Dielectric Tensor and Magneto-Optical Kerr Effect for Mn-Sb-M (M=Au, Pd) Films Consisting of MnSb and MMnSb Phases

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The contribution of the unique magneto-optical structure with the MnSb and MMnSb (M=Au, Pd) phases to the magneto-optical spectra of the composites films with various MnSb-MMnSb volume fraction was discussed in connection with the dielectric tensor analysis. As results, it was found; (1) The Mn-Sb-M (M=Au, Pd) films after annealing at 300°C consisted of MnSb with the hexagonal phase and MMnSb with the f.c.c. phase. (2) For the Mn-Sb-Au films, the magneto-optical Kerr effect was originated from the off-diagonal part of dielectric tensor, ϵ_{xy} , of the hex. MnSb phase. (3) For the Mn-Sb-M (M=Pd, Pt) films, the ϵ_{xy} maxima of ferromagnetic MMnSb (M=Pd, Pt) phases did not change monotonously against volume fraction of MnSb-MMnSb phases.

Key words: magneto-optical Kerr effect, hex. MnSb phase, f.c.c. AuMnSb and PdMnSb phases, dielectric tensor, plasma edge

1. Introduction

The present authors have already reported that an enhancement of a magneto-optical (MO) Kerr rotation angle, θ_K^{sub} , about 1.0°, at visible short wavelength of $\lambda=530$ nm (measured from the glass substrate side) was realized for the Mn₅₀Sb₄₄Pt₆ film (50at%Mn, 44at%Sb and 6at%Pt) after annealing at 300°C¹⁾. Furthermore, it was clarified that the real part of off-diagonal component of dielectric tensor, ϵ_{xy} , caused this enhancement for the MnSb-PtMnSb composites films²⁾. To discuss the inducement of the θ_K maximum originated from ϵ_{xy} maximum for other MnSb-MMnSb composites films with the composition around Mn₅₀Sb₄₄M₆, the evaluation of MO properties and dielectric spectra was carried out for Mn-Sb-Au films and Mn-Sb-Pd films. However, this phenomenon was not enhanced so much for these Mn-Sb-M (M=Au, Pd) films compared with Mn-Sb-Pt films³⁾. It is necessary to pay attention to the unique ϵ_{xy} structure for each phase which is the basis of the ϵ_{xy} spectra of the composites film.

In this study, the contribution of the unique MO structure with the MnSb and MMnSb (M=Au, Pd) phases to the spectra of the Mn-Sb-M film was discussed using the films with various MnSb-MMnSb volume fraction.

2. Experimental Procedure

Mn-Sb-M (M = Au, Pd) films (magnetic layer : 1000 Å, SiO₂ coating-layer : 50 Å) were sputter-deposited at R.T. onto glass substrates under a vacuum better than 2.0×10^{-6} Torr. A composite target consisting of MnSb sintered target (4 inch diameter) with M (M=Au, Pd) fan shaped sheets was used. Films were annealed at 300°C for 10

hours in a vacuum less than 4×10^{-6} Torr. Structure of the films was examined by XRD technique (Co-K α). Concentration of the films was determined by EPMA. All the optical and MO measurements were examined from the film side under the wavelength region 250~1000 nm (5.00~1.24 eV). Complex refractive index of a magnetic layer, $n+ik$, was evaluated by rotating-analyzer ellipsometry. Difference between complex refractive index of right and left polarized light, $\Delta n+i\Delta k$, was consistently determined from n , k , experimentally observed MO Kerr rotation and ellipticity, θ_K^{obs} and η_K^{obs} , by applying matrix method considering interference in a coating layer⁴⁾. In this paper, θ_K represents the MO Kerr rotation which is calculated in the case that the incident light came from a vacuum to a magnetic layer directly. Diagonal and off-diagonal components of dielectric tensor, $\epsilon_{xx}=\epsilon_{xx}'+i\epsilon_{xx}''$ and $\epsilon_{xy}=\epsilon_{xy}'+i\epsilon_{xy}''$, were calculated using n , k , Δn and Δk .

3. Results and Discussion

3.1 Structure

Figures 1 (a) and (b) show the composition of Mn-Sb-Au films (a) and Mn-Sb-Pd films (b) fabricated in this

Fig.1 Compositions of the Mn-Sb-M (M=Au (a) and Pd (b)) films.

Table 1 Sample name, composition and θ_K maximum for Mn-Sb-Au films

Name	MnSb	Au-A	Au-B	Au-C	Au-D
Mn (at%)	53.8	49.24	46.85	42.76	40.46
Sb (at%)	46.2	43.86	40.48	34.98	32.17
Au (at%)	0.00	6.90	12.67	22.26	27.37
θ_K^{max} (deg.)	0.413	0.282	0.211	0.154	0.000

Table 2 Sample name, composition and θ_K maximum for Mn-Sb-Pd films

Name	MnSb	Pd-A	Pd-B	Pd-C	Pd-D
Mn (at%)	53.8	49.06	46.76	44.16	38.66
Sb (at%)	46.2	43.93	41.30	38.37	33.90
Pd (at%)	0.00	7.01	11.93	17.47	27.44
θ_K^{max} (deg.)	0.413	0.280	0.235	0.373	0.407

Fig.2 XRD patterns for the Mn-Sb-M (M=Au (a) and Pd (b)) films after annealing at 300°C.

study. In these figures, the compositional line of (MnSb)_{50-0.5x}M_x is also shown. The compositions of both the Mn-Sb-Au and Mn-Sb-Pd films are found to be near the line mentioned just above. The sample names, compositions and the values of θ_K maximum, $\theta_K^{\max}$ (discussed below) for Mn-Sb-Au and Mn-Sb-Pd films are summarized in Table 1 and Table 2, respectively.

Figure 2 (a) shows the XRD patterns of the Mn-Sb-Au films after annealing at 300°C against the Au content from the MnSb film to the Au-D film. Diffracted lines due to both of the MnSb and AuMnSb phases were observed for all films except the MnSb film and the Au-D film examined in this study. This structural feature is also observed for Mn-Sb-Pd films as shown in Fig.2 (b). Furthermore, the lattice constant of the hexagonal phase, a_{hex} , for these films calculated by using the hex-(110) diffracted line showed almost the same value of 4.125 Å independent of additional atoms. This fact is considered as an evidence that the hex-MnSb phase without the M atoms is formed in Mn-Sb-M (M=Au, Pd) films. In consequence, the structure of the Mn-Sb-M (M=Au, Pd) films after annealing at 300°C are found to consist of the hex. MnSb phase and the f.c.c. MMnSb phase.

3.2 Optical properties

It is well-known that the MO Kerr effect is related to the components of dielectric tensor by the equation⁵⁾.

$$\theta_K + i\eta_K = \frac{\epsilon_{xy}}{\sqrt{\epsilon_{xx}(1 - \epsilon_{xx})}} \quad (1)$$

From this equation, it is suggested that the maxima of the MO Kerr effect can be realized when ϵ_{xy} takes maximum or ϵ_{xx} is 0 (a plasma edge).

C1_b typed MMnSb compounds are metallic for majority-spin electrons and semiconducting or insulating for minority-spin electrons⁶⁻⁷⁾. Therefore, the coupled plasma edge, as a result of the sum of a Drude term due to majority-spin band and a Lorentz term due to minority-spin band, appears in a low energy from near ultraviolet to infrared region. Furthermore, for composites films including a C1_b phase, it is expected that the effective coupled plasma edge, as a result of several phases mixture,

will be varied by changing the volume fraction of the phases in the film. Therefore, to evaluate the contribution of the plasma edge to the MO Kerr effect for MnSb-MMnSb (M=Au, Pd) composites films, at first ϵ_{xx} for the films was determined.

In Fig.3, ϵ_{xx} spectra for Mn-Sb-M (M=Au, Pd) films after annealing at 300°C are shown. For the Au-D film consist of the f.c.c. AuMnSb phase, ϵ_{xx} showed the value about -2 for the energy range of 5.00~3.20 eV. For the energy range less than 3.20 eV, ϵ_{xx} showed a remarkable increment with decreasing the energy. Taking the spectral shape of a Drude term into account, the coupled plasma edge for the AuMnSb phase expected to exist at the energy region less than 1.24 eV which is lower than the limit of the present measurement system. For the Mn-Sb-Au films, the shape of ϵ_{xx} spectra monotonously changed as the Au content changed. For these films, no effective plasma edge could be observed in the examined energy region.

While for the Pd-D film with the f.c.c. PdMnSb phase, the coupled plasma edge was observed at 1.95 eV which is similar to that of the C1_b typed PtMnSb phase⁸⁾. For the Mn-Sb-Pd films, the shape of ϵ_{xx} spectra monotonously changed as Pd content changed, and for the Pd-C film the effective plasma edge became to be detected. Therefore, θ_K spectra for the MnSb-PdMnSb composites films is expected to be drastically changed in according with the volume fraction of the PdMnSb phase.

3.3 Mechanism of the MO Kerr effect for the Mn-Sb-M (M=Au, Pd) films

In this section, the mechanism of the MO Kerr effect for the Mn-Sb-M (M=Au, Pd) films is discussed based on the results from the structural and dielectric tensor analyses. In Fig.4, the spectra of θ_K and ϵ_{xy} for Mn-Sb-Au films with the various Au content after annealing at 300°C are shown. For the θ_K spectrum of the MnSb film, two small maxima were observed at the energy of 2.48 eV and 3.40 eV, respectively. As the Au content increased, θ_K spectra changed monotonously from the spectrum of the

Fig.3 ϵ_{xx} spectra for the Mn-Sb-M (M=Au and Pd) films after annealing at 300°C.

Fig.4 θ_K and ϵ_{xy}' spectra for the Mn-Sb-Au films after annealing at 300°C.

MnSb film to that of the Au-D film and no MO effect was observed in the Au-D film with the AuMnSb phase. While in ϵ_{xy}' spectra for the MnSb film, two small maxima were observed at the same energy as the θ_K maxima. With increasing the Au content, both ϵ_{xy}' maxima decreased and vanished completely for the Au-D film because of the paramagnetism at R.T. of the AuMnSb phase. This indicates that the θ_K maxima observed at around 2.48 eV and 3.40 eV for the Mn-Sb-Au films are caused by the maxima of ϵ_{xy}' of the hex. MnSb phase.

In Fig.5, the spectra of θ_K and ϵ_{xy}' for the Mn-Sb-Pd films with the various Pd content after annealing at 300°C are shown. As the Pd content increased, θ_K spectra changed from that of the MnSb film to that of the Pd-D film which showed a large maximum at 1.95 eV, a small maximum at about 2.95 eV and a minimum at 4.70 eV. While in ϵ_{xy}' spectra, as the Pd content increased from the MnSb film, ϵ_{xy}' maxima appeared at near 1.85 eV (Pd-A), and it shifted to 2.05 eV (Pd-B, C, D). In addition, another ϵ_{xy}' maximum appeared at 2.95 eV (Pd-C, D). Both maxima at 2.05 eV and at 2.95 eV consider to be originated from the MO structures in the ferromagnetic PdMnSb phase. Therefore, the contribution of the ϵ_{xy}' maximum of the PdMnSb phase at 2.05 eV against the volume fraction of MnSb-PdMnSb phases is different from that of 2.95 eV. Comparing the spectra of θ_K with that of ϵ_{xy}' , it can be found the θ_K maximum and minimum at 2.95 eV and 4.70 eV are originated from the ϵ_{xy}' structure of the f.c.c. PdMnSb phase. While the θ_K maximum at 1.95 eV is located a little lower than the ϵ_{xy}' maximum at 2.05 eV of the f.c.c. PdMnSb phase. According to ϵ_{xx} spectra shown in Fig.3, this θ_K maximum at 1.95 eV is found to be caused by the coupled or effective plasma edge.

Taking the results of MnSb-MMnSb (M=Au, Pd, Pt⁷⁾) composites films' case into account, the ϵ_{xy}' maxima of ferromagnetic MMnSb (M=Pd, Pt) phases do not change monotonously against volume fraction of MnSb-MMnSb phases. This fact suggests that in MnSb-MMnSb

Fig.5 θ_K and ϵ_{xy}' spectra for the Mn-Sb-Pd films after annealing at 300°C.

composites film, the formation and microstructure of the MMnSb phase strongly affected the ϵ_{xy}' structure of the ferromagnetic MMnSb phase.

4. Conclusion

The contribution of the unique magneto-optical structure with the MnSb and MMnSb (M=Au, Pd) phases to the magneto-optical spectra of the composites films with various MnSb-MMnSb volume fraction was discussed in connection with the dielectric tensor analysis. As results, it was found;

- (1) The Mn-Sb-M (M=Au, Pd) films after annealing at 300°C consisted of MnSb with the hexagonal phase and MMnSb with the f.c.c. phase.
- (2) For the Mn-Sb-Au films, the MO Kerr effect was originated from ϵ_{xy}' of the hex. MnSb phase.
- (3) For the Mn-Sb-M (M=Pd, Pt) films, the ϵ_{xy}' maxima of ferromagnetic MMnSb (M=Pd, Pt) phases did not change monotonously against volume fraction of MnSb-MMnSb phases.

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