Enhancement of the Magneto-Optical Kerr Rotation in Fe/Cu Bilayered Films

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It is shown in Fe/Cu bilayered films that the magneto-optical polar Kerr rotation can be enhanced by an effect of the plasma resonance of the free charge carriers in Cu. The strong enhancement is observed around 560 nm which corresponds to the plasma edge of Cu metal. The magnitude of the Kerr rotation reaches up to above twice as large as that of Fe. This is the first example of substantial enhancement of Kerr rotation without use of the interference effect.

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The magneto-optical Kerr effect is of considerable interest since it is useful for readout in magneto-optical memory systems. For these applications a large Kerr effect is required. Large Kerr rotations were observed in UAs_xSe_{1-x}, TmS, TmSe, $Tm_{1-x}Eu_xSe$, etc., and the relation with plasma edge splitting was studied by Reim and co-workers.[1-3] After that, Feil and Haas have shown that the large Kerr rotation of these materials and PtMnSb can be interpreted as an effect of the plasma resonance of free charge carriers.[4] However, this large Kerr rotation is a specific property of such materials and cannot be controlled. Recently, we have reported[5-7] that the Kerr-rotation spectrum in an Fe/Cu multilayered film has a peak at the wavelength of the plasma frequency coupled with interband transitions in Cu where the real part of the diagonal dielectric tensor approaches zero and the reflectivity decreases abruptly (in the following, we call this frequency "plasma edge"). These results show that the Kerr rotation is affected by the plasma edge of adjacent nonmagnetic metals. In order to make clear the proximity effect of nonmagnetic metals, we have measured the Kerr-rotation spectra in bilayered films. In Fe/Cu bilayered films we have found that the Kerr rotation reaches up to above twice as large as that in metallic iron. The results suggest that the magneto-optically active electronic transition in Fe interplays with the plasma resonance of adjacent Cu metal. As far as we know, there has been no effective method for enhancement of the Kerr effect. This is the first example of substantial enhancement of Kerr rotation without the use of the interference effect of light.

Compositionally modulated multilayered films (CMF, artificial superlattice), where different metallic elements are stacked alternately, have become of current interest in recent years, since they have possibilities of new phenomena and applications.[8] So far, many magnetic CMF systems such as Ni/Cu, Fe/V, Fe/Mg, and Pd/Co have been investigated. Most of the previous experimental studies have been mainly concerned with the structural characterization and the magnetic properties such as magnetization and magnetic anisotropy. Investigations of the Kerr effect have hardly been done. In this paper, we report the experimental results and numerical calculations of the wavelength dependence of magneto-optical polar Kerr rotation in Fe/Cu bilayered films.

All samples were deposited on glass substrates by means of rf sputtering with two targets. In order to avoid the mixing of sputtered atoms, a grounded shroud was used as the isolator. The substrate temperature was maintained at about 20 °C by water cooling during the film deposition. The thickness of each layer was controlled by the deposition time under constant sputtering conditions. The sputtering conditions were as follows: Ar pressure = 20 mTorr, electrode distance = 35 mm, deposition rate = 1.0 Å/sec for Fe and 1.7 Å/sec for Cu. The crystal structure was examined by x-ray diffraction method. The purity of the raw materials used in this experiment was as follows: Fe, 99.95%; Cu, 99.99%.

The wavelength dependence of magneto-optical polar

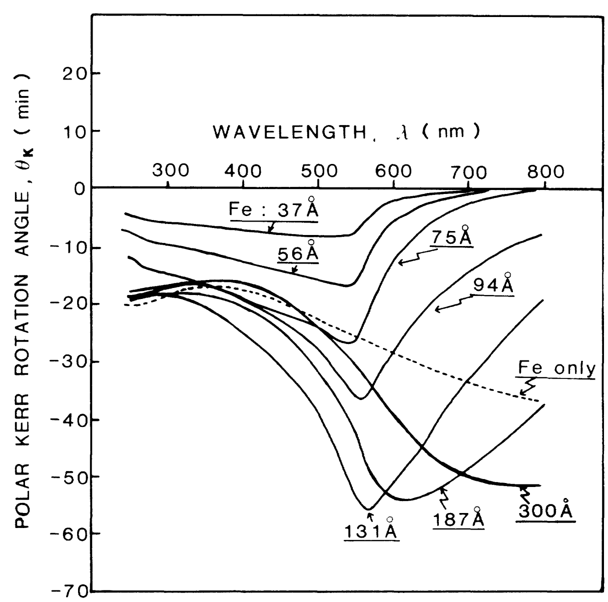

FIG. 1. Wavelength dependence of θ_K in various kinds of Fe/Cu bilayered films in which Fe is deposited on a Cu film of 2400 Å.

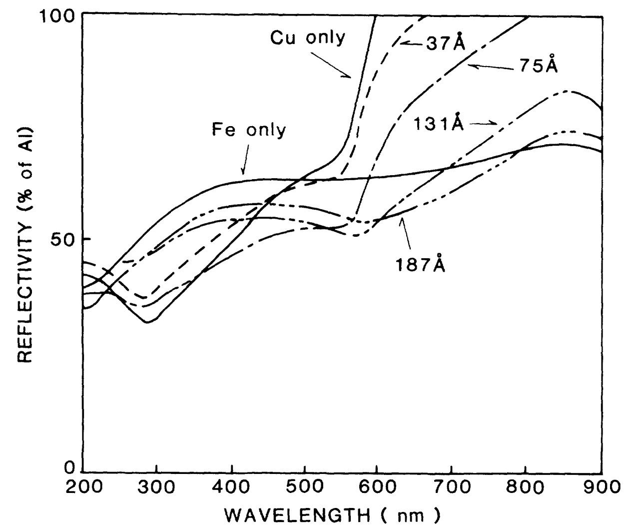

FIG. 2. Wavelength dependence of reflectivity R in various kinds of Fe/Cu bilayered films in which Fe is deposited on a Cu film of 2400 Å.

Kerr-rotation angle θ_K was measured with use of a polarization-modulation–type Kerr spectrometer (Jasco model K-250) in the wavelength region from 250 to 800 nm under the condition of saturation magnetization. The incident angle of light was 10° to the film normal.

In Fig. 1 is shown the wavelength dependence of θ_K in various thicknesses of Fe deposited on a thick (2400 Å) Cu layer. The wavelength dependence of θ_K of Fe metal is shown as a comparison. As seen in the figure, when the Fe layer is very thin, the θ_K value is low and it becomes zero in the wavelength region beyond 700 nm. However, as the Fe layer becomes thicker, a θ_K peak appears around 560 nm corresponding to the plasma edge of Cu. It is found that the peak of θ_K reaches a maximum value at Fe layer thickness of $\simeq$130 Å, and then it moves towards the longer-wavelength side and decreases with the increase of Fe layer thickness. In these cases, the Fe layers are crystalline phase with almost bcc structure. The θ_K spectra in Fe/Cu bilayered films are similar to the results of Fe/Cu compositionally modulated multilayered films.[5-7]

Figure 2 shows the wavelength dependence of the reflectivity R in Fe/Cu bilayered films in which the top layer is Fe. The reflectivity has a tendency to decrease with the increase of Fe layer thickness. In the wavelength region between 300 and 600 nm, R is lower than that of the Fe metal.

In Fig. 3 is shown the wavelength dependence of θ_K in Fe/Cu bilayered films in which a Cu layer is deposited on a thick Fe layer (1500 Å). The shapes of the θ_K spectra are similar to that of bulk Fe and the value of θ_K decreases with the increase of Cu layer thickness. However, a clear peak appears at about 560 nm in the film with the Cu layer thickness of 210 Å.

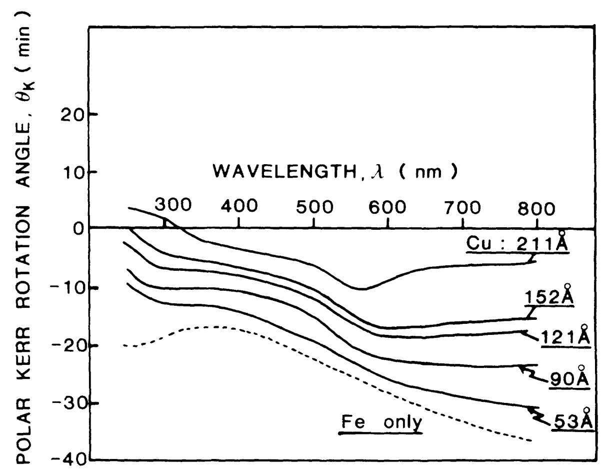

FIG. 3. Wavelength dependence of θ_K in various kinds of Cu/Fe bilayered films. The top layers are Cu.

We have calculated the magneto-optical polar Kerr-rotation angles θ_K in the bilayered films having the structure shown in Fig. 4. When the refractive indices of the top magnetic layer (e.g., Fe) and the lower metal layer (e.g., Cu) are denoted as $n_\pm = n \pm \Delta n$ and n_s, respectively [the signs $\pm$ correspond to the right (+) and left (−) circularly polarized light], the effective refractive indices of the bilayered films for circularly polarized light are represented by

$$\tilde{n}_\pm = \frac{1 - r'_\pm \beta_\pm}{1 + r'_\pm \beta_\pm} n_\pm, \quad (1)$$

$$r'_\pm = (n_\pm - n_s)/(n_\pm + n_s), \quad (2)$$

$$\beta_\pm = e^{2idn_\pm \omega/c}, \quad (3)$$

where $r'_\pm$ is the complex amplitude of reflectivity at the interface of two layers for the right and left circularly polarized light. $\beta_\pm$ is associated with both the phase shift and the amplitude attenuation of light. d is the

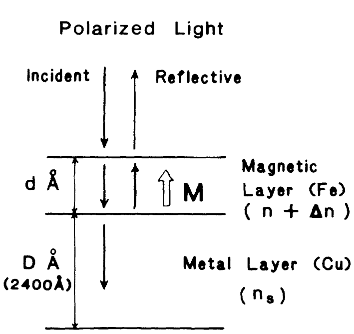

FIG. 4. Schematic drawing of cross section and optical path in the Fe/Cu bilayered films in which the top layer is Fe. Refractive indices are $n_\pm = n \pm \Delta n$ for Fe and n_s for Cu.

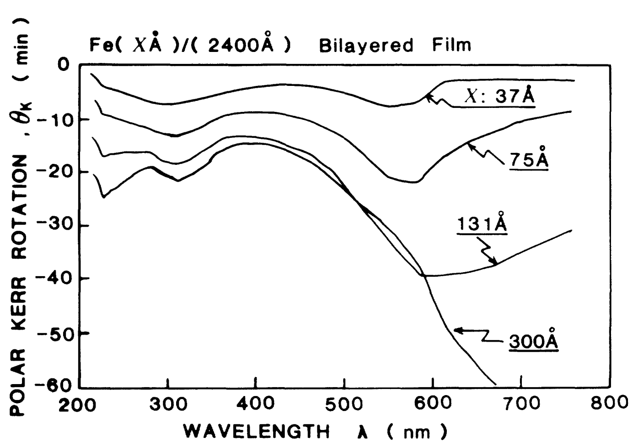

FIG. 5. Wavelength dependence of θ_K calculated numerically from Eq. (5) in various kinds of Fe/Cu bilayered films in which the top layers are Fe.

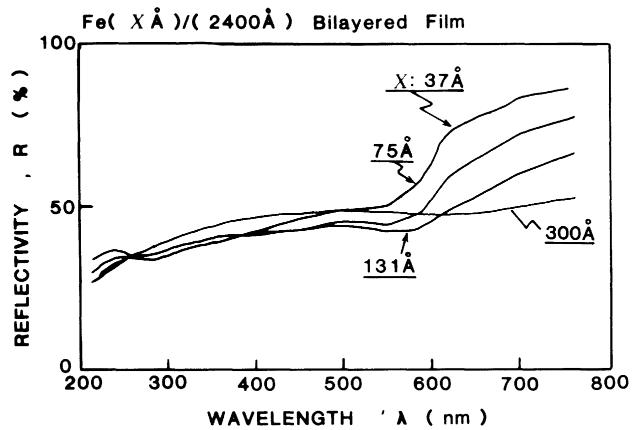

FIG. 6. Wavelength dependence of R calculated numerically from Eq. (6) in various kinds of Fe/Cu bilayered films in which the top layers are Fe.

thickness of the magnetic layer, ω is the frequency of light, and c is the velocity of light. The complex amplitude $r_\pm$ of reflectivity in the bilayered film is given as the following equation from Fresnel's formula:

$$r_\pm = (1-\tilde{n}_\pm)/(1+\tilde{n}_\pm). \quad (4)$$

The magneto-optical polar Kerr-rotation angle θ_K and the reflectivity R of the bilayered films are represented by the following equations:

$$\theta_K = \tfrac{1}{2}\,\mathrm{Arg}\,(r_+/r_-), \quad (5)$$

$$R = (|r_+|^2 + |r_-|^2)/2. \quad (6)$$

We can calculate the θ_K values of the Fe/Cu bilayered films according to Eq. (5) using the optical constants of Fe and Cu metals.[9-11] Figure 5 shows the results of the numerical calculation of θ_K in various layer thicknesses of Fe deposited on thick Cu films. These numerical calculations are in fairly good agreement with the experimental results shown in Fig. 1. However, the wavelength and the layer thickness of Fe giving a maximum enhancement of θ_K are different from those of the experimental results. One reason for this discrepancy is thought to be the uncertainty of the optical constants used here.

Figure 6 shows the results of the numerical calculation of the reflectivity R of Fe/Cu bilayered films which have a top layer of Fe. The agreement with the experimental results shown in Fig. 2 is quite good.

The enhancement of θ_K occurs around 560 nm which corresponds to the plasma edge of Cu metal in the bilayered films. The peak moves towards the longer-wavelength side with the increase of Fe thickness larger than $\simeq$130 Å. On the other hand, in the films with top surface of Cu, the θ_K values decrease with the increase of Cu layer thickness. All these θ_K behaviors can be explained well by numerical calculation with the optical constants of Fe and Cu. That is, the enhancement of θ_K results from a change of effective dielectric constants due to the plasma resonance absorption. The result denies the possibility that the θ_K enhancement originates from magneto-optically active electronic transitions induced by the vicinity of interface between Fe and Cu layers. Moreover, the position of the θ_K peak whose wavelength corresponds to the plasma edge of Cu hardly moves even if the thickness of the Fe layer varies as shown in Fig. 1. From this fact, we think that the interference effect of light is not responsible for the enhancement of θ_K.

It is thought that the enhancement of Kerr rotation in bilayered or multilayered films is due to the plasma resonance of free carriers in nonmagnetic metals. The results show that the plasma resonance enhancement of Kerr rotation, which is observed in TmS, TmSe, PtMnSb, and so on,[2-4] can be realized in the multilayered films composed of the films with a magneto-optically active electronic transition and with the plasma resonance absorption in an observable wavelength region. We believe that the phenomena described here will provide a promising method for enhancement of Kerr rotation in magneto-optical storage media.

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