$CrPt_3$ thin film media for perpendicular or magneto-optical recording

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The magnetic properties of $CrPt_3$ $L1_2$ ferrimagnetic thin films have been studied. Films were produced by sputtering multilayers of Cr and Pt onto silicon nitride coated silicon substrates. The as-deposited films are nonmagnetic. An anneal at ~800 °C results in ferrimagnetic behavior with a perpendicular easy-axis. X-ray diffraction and transmission electron microscopy (TEM) measurements show that (111) $CrPt_3$ is the only crystalline phase present after annealing. Rocking curves with a full width at half maximum as low as 1.8° indicate good crystallographic orientation. Magnetic properties of the films vary with composition, annealing temperature and time, layer thickness, and sputtering conditions. The films exhibit large coercivities, H_c, that can be tuned in the range 1500–8000 Oe. Saturation magnetization, M_s, is typically 150–200 emu/cc. Squarenesses, *S*, as high as 0.99 have been found. A uniaxial magnetic anisotropy constant, K_u, of up to 8×10^6 erg/cc was achieved. TEM micrographs show a 35 nm average grain size and complete interdiffusion of the Cr and Pt. Magneto-optical hysteresis loops at 632.8 nm wavelength reveal Kerr rotations of about 0.21° when the films are overcoated with a quarter-wavelength dielectric.
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I. INTRODUCTION

Ferrimagnetism in the Cr–Pt alloy system stems from the $CrPt_3$ ordered $L1_2$ phase.[1] The saturation magnetization in bulk Cr–Pt alloys has a maximum of approximately 240 emu/cc near stoichiometric $CrPt_3$.[2] The Curie temperature of the $CrPt_3$ phase increases with increasing Cr concentration from −273 °C at ~83 at. % Pt to ~900 °C at 52 at. % Pt.[1] Bulk studies have reported coercivities in the range 150–2900 Oe, depending on composition.[3] Neutron diffraction measurements on stoichiometric $CrPt_3$ reveal localized moments of 2.33 and $-0.27\,\mu_B$ on the Cr and Pt atoms, respectively.[4] Theoretical band–structure calculations predict a magneto-optical Kerr rotation, θ_k, for $CrPt_3$ at blue laser wavelength (~440 nm) of about 0.45° and one at red laser wavelength (632.8 nm) of about 0.20°.[5] In this study, we have investigated the magnetic and magneto-optical (MO) properties of $CrPt_3$ thin films. To our knowledge, this is the first such experimental study of $CrPt_3$ thin films.

II. EXPERIMENTAL PROCEDURES

Cr-Pt multilayer thin films were deposited from two elemental targets onto (100) silicon wafers which were coated with 5000 Å of amorphous silicon nitride. The deposition was accomplished either by radio-frequency-diode sputtering in a Leybold–Heraeus Z-400 sputtering system or direct-current-magnetron sputtering in a Leybold–Heraeus Z-650 sputtering system. In both sputtering systems the Ar flow rate was set at 125 sccm, and the base pressure was always less than 8×10^{-7} Torr. In the Z-400 system, 100 W sputtering power was used for both targets, and the film thickness was varied by changing the sputtering time. In the Z-650 system, sputtering time was held constant and target power was varied to change film thickness. Films were deposited as alternating layers of Cr and Pt, with as few as one bilayer and as many as 200. The films were then annealed in an inert Ar atmosphere at temperatures of 750, 800, and 850 °C for 5 min, unless otherwise stated.

Microstructure and texture was studied with a transmission electron microscope (TEM) and an x-ray diffractometer (XRD), using Cu-K_α radiation. Magnetic properties were studied using a vibrating sample magnetometer and an alternating gradient magnetometer, with 14 kOe maximum applied fields. Anisotropy constants were measured using torque magnetometry with a 20 kOe applied field. Rocking curves were obtained using a Phillips high-resolution diffractometer. The Curie temperature was measured at a constant 20 kOe magnetic field while increasing temperature and recording when magnetization vanishes. MO hysteresis loops were measured at He–Ne wavelength (λ=632.8 nm), with a 5 kOe maximum applied field.

III. RESULTS

The as-deposited multilayer films consist of layers of (110) Cr and (111) Pt, as indicated by the x-ray diffraction patterns in Fig. 1(a) and are not magnetic. When the films are deposited on a Si_3N_4 coated Si substrate and annealed at a temperature in the range 750–850 °C, the result is a magnetic polycrystalline (111) $CrPt_3$ film. If the Cr and Pt layers are deposited in stoichiometric proportions (Pt/Cr=3), then no other crystalline phases are present after the anneal, as shown in Fig. 1(b). The silicon nitride coating is essential to obtaining a $CrPt_3$ film in that it acts as a diffusion barrier preventing interdiffusion of the Cr and Pt with the Si substrate during the high-temperature anneal. If the films are deposited onto a bare Si substrate and annealed, the resulting samples are nonmagnetic and XRD measurements reveal a complex set of peaks, indicative of silicide formation.

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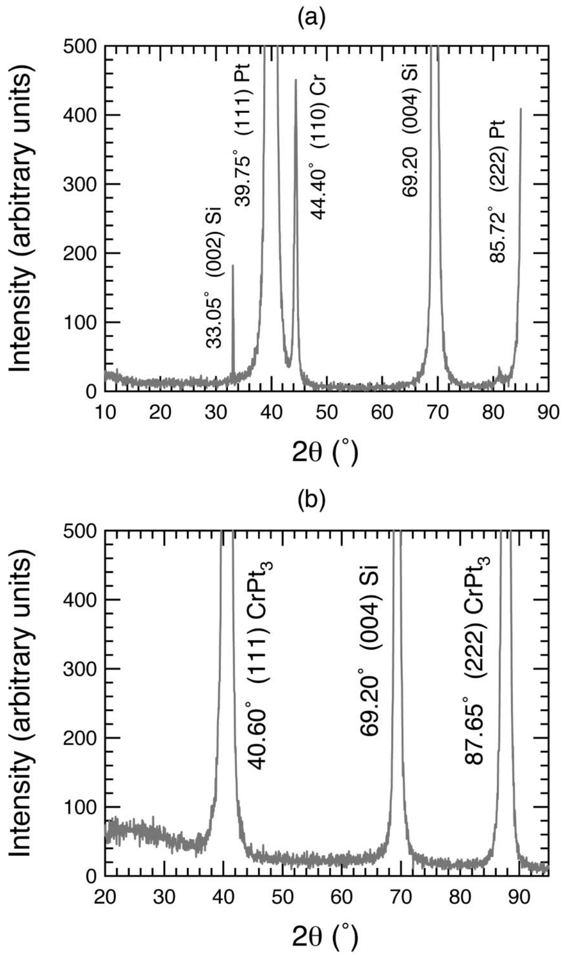

FIG. 1. XRD θ–2θ scans for (a) an unannealed sample consisting of a 2000 Å Pt layer on top of a 750 Å Cr layer and (b) a stoichiometric $CrPt_3$ 10 bilayer sample with an anneal at 850 °C in an Ar atmosphere for 5 min and a total thickness of 2000 Å.

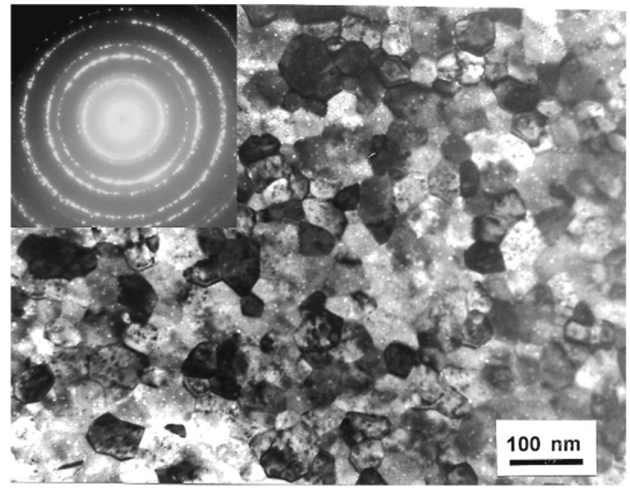

FIG. 2. Bright field TEM image of stoichiometric $CrPt_3$ sample annealed at 800 °C for 120 s. The inset is a (SADP). The small white spots are an additional fcc phase, probably pure Pt.

Plan view TEM images were taken in both bright-field and dark-field modes for stoichiometric $CrPt_3$ annealed at 800 °C for 2 min. The TEM images reveal an average grain size of 35 nm. The bright field TEM image, shown in Fig. 2, appears to be totally interdiffused $CrPt_3$—confirming the XRD measurements. However, the selected area diffraction pattern (SADP) shows the presence of extra reflections that belong to an fcc phase. This extra phase is likely to be pure platinum, though the measured lattice parameter is slightly larger than that of Pt. The SADP shows (111) texture of $CrPt_3$, also confirming the XRD measurements.

Auger electron spectroscopy with depth profiling was used to study the extent and uniformity of the thermal interdiffusion process for a stoichiometric single bilayer $CrPt_3$ sample annealed at 800 °C for 2 min. Complete interdiffusion of Cr and Pt was evident and the composition ratio was confirmed to be Pt/Cr$\sim$3.

Our $CrPt_3$ thin films have a perpendicular ''easy'' axis orientation after annealing. The sin 2θ dependence of the out-of-plane torque curves confirms the uniaxial anisotropy. The magnetic properties for a set of stoichiometric multilayer $CrPt_3$ samples with a constant total film thickness of 2000 Å is shown as a function of annealing temperature and number of layers in Fig. 3. The coercivity, H_c, can be varied over a wide range, 1500–7900 Oe, by selecting the annealing temperature and number of bilayers deposited. A saturation magnetization, M_s, of 200 emu/cc is achievable. The fact that this is close to the bulk value[6] of 240 emu/cc suggests that the films are nearly completely crystallized. A squareness value as high as 0.97 is achievable under favorable deposition and annealing conditions. An anisotropy constant, K_u, as high as 8×10^6 erg/cc is observed. As can be seen in Fig. 3, all of the basic magnetic properties improve as the annealing temperature is increased. In addition, there is a general improvement in H_c, M_s, and S as the number of deposited bilayers is increased. However, larger values of K_u seem to occur for a smaller number of bilayers. The improvement in magnetic properties with increase in annealing temperature has been noted for bulk $CrPt_3$ alloys.[7]

A few samples were subjected to *in situ* heating by applying a 45 mA current to the substrate table while sputter depositing the films. This corresponds to an estimated temperature of 650 ± 50 °C. A comparison of magnetic properties for nominally identical samples where one set was exposed to *in situ* heating and the other was not is shown in Table I. *In situ* heating is seen to increase the saturation magnetization, M_s. *In situ* heating and a high annealing temperature (850 °C) seem to combine in a synergistic fashion, increasing H_c, S, and K_u in addition to M_s.

The Curie temperature of all the stoichiometric $CrPt_3$ samples falls in the range of 200 ± 25 °C. The Curie temperature is relatively insensitive to both annealing temperature and number of deposited bilayers.

The Kerr rotation, θ_k was derived from MO hysteresis loops. The measured value of θ_k was largest for samples with a very large number of layers (i.e., very small deposited layer thickness) for samples with a total thickness of 2000 Å. The highest value of θ_k found on a nonovercoated sample

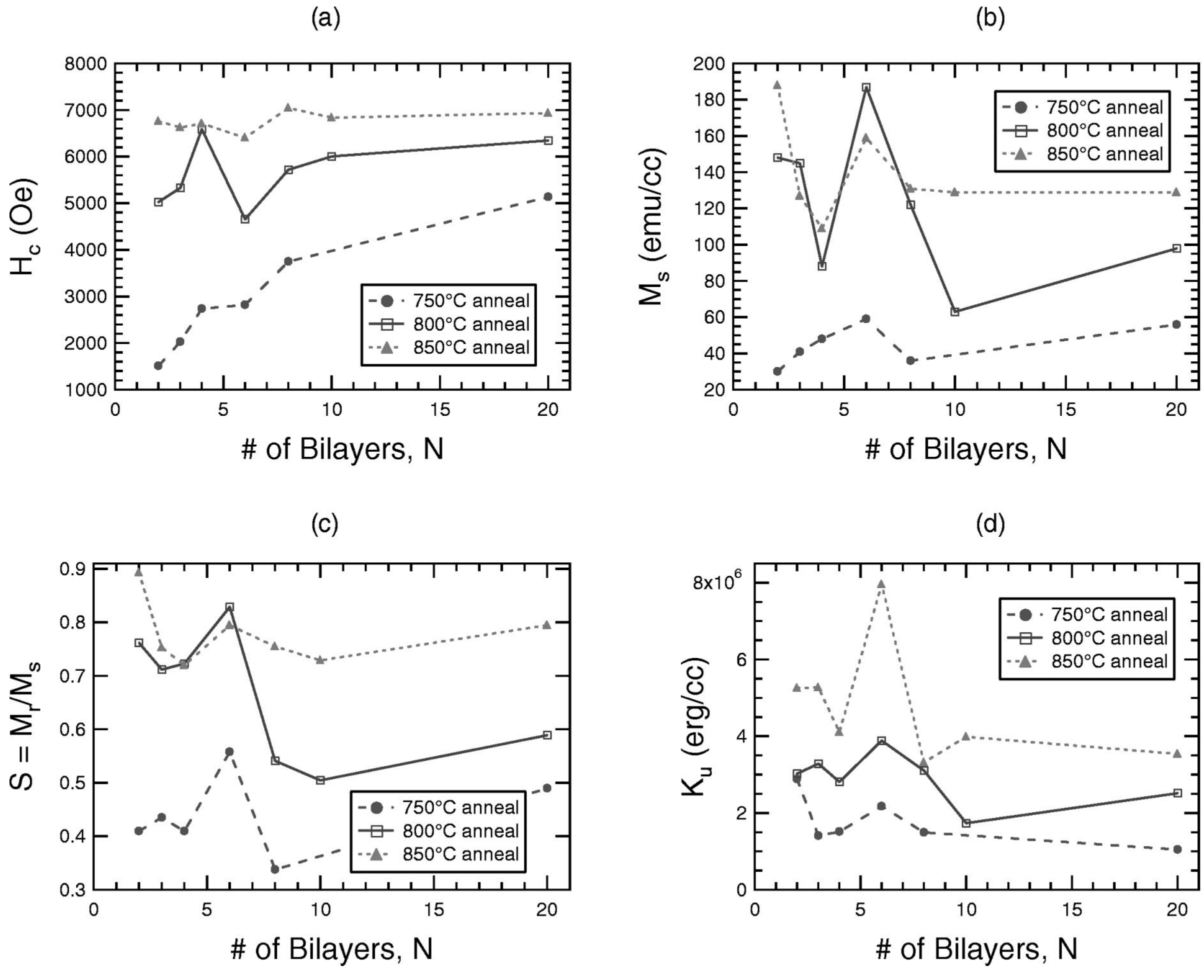

FIG. 3. Magnetic properties for samples with a constant overall thickness of 2000 Å and constant anneal time of 5 min with a varying anneal temperature and varying number of bilayers. All results correspond to a field applied along the easy axis, unless otherwise specified. (a) Coercivity, H_c; (b) Saturation magnetization, M_s; (c) Remanent squareness, *S*; and (d) Anisotropy constant, K_u.

was 0.10°. When this same sample was cleaned by sputter etching off the top 30 Å and capping it with an approximately quarter-wavelength silicon nitride antireflection coating, this value increased to 0.21°. A theoretical value[5] of ~0.2° is predicted for a nonovercoated sample at the 6328 Å He–Ne laser wavelength.

TABLE I. Effect of *in situ* heating during sputter deposition. For all samples, 20 bilayers of stoichiometric $CrPt_3$ were deposited.

	Anneal (°C)	H_c (Oe)	M_s (emu/cc)	S	K_u (10^6 erg/cc)
No *in situ*	750	5140	55.5	0.490	1.05
heating	800	6350	97.8	0.589	2.52
	850	6940	129.2	0.795	3.54
In situ	750	711	90.6	0.325	0.41
heating	800	4830	133.7	0.907	5.19
	850	7900	198.4	0.966	3.87

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