Nanocomposite Co$_{1-x}$Pt$_x$:C films for extremely high-density recording

Y. F. Zhang*, W. Qin, X. Y. Zhang, and Y. Wang

Key Laboratory for Thin Film and Microfabrication of Ministry of Education, Research Institute for Micro/Nanometer Science and Technology, Shanghai Jiao Tong University, Shanghai 200030, PR China

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Nanocomposite CoPt:C films were fabricated by sputtering Co, Pt and C onto water-cooled Si(100) substrates with subsequent annealing. The microstructure and the magnetic properties of these CoPt:C films were investigated as a function of Pt concentration. It was found that the orientations of CoPt grains and the magnetic properties are related strongly to the Pt content. Perpendicular anisotropy was observed in the films with high Pt content. By changing Pt concentrations, films with adjustable coercivity, a grain size less than 10 nm and strong perpendicular magnetic anisotropy were obtained. The crystal lattice structure and the intergranular interactions were proposed to be key factors in the magnetic properties of the CoPt:C films.

1 Introduction

In the past few years the areal density ($D_A$) of magnetic recording media has been increasing at an annual rate of about 60%, and more recently increasingly driven to 100% per year due to the introduction of giant magnetoresistive heads [1]. In order to have adequate signal-to-noise ratio, media with higher $D_A$ require that magnetic grains should be small with a uniform size distribution, yet large enough for adequate thermal stability and high coercivity. For extremely high-density recording (EHDR) media, a coercivity ($H_c$) of above 4 kOe and weakly exchange-coupled grains of less than 10 nm in size are necessary [2]. In order to meet these requirements investigations have been done in recent years on Co-based granular alloys with large magnetic anisotropy and square perpendicular hysteresis loops for potential applications as magnetic media. Although the Co-sputtered Co–C nanogranular morphology seems to be promising for applications in low-noise media, the coercivity of these types of films remains too low, typically a few hundred oersteds [3].

Recently, nanocomposite CoPt:C thin films consisting of high-anisotropy fct CoPt nanocrystallites (L1$_0$ phase) have been proposed as potential candidates for the next generation of magnetic recording media. The C concentration and grain size dependences of the magnetic properties of CoPt:C films have been investigated by some authors [4, 5]. In fact, the Pt concentration is also an important factor in forming thin films suitable for EHDR media. In the present work the structure and the magnetic properties of CoPt:C films with various Pt concentrations are investigated.
Table 1  Experimental data for layer thickness of multilayer structure of [Co/Pt/Co/C], and the corresponding Pt concentration.

<table>
<thead>
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<th>layer thickness (nm)</th>
<th>n</th>
<th>Co</th>
<th>Pt</th>
<th>Co</th>
<th>C</th>
<th>Pt (at%)</th>
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<tr>
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<tr>
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<tr>
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<td>1.3</td>
<td>18</td>
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<td>1.2</td>
<td>0.6</td>
<td>1.3</td>
<td>18</td>
<td>43</td>
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</tbody>
</table>

2 Experimental

All of the CoPt:C films with multilayer structures of [Co/Pt/Co/C], were magnetron sputtered onto water-cooled Si(100) substrates using pure Co, Pt and C targets. The base pressure was $2 \times 10^{-7}$ Torr and the Ar pressure during sputtering was $4 \times 10^{-3}$ Torr. The Pt concentration was varied from 43 to 61 at%, which could be easily controlled by changing the thicknesses of the Pt, Co and C layers (see Table 1). To obtain CoPt nanocrystallites, as-deposited films were annealed in vacuum ($10^{-6}$ Torr) at 600 °C for 12 min. The structures of samples were characterized using X-ray diffraction (XRD) with Cu Kα radiation. The magnetic properties were measured using an alternating gradient force magnetometer (AGFM). Magnetic domain images were obtained using a commercial magnetic force microscope (MFM).

3 Results and discussion

The annealing leads to the breakup of the continuous films and the formation of a heterogeneous morphology consisting of CoPt nanocrystallites separated by a nonmagnetic matrix [6]. Figure 1 shows the XRD patterns of CoPt:C films with various Pt concentrations, annealed at 600 °C. It can be seen that the annealed films are (111) textured. The (111) peak becomes weaker and wider and shifts towards smaller angles with increasing Pt concentration. The average grain size can be estimated using the width at half maximum of the (111) diffraction peak according to Scherrer’s formula [7]. As shown in Fig. 2a, the average grain size of CoPt nanocrystallites decreases with increasing Pt concentration. Here, the grain size obtained by Scherrer’s formula is in fact that perpendicular to the sample plane. However, the CoPt...
nanocrystallites produced by annealing may be regarded as approximately spherical in shape [4], and therefore the grain size perpendicular to the sample plane may be assumed approximately equal to that parallel to the sample plane. The shift of the XRD peak towards smaller angle with increasing Pt concentration indicates the expansion of the crystal lattice space of nanocrystallites. This could be attributed to the Co atoms being gradually substituted by Pt atoms with increasing concentration of Pt, the atomic radius of which is larger than that of Co. The space $d_{111}$ between [111] planes as a function of Pt concentration is shown in Fig. 2b.

The change of saturation magnetization $M_s$ with Pt concentration is shown in Fig. 2c, from which it can be seen that $M_s$ decreases with increasing Pt concentration. Since $M_s$ depends on the composition of the CoPt alloy, the decrease of $M_s$ indicates that some Co atoms have been substituted by Pt atoms, which was confirmed by the shift of the (111) peak towards smaller angle.

The magnetic measurements show that the shape of the hysteresis loop is also dependent on the Pt content. The hysteresis loops for two samples (Co$_{57}$Pt$_{43}$:C and Co$_{44}$Pt$_{56}$:C) are shown in Fig. 3. It is clear that the hysteresis loop for the sample with low Pt content shows random orientation and the loop for the sample with high Pt content shows perpendicular magnetic anisotropy. This result indicates that the magnetic anisotropy can be controlled by adjusting the Pt content.

We used MFM images to study the magnetic interactions of nanostructured films. Figure 4 shows the MFM images of the CoPt:C thin films with different Pt concentrations. All the magnetic images were obtained using a high-coercivity CoPt MFM tip, which was magnetized along the $z$-direction (perpendicular to the sample surface). The samples were in the thermally demagnetized states. The contrast between light and dark in Fig. 4 corresponds to the strength of stray-field gradient on the sample surface. The lighter color represents a larger frequency shift of the MFM tip for which the magnetization of the sample and MFM tip are in the same direction. The Co$_{57}$Pt$_{43}$:C film shows a granular domain structure (Fig. 4a), while the Co$_{44}$Pt$_{56}$:C film shows a maze-like domain structure and strong perpendicular components (Fig. 4b). There are two kinds of magnetic interactions among the grains: intergranular exchange...
coupling and dipolar interactions. The granular domain structure of the Co$_{57}$Pt$_{43}$:C film shows weak interactions between the grains. The maze-like domain structure of the Co$_{44}$Pt$_{56}$:C film reflects the existence of strong intergranular exchange coupling between grains.

Figure 5 shows the coercivity ($H_c$) of CoPt:C films as a function of Pt concentration. $H_c$ first increases slowly from 3.2 to 4.0 kOe when Pt concentration increases from 43 to 53 at%, then $H_c$ starts to decrease rapidly when Pt concentration is further increased. The maximum coercivity (about 4.0 kOe) of CoPt:C is obtained with an optimum composition (53 at% Pt). Since the coercivity is closely related to the mag-
netocrystalline anisotropy of an individual grain, the different Pt concentrations would result in different magnetocrystalline anisotropies [8]. Experimental results showed that the standard CoPt L1₀ phase is of a fct structure and a very high anisotropy (up to $4.9 \times 10^7$ erg/cm$^3$) [9]. Therefore, the CoPt:C film of composition approaching to the standard L1₀ phase will have a high coercivity. Besides this reason, it may also be related to the change in magnetostatic coupling among grains with Pt concentration, which is indicated in the MFM images (see Fig. 4).

It can also be clearly seen from Fig. 5 that for the Co$_{47}$Pt$_{53}$:C film the out-of-plane coercivity is much larger than the in-plane coercivity. This may be attributed to the special crystal structure of the L1₀ phase. For fct CoPt alloy (L1₀ phase), the lattice parameter of the c-axis is smaller than that of the a-axis and the easy axis of the L1₀ phase is the (001) orientation. In a (111) texture film, the (111) texture places the c-axis out of the film plane by a given angle. Therefore, this kind of film may produce strong perpendicular magnetic anisotropy.

### Conclusion

The microstructure and the magnetic properties of CoPt:C films with different Pt concentration have been investigated. The increase of Pt reduces the grain size and saturation magnetization and changes the magnetic interactions among grains. The maximum coercivity was obtained with an optimum composition (Co$_{47}$Pt$_{53}$:C). The nanocomposite CoPt:C films with grain size less than 10 nm, high coercivity and strong perpendicular magnetic anisotropy could be fabricated by varying the Pt concentration.

### Acknowledgements

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### References