of Co for Pt will increase the M_s , M_r , and H_c of the $\text{Co}_{77.5}\text{Tb}_{22.5}$ film.

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