LARGE PERPENDICULAR-ANISOTROPY, HIGH-COERCIVITY Co-Pt ALLOYS FOR MAGNETO-OPTICAL RECORDING.

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Abstract- We report the development of Co-Pt alloy films with large perpendicular anisotropy and high coercivity (>4 kOe) grown directly onto amorphous, non-metallic substrates. This has made possible magneto-optical recording in these alloys with CNR values exceeding, for the first time, 57 dB at 488 nm.

KEYWORDS: Co-Pt, ALLOY, PERPENDICULAR ANISOTROPY, MAGNETO-OPTICAL RECORDING.

INTRODUCTION

High-vacuum evaporation of Co-Pt alloy films, for magneto-optical recording has recently been reported by Weller et al.[1]. Such alloy films have the advantages in this application over Co/Pt multilayers or rare earth-based amorphous alloys of simplicity in growth and larger MO signal[1], especially in the blue spectral region. However, a road block to the utilization of such alloys is their low coercivity (≤ 1 kOe) when grown on dielectric underlayers such as amorphous SiN films or fused silica (quartz) substrates. This leads to difficulties in writing stable marks for MO recording and to a low carrier to noise (CNR) ratio of ≤ 50 dB. In this paper we report the structural and magnetic characterization of polycrystalline $\text{Co}_x\text{Pt}_{1-x}$ ($x \sim 0.25$) alloy films deposited onto substrates of amorphous carbon, amorphous SiN and fused silica at temperatures ranging from 30 to 500°C. The results are compared with those for highly [111] oriented epitaxial alloy films grown onto basal-plane sapphire substrates under identical conditions.

Perpendicular anisotropy and maximum (as a function of deposition temperature) coercivities ≥ 4 kOe are achieved for polycrystalline films deposited, at $\sim 300^\circ\text{C}$, on all amorphous substrates. On the other hand, the epitaxial films exhibit perpendicular anisotropy and a significantly lower maximum coercivity at this temperature. Structural characterization of the films by

X-ray diffraction and transmission electron microscopy (TEM) reveals that the maximum in coercivity occurs near the onset of chemical ordering in the films.

EXPERIMENTAL TECHNIQUES

The films were grown in a MBE system (VG Semicon-Fisons VG 80M) in a background pressure of below 2×10^{-10} Torr. Co-evaporation from electron beam sources for Co and Pt was used and the respective growth rates were $\approx 0.034 \text{ \AA/s}$ for Co and $\approx 0.111 \text{ \AA/s}$ for Pt. Films of $\sim 200 \text{ \AA}$ thick were deposited onto a variety of amorphous substrates including amorphous carbon films ($\sim 100 \text{ \AA}$ thick) on mica and SiN films on amorphous carbon on mica. The strategy for using carbon films was to facilitate transmission electron microscopy of the alloys. Foils for transmission electron microscopy were formed by simply detaching the carbon films from mica. This method worked for a wide range of substrate temperatures from 30 to 500°C permitting the structural examination of alloy films grown within this temperature range. Additionally, films were grown directly onto silica, carbon on silica, SiN on silica, carbon on silicon (111), silicon (111), carbon on basal-plane sapphire and basal-plane sapphire. The magnetic properties of the films were studied using polar Kerr magnetometry, vibrating sample magnetometry (VSM) and torque magnetometry. Transmission electron microscopy was carried out using JEOL 4000EX (400 keV) and Akashi (200 keV) electron microscopes.

X-ray diffraction studies were carried out using a Siemens diffractometer for θ - 2θ scans and rocking curve scans.

EXPERIMENTAL RESULTS

Figure 1 shows polar Kerr loops (633nm) recorded from a series of films of composition $x \approx 0.24$, 200Å thick grown at different growth temperatures onto carbon on mica. There is a progressive increase in perpendicular anisotropy and coercivity from 30 to 300°C. Above this temperature the perpendicular anisotropy and coercivity collapse and the anisotropy is in-plane at 500°C. This trend was also found for films grown directly onto basal-plane sapphire substrates. In this case the films were highly oriented with [111] as the growth axis.

Figure 2 shows the temperature dependence of coercivity for both sets of films. The coercivity peaks at a growth temperature of $\approx 300^\circ\text{C}$ for both sets of films although the peak coercivity of the epitaxial films is significantly lower.

Figure 3 shows X-ray rocking curves for a film of CoPt_3 grown simultaneously onto carbon on mica and directly onto basal-plane sapphire at 300°C . Note that the lattice constant of CoPt_3 (3.829Å) is only 2% smaller than the in-plane spacing of hollow sites in the O-terminated surface of sapphire. This geometric fit leads to highly oriented [111] growth of CoPt_3 on sapphire. In fact, the film grows with a 180° twinning of Pt about the [111]

axis. The rocking curve of the epitaxial film is only 0.7° FWHM compared with $\approx 20^\circ$ for the alloy film grown on amorphous carbon. This latter film has little or no preferred texture and the θ - 2θ scans reveal (002), (022), (311) and other orientations in the film.

The polycrystalline film has a much greater coercivity than the epitaxial film as shown by comparison of polar

Figure 2.
 Coercivity versus substrate temperature for polycrystalline and epitaxial films of CoPt_3

Figure 1.
 Polar Kerr loops (633nm) for polycrystalline films of CoPt_3 on mica substrates.

Kerr loops (Figure 3) for the two samples. This behaviour contrasts with that for Co/Pt multilayers[2,3] where for films without [111] texture the magnetic anisotropy was in-plane for Co thicknesses $\geq 5\text{Å}$. Subsequent studies[4] of alloy films, grown epitaxially along the 3 three major axes of the alloy, show that the perpendicular anisotropy is largely independent of growth orientation, but that orientation does influence the coercivity of the alloy films. The high coercivity and relatively square loop for the polycrystalline sample is advantageous for preparation of films for MO media. Unlike Co/Pt multilayers, it is not necessary to optimize the texture axis.

Table 1 summarizes the anisotropy energy for films grown onto various substrates. Note that the anisotropy energy (K_u) tracks with coercivity for these samples and is lowest for the epitaxial film grown onto basal-plane sapphire. Measurements of anisotropy energies and coercivities for alloy films grown onto SiN films on glass

Figure 3.
X-ray rocking curves for alloy (111) peak:
(a) for CoPt₃ on carbon film on mica.
(b) for CoPt₃ on sapphire (0001).

(c), (d) corresponding polar Kerr loops.
 $\theta_k = 0.2^\circ$ in both cases.

and silica revealed values similar to that for deposition on silica.

Transmission electron microscopy studies were carried out on alloy films grown onto carbon on mica at 30, 100, 200, 300, 400 and 500°C. In addition, films grown onto SiN on carbon at 300°C were also examined. It was found that the grain size of the films increased smoothly with temperature but that there was a greater spread in grain size for the films grown above 300°C. This illustrated by

Figure 4.

Plot of grain size versus growth temperature for 200Å-thick polycrystalline CoPt₃ films on amorphous carbon on mica.

the plot of grain size versus growth temperature shown in Figure 4. Note that the pairs of data points, at each temperature, indicate the spread in grain size.

In films grown above 300°C rings of extra diffraction spots were observed, which corresponded to superstructure diffraction from the chemically ordered

L1₂ phase. Isolated clusters of this phase were observed in films grown at 500°C (see Figure 5). At 400°C the clusters are more dispersed whilst at 300°C they are barely detectable by TEM diffraction or imaging. However, recent synchrotron X-ray diffraction studies[4] has confirmed that chemical ordering is present in both polycrystalline and epitaxial alloy films grown at 300°C. The coherence length for chemical ordering at 300°C is, however, very short (<8Å).

DISCUSSION

The growth of high coercivity CoPt₃ alloy films prepared on amorphous substrates has opened up the prospect for alloy media MO discs. We have prepared quadrilayer structures comprising: glass disc / 400Å SiN / 200Å CoPt₃ / 200Å SiN / 500Å Al. Dynamic testing at 488nm has been carried out and a CNR value of 57.5dB obtained. Further refinements of the structure can be expected to improvements in CNR.

The development of perpendicular anisotropy may be related to the onset of partial chemical ordering[5] in the film at ~300°C. At this temperature a dispersion of the ordered phase exists[4] and the

Figure 5.

High-resolution plan-view micrograph showing an ordered L₁₂ region within a grain of a CoPt₃ film grown at 500°C. The ordered region is about 30 Å across and the lattice fringes are from (111) planes; the fringe spacing is 2.21 Å.

TABLE 1.
 Anisotropy Energies (K_u) for 200 Å CoPt₃ Films grown onto various substrates at 300°C.

Substrate	Film structure	H_c (kOe)	K_u (erg/cm ³)
c/ Al_2O_3	poly	4.4	2.67×10^6
Al_2O_3	epitaxial	0.9	1.68×10^6
c/silicon (111)	poly	4.3	2.45×10^6
silica	poly	5.5	3.84×10^6

coherence length of this phase may be anisotropic. If the ordered regions are lamellar and parallel to the film plane then more Co-Co pairs will exist along the film normal since the ordered phase contains no Co-Co nearest neighbors. This could give the uniaxial anisotropy observed. At temperatures below 300°C there is negligible

ordering whilst at temperatures above 300°C the ordered regions may become condensed into clusters, via both lateral and vertical diffusion. The anisotropy in coherence length will then be suppressed leading to a peak in perpendicular anisotropy with substrate temperature, as we observe. This idea is tentative and is presently being

tested by synchrotron diffraction and EXAFS. This will be the subject of a future publication.

CONCLUSIONS

- High perpendicular anisotropy, high ($\sim 4\text{kOe}$) coercivity CoPt_3 alloy films have been grown on a variety of amorphous dielectric substrates.
- The coercivity and anisotropy depend on deposition temperature and a peak coercivity is reached at $\sim 300^\circ\text{C}$ for growth of the alloy on both amorphous and single crystal-sapphire substrates.
- Dynamic writing experiments have demonstrated a CNR of 57.5dB at 488nm.
- A tentative model for the magnetic anisotropy is suggested.

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