MAGNETO-OPTICAL SPECTRA OF MnPt_3 AND $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ ALLOY FILMS

S. Iwata, T. Kato, M. Kokuryu, and S. Tsunashima

Dep. of Electronics, Nagoya University, Nagoya 464-01, Japan

Abstract - The magnetic and magneto-optical properties of ordered $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ alloy ($0 \leq x \leq 0.45$) films were investigated. The films were prepared by annealing $\text{Mn}_{1-x}\text{Fe}_x/\text{Pt}$ multilayers at a temperature of 800°C . The MnPt_3 alloy films was found to exhibit very large magneto-optical Kerr rotation, which reaches a maximum value of -1.2 deg at 1.24 eV. From the spectra of the off-diagonal component of conductivity tensor together with the diagonal component of dielectric tensor, it is suggested that the large Kerr rotation is due not to the plasma resonance but to strong interband transitions. MnPt_3/Co multilayer films were also prepared by MBE, and found to exhibit perpendicular magnetic anisotropy induced by the multilayered structure.

KEYWORDS: MAGNETO-OPTICAL EFFECT, KERR SPECTRA, CONDUCTIVITY TENSOR, MnPt_3 ORDERED ALLOY, $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ ALLOY, MnPt_3/Co MULTILAYER

INTRODUCTION

Since Co/Pt alloy and multilayer films exhibit large Kerr rotation in short wavelength region, they are considered to be potential candidates for magneto-optical recording media using blue laser[1, 2]. Kerr enhancement at the short wavelength is also observed in other systems consisting of Pt and 3d transition metals, namely, Fe-Pt and Ni-Pt systems[2, 3]. While Mn is one of 3d transition metals, a few reports have been made on the magneto-optical properties of Mn-Pt system[2]. Furthermore, from the fact that the intermetallic compounds consisting of Mn, such as PtMnSb [4] and MnBi [5], exhibit very large Kerr rotation, Mn-noble metal systems are considered to be magneto-optical materials of great interest. Although most of Mn alloys with noble metals are antiferromagnetic, it is known that MnPt_3 and MnAu_4 ordered alloys are ferromagnetic[6,7].

Recently, we have reported that ordered MnPt_3 alloy film exhibits very large Kerr rotation[8]. In this reports, detailed magneto-optical properties of MnPt_3 alloy and quasibinary $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ alloys, which are ferromagnetic for $x < 0.57$ at room temperature [9], are described.

While the MnPt_3 alloy film shows a large Kerr rotation, it is difficult to apply the film to a magneto-optical recording medium. Because the MnPt_3 film with cubic Cu_3Au type crystal structure does not exhibit perpendicular anisotropy. Finally, we tried to prepare MnPt_3/Co multilayer films in order to enhance the perpendicular magnetic anisotropy through the interface effect.

EXPERIMENT

Ordered MnPt_3 films were obtained by annealing Mn/Pt multilayer films (MLFs), which were prepared by rf magnetron sputtering onto fused quartz substrates.

The Mn content in MLFs was controlled by changing the thickness of the Pt layer while fixing the Mn layer thickness at 0.3nm . The MLFs were annealed for 1h under a pressure less than $3 \times 10^{-5}\text{Pa}$. $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ alloy films were similarly prepared by annealing (Mn-Fe)/Pt MLFs.

MnPt_3/Co MLFs were grown by MBE onto $\text{MgO}(111)$ with Ag and Pt under layers at temperature of 300°C under a pressure less than $5 \times 10^{-8}\text{Pa}$. The MnPt_3 layers were deposited by co-evaporation from e-beam sources.

The structure and the composition of the films were characterized by X-ray diffractometry (XRD) using the $\text{Cu-K}\alpha$ radiation and EPMA, respectively. The magnetic properties were measured by a vibrating sample magnetometer (VSM). Kerr rotation θ_K and Kerr ellipticity η_K were measured from the substrate side by the polarized angle modulation method, where Soleil-Babinet's compensator was used for the measurement of η_K . The optical constants of the film, n and k , were estimated as follows. The reflectivity R and transmissivity T were measured for the MnPt_3 film with a thickness of 20nm by spectrophotometer, where the film thickness was chosen so that T as well as R became larger than 10 %. On the other hand, the R and T were formularized as a function of n , k , n_0 and d , $R(n, k, n_0, d)$ and $T(n, k, n_0, d)$, taking account of the interference of the light in the film, where n_0 is the refractive index of the substrate (fused quartz) and d the thickness of the film. The n and k of the film were found by solving the equations, $R_{\text{meas}} = R(n, k, n_0, d)$ and $T_{\text{meas}} = T(n, k, n_0, d)$, using the n_0 and the measured R_{meas} , T_{meas} and d .

RESULTS

MnPt₃ Alloy Film

Figure 1 shows the saturation magnetization M_s at room temperature after annealing the samples made of $[\text{Mn}(3\text{ \AA})/\text{Pt}(11\text{ \AA})]_{120}$ multilayers. The M_s increases with annealing temperature and takes a maximum at 800°C . Figure 2 shows the XRD patterns for the samples before and after annealing. For the sample annealed at 800°C , the diffraction peaks from the superstructure of ordered MnPt_3 phase can be observed while only (111) and (200) diffraction peaks of fcc Pt can be seen for the as-deposited sample, which does not show ferromagnetic behavior at 77K. The lattice constant $a=3.88\text{ \AA}$ for the annealed sample estimated from Fig.2 agrees well with the reported one ($3.89\text{ \AA}$)[10].

Fig. 1 Annealing temperature dependence of M_s for $\text{Mn}(3\text{ \AA})/\text{Pt}(11\text{ \AA})$ multilayer films, where annealing was done for 1 hours.

Fig. 2 X-ray diffraction patterns of as-deposited film (Mn/Pt multilayer) and annealed one (MnPt_3 alloy).

Figure 3 shows the temperature dependence of M_s for the annealed sample. Since the M_s at 77K approximately coincides with the bulk value [11], it is considered that most of the film consists of ordered MnPt_3 phase.

Figure 4 shows the spectra of the Kerr rotation θ_K and the Kerr ellipticity η_K measured from the substrate side of the MnPt_3 film. The θ_K shows a large negative peak value of -1.18° at 1.2 eV and a small positive peak at 3.3 eV. The θ_K spectrum of MnPt_3 film is compared with other magneto-optical materials consisting of Mn as shown in Fig 5[4,5,12,13], where the referred data measured from a material surface are multiplied by the reflective index $n_0(\lambda)$ of fused quartz in order to compare with the data measured from a

Fig. 3 Temperature dependence of M_s for an MnPt_3 alloy film. The closed circle shows the value[11] reported for a bulk MnPt_3 alloy.

Fig. 4 Spectra of the Kerr rotation θ_K and ellipticity η_K for an MnPt_3 alloy film.

substrate side. The spectral shape of MnPt_3 with a large negative peak at low energy side is similar to those of MnBi [5] and PtMnSb [4] while the negative peak of MnPt_3 appears at slightly lower energy.

In order to investigate the correlation between the Kerr spectra and the electronic structure, the dielectric and conductivity tensors were estimated from n , k , n_0 , θ_k and η_k . Both the real part $|\epsilon_{XX}'|$ and the imaginary part ϵ_{XX}'' decrease with increasing photon energy as shown in Fig. 6. The magnitude of $|\hat{\epsilon}_{XX}|$ is still much larger than 1 at 1.2 eV where the θ_k takes the negative peak. This implies that the large Kerr rotation of MnPt_3 does not originate from the plasma enhancement [14], which arises when $\hat{\epsilon}_{XX}^{1/2} (1 - \epsilon_{XX})$ is approaching zero. Figure 7 shows the real and the imaginary parts of $\hat{\sigma}_{XY}$, where $\hat{\sigma}_{XY} (= \sigma_{XY}' + i\sigma_{XY}'')$ is the off-diagonal component of the conductivity tensor. The σ_{XY}'' spectrum shows the positive maximum at 1.2 eV, which corresponds to the peak of θ_k . This suggests that the large Kerr rotation of MnPt_3 is due to strong interband transition. Recently, Oppeneer et al. demonstrated by first principle calculation that the spin-orbit-coupling strength on Pt plays an important role in the large magneto-optical effect of MnPt_3 [15]. The calculated spectrum of MnPt_3 , which shows a large negative peak at 0.9 eV, approximately agree with the experimental spectrum

Fig. 5 Kerr spectra of MnPt_3 alloy measured from a substrate side and other magneto-optical materials containing Mn; PtMnSb (C1b type) [2], MnBi [5], MnSb [13] and PtMnSb (NiAs type) [12], where the referred data measured from a material surface are multiplied by the reflective index $n_0(\lambda)$ of fused quartz in order to compare with the data measured from a substrate side.

Fig. 6 Spectra of the diagonal component of the dielectric tensor for the MnPt_3 alloy film.

Fig. 7 Spectra of $\hat{\sigma}_{XY}$ for the MnPt_3 alloy film.

except high energy region.

$\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ Ordered Alloy Films

In the next place, the variation of the Kerr spectra of the MnPt_3 alloy was investigated by substituting Fe for a part of Mn. Figure 8 shows the XRD patterns for $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ films prepared by annealing at 800°C. The appearance of the diffraction peaks, such as (100) and (110), indicates the formation of quasibinary ordered phase. Figure 9 shows the composition

dependence of the lattice constant a estimated from X-ray diffraction peaks and the saturation magnetization M_s at room temperature. The lattice constant a slightly decreases with increasing Fe content x . The lattice constant itself is slightly smaller than bulk values but the slope of the change approximately agrees with the

Fig. 8 X-ray diffraction patterns of $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ films.

Fig. 9 Dependence of lattice constant a and saturation magnetization M_s on Fe content x for $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ films, where the lattice constants for bulk MnPt_3 [10] and FePt_3 [16] are also shown.

straight line connecting the lattice constants of MnPt_3 and FePt_3 alloys[10, 16]. The saturation magnetization M_s is almost constant until $x=0.4$, whereas it abruptly decreases for $x>0.5$. This is consistent with the fact that the Curie temperature of $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ phase decreases down to room temperature at $x=0.57$ [9].

Figure 10 shows the θ_k and η_k spectra measured from substrate side of $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ films with Fe content x as a parameter. The negative peak of the θ_k at low energy shifts toward lower energy side and decreases in magnitude with increasing Fe content. The positive peak around 3.2 eV also becomes less remarkably with increasing x and an additional peak appears around 2.3 eV for the samples with $x \geq 0.24$. In the η_k spectra, a variation corresponding the additional peak can be seen. The decrease in θ_k with increasing Fe content, which does not correspond the change of M_s , and the additional peak at 2.3 eV, which may related to the negative peak at 2.0 eV for ordered FePt alloy [17], are considered to originate from the variation of electronic structure.

Fig. 10 Spectra of the (a) Kerr rotation θ_k and (b) ellipticity η_k of $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ films.

MnPt₃/Co Multilayer Films

As the ordered MnPt₃ films have found to be able to be grown by MBE onto MgO(111) at 300°C without post annealing, the multilayer films were also prepared at 300°C as Pt(2nm)/[Co(0.6nm)/MnPt₃(2nm)]₂₀/Pt(10nm)/Ag(30nm)/MgO(111). It was confirmed by the observation of RHEED patterns during the deposition that the each of the layers in the film is epitaxially grown as MgO(111), [101] // Ag, Pt, MnPt₃/Co (111), [101]. Figure 11 shows the low angle XRD pattern for the multilayer film. The appearance of small angle X-ray diffraction peaks corroborates the formation of multilayered structure. The formation of ordered MnPt₃ phase in the multilayer films were confirmed as follows. Since the annealed MnPt₃ film has random crystal orientations, the X-ray diffraction peaks from the superstructure could be detected by θ -2 θ scan as mentioned above. However, as the multilayer films were epitaxially grown on the single crystal Pt (111) plane, it is necessary to perform off-axial scans in order to find the diffraction peaks due to the superstructure. By searching in the Q_z - Q_x plane of the reciprocal space, {112} diffraction peak was found as shown in Fig.12, where Q_z is the scattering vector component perpendicular to the film plane and Q_x the in-plane component parallel to [11 2] direction. This suggests the formation of ordered MnPt₃ phase in the multilayer film.

Figure 13 shows the hysteresis loops measured applying a field in the film plane and the film normal direction. For the sputtered film with a single MnPt₃ layer, the easy axis of magnetization lies in the film plane owing to its shape anisotropy. On the other

Fig.11 Low angle XRD pattern for MnPt₃/Co multilayer film.

Fig. 12 Reciprocal space mapping around the {112} X-ray diffraction peak for MnPt₃/Co multilayer film.

Fig. 13 Hysteresis loops of MnPt₃ alloy and MnPt₃/Co multilayer films measured at room temperature.

hand, in the case of multilayer film the hysteresis loops for in-plane and film normal become close to each other. This implies that perpendicular magnetic anisotropy is induced through the multilayer structure. Although the perpendicular anisotropy is not sufficient to obtain perpendicularly magnetized films, there is possibility that the perpendicular anisotropy is further enhanced by optimizing the film structure and the growth conditions.

SUMMARY

Ordered MnPt_3 and quasibinary ordered $\text{Mn}_{1-x}\text{Fe}_x\text{Pt}_3$ alloy films were prepared by annealing (Mn-Fe)/Pt multilayers and the magneto-optical properties of the films were investigated.

The MnPt_3 alloy film exhibits very large Kerr rotation which reaches a maximum value of -1.2° at 1.24 eV (as measured from the substrate side). At this energy, while the imaginary part σ_{XY}'' of the off-diagonal component of conductivity tensor takes a maximum, the diagonal component $\hat{\epsilon}_{XX}$ of dielectric tensor has a large value. This suggests that the large Kerr rotation is due not to the plasma resonance but to strong interband transitions. By substituting Fe for a part of Mn, the peak value of θ_K at 1.24 eV decreases remarkably and an additional peak appears at 2.3 eV .

Finally, the MnPt_3/Co multilayer films were prepared by MBE. The perpendicular anisotropy was induced through multilayered structure while it is not sufficient to obtain perpendicularly magnetized films.

ACKNOWLEDGMENTS

The authors would like to thank Mr. Y. Adachi and Mr. M. Kumazawa of Nagoya University for EPMA analysis and experimental assistance, respectively. This work was supported by a Grant-in-Aid for Scientific Research from Ministry of Education, Science and Culture.

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