SURFACE PLASMA RESONANCE ON MAGNETO-OPTICAL KERR EFFECT IN Fe, Co ISLAND FILMS

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Abstract - The magneto-optical properties of Fe, Co films deposited on fused quartz substrates have been investigated. The AFM observations and ellipsometric data show that the film makes island structure on the substrates in the early stages of deposition. A new peak appears in the spectra of the real parts of $\omega\sigma_{xy}$ for films thinner than 60 Å. It shifts to the higher energy side with decreasing thickness.

KEY WORDS : ISLAND FILM, CONDUCTIVITY TENSOR, SURFACE PLASMA RESONANCE

INTRODUCTION

Composite materials with fine structures, such as multilayered films, or particulate films in which fine magnetic particles arrayed have the possibility of producing a new magneto-optical material. In the metallic composite materials, it is considered the free-electron polarization localized in surface or interface plays a major role in optical absorption. This paper reports the experimental and analytical results on magneto-optical properties of Fe, Co island films, which can be regarded as particulate films.

EXPERIMENTAL

The Fe, Co thin films were deposited on fused quartz substrates at room temperature. The mass thickness of the films were measured by a calibrated quartz thickness monitor. The deposition rates of Fe and Co were 2 Å/min and the pressure during deposition was $5\sim7\times10^{-9}$ Torr.

After the deposition, the sample was transferred from the deposition chamber to another measurement chamber where it is aligned between the poles of an external electromagnet and ellipsometric measurements were performed *in-situ*. During the measurements the pressure was below 2×10^{-9} Torr. Longitudinal Kerr rotation θ_k and ellipticity η_k spectra were

measured at room temperature using s-polarized light in the photon energy range 1.8 to 4.6 eV. These measurements were performed at remanent states ($H=0$) with sweeping the magnetic field. By this method, the background Faraday rotation arising from the vacuum windows was eliminated. The relative amplitude attenuation ρ was also measured to determine the optical constants n and k .

Off-diagonal elements of the conductivity tensor of films, $\omega\sigma_{xy}$, were calculated from the values of θ_k , η_k , n and k measured. In the calculation, we considered a plane-parallel isotropic film and used the medium propagation matrix D presented by Bader *et al.*[1].

EXPERIMENTAL RESULTS

AFM observations and ellipsometric data show that the film makes islands structure on the substrates in early stages of deposition and that the film becomes homogeneous in an optical sense above about 50 Å. Typical island dimension estimated from AFM data is about 100 Å for 20 Å thick Co.

Figures 1 (a) and (b) show the real and imaginary parts of $\omega\sigma_{xy}$ for Co deposited on fused quartz substrates, respectively. The experimental data of bulk hcp Co[2] are also shown by solid curves in the figures for reference. It is clearly seen that the spectral shapes of both real

and imaginary parts of $\omega\sigma_{xy}'$ strongly depend on thickness. The $\omega\sigma_{xy}'$ spectrum, as seen in figure 1 (a), crosses zero at about 2.5 eV for 100 Å thick Co, and at 4.0 eV for 60 Å Co. Below 60 Å, $\omega\sigma_{xy}'$ becomes positive in the all energy range observed and a new broad peak appears. The peak shifts to the higher energy side with decreasing thickness. Corresponding to this peak, $\omega\sigma_{xy}''$ spectra exhibit dispersion type spectra (Figure 1(b)).

In figures 1 (c) and (d) are shown the result

for Fe. The most striking feature of these results is that a very similar dependence of spectra on thickness is observed for Fe. This indicates that the dependence described above are mainly due to the film structure.

DISCUSSION

Assuming the dimension of the structure is much smaller than the penetration depth of the light, an island film behaves as if it were

Fig.1 Spectra of off-diagonal parts of the effective conductivity tensor: (a) the real and (b) the imaginary parts of $\omega\sigma_{xy}$ for Co, (c) the real and (d) the imaginary parts of $\omega\sigma_{xy}$ for Fe; The solid curves show the experimental data of bulk hcp Co and bcc Fe after Buschow[2].

homogeneous, and we can describe the film in terms of effective dielectric tensor ϵ^{eff} . To a first approximation, we treat the island film as a composite material in which spherical magnetic particles dispersed three-dimensionally. The off-diagonal elements of ϵ^{eff} for the composite material are described by the following equation [3] :

$$\epsilon_{xy}^{\text{eff}} = \frac{f\epsilon_{xy}}{\left[1 + \frac{(1-f)(\epsilon_{xx}-1)}{3}\right]} \quad (1)$$

Here ϵ_{xx} and ϵ_{xy} are the diagonal and off-diagonal elements of the dielectric tensor of the magnetic particles, and f is a volume fraction of it.

Fig.2 Calculated spectra for various packing factor f ; (a) the real and (b) the imaginary parts of $\omega\sigma_{xy}^{\text{eff}}$ for Co , (c) the real and (d) the imaginary parts of $\omega\sigma_{xy}^{\text{eff}}$ for Fe. The symbols show experimental results.

For the simple case, we may write ϵ_{xx} as in a following form, known as the "Drude term".

$$\epsilon_{xx} = 1 - \frac{\omega_p^2}{\omega^2} \quad (2)$$

Eq.(1) becomes,

$$\epsilon_{xy}^{eff} = \frac{f\epsilon_{xy}}{\left[1 - \frac{\omega_p^{s2}}{\omega^2}\right]}, \quad (3)$$

where ω_p^s is given by

$$\omega_p^s = \left[\frac{(1-f)}{3}\right]^{\frac{1}{2}} \omega_p. \quad (4)$$

We have an enhancement at a frequency that makes the denominator zero in Eq.(3). This is known as the "surface plasma resonance" and the frequency, given by Eq.(4), is the surface plasma frequency.

In Figures 2 (a), (b) the spectra of $\omega\sigma_{xy}$ for Co island films are compared to the theoretical ones. The calculated results for various values of f are shown by solid curves. In the calculation, we use Eq.(1) and the experimental values of ϵ_{xx} and ϵ_{xy} of a 100 Å thick film. The spectrum of the real part of $\omega\sigma_{xy}^{eff}$ calculated exhibits a broad peak at around 3~4 eV and it shifts to the higher-energy side with decreasing f . This peak corresponds to the surface plasma resonance at $\hbar\omega_p^s = 3.2$ eV, calculated by Eq.(4) using the

value of $f = 0.5$ and $\hbar\omega_p = 7.8$ eV for bulk Co. Experimental results for 20 and 30 Å thick Co agree qualitatively with the calculated ones. The $\omega\sigma_{xy}'$ spectrum of 30 Å thick Co exhibits a broad peak at 3.3 eV. It shifts to 4.0 eV for the 20 Å Co. The behavior is very similar to theoretical results when the volume fraction f decreases. Similar results are obtained for the Fe island films (Figure 2 (c), (d)). The $\omega\sigma_{xy}'$ spectrum of 30 Å thick Fe exhibits a broad peak at 2.2 eV and it shifts to 3.2 eV for the 20 Å Fe.

CONCLUSION

The surface plasma resonance greatly affects magneto-optical effect in island films. The resonance can be described by an effective dielectric tensor.

ACKNOWLEDGMENT

This work is supported by a Grant-in-Aid for Scientific Research on Japanese Junior Scientist (No.00050612) from the Ministry of Education, Science and Culture.

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