Structure and MO Kerr Effect for MnSbM(M=Pt, Au, Pd) Films

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Abstract—The MO (Magneto-Optical) Kerr effect for the $Mn_{51}Sb_{43}M_6$ (M=Pt, Au and Pd, and Mn:51at%, Sb:43at% and M:6at%) films was discussed from the viewpoints of the structure and dielectric tensor analyses. It was clarified; (1) The $Mn_{51}Sb_{43}M_6$ films after annealing at 300°C were found to consist of MnSb with the hexagonal phase and MMnSb with the f.c.c. phase. (2) The volume fraction of MMnSb with the f.c.c. phase, $V_{f.c.c.}$, in the MnSbM film annealed at 300°C was significantly more than estimated value. (3) The off-diagonal part of dielectric tensor, ε_{xy}', of MMnSb with the f.c.c. phase played a dominant role in the MO Kerr effect.

I. INTRODUCTION

The present authors have already reported that the giant Kerr rotation angle, θ_K, about 1.0°, at short wavelength of λ=530nm (measured from glass substrate side) was realized for the $Mn_{50}Sb_{44}Pt_6$ film (Mn:50at%, Sb:44%at%, Pt:6at%) after annealing at 300°C [1,2,3]. However, K.Sato et al. reported that this MO Kerr effect could not be observed for the MnSbPt bulk specimen with the similiar composition to the $Mn_{50}Sb_{44}Pt_6$ film [4]. Therefore, the mechanism of this unique MO Kerr effect has not been clarified yet. In this study, in addition to Pt atom, Au, and Pd atoms with the similiar electronic structure to Pt atom were also selected as the addition. At the same time, the structural analysis was made and the spectra of diagonal and off-diagonal dielectric tensors, ε_{xx} and ε_{xy}, were determined for the MnSbM (M=Pt, Au, Pd) films. Based on these results, the relationship between the structure and the optical properties as well as the origin of the MO Kerr effect for the MnSbM films were discussed.

II. EXPERIMENTAL PROCEDURE

$Mn_{51}Sb_{43}M_6$ (M=Pt, Au, Pd) films were sputter-deposited at room temperature onto glass substrates under a vacuum better than 2.0×10^{-6} Torr. The construction of these films consisted of a magnetic layer of 1000Å and a SiO_2 coating-layer of 50Å. Structural analysis was performed by using the XRD technique (Co-Kα) for the MnSbM films after deposition and after annealing at 300°C for 10 hours. The concentration of these films was determined by EPMA with the ZAF correction. The Optical constants (refractive index, n, and extinction coefficient, κ) were evaluated from the film side by rotating-analyzer ellipsometry within the photon energy range between 1.25 and 5.0 eV. In addition, the MO Kerr rotation and ellipticity, θ_K and η_K, were measured from the film side under the magnetic field of 18kOe and the photon energy range between 1.25 and 5.0 eV. The diagonal component of the dielectric tensor, ε_{xx}, was calculated by using n and κ. The off-diagonal component, ε_{xy}, was consistently determined by using n, κ, θ_K and η_K [5].

III. RESULTS AND DISCUSSION

A. Structure

Fig.1 shows the X-ray diffraction patterns of the MnSbAu and MnSbPt films as a function of the annealing temperature. For comparison, X-ray diffraction patterns of $Mn_{54}Sb_{46}$ film (hereafter described as hex-MnSb) with the hexagonal structure, $Au_{30}Mn_{40}Sb_{30}$ film (hereafter described as fcc-AuMnSb) and $Pt_{28}Mn_{40}Sb_{32}$ film (hereafter described as fcc-PtMnSb) with the f.c.c. structure after annealing at 300°C are also shown in these figures. For both MnSbAu and MnSbPt films, in the as-deposited state, the diffracted lines due to (110) plane of the hexagonal structure were mainly observed. After annealing at 300°C not only diffracted lines of the hexagonal structure but also diffracted lines of the f.c.c. structure were detected. This change in structure before and after annealing at 300°C was also observed in the case of the MnSbPd film. This means that by annealing, the MMnSb with the f.c.c. phase will be separated from the hexagonal phase. In addition, the lattice constant of hexagonal phase, a_{hex}, for these films annealed at 300°C was calculated by using the Bragg angle of (110) diffracted line shown in Fig.1. a_{hex} for the hex-MnSb and MnSbM films after annealing at 300°C were almost the same, and showed the value of 4.12Å. This fact may be considered as an evidence that the hexagonal phase for the MnSbM films exists as the structure
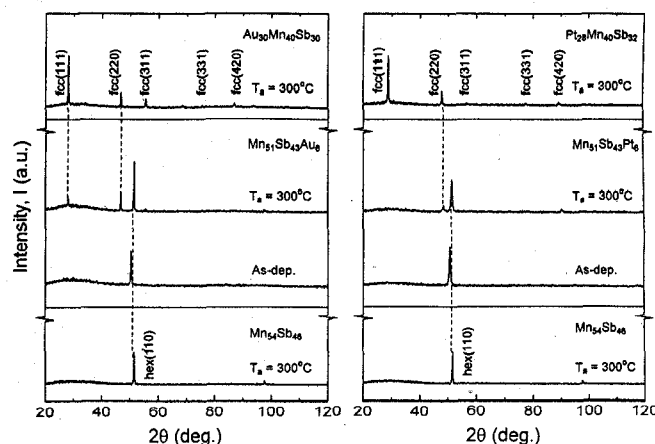

Fig.1 Changes of XRD pattern for the MnSbAu and MnSbPt films against annealing temperature. XRD patterns for the hex-MnSb, fcc-AuMnSb and fcc-PtMnSb films were also shown.
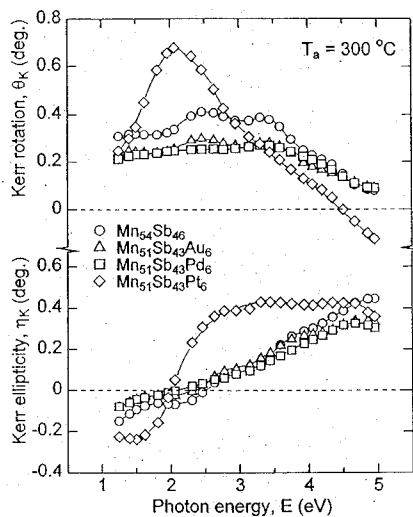
Fig.2 Spectra of MO Kerr rotation, θ_K, and Kerr ellipticity, η_K, for the MnSbM (M=Pt, Au, Pd) and hex-MnSb films annealed at 300°C.

Fig.3 Spectra of real part of diagonal (ε_{xx}') and off-diagonal (ε_{xy}') of the dielectric tensor for the MnSbPt, hex-MnSb and fcc-PtMnSb films annealed at 300°C.

Fig.4 Spectra of real part of diagonal (ε_{xx}') and off-diagonal (ε_{xy}') of the dielectric tensor for the MnSbAu, hex-MnSb and fcc-AuMnSb films annealed at 300°C.

Fig.5 Spectra of real part of diagonal (ε_{xx}') and off-diagonal (ε_{xy}') of the dielectric tensor for the MnSbPd, hex-MnSb and fcc-PdMnSb films annealed at 300°C.

of MnSb with the hexagonal phase without the M atom. Therefore, the structure of the MnSbM (M=Pt, Au, Pd) films after annealing at 300°C are found to consist of MnSb with the hexagonal phase and MMnSb with the f.c.c. phase .

B. Optical and magneto-optical properties

Fig. 2 shows θ_K and η_K spectra for the hex-MnSb and MnSbM films annealed at 300°C. Marked differences in the magneto-optical spectra existed between them. For the MnSbPt film, a strong optical dispersion of the MO effect appeared at around 2.1 eV, where θ_K showed a maximum of 0.7° . However, no remarkable optical dispersion of the MO effect was observed for the MnSbAu and MnSbPd films, and the value of θ_K was smaller than that of the hex-MnSb film.

In order to clarify the difference in the MO Kerr effect among these films, dielectric tensor analysis was carried out. Figs.3-5 show the spectra of real part of diagonal and off-diagonal dielectric tensor, ε_{xx}' and ε_{xy}', for the MnSbM films annealed at 300°C. In these figures, the ε_{xx}' and ε_{xy}' spectra for the hex-MnSb and fcc-MMnSb films after annealing at 300°C are also shown for comparison. It was obvious that ε_{xx}' and ε_{xy}' spectra of the MnSbM films were located between the spectra of the hex-MnSb and fcc-MMnSb film. Moreover, in the ε_{xx}' and ε_{xy}' spectra of the MnSbM films, structures seen in the ε_{xx}' and ε_{xy}' spectra of the hex-MnSb and fcc-MMnSb films were observed. Those results obtained from the optical analysis also support that the MnSbM films after annealing at 300°C consist of MnSb with the hexagonal phase and MMnSb with the f.c.c. phase.

In addition, the calculated ε_{xx}' and ε_{xy}' spectra for the Mn-Sb-M films consisted of two-phase mixture with various volume fraction of MMnSb with the f.c.c. phase, $V_{f.c.c.}$,in the whole film are also drawn in Figs.3-5. The effective ε_{xx}' spectra were calculated by applying the theory of Maxwell-Garnett [6] on the assumption of a composite containing spherical particles embeded in the host medium. The ε_{xy}' spectra were calculated by the equation derived by M.Abe [7], which can be applied to the magnetized granular composite.
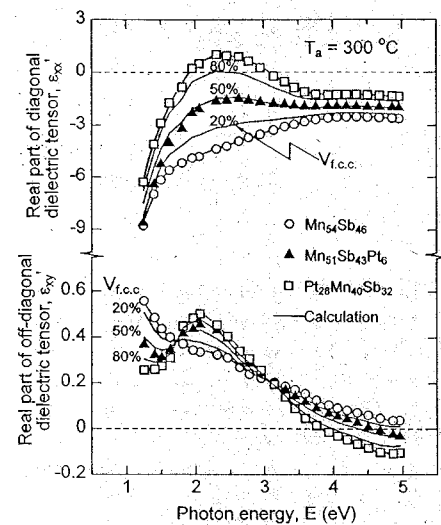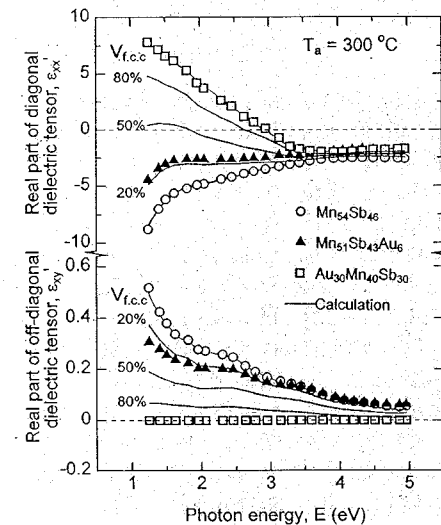
In these calculation, ε_{xx}' and ε_{xy}' spectra of the hex-MnSb and fcc-MMnSb films after annealing at 300°C were used as the standards. It can be found that the calculated ε_{xx}' and ε_{xy}' spectra changed from the spectra of the hex-MnSb film to those of the fcc-MMnSb films with increasing $V_{f.c.c.}$. Based on the assumption that all M atoms contribute to the formation of MMnSb with the f.c.c. phase, the value of $V_{f.c.c.}$ is estimated to be about 20%. However, the experimentally obtained spectra of both ε_{xx}' and ε_{xy}' for the MnSbPt film did not agree with the calculated spectra for $V_{f.c.c.}$=20% but about for $V_{f.c.c.}$=50% , which was different from the result for the MnSbPt bulk specimen[4]. In contrast with the MnSbPt film, the experimental spectra of ε_{xx}' and ε_{xy}' for the MnSbAu and MnSbPd films are well fit by the calculated spectra for $V_{f.c.c.}$=20% . Thus, the volume fraction of PtMnSb with the f.c.c. phase formed by annealing at 300°C is significantly increased even with little Pt addition, which can be considered to take an important role in the enhancement of the MO Kerr effect for the MnSbPt films.

C. Mechanism of magneto-optical properties for MnSbM films

In this section, the mechanism of the MO Kerr effect for the $Mn_{51}Sb_{43}M_6$ (M=Pt, Au, Pd) films is discussed based on the results from the structure and dielectric tensor analyses.

For the MnSbM (M=Pt, Au, Pd) films, as seen in Figs.3-5, no coupled plasma edge (ε_{xx}' =0) could be observed within the energy range examined in the present study. For the MnSbPt film, we found a strong dispersion of ε_{xy}' at around 2.1 eV (Fig.3) where a very sharp resonancelike peak was observed in θ_K spectrum (Fig.2) . Furthermore, for the MnSbAu and MnSbPd films, a weak structure of ε_{xy}' was found at around 2.5 eV and 3.5 eV , respectively (Figs.4-5) , where θ_K also showed a small peak (Fig.2) . Therefore, these results suggest that the MO Kerr effect is originated from ε_{xy}' for the MnSbM films.

In the next step, the influence of ε_{xy}' spectra of the formed MnSb and MMnSb phases on those of the MnSbM films annealed at 300°C will be discussed. Fig.6 shows ε_{xy}' spectra of the MnSbM, hex-MnSb and fcc-MMnSb films after annealing at 300°C. In this figure, θ_K spectra of the MnSbM films are also shown. For the hex-MnSb film after annealing at 300°C, no remarkable dispersion was observed in the ε_{xy}' spectrum between 1.25 and 5.0 eV. On the other hand, concerning the ε_{xy}' spectrum of the other phase of MMnSb, we could find a strong dispersion at around 2.1 eV for the fcc-PtMnSb film,. In contrast with that, for the fcc-AuMnSb and fcc-PdMnSb films, no strong dispersion was observed in the ε_{xy}' spectrum between 1.25 and 5.0 eV. Therefore, according to the result that the large θ_K was observed at around 2.1 eV for the MnSbPt film, we conclude that ε_{xy}' of MMnSb with the f.c.c. phase plays a dominant role in the MO Kerr effect for the MnSbM films.
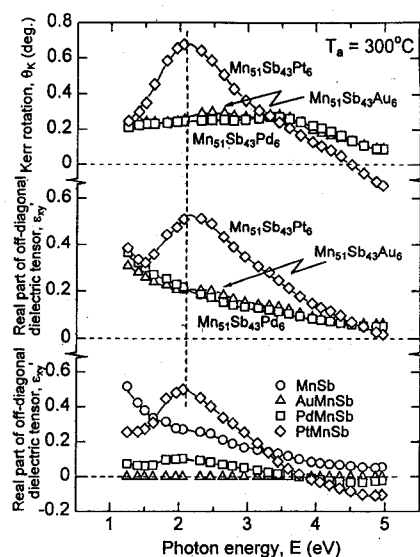

Fig.6 Spectra of real part of off-diagonal (ε_{xy}') of the dielectric tensor for the MnSbM (M=Pt, Au, Pd), hex-MnSb, fcc-MMnSb films annealed at 300°C. θ_K spectra of the MnSbM films were also shown.

IV. CONCLUSION

The mechanism of the MO effect for the $Mn_{51}Sb_{43}M_6$ (M=Pt, Au, Pd) films was discussed from the viewpoints of the structure and optical properties. As results, it was found;

(1) The $Mn_{51}Sb_{43}M_6$ films after annealing at 300°C consisted of MnSb with the hexagonal phase and MMnSb with the f.c.c. phase.

(2) The volume fraction of formed PtMnSb with the f.c.c. phase in the MnSbPt film annealed at 300°C was significantly more than estimated value.

(3) ε_{xy}' of MMnSb with the f.c.c. phase played a dominant role in the MO Kerr effect.

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