Influence of crystal structure on the perpendicular magnetic anisotropy of an epitaxial CoPt alloy

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By molecular beam epitaxy CoPt\textsubscript{1.1} alloys were simultaneously prepared on Mo seeding layers on \textit{Al\textsubscript{2}O\textsubscript{3}}(11–20), (1–102), and (1–100) substrates, respectively. Distinct crystal structures and chemical ordering of the CoPt\textsubscript{1.1} alloys were observed for substrate temperatures of 300 and 400 °C. Structural and magnetic observations for CoPt\textsubscript{1.1} alloys grown on separate sapphire substrates show that the appearance of the ordered \textit{L\textsubscript{1}1} phase results in an enhancement of the perpendicular magnetic anisotropy and Kerr rotations in the CoPt alloys. © 1999 American Institute of Physics.

Co–Pt alloys\textsuperscript{1–7} and multilayers\textsuperscript{8–11} (MLs) with large perpendicular magnetic anisotropy (PMA) and enhanced Kerr rotations have attracted considerable interest both for basic research and for the development of future magnetooptical recording media. CoPt alloys are more promising for application in some aspects of easy manufacturing and better chemical stability in comparison to Co–Pt MLs. In an ordered CoPt alloy the reduced thickness of the Co layer (to a single monolayer) together with the symmetry breaking in the Co–Pt interfaces, similar to that of the Co/Pt MLs, can result in a change of preferred Co magnetization from in-plane to perpendicular alignment. As a consequence, the PMA and Kerr rotations of CoPt alloys are often very sensitive to the crystal structure and chemical ordering.\textsuperscript{1–7} A particularly interesting case is the Co–Pt alloy with a 1:1 ratio where a distinct ordered structure, an \textit{L\textsubscript{1}0} or \textit{L\textsubscript{1}1} (Ref. 5) type phase, has been established. The \textit{L\textsubscript{1}1} phase is a metastable structure because it does not exist in the bulk phase diagram. Schematic diagrams of the \textit{L\textsubscript{1}0} and \textit{L\textsubscript{1}1} structures are shown in Figs. 1(a) and 1(b) for the convenience of the reader.

In this article, we report the influence of crystal orientation and chemical ordering on the PMA effect in epitaxial CoPt\textsubscript{x}(\textit{x} \simeq 1.1) alloys. By employing a separate underlying template and varying the growth temperature, the crystal structure and PMA effect have been studied. The structural and magnetic observations of CoPt alloys grown on the distinct substrate show that the appearance of an ordered \textit{L\textsubscript{1}1} phase tends to increase the PMA and Kerr rotation of the CoPt alloys.

The CoPt\textsubscript{1.1} alloy films were prepared by a Vacuum Product molecular beam epitaxy (MBE) (MBE-930) system. Details of the chamber in which crystal growth took place are provided elsewhere.\textsuperscript{12} CoPt\textsubscript{1.1} alloys of \textasciitilde 500 Å were simultaneously grown on 200 Å Mo seeding\textsuperscript{13} layers on epitaxial grade \textit{Al\textsubscript{2}O\textsubscript{3}}(11–20), \textit{Al\textsubscript{2}O\textsubscript{3}}(1–102), and \textit{Al\textsubscript{2}O\textsubscript{3}}(1–100) substrates. To enable the growth of high-quality CoPt\textsubscript{1.1} alloy films, the sapphire substrates were chemically pre-cleaned and then introduced into the growth chamber and outgassed at \textasciitilde 1050 °C for 1 h under ultrahigh vacuum conditions before the initial deposition. The base pressure of the MBE system was of about 2 \times 10\textsuperscript{−10} Torr. Pure (99.99%) Co and Pt materials were evaporated from a separate e-beam source. During deposition of the CoPt alloys, the growth pressures were controlled below 5 \times 10\textsuperscript{−9} Torr, and the deposition rates were \textasciitilde 0.2–0.3 Å/s.

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FIG. 1. Schematic diagrams showing the lattice geometry of the (a) \textit{L\textsubscript{1}0} and (b) \textit{L\textsubscript{1}1} structures of the CoPt alloy.
To retain sample uniformity the sample holder was rotated at a constant speed of ~30 rpm. The thickness and 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 °C for the Mo seeding layers, and was 300 and 400 °C for the CoPt_{1.1} alloys that followed. No postannealing treatment was employed in this work.

The composition of the CoPt_{1.1} alloy was determined by an Auger-sputtering technique. The crystal structure was measured by reflection high-energy electron diffraction (RHEED) and x-ray diffraction (XRD). The magnetic properties were investigated by the polar magneto-optical Kerr effect (PMOKE) and the extraordinary Hall effect (EHE). The PMOKE and EHE measurements were carried out at room temperature in a magnetic field $H$ up to 15 kOe. The penetration depth of the He–Ne laser for the PMOKE experiment was ~200 Å. The results of EHE measurements are in good agreement with the PMOKE studies; the latter are presented in this article.

On an Al$_2$O$_3$(11–20) substrate a Mo seeding layer was grown as a (110) structure. Subsequent CoPt$_{1.1}$ alloys were grown as a disordered face-centered-cubic (fcc) (111) phase at 300 °C, as shown by the XRD spectra shown Fig. 2(a). However, a (partially) ordered $L_{11}(111)$ phase of CoPt$_{1.1}$ was established at 400 °C, as indicated by the XRD spectrum shown in Fig. 2(b). Note that the appearance of a superlattice peak at $2\theta \sim 20° - 21°$ [indexed as $S_1$ in Fig. 2(a)] suggests that the diffraction peak corresponds to a (partially) ordered $L_{11}(111)$ phase, similar to that reported by Itawa et al.\textsuperscript{5} recently. In the $L_{11}(111)$ [see Fig. 1(a)] or the fcc (111) phase there is no modulated superstructure along the (111) direction. For the fcc (111) and $L_{11}(111)$CoPt$_{1.1}$ alloys the polar Kerr coercivity and squareness ($M_r/M_s$) are 0.2 kOe (0.12) and 1.1 kOe (0.97), respectively, as shown in Figs. 2(c) and 2(d). The Kerr rotations of the fcc (111) and $L_{11}(111)$ samples are 0.28° and 0.39°, respectively. The $L_{11}(111)$ phase was stabilized at lower temperature on a MgO(111) substrate\textsuperscript{5} and the other substrate (Al$_2$O$_3$(1120)) discussed below, indicating that this metastable phase is rather sensitive to the underlying template.

On the Al$_2$O$_3$(1–102) substrate the Mo seeding layer was grown as a (100) structure. The subsequent CoPt$_{1.1}$ alloys were grown as an $L_{11}(100)$ structure at 300 °C and mainly as a slightly ordered $L_{1}(100)$ structure at 400 °C, as shown in Figs. 3(a) and 3(b). For the $L_{11}(111)$ + $L_{1}(100)$ sample the polar coercivity and squareness are ~2.4 kOe and 0.38; they are 0.9 kOe and 0.21, for the $L_{1}(100)$ sample, as shown in Figs. 3(c) and 3(d). The Kerr rotations of the $L_{11}(111) + L_{1}(100)$ and $L_{1}(111)$ samples are 0.31° and 0.20°, respectively. Although the $L_{1}(100)$ phase is also partially ordered [indexed as $S_0$ in Figs. 3(a) and 3(b)], it does not seem to strengthen the PMA effect.

In addition, on the Al$_2$O$_3$(1–100) substrate the Mo seeding layer was grown as a (110) plane. Subsequent CoPt$_{1.1}$ alloys were grown as the $L_{1}(111)$ + hcp(1–100) phase at 300 °C and mainly the hcp (1–100) phase at 400 °C, as displayed in Figs. 4(a) and 4(b). For the $L_{1}(111)$ + hcp(1–100) sample the polar coercivity and squareness are ~2.3 kOe and 0.33; they are 1.9 kOe and 0.29 for the hcp (1–100) sample. The Kerr rotations of the $L_{1}(111)$ + hcp(1–100) and hcp(1–100) samples are 0.4° and 0.36°, respectively. Again, the emergence of the $L_{1}(111)$ phase has a tendency to magnify the PMA effect.
In summary, we have studied CoPt$_{1.1}$ alloys prepared on Mo seeding layers on Al$_2$O$_3$ (11–20), (1–102), and (1–100) substrates by MBE. Distinct crystal structures and chemical ordering of the CoPt$_{1.1}$ alloys were observed for substrate temperatures of 300 and 400 °C. On the Mo$_{100}$/Al$_2$O$_3$ (1–102) and Mo$_{211}$/Al$_2$O$_3$ (1–100) templates the L$1_1$(111) phase mixed with the other phase appears at 300 °C and deteriorates greatly at 400 °C. In contrast, on the Mo$_{110}$/Al$_2$O$_3$ (11–20) template the L$1_1$(111) phase is much purer and stronger at 400 °C, and becomes weaker at 300 °C. The observations of CoPt$_{1.1}$ alloys on distinct Mo seeding layers (and sapphire substrates) show that the appearance of the ordered L$1_1$(111) phase results in an enhancement of the perpendicular magnetic anisotropy and the Kerr rotations. We have demonstrated here that there is a strong correlation between the crystal structure and perpendicular magnetic anisotropy in Co–Pt alloy systems.

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14. The PMA effects of the 300 and 400 °C as-deposited CoPt alloys are better than those grown at 200 and 500 °C.

FIG. 4. (a), (b) X-ray diffraction spectra and (c), (d) normalized Kerr rotation loops scanned from 500 Å CoPt$_{1.1}$/200 Å Mo/Al$_2$O$_3$(1–100).