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CALCULATION OF MAGNETO-OPTICAL SPECTRA IN COMPOSITIONALLY-MODULATED MULTILAYERED FILMS

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Abstract. - Magneto-optical spectrum of compositionally modulated multilayered thin films (CMF) of transition metal/noble metal structure is calculated by using virtual optical constant method, by which most of the experimental results are explained. The physical reasons of enhancement of magneto-optical effect are discussed.

Compositionally-modulated multilayered films (CMF) are of recent interest among researchers of new magnetic materials. Magneto-optical studies in those of transition metal/noble metal structure by Katayama et al. [1, 2] have gained much attention, as they first showed the possibility of controlling the magneto-optical Kerr effect (MOKE) by employing the CMF structure. One of their results is shown in figure 1a, in which an enhancement of MOKE in Fe/Cu CMF around the wavelength of the absorption edge of Cu is observed.

We have carried out a simulation of MOKE spectrum in CMF with the same composition and thickness ratio in terms of the virtual optical constant method proposed by Ohta et al. [5] by using reported values of the diagonal and off-diagonal elements of the dielectric tensors in Fe and Cu [6, 7] with no adjustable parameters employed. The calculated virtual optical constants can be interpreted as the renormalization of the multiple reflection and interference effects into a single set of optical constants, which should converge to the value deduced from the averaged dielectric constant in the limit of the least modulation length. Most of the experimental MOKE spectra have been quantitatively explained [3, 4] as shown in figure 1b. The fact that the multiple reflection plays an important role in the magneto-optical spectrum of CMF means that consideration of the light-phase is important even in such a layer as order of magnitude thinner than the wavelength of light.

Next, we discuss on the physical meaning of the enhancement of the MOKE in the transition metal/noble metal CMF's. In our previous papers [3, 4] we suggested that the enhancement of MOKE is caused by the reduction of dielectric constant due to the plasma resonance at the wavelength of the absorption edge in the noble metal. Strictly speaking, however, silver is the only one in the three noble metal species that has a plasma edge at the absorption edge; i.e. the real part of the dielectric constant crosses zero only in Ag but remains negative in Au and Cu.

Fig. 1. - Spectra of polar Kerr rotation in Fe/Cu CMF's. Curves denoted as “Cu(Fe)-surface” are those with 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 a Fe film is also shown in the figure. (a) Experiment [2], (b) calculation.

To clarify the nature of the enhancement of MOKE due to plasma resonance, we have calculated MOKE spectra in Fe/noble metal CMF's with Fe at the surface, keeping the thickness ratio of Fe/noble metal constant (= 0.62) and the modulation length $D = 162\,\AA$. The results are shown in figure 2. A sharp and clear
peak of MOKE appears in the Fe/Ag CMF, while broad peaks are seen in Fe/Cu and Fe/Au. This tendency is consistent with that observed by the experiments [1].

When $D$ is increased the MOKE peak shifts to longer wavelength in both Fe/Cu and Fe/Ag CMF’s as shown in figures 3a and b. For large $D$ ($>1000$ Å), the plasma-enhanced peak is broadened in both Fe/Cu and Fe/Ag CMF’s, and gross features in the spectral dependence of the MOKE seems to be independent of the noble metal species. Since the penetration depth of the light is limited to no more than 1 or 2 layers for such a large $D$, the noble metal simply behaves as a reflecting mirror in the back of the magneto-optical layer. Enhancement of MOKE due to the interference between Kerr (reflection) and Faraday (transmission) effects occurs in this case. The tendency is consistent with the experimental Kerr spectrum in bi-layered films [8].

Although most of the calculated results can account for the experimental results quantitatively, they showed substantial disagreement in the small $D$ limit: the experimental value of peak Kerr rotation decreases rapidly as $D$ becomes smaller than 50 Å, while the calculated rotation tends to a finite value as $D$ goes to zero. The discrepancy seems to result from the deviation from an ideal Fe/Cu structure: The tendency has been explained by assuming that single atomic layer (about 2 Å) at both interfaces of the Fe-layer loses magneto-optical effect [3]. We tentatively attribute the loss of magneto-optical effect to slight alloying between Fe and noble metal, although Fe and Cu are not alloy-making pair in equilibrium. On the contrary, in the case of the Fe/Ge CMF’s, where Fe and Ge are alloy-making pair in equilibrium condition, experimental MOKE spectra could hardly been explained by the simple optical theory [9]. Alloying effect seems to be essential in the latter case.

In summary, the enhancement mechanism of MOKE in CMF of Fe/noble metal structures can be classified in two categories: (1) small $D$ limit, in which the plasma enhancement is significant and (2) large $D$ limit, in which the reflector effect by the noble metal works. We have, thus, become able to predict and design the MOKE spectra in CMF’s of transition metal/noble metal structure provided that no alloying effects occur.

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