Structure and perpendicular magnetic anisotropy of a new CoPt$_x$ alloy grown by MBE

J.C.A. Huang$^{a, *}$, T.H. Wu$^b$, A.C. Hsu$^a$, L.C. Wu$^a$, Y.M. Hu$^a$

$^a$Physics Department, National Cheng-Kung University, Tainan, Taiwan, ROC
$^b$Department of Humanities and Science, National Yunlin University of Science and Technology, Toulin, Taiwan, ROC

Abstract

High-quality, epitaxial CoPt$_x$ alloy films were prepared on Mo(2 1 1) seeding layer on Al$_2$O$_3$ (1 1 0 0) substrate at growth temperature of ~ 400°C. A new FCC (3 1 1) orientation with modest perpendicular magnetic anisotropy is established for large Pt/Co composition ratio ($x$) (2 < $x$ < 3). With decreasing of $x$ to about 1.1–1.5, an ordered L1$_1$-like phase together with a weaker HCP (1 – 1 0 0) peak was observed by X-ray diffraction. The development of the L1$_1$ phase in turn results in an enhancement of perpendicular coercivity and squareness of the Kerr rotation loop. Annealing at high-temperature (650°C) results in a structure change and deterioration of the perpendicular magnetic anisotropy. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Molecular beam epitaxy; Perpendicular magnetic anisotropy; Kerr rotation; Crystal structure; Chemical ordering; Alloy composition; Annealing

1. Introduction

Co–Pt multilayers and alloys with large perpendicular magnetic anisotropy (PMA) and enhanced Kerr rotations have been intensively studied for the development of future magneto-optical recording media [1]. The Co–Pt alloy films are more promising for application in the aspects of easy manufacturing and better chemical stability. Generally the PMA and Kerr rotations in the alloy films are sensitive to the alloy composition [2,3], crystal structure [4,5] and chemical ordering [5–7]. Previous work on Co–Pt alloy films focused more in the case of 1:1 composition (Co$_1$Pt$_1$) with (1 1 1) or (1 0 0) growth orientation. In this investigation, we report the interplay of the crystal structure and the PMA effect in epitaxial CoPt$_x$ ($X$ = 1.1–4.8) alloy films with large Pt/Co composition ratio and an extraordinary high-index (3 1 1) orientation. The variation of the crystal structure or chemical ordering, thus the PMA effect, of the Co–Pt alloys were studied by change of the alloy composition ratio and using high-temperature (650°C) annealing treatment.

2. Sample preparation and characterization

The CoPt$_x$ alloy films were prepared by a vacuum product made molecular beam epitaxy (MBE) system. Details of the chamber in which crystal growth took place were provided elsewhere [8]. The CoPt$_x$ (1 < $x$ < 5) alloys of about 500 Å were grown on 150 Å Mo (2 1 1) seeding layer [9] on epitaxial grade Al$_2$O$_3$ (1–1 0 0) substrates. To enable the growth of high-quality CoPt$_x$ alloy films, the sapphire substrates were chemically pre-cleaned and then introduced into the growth chamber and outgassed at ~ 1050°C for 1 h under ultra-high-vacuum condition before initial deposition. The base pressure of the MBE system is of about 2 × 10$^{-10}$ torr. It is unlikely that residual gases played a role in determining the epitaxial growth and magnetic property of the
CoPt$_x$ films. Pure (99.99%) Co and Pt materials were evaporated from separate e-beam source. During deposition of the CoPt$_x$ alloys, the growth pressures were controlled below $5 \times 10^{-9}$ Torr, the deposition rates at $\sim 0.2-0.3$ Å/s. The thickness of the deposition rates of the films were calibrated by a quartz crystal monitor located very close to the sample holder. The growth (substrate) temperature was kept at $900^\circ$C for the Mo seeding layer, and $200-500^\circ$C for the CoPt$_x$ alloys. To retain the sample uniformity the sample holder was rotated with a constant speed of $\sim 30$ rpm.

The alloy composition of the CoPt$_x$ films was studied by Auger-sputtering technique. The bulk structure of the CoPt$_x$ alloys were measured by X-ray diffraction (XRD) using Cu K$_\alpha$ radiation. Magnetic property was investigated by polar magneto-optical Kerr effect (PMOKE). The PMOKE measurement is carried out at room temperature in a magnetic field $H$ up to 15 kOe. The penetration depth of the He–Ne laser for PMOKE experiment is of $\sim 200$ Å.

3. Results and discussion

We have studied the dependence of PMA upon the alloy composition for substrate kept at the optimal growth temperature of $400^\circ$C.$^1$ We observed a nearly pure FCC (3 1 1) structure for large Pt/Co composition ratio $x > 2$. Evidence of the FCC (3 1 1) structure for $x = 4.8$ and 2.4 are shown by the XRD spectra in Fig. 1a and b. Note that the growth of the extraordinary FCC CoPt$_x$(3 1 1) phase for large Pt contents is owing to the very good match between the unit cell of CoPt$_x$(3 1 1) plane (e.g. 2.69 Å $\times$ 8.93 Å for $x = 2.4$) and two unit cells (2.72 Å $\times$ 8.90 Å) of the Mo(2 1 1) seeding layer. Schematic diagrams of the lattice geometry and epitaxial relations of FCC CoPt$_x$(3 1 1) and Mo(2 1 1) are provided in Fig. 2 for the convenience of the reader.

PMOKE studies reveal that the Kerr rotation and PMA are very small for CoPt$_x$(3 1 1) with $x > 4$ (Fig. 3a). With decreasing of the Pt/Co composition ratio below 3 (and above 2), the Kerr rotation increases quite rapidly with, however, modest perpendicular coercivity (0.7–1.5 kOe) and squareness ($M_r/M_s \sim 0.7–0.9$) of the $M–H$ loop. Example of the Kerr rotation loop for $x = 2.4$ is shown in Fig. 3b.

With further decreasing of the Pt/Co alloy composition ratio to about $1.1 < x < 1.5$, a tetragonal peak and a smaller HCP peak is developed at $20 \sim 41^\circ$ and $39^\circ$, respectively, and the FCC (3 1 1) orientation is strongly suppressed, as shown in Fig. 1c for $x = 1.5$. In addition, the appearance of a superlattice peak at $20 \sim 20–21^\circ$ (see Fig. 1c) suggests that the tetragonal peak corresponds to a partially ordered L$_1_1(1 1 1)$-like phase, similar to that reported by Itawa et al. [5] recently. The ordered L$_1_1(1 1 1)$-like phase in turn results in an enhancement of the perpendicular coercivity ($\sim 3$ k Oe) and squareness ($M_r/M_s > 0.95$) of the $M–H$ loop, and maintains the Kerr rotations at rather good level (Fig. 3c).

We have also studied the high-temperature ($650^\circ$C for 4 h) annealing treatment on the crystal structure, chemical ordering and PMA effect of the CoPt$_x$ alloy films.

---

$^1$ Generally we found that the best growth-temperatures are between $300^\circ$C and $400^\circ$C for Co–Pt alloys with large Kerr rotation and PMA effect. The results at $300-400^\circ$C are much better compared to those grown at $200^\circ$C and $500^\circ$C.
Fig. 3. PMOKE hysteresis loops from 400°C as-deposited alloy films of 500 Å thick (a) CoPt_{4.8}, (b) CoPt_{2.4} and (c) CoPt_{1.5} grown on 150 Å thick Mo seeding layer on Al_{2}O_{3} (1–1 0 0) substrate.

Fig. 4. X-ray diffraction spectra from 650°C annealed alloy films of 500 Å thick (a) CoPt_{4.8}, (b) CoPt_{2.4} and (c) CoPt_{1.5} grown on 150 Å thick Mo seeding layer on Al_{2}O_{3} (1–1 0 0) substrate.

For large Pt/Co composition ratio, the XRD measurements show enhancement of diffraction peaks (compare Fig. 4a and b with Fig. 1a and b) around 33–35° suggesting that the FCC (3 1 1) structure is not stable for such high-temperature annealing. Details of the structural stability of FCC (3 1 1) orientation is under investigation and will be published elsewhere [10]. In addition, the superlattice peak of the ordered L1_1 (1 1 1)-like phase also disappeared (Fig. 4c) upon 650°C annealing. Accordingly, the PMA effect and Kerr rotation of the 650°C annealed samples deteriorate (as shown in Fig. 5) in comparison to those of the 400°C as-deposited films. Our investigations clearly demonstrate that there is a strong correlation between the PMA phenomena and the crystal structure and chemical ordering of the Co–Pt alloy films.

We are grateful for the financial support by the ROC NSC under grant Nos. 87-2112-M-006-014 and 87-2732-M-006-001.

References


