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Magneto-optical Spectra in Pd/Co Multilayers and Related Alloys

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The magneto-optical Kerr spectra of Pd/Co multilayers and alloys prepared by DC magnetron sputtering system using an ultra-high vacuum chamber were measured between 1.24 and 5.90 eV. Analysis of the permeability tensor showed that the effect of plasma enhancement of the Kerr effect in Pd/Co multilayers was not so large as that in Pt/Co multilayers. The Kerr rotation spectra of multilayers had a different feature around 3 eV from that of corresponding alloys. We performed a simulation of Kerr rotation spectra by a virtural optical constant method assuming the presence of an interfacial PdCo alloy. It was found that the Kerr rotaiton spectra could not be explained by this assumption, suggesting that magnetically polarized Pd should be taken into account. We then performed a simulation assuming the presence of "magnetic Pd." As a result, we found that the peaks around 2.7 eV and 4.7 eV resulted from the "magnetic Pd" layers and the PdCo/Co layers, respectively.

Key words: Pd/Co multilayers, magneto-optical Kerr spectra, plasma enhancement, interfacial alloy, magnetic polarization.

1. Introduction

Pd/Co and Pt/Co superlattices, which have perpendicular magnetic anisotropy and relatively large magneto-optical Kerr effect in short wavelengths, are extensively studied as high density megneto-optical recording materials of next generation.[1)~3)]

Concerning magneto-optical properties, Kerr rotation spectra of multilayers and corresponding alloys prepared by ordinary sputtering technique have already been reported. Nakamura *et al.* carried out simulation of the spectra by means of the virtual optical constant method and found that specra cannot be explained without assuming the presence of PdCo alloy at the interface of multilayers.[4)]

In our previous studies, we also revealed the presence of an interfacial alloy in Pt/Co and Pt/Fe multilayers which were prepared by ordinary DC magnetron sputtering.[5)] However, there have been few works on the magneto-optical spectra in well-controlled superlattices of Pd/Co.

In this paper, we report on the preparation of well-controlled supuerlattices of Pd/Co by DC magnetron sputtering system using an ultra-high vacuum chamber, results of magneto-optical measurements and analyses by the similar simulation technique as previously performed in Pt/Co and Pt/Fe. We will discuss the dependence of spectra on thicknesses of interfacial alloy, as well as the presence of magnetically polarized Pd atoms adjacent to Co or PdCo layer.

2. Experimental

All the samples used in the present study were prepared by DC magnetron sputtering system at Korea Advanced Institute of Science and Technology (KAIST). The sample was sputter-deposited from 2-in-diameter Co and Pd targets onto glass substrates. A stainless plate with two target-size holes was placed between the targets and substrate table to prevent cross contamination of their sputtered fluxes. The base pressure and Ar gas pressure were 5×10^{-9} Torr and 10 mTorr, respectively. Multilayers were so designed that the Pd layer has a thickness between 6Å and 8Å while keeping the Co layer thickness 4Å. Concerning alloy films the composition was either equal to multilayer composition ($Pd_{63}Co_{37}$) or systematically changed to Pd-rich side ($Pd_{73}Co_{27}$ and $Pd_{84}Co_{16}$). The composition was determined by X-ray fluorescence (XRF) or electron probe microanalysis (EPMA), the layered structure was examined by X-ray diffraction (XRD).

Magneto-optical Kerr spectra were measured between 1.24 and 5.90 eV by means of the polarization modulation technique. Details of apparatus was described elsewhere.[6)] Reflectivity spectra between 0.5 and 6.7 eV were measured using a HITACHI U-3410 spectrophotometer. In addition, reflectivity spectra between 2.5 and 25 eV were measured using a Seya-Namioka

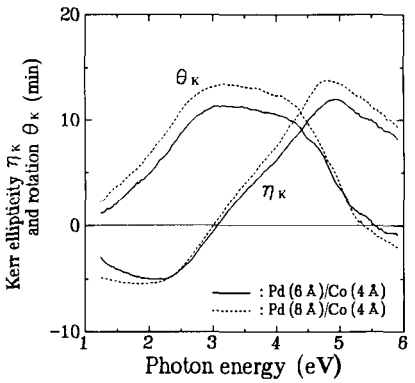

Fig. 1 Kerr ellipticity η_K and rotation θ_K spectra of Pd(6 Å)/Co(4 Å) and Pd(8 Å)/Co(4 Å) multilayers.

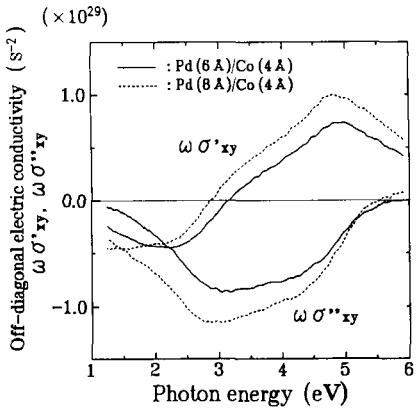

Fig. 2 Real and imaginary parts of the off-diagonal element of the electric conductivity tensor $\omega\sigma_{xy}$ in Pd/Co multilayers.

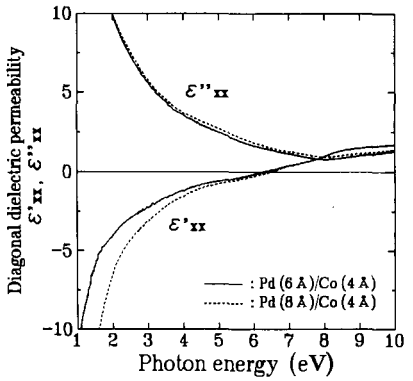

Fig. 3 Real and imaginary parts of the diagonal dielectric permeability ε_{xx} in Pd/Co multilayers.

type spectrometer at the beam line BL-1 in the Synchrotron Radiation Laboratory of ISSP, University of Tokyo. Combination of the these spectra resulted in the reflectivity spectra between 0.5 and 25 eV. Optical constants n and k were deduced from reflectivity spectra by the use of Kramers–Kronig analysis, with the help of optical constants measured by spectroscopic ellipsometry between 1.5 and 5.0 eV. Using these values we calculated the off-diagonal element of conductivity tensor to discuss the origin of magneto-optical Kerr effect.

3. Results and discussion

Magneto-optical Kerr spectra of Pd/Co multilayers are shown in Fig. 1. The Kerr rotation spectra show a peak around 3 eV and shoulder at 4.2 eV. The peak values of Kerr rotation in Pd(6Å)/Co(4Å) and Pd(8Å)/Co(4Å) are 11.3 min and 13.3 min, respectively. Kerr ellipticity spectra show a peak around 4.8 eV and cross zero around 3 eV. Curiously enough, the multilayer with larger Pd thickness shows a larger magneto-optical effect.

Figure 2 shows spectra of the off-diagonal element of optical conductivity $\omega\sigma_{xy}$ deduced from the magneto-optical spectra. The overall spectral shape of $\omega\sigma'_{xy}$ and $\omega\sigma''_{xy}$ are quite identical to η_K and $-\theta_K$, respectively. This fact suggests that the observed magneto-optical effect results essentially from the off-diagonal element of optical conductivity and the effect of diagonal permeability is negligible.

Figure 3 shows spectra of diagonal elements of permeability ε_{xx} obtained by the Kramers–Kronig analysis of the reflectivity spectra. Spectra of the real part of ε_{xx} cross zero at 6.4 eV, that is, Pd/Co multilayers have a plasma edge at that energy. In the case of Pt/Co multilayers, a plasma edge exists at 6.2 eV, where Kerr ellipticity undergoes a great enhancement. However, Kerr ellipticity of Pd/Co multilayers decreases with increasing photon energy toward the plasma edge, as shown in Fig. 1. Thus, the plasma enhancement is not so obvious in Pd/Co as in Pt/Co, which may be accounted for by the smallness of the absolute value of $\omega\sigma_{xy}$ around the energy of the plasma edge, as shown in Fig. 2.

Figure 4 shows magneto-optical spectra of PdCo alloys with different compositions, together with the spectrum of the superlattice. Considerable agreement of Kerr rotation spectra between superlattice and alloy is observed for 4.5~5.9 eV region, suggesting that the inter-

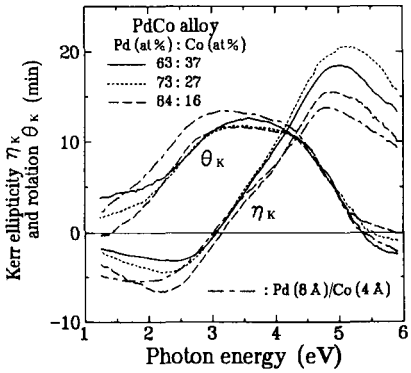

Fig. 4 Kerr ellipticity η_K and rotation θ_K spectra of Pd(8Å)/Co(4Å) multilayers and related PdCo alloys.

face of multilayers undergoes alloying. However, a clear difference is found in the spectra around 3 eV.

We simulated Kerr rotation spectra of Pd/Co superlattice by means of the virtual optical constant method assuming the presence of PdCo alloy at the interface, as illustrated in Fig. 5(a), where X denotes the thickness of PdCo alloy at the interface. The total thickness of PdCo alloy is therefore twice X Å in one period. The composition of alloy at the interface was determined to keep total composition of films the same as that of the multilayer analyzed by EPMA. Further details of the simulation were described in previous paper.[5] Figure 6 shows Kerr rotation spectra in Pd(8Å)/Co(4Å) thus simulated. In the case of $X=0$, that is, without interfacial alloys, Kerr rotation spectrum thus calculated quite different from the experimental one in terms of absolute value and the shape of spectrum. Increasing alloy thickness, calculated spectra approach experimental one for photon energies above 4 eV, while a feature around 3 eV cannot be explained. This situation does not change for any compositions of alloys assumed at the interface. The result of simulation suggested that the Kerr spectra of Pd/Co multilayers could not be obtained only by the assumption of interfacial PdCo alloy.

We took into account the induced magnetization of Pd atoms at the interface for the next step. In this case, calculation of virtual optical constant method requires the information of σ_{xy} in magnetically polarized Pd (hereafter will be referred to as "magnetic Pd"). However, since

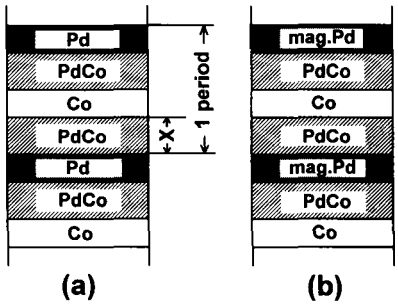

Fig. 5 A structure for the simulations of MO spectra in Pd/Co multilayers, (a) assuming the presence of an interfacial alloy and (b) assuming the presence of an interfacial alloy and "magnetic Pd".

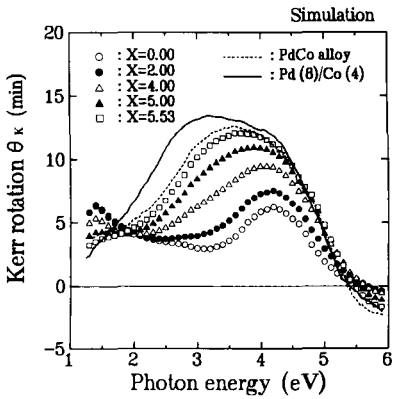

Fig. 6 Simulated Kerr rotaion spectra θ_K in Pd/Co multilayers, assuming the presence of an interfacial alloy.

"magnetic Pd" does not exist we made a rough estimation as follows. Increasing Pd composition in PdCo alloy, a systematic change such as a peak-shift in $\omega\sigma_{xy}$ spectra was found for 2 to 3 eV. We calculated the difference between σ_{xy} of $Pd_{84}Co_{16}$ and that of $Pd_{63}Co_{37}$. We ascribed this difference to the Pd contribution in the PdCo alloy, the value being equivalent to 20% Pd. We then multiplied this difference by five to calculate the spectra of σ_{xy} for "magnetic Pd". Here we neglected the contribution of the reduction of Co composition, since the spectral feature of σ_{xy} in Co does not show a strong variation in the energy range of 2~3 eV. Real and imaginary parts of $\omega\sigma_{xy}$ spectra of the "magnetic Pd" thus estimated are shown in Fig. 7, together with those of Co. The spectra show characteristic structures at 2.2 eV and 2.7 eV, which have never been found in PdCo alloys. We carried out again the simula-

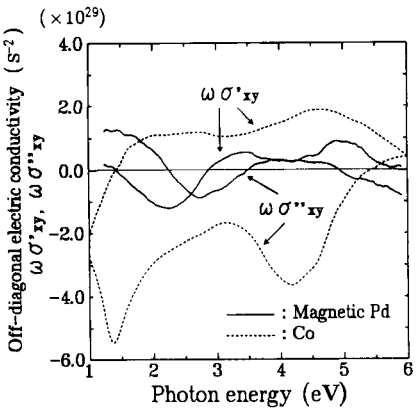

Fig. 7 Off-diagonal element of the electric conductivity tensor $\omega\sigma_{xy}$ in estimated "magnetic Pd" and Co atoms.

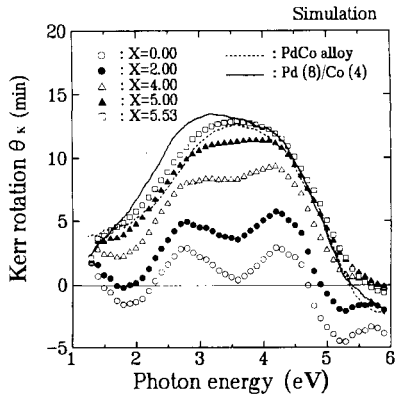

Fig. 8 Simulated Kerr rotation spectra θ_K in Pd/Co multilayers, assuming the presence of "magnetic Pd".

tion using these values of σ_{xy} in "magnetic Pd", assuming a model illustrated in Fig. 5(b) where the Pd layer was replaced by the "magnetic Pd" for the structure shown in Fig. 5(a). The spin direction in the "magnetic Pd" layer was assumed to be parallel to PdCo and Co layers. As a result, a peak around 2.7 eV appeared in the resulted Kerr rotation spectra as shown in Fig. 8, from which we recognize that the peak around 2.7 eV was due to "magnetic Pd". It should be noted that if we neglect the PdCo alloy, Kerr rotation spectrum could not be reproduced as shown by the open circles in Fig. 8, suggesting PdCo alloy is essentially necessary to simulate the Kerr spectra of Pd/Co.

Consequently, it becomes evident that Kerr spectra of Pd/Co superlattices consist of contributions from Co (around 4.2 eV), PdCo layer at the interface (around 3.6 eV) and "magnetic Pd" (2.7 eV).

We know that our estimation of σ_{xy} in "magnetic Pd" is rather crude. In order to get more precise knowledge of this value, it may be necessary to obtain the magneto-optical spectra in pure Pd atoms magnetized in a high magnetic field. The band calculations in "magnetic Pd" is also required.

4. Conclusion

Kerr rotation spectra of Pd/Co superlattices prepared by DC magnetron sputtering system using an ultra-high vacuum chamber showed a peak around 3 eV and a shoulder at 4.2 eV. From the virtual optical constant analysis we found the spectra could be reproduced by assuming the presence of "magnetic Pd". Further studies are necessary to confirm the existence of "magnetic Pd" and to get exact values of magneto-optical constant in the hypothetical material.

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