Perpendicular Magnetic Anisotropies and Kerr Spectra of (Cr_{1-x}V_x)Pt_3 Ordered Alloy Films

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(Cr_{1-x}V_x)Pt_3 alloy films were obtained by annealing (Cr-V)/Pt multilayer films prepared by rf magnetron sputtering. The structure and magnetic and magneto-optical properties for the alloy films were investigated. The CrPt_3 (x = 0) film exhibited an uniaxial anisotropy of \( K_u = 2.4 \times 10^6 \) erg/cc and a saturation magnetization of \( M_s = 235 \) emu/cc. The saturation magnetization and the uniaxial anisotropy decreased with increasing V substitution x. On the other hand, variations of the Kerr spectral shape with increasing substitution x were observed. The \( \theta_K \) peak around 1 eV of the CrPt_3 film shifted lower energy side with increasing x, and the (Cr_{0.37}V_{0.63})Pt_3 alloy film showed a plateau around 2 eV in the Kerr spectrum. The X-ray magnetic circular dichroism taken in the V 2p–3d excitation region indicated that the V has a ferromagnetic moment and align parallel to the Cr moment.

Key words: magnetic anisotropy, Kerr spectra, CrPt_3, VPt_3, X-ray magnetic circular dichroism

1. Introduction

Noble metal–transition metal systems are considered to be potential candidates for magneto-optical recording media using blue lasers^1,2, and their magneto-optical spectra and magnetic properties have been extensively studied. However, many studies have focused on noble metal–Fe, Co, Ni systems, while few have been reported on noble metal–Mn, Cr, V systems.

We have already reported that MnPt_3 and CrPt_3 ordered alloy films with Cu_3Au structure exhibit large magneto-optical Kerr rotations of –1.2 deg and –0.7 deg at photon energy around 1.2 eV^3,4, respectively. The shapes of the Kerr spectra of the two alloy films are similar to each other, but they show quite different magnetic anisotropies; MnPt_3 does not show perpendicular magnetic anisotropy^3 while CrPt_3 shows a large perpendicular anisotropy^4,5.

The large anisotropy of CrPt_3 is explained by the magneto-elastic contribution coming from its large magnetostriction constant and large lattice distortion which arises from the high temperature heat treatment to obtain the ordered CrPt_3 films on a fused quartz substrate^6.

For the systematic investigation of the transition metal–Pt_3 alloys, we further tried to study the magnetic anisotropy and the magneto-optical spectrum of VPt_3. However, due to the difficulty to fabricate highly ordered VPt_3 alloy films with Cu_3Au structure, there are no reports on those properties of VPt_3. Thus we tried to make (Cr_{1-x}V_x)Pt_3 alloy films, and investigated the contribution of the V moment on magnetic anisotropies and magneto-optical spectra.

2. Experiment

(Cr_{1-x}V_x)Pt_3 alloy films were obtained by annealing (Cr-V)/Pt multilayer films prepared by an rf magnetron sputtering system on fused quartz substrates. The Pt content was controlled by changing the thickness of the Pt layer while fixing the Cr-V layer thickness at 0.4 nm. To obtain the ordered state, the multilayers were annealed at a temperature of 850 °C for 15 min under a pressure lower than 3 × 10^{-4} Pa, and then cooled down to room temperature at a rate of 10 °C/min.

The film structure was characterized by X-ray diffractionmetry (XRD) using Cu Kα radiation, and the composition was determined by electron probe microanalysis (EPMA). Hysteresis loops and magnetic anisotropy was measured with an alternating gradient magnetometer (AGM) and a torque magnetometer, respectively. Kerr rotation \( \theta_K \) was measured from the substrate side by a polarized angle modulation method. X-ray magnetic circular dichroism spectra were taken at the beam line BL25SU of SPring-8 in Hyogo, Japan. A nearly perfect circular polarized X-ray from twin helical undulator was monochromatized by grating and its helicity was switched at a rate of 1 Hz. The spectra were measured by total electron yield method at room temperature under a magnetic field of 14 kOe applied perpendicular to the film plane.

3. Results and Discussion

Figure 1 shows \( \theta–2\theta \) XRD profiles measured for (Cr_{1-x}V_x)Pt_3. There was no significant variation in the profiles with V substitution as seen from two profiles of the films having \( x = 0.32 \) and 0.63. The broad peak around 20 = 20 ° is due to the fused quartz substrate. In the profiles, fundamental peaks such as \{111\} and \{200\} suggest that the films have polycrystalline fcc-based structures. Superlattice lines such as \{100\} and \{211\} are an unambiguous proof of the formation of ordered Cu_3Au phase. One dimension long-range order parameter \( S \) was estimated from the integrated intensity ratio of the superlattice \{100\} peak to the fundamental \{200\} peak in the same manner as Ref. 7. For the estimation, we used the Lorentz polarization factor for polycrystal with completely random orientation. The parameter \( S \) was estimated to be 0.9 ± 0.1 for all the (Cr_{1-x}V_x)Pt_3 films, which suggests that the films are close to perfectly ordered alloy.

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Figure 2 shows hysteresis loops of (a) $x = 0$, (b) 0.32, and (c) 0.67 in the (Cr$_{1-x}$V$_x$)Pt$_3$ alloy films measured at room temperature. Solid and dashed lines represent the loops measured applying a magnetic field along in-plane and out-of-plane directions, respectively. Saturation magnetization $M_s$ and coercivity $H_c$ for the CrPt$_3$ film are 235 emu/cc and 4 kOe, respectively, and the $M_s$ approximately coincides with the bulk value of 240 emu/cc$^8)$. As shown in Fig. 2, the saturation magnetization $M_s$ decreases with the increase of the substitution $x$, which is considered to be due to not only lower magnetic moment of V (1.0 $\mu_B$) compared to that of Cr (2.3 $\mu_B$)$^9)$ but also lower Curie temperature of (Cr$_{1-x}$V$_x$)Pt$_3$ approaching 240 K in VPt$_3$$^{10)}$.

Figure 3 shows the dependence of the uniaxial anisotropy $K_u$ and the demagnetizing energy $2\pi M_s^2$ on the vanadium substitution $x$ in the (Cr$_{1-x}$V$_x$)Pt$_3$ alloy films. The data were taken at room temperature. As reported previously$^{10}$, the CrPt$_3$ ($x = 0$) exhibits large $K_u$ of 2.4 $\times$ 10$^6$ erg/cc, which is much larger than $2\pi M_s^2$ of 3.5 $\times$ 10$^5$ erg/cc. In the (Cr$_{1-x}$V$_x$)Pt$_3$, $K_u$ and $2\pi M_s^2$ gradually decreases in magnitude with increasing substitution $x$, but the $K_u$ is still much larger than the $2\pi M_s^2$ at $x = 0.6$, unlike the case of (Cr$_{1-x}$Mn$_x$)Pt$_3$ alloy films$^{11)}$. The (Cr$_{1-x}$Mn$_x$)Pt$_3$ alloy films exhibit $2\pi M_s^2$ of 4.6 $\times$ 10$^5$ erg/cc at $x = 0.55$, which almost compensates the corresponding uniaxial anisotropy $K_u$ of 5 $\times$ 10$^5$ erg/cc, and thus the effective anisotropy of (Cr$_{0.45}$Mn$_{0.55}$)Pt$_3$ is almost zero. The large anisotropy of CrPt$_3$ is explained by the magnetoelastic contribution coming from its large magnetostriction constant and large lattice distortion which arises from the high temperature heat treatment to obtain the ordered CrPt$_3$ films on a fused quartz substrate$^{6,11)}$. The decrease of uniaxial anisotropy with increasing substitution $x$ in the (Cr$_{1-x}$Mn$_x$)Pt$_3$ films is considered to be due to the small magneto-elastic anisotropy of the MnPt$_3$ which has small magnetostriction constant$^{10)}$. On the other hand, (Cr$_{1-x}$V$_x$)Pt$_3$ films exhibit quite large $K_u$ compared to corresponding $2\pi M_s^2$ up to $x = 0.6$, which suggests positive magneto-elastic anisotropy of VPt$_3$.

Figure 4 shows Kerr spectra with various vanadium substitution $x$ in (Cr$_{1-x}$V$_x$)Pt$_3$ alloy films. The Kerr rotation $\theta_K$ was measured at room temperature through fused quartz substrates. The CrPt$_3$ alloy film exhibits a large negative $\theta_K$ of $-0.65$ deg at 1.2 eV, and a positive $\theta_K$ of 0.36 deg at 3.1 eV. These peaks decreases in magnitude with increasing vanadium substitution $x$. This is considered to be partly
Fig. 3 Dependence of uniaxial anisotropy $K_u$ (closed circles) and demagnetizing energy $2\pi M_s^2$ (open circles) on V substitution x in the $(\text{Cr}_{1-x}\text{V}_x)\text{Pt}_3$ alloy films.

Fig. 4 Kerr spectra with various vanadium substitution x in $(\text{Cr}_{1-x}\text{V}_x)\text{Pt}_3$ alloy films. The Kerr rotation $\theta_K$ was measured at room temperature through fused quartz substrates. Due to the decrease of $M_s$ at room temperature as shown in Fig. 2. Besides the decrease of $\theta_K$ peak values, variations of the spectral shape with increasing substitution x are observed. The negative and positive peak positions around 1 eV and 3 eV shift lower and higher energy side with increasing substitution x, respectively. Furthermore, the $(\text{Cr}_{0.37}\text{V}_{0.63})\text{Pt}_3$ alloy film exhibits a plateau around 2 eV in the Kerr spectrum. These changes in the spectral shape are considered to be due to the ferromagnetic contribution of vanadium in $(\text{Cr}_{1-x}\text{V}_x)\text{Pt}_3$ alloy films. The change of the spectral shape with the substitution is also observed in $(\text{Mn}_{1-x}\text{Fe}_x)\text{Pt}_3$ system, whose Kerr spectra have a negative peak around 2.3 eV when x is increased above 0.24.

In order to insight element specific contribution to the magnetization in the $(\text{Cr}_{1-x}\text{V}_x)\text{Pt}_3$ alloy films, XMCD spectra were taken at Cr and V L$_2$-3 edges. Figure 5 shows total electron yield and MCD spectra taken for the $(\text{Cr}_{0.56}\text{V}_{0.44})\text{Pt}_3$ alloy film in (a) Cr and (b) V 2p–3d excitation.

Fig. 5 Total electron yield (upper) and MCD (lower) spectra taken for the $(\text{Cr}_{0.56}\text{V}_{0.44})\text{Pt}_3$ alloy film in (a) Cr and (b) V 2p–3d excitation regions. The solid $I_+$ and dashed $I_-$ lines are for the magnetization parallel and antiparallel to the photon helicity, respectively. The intensities of $I_+$ and $I_-$ are normalized by the L$_3$ edge jump of $(I_+ + I_-)/2$.
tation regions. Solid I+ and dashed I− lines represent normalized absorption spectra measured for the photon spin parallel and antiparallel to the 3d majority electron spin, respectively. The intensity is normalized so that the L3 edge jump in the (I+ + I−) /2 spectrum can become equal to 1. The absorption spectra in the Cr 2p–3d excitation region show two large positive peaks at 576.4 eV and 585.4 eV which correspond to Cr L3 and L2 absorption edges, respectively. In addition, the peak at 577.7 eV is thought to be due to oxygen which might exist on Au mesh for monitoring the intensity of incident X-ray. The MCD spectrum of Cr which obtained from I+ - I− have an absorptive structure in the L3 region and a dispersive structure in the L2 region. The spectral shape is almost the same as that of previously reported CrPt3 film, except for lower MCD signal compared to CrPt3 [11]. The decrease of the MCD signal may be associated with a reduction in Curie temperature from the CrPt3 to the (Cr0.56V0.44)Pt3.

As shown in Fig. 5 (b), absorption spectra of V have two large positive peaks at L3 and L2 edges. The small peak at 532 eV is oxygen K absorption edge. The spectral shape of V MCD is similar to that of Cr MCD. The MCD spectrum of V is much smaller contrast than that of Cr, but clearly indicates that the V has a ferromagnetic moment which align parallel to the Cr moment. The contribution of V moment is thought to result in the changes in the Kerr spectral shape in (Cr1-xVx)Pt3 alloy films. We do not state here about orbital to spin magnetic moment ratio <Lz> / 2 <Sz> because of insufficient energy separation between L1 and L2 peaks. (The overlap of the L1 and L2 peaks results in the underestimation of <Sz> as pointed out by Teramura et al.[13].) However, larger orbital moment of V compared to Mn is expected qualitatively from the shape of MCD spectra of V and Mn [11]. The expectation might be also supported by the fact that (Cr1-xVx)Pt3 films exhibit quite large Ks compared to corresponding 2πMs2 up to x = 0.6, while (Cr0.45Mn0.55)Pt3 has almost zero effective anisotropy.

4. Summary

(Cr1-xVx)Pt3 alloy films were prepared by an rf magnetron sputtering and a post annealing, and their structure and magnetic and magneto-optical properties were studied to investigate the contribution of V moment on the magnetic anisotropies and the magneto-optical spectra. From the dependence of the uniaxial anisotropy and demagnetizing energy on V substitution x, (Cr1-xVx)Pt3 films was found to exhibit quite large Ks compared to corresponding 2πMs2 up to x = 0.6. The Kerr spectra of (Cr1-xVx)Pt3 films varied with increasing substitution x, and exhibited a plateau around 2 eV for x = 0.63. These features is considered to be related to the ferromagnetic contribution of V moment which was proven by XMCD measurements.

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