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Interpretation of Magneto-Optical and Reflectivity Spectra in Compositionally Modulated Multilayered Fe/Cu Films

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Anomalous behavior of magneto-optical Kerr spectra in compositionally modulated multilayered Fe/Cu films is analyzed using virtual optical constant calculations. Calculated spectra are in good agreement with experimental results published previously. The enhancement of the Kerr rotation in Fe/Cu films around the absorption edge of Cu is interpreted in terms of the existence of hybrid plasma in these materials.

KEYWORDS: magneto-optical Kerr effect, enhancement of Kerr rotation, reflectivity spectrum, compositionally modulated multilayered film, Fe/Cu multilayer, absorption edge of Cu, plasma resonance, virtual optical constant, theoretical calculation

Magneto-optical properties of compositionally modulated multilayered films (CMF) (*e.g.*, Fe/Cu, Fe/Au, Co/Cu, Co/Ag) of transition metal/noble metal structure have been studied in detail by one of the authors(T.K).[1,2] The essential points of the experimental results can be summarized as follows:

(1) The spectrum of Kerr rotation ϕ_K in an Fe/Cu CMF shows a peak around 560 nm where the absorption edge of Cu exists as illustrated in Fig. 1(a). The peak value exceeds the value of pure Fe for a certain preparation condition.

(2) Reflectivity spectra of the films have breaks around 560 nm similar to that of Cu as shown in Fig. 2(a). Slopes of reflectivity spectra at the breaks for CMF's have values between those for Cu and Fe.

(3) The peak position of ϕ_K shows only a slight shift as the modulation length is varied.

(4) The peak position of ϕ_K follows the shift of the absorption edge of the noble metal in the sequence of Cu→Au→Ag.

(5) The spectral shapes as well as the absolute values of ϕ_K differ depending on whether Fe or Cu is the uppermost layer as shown in Fig. 1(a).

(6) Peak value of ϕ_K increases as the modulation length increases when Fe is the uppermost layer, while it decreases when Cu is the uppermost layer as shown by triangles in Fig. 3.

Two possibilities are discussed: one is the case where a Cu atom becomes magnetically polarized at the boundary due to the Fe moment, resulting in a magneto-optical effect at the absorption edge transition, and the other one is the case where ϕ_K is enhanced due to the reduced dielectric constant at the absorption edge wavelength of Cu. We came to the conclusion that the former did not hold as far as our CMF films are concerned. The main reasons are as follows:

(1) The ϕ_K spectrum does not indicate the superposition of Cu-contribution to the Fe spectrum.

(2) The trend of enhancement is the reverse of that expected from the increase of the spin-orbit interaction in the sequence from Cu, Ag to Au.

The details of the discussion will be published

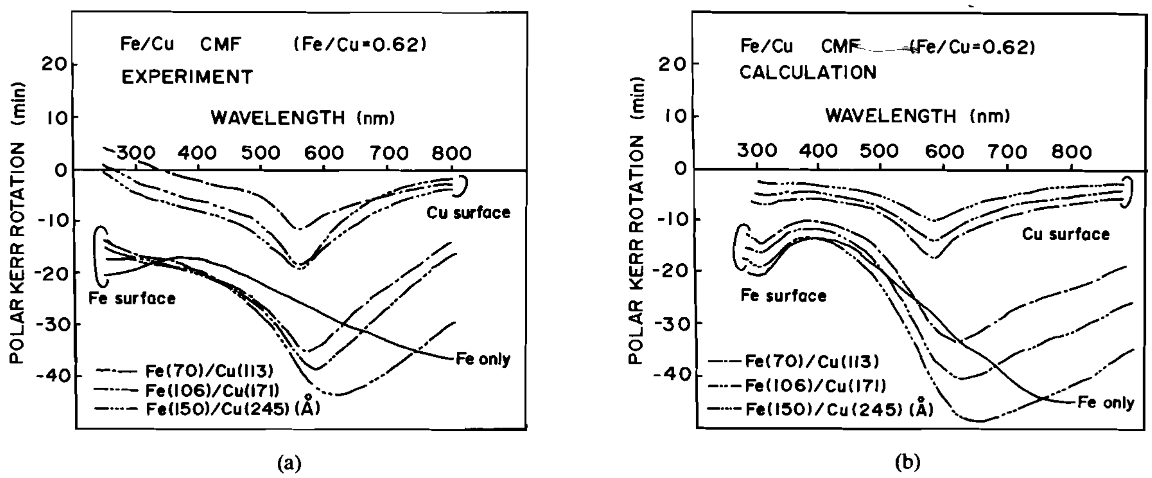
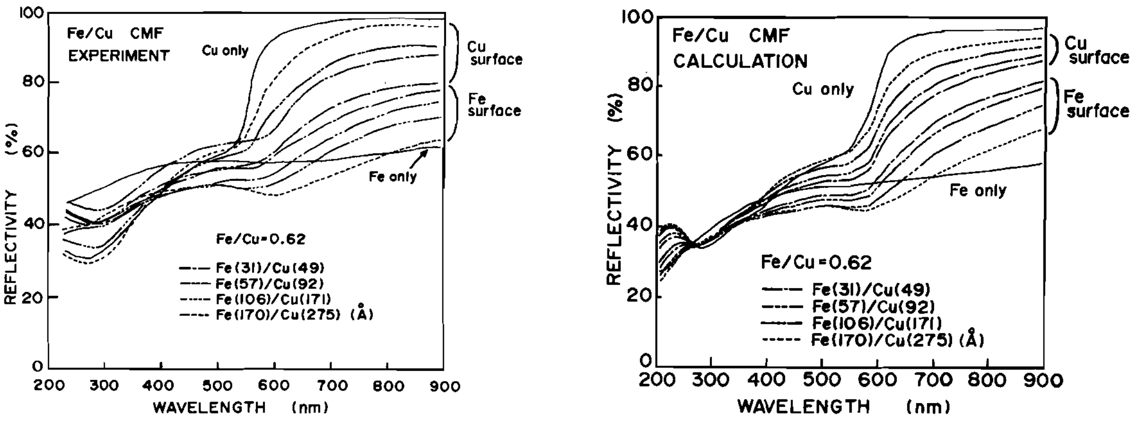


Fig. 1. Spectra of polar Kerr rotation in Fe/Cu CMF's. Curves denoted as "Cu(Fe)-surface" are those with a Cu(Fe) layer at the uppermost surface. Fe/Cu thickness ratio is kept constant (=0.62) and modulation length is taken as a parameter. Kerr rotation spectrum in an Fe film is also shown for reference. (a) Experiment (b) Calculation.



(a) (b)

Fig. 2. Reflectivity spectra in Fe/Cu CMF's for Fe-surfaced and Cu-surfaced cases. (a) Experiment (b) Calculation.

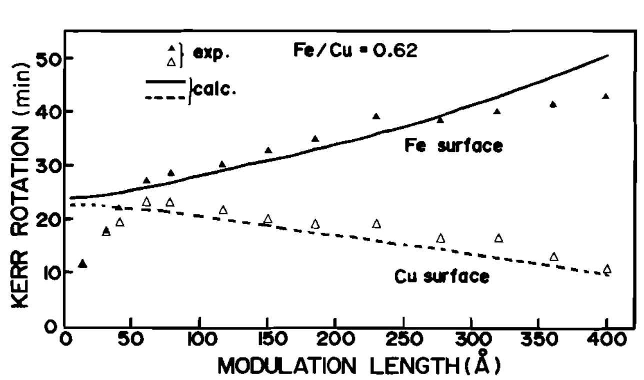


Fig. 3. Dependence of Kerr rotation peak value on the modulation length in CMF's for Fe-surfaced and Cu-surfaced cases.

elsewhere.[3)]

We, therefore, evaluated the ϕ_K spectrum of CMF' s in terms of a macroscopic model, in which the virtual optical constant method[4)] was adopted. The important point of this method is that a film layer with the complex refractive index $\hat{n}_1^{\pm}$ and the thickness h_1 on a substrate with $\hat{n}_2^{\pm}$ can be replaced by a bulk material with the virtual optical constant $N^{\pm}$ and infinite length, where $\hat{n}_1^{\pm}=n_1^{\pm}-ik_1^{\pm}$, $\hat{n}_2^{\pm}=n_2^{\pm}-ik_2^{\pm}$ and $\hat{N}^{\pm}=N^{\pm}-iK^{\pm}$, the $\pm$ signs denoting right and left circular polarizations. For multilayered films, the virtual optical constant method is applied to the lowermost and the second lowest layers, and the same procedure is applied to the obtained virtual material and the next layer in repetition, thus providing a virtual index $\hat{N}_L^{\pm}$ for the total film. From the obtained value of $\hat{N}_L^{\pm}$, we can calculate the Kerr rotation ϕ_K and reflectivity R by using the formulae:

$$\phi_K=Re[\hat{\varepsilon}_{XY}/\{\hat{N}(1-\hat{N}^2)\}] \quad (1)$$

$$\hat{\varepsilon}_{XY}=(\hat{N}_L^{+2}-\hat{N}_L^{-2})/2i \quad (2)$$

$$\hat{N}=(\hat{N}_L^{+2}+\hat{N}_L^{-2})/2 \quad (3)$$

and

$$R=|\hat{r}^++\hat{r}^-|^2/4+|\hat{r}^+-\hat{r}^-|^2/4 \quad (4)$$

where

$$\hat{r}^{\pm}=(1-\hat{N}_L^{\pm})/(1+\hat{N}_L^{\pm}). \quad (5)$$

In the above analysis we assumed $n=1$ for the air medium. We used data listed in the tables of Landolt-Börnstein[5)] for ε_{xx} of Cu and Fe, and data of Krinchik and Artemjev[6)] for ε_{xy} of Fe. We performed the calculation of the spectrum taking into account all the layers from the uppermost to that in which the light intensity reduces to 1/100 of the incidence at a given wavelength. Details of the calculation will be published elsewhere.[3)]

In Fig. 1(b) are shown calculated magneto-optical Kerr rotation spectra for Fe/Cu CMF's taking the modulation length as a parameter. The ratio of Fe/Cu thickness is kept constant($=0.62$). The tendency is quite similar to the experimental data shown in Fig. 1(a), although peak positions of ϕ_K are slightly different. In this figure we can clearly see the enhancement of Kerr rotation ϕ_K around 560 nm in calculated spectra for CMF's, which can explain the experimental data.

Figure 2(b) shows calculated reflectivity spectra in CMF's with similar composition to those presented in Fig. 1(b). The spectral features are in good agreement with the experimental ones shown in Fig. 2(a). Experimental reflectivity values in the short wavelength region are somewhat larger than calculated ones; this may be attributed to the deterioration of the Al mirror used as a reference in the experiment. In Fig. 3 are plotted peak Kerr rotation angles against modulation length for Fe-surfaced and Cu-surfaced films. Calculated and experimental values are in satisfactory agreement, at least for modulation lengths less than 250 Å.

Experimental values of the ϕ_K peak deviate from calculated ones especially in CMF's with a modulation length smaller than 60 Å, as shown in Fig. 4. Such a tendency can be explained if one assumes that the Fe layer with 2.0 Å thickness (nearly one atomic layer of Fe) at both boundaries loses its magnetic moment due to alloying as shown by the dotted line in Fig. 4. Such reduction of the magnetic moment has been confirmed by Mössbauer spectroscopy studied in the Electrotechnical Laboratory (unpublished).

Finally, we briefly discuss the physical reason for enhancement of ϕ_K in Fe/Cu CMF's compared with pure Fe film. At the energy of the absorption edge in Cu there

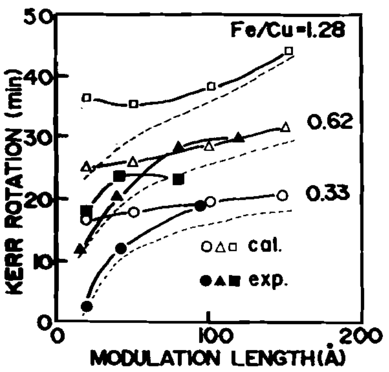


Fig. 4. Dependence of Kerr rotation peak value on the modulation length for several values of Fe/Cu thickness ratio: Closed symbols denote experimental values and open symbols denote calculated values. Dotted lines represent the values assuming that the Fe layer at the interface loses its magnetic moment.

appears a hybrid plasmon due to the superposition of the Drude-like intraband excitation and the interband transition.[7] This brings about a real part of $\hat{\varepsilon}_{xx} \simeq 0$ around the absorption edge, which, in turn, gives a small value of $|\hat{N}|$ (virtual optical constant) for Fe/Cu film. Such a reduction of $\hat{N}$ introduces the enhancement of ϕ_K as described in equation (1).

The slight shift in the peak position of ϕ_K when the modulated length is varied can be attributed to the multiple reflection and interference effect due to the multilayered structure. For further interpretation, microscopic analysis in terms of a plasmon-polariton picture may be necessary. Such treatment is now under investigation by Dr. Y. Suzuki of the Electrotechnical Laboratory and will appear in a later publication.

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