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**Invited**

# Enhancement of the Magneto-Optical Kerr Rotation in Magnetic Multilayered Films

Toshikazu KATAYAMA, Toshio SUGIMOTO[a], Yoshishige SUZUKI and Yoshikazu NISHIHARA

Electrotechnical Laboratory, Umezono, Tsukuba, Ibaraki 305, Japan.
a : College of Sci. & Technol., Nihon Univ., Narashinodai, Funabashi, Chiba 274, Japan.

Magnetic compositionally modulated multilayer films (CMF) containing noble metals were prepared and its magnetic and magneto-optical properties were investigated. As the results, an enhancement of magneto-optical Kerr rotation $\theta_K$ was observed at the plasma edge of noble metals. The magnitude of $\theta_K$ peak becomes larger than those of Fe and Co metals when the CMF's have a suitable layer thickness ratio of magnetic to noble metals. And, it turns out also that there is an optimum value of the modulation length D for the enhancement of $\theta_K$. These spectra are explainable principally by numerical calculation of $\theta_K$ using a virtual optical constants.

## 1. INTRODUCTION

Compositionally modulated multilayer films (CMF,artificial superlattice) have attracted great interests. So far, many magnetic CMF systems have been investigated and interesting phenomena such as the occurence of long range helimagnetic ordering and perpendicular anisotropy have been reported for a certain kinds of magnetic CMF's.[1),2)] We have reported that an enhancement of $\theta_K$ is observed at the plasma edge of noble metals in the CMF's such as Fe/Cu, Co/Cu, Fe/Au, Co/Au, Co/Ag, etc.[3)~5)]

The magneto-optical Kerr effct is of considerable interest because of usefulness for read-out in magneto-optical memory systems. For these applications, a large Kerr effect is required. In this paper, we report mainly the studies of polar Kerr rotation ($\theta_K$) spectra in the CMF's which consist of 3d magnetic metals of Fe or Co and noble metals of Cu, Au and Ag. And we report also the studies on CMF's containing Pt and Pd which are expected to be spin-polarized by the proximity effect with magnetic elements.

## 2. EXPERIMENTAL PROCEDURES

All CMF samples were deposited on rotating glass substrates by means of RF sputtering using two or three targets. A grounded shroud was used as an isolator to avoid mixing of sputtered atoms. The substrate temperature was maintained at about 20℃ by water cooling during the film deposition. The compositionally modulation length (D) was controlled by the rotating speed of the substrate under the constant sputtering conditions.

The crystal structure and D were examined by both low and high angle X-ray diffraction methods. $\theta_K$ spectra were measured with a Kerr spectrometer (Jasco K-250) in the wavelength region from 250 to 800nm under the condition of saturation magnetization. The incident angle of light was 10° from the normal to the surface of CMF. The total film thickness was checked by a talystep. Each layer thickness of CMF was determined from the deposition rates of the component metals.

## 3. EXPERIMENTAL RESULTS

### 3-1. X-RAY DIFFRACTION

Structures of all CMF's was examined by

both low and high angle X-ray diffraction methods. A presence of the periodic structure was confirmed beyond ~9A for Co/Cu, Fe/Cu, Co/Au, Fe/Au, Co/Pt and beyond ~15A for Fe/Ag, Co/Ag CMF's. And it is considered that the crystallinity of CMF's containing Au and Pt is, in general, better than that of Fe/Ag and Fe/Cu CMF's from the results of the high angle X-ray diffraction.

### 3-2. MAGNETO-OPTICAL KERR EFFECT

Figure 1 shows the wavelength dependence of $\theta_K$ (spectra) in Fe/Cu CMF's with the layer thickness ratio of about 0.62. The value of $\theta_K$ is low and the spectrum is relatively simple in Fe(5A)/Cu(9A) CMF. Namely, no $\theta_K$ peak is observed at wavelength from 300 to 800nm. The spectrum is similar to that of sputtered solid solution alloy of Fe and Cu metals. However, a new peak of $\theta_K$ appears around 560nm, corresponding to the coupled plasma edge of the free carrier in Cu metal, in Fe(15A)/Cu(25A) and Fe(30A)/Cu(50A) CMF's. These spectra are quite different from that of Fe metal film. Here, the plasma edge is coupled with interband transitions in Cu, where the real part of the diagonal dielectric tensor approaches zero and reflectivity R decreases considerably. In Co/Cu CMF's, a similar enhancement of $\theta_K$ was observed at the same wavelength corresponding to the plasma edge of Cu.

Figure 2 and 3 show the $\theta_K$ spectra of in Co/Au and Co/Ag CMF's with several kinds of D. These results are similar to the cases of Co/Cu and Fe/Cu CMF's except for the wavelength where the $\theta_K$ peak appears. Namely, in large D region, a new peak appears around $\lambda$=500 and 310nm corresponding to the plasma edge of Au and Ag, respectively. A similar $\theta_K$ enhancement appears also in Fe/Au and Fe/Ag CMF's systems.

Thus, it turned out that $\theta_K$ is enhanced around the wavelength which corresponds to the plasma edge of noble metals in magnetic CMF's with relatively large D. Therefore, we have studied the layer thickness ratio dependence of $\theta_K$ spectra in Fe/Cu CMF's. From the experiments, it is found that the enhancement of $\theta_K$ is sensitive to the thickness ratio of

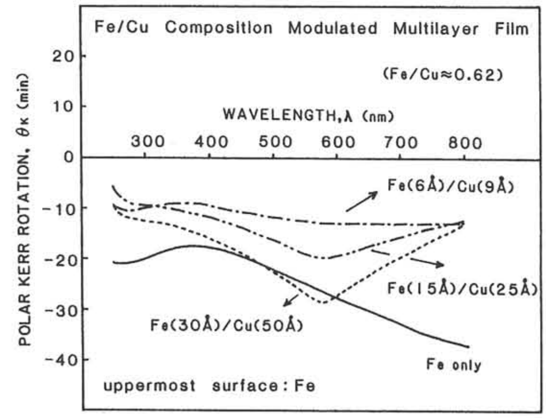


Fig.1 $\theta_K$ spectra in three kinds of Fe/Cu CMF's. The $\theta_K$ spectrum of Fe metal film is shown as a comparison. The Fe/Cu layer thickness ratio is about 0.62.

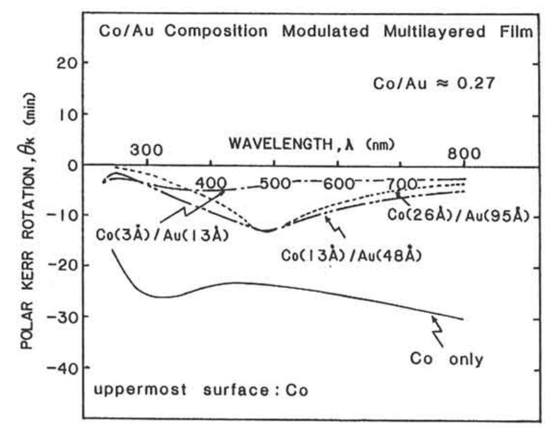


Fig.2 $\theta_K$ spectra in Co/Au CMF's with different D.

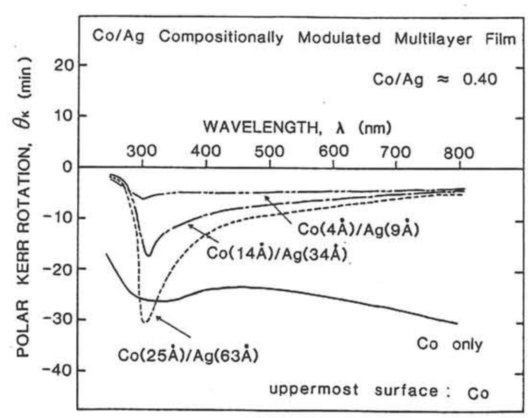


Fig.3 $\theta_K$ spectra in Co/Ag CMF's with different D.

Fe and Cu layers and $\theta_K$ peak moves towards the longer wavelength side with increasing D. Namely, there are optimum values of both Fe/Cu thickness ratio and D for the maximum enhancement of $\theta_K$.

In order to make clear the mechanism of the enhancement of $\theta_K$, we measured the behaviours of $\theta_K$ spectra in these bilayer systems.[6] $\theta_K$ enhancement is observed also in magnetic bilayer systems such as Fe/Cu, Co/Ag. It is found that, in the Fe/Cu system, when the Fe is very thin, $\theta_K$ is low and it becomes zero in the wavelength region beyond 700nm. However, as the Fe layer becomes thicker, $\theta_K$ peak appears around 560nm corresponding to the plasma edge of Cu. $\theta_K$ peak reaches up to a maximum value , which is larger than that of multilayers, at Fe=~130A and then it moves towards the longer wavelength side and decreases with the increase of Fe layer thickness.

## 4. DISCUSSION

Regarding an origin of the $\theta_K$ enhancement phenomena observed here, we considered the following three possibilities: 1) Proximity effect associated with spin polarization, 2) optical multiple interference effect, and 3) Plasma resonance effect.

When the proximity effect of magnetic layers is effective, it is probable that the electronic band structure of noble metal is modified by adjacent magnetic layers and that the spin polarization is induced in the noble metal layers by this proximity effect. In this cases, the Kerr rotation will increase with increasing the number of the interfaces, namely, decreasing D. However, the experimental results without Pt and Pd systems are opposite to the prediction in the range of optical penetration depth.

It is considered that an ordinary interference effect does not play a responsible role for the appearence of $\theta_K$ peak in these Fe/Cu CMF's, since the R does not drop considerably at the wavelength of plasma edge. From the results of numerical calculations, however, it is probable that the zeroth order multiple reflection occurs in the bilayered system.

K.Sato et al. have analyzed the $\theta_K$ spectra in Fe/Cu CMF's based on the calculations using virtual optical constants.[7] And they showed that the calculated $\theta_K$ spectra are in good agreement with the experimental results and the enhancement of $\theta_K$ in Fe/Cu CMF's appeared around the plasma edge of Cu is interpreted in terms of the existence of hybrid plasma in these materials. In Fig.4 are shown the calculated $\theta_K$ spectra for Fe/Cu CMF's taking D as a parameter.[7] The ratio of Fe/Cu thickness is ~0.62. The calculated spectra are similar to the experimental results although the peak positions of $\theta_K$ are slightly different. In this figure, we can clearly observe the $\theta_K$ enhancement around 560nm. They also indicated that the calculated R spectra are in good agreement with the experimental data.

Feil and Haas have reported the $\theta_K$ enhancement due to the plasma respnance of free carriers in metalic magnetic substance.[8] It is probable that the effective dielectric constants nearly satisfy the condition of the

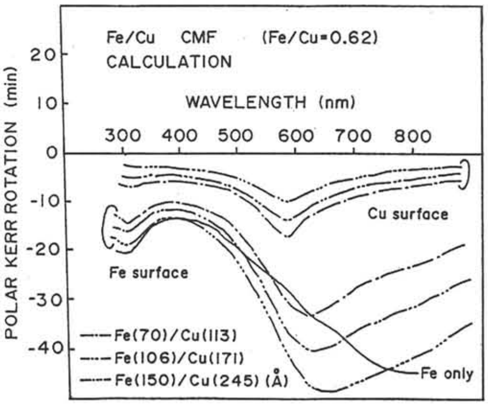


Fig.4 Calculated $\theta_K$ spectra in various kinds of Fe/Cu CMF's.[6] The curves of CMF's with the top surface of Fe or Cu are indicated. And calculated $\theta_K$ spectrum of Fe is also shown as a comparison. Fe/Cu layer thickness ratio is kept constant (=0.62).

plasma resonance enhancement in the CMF's with the D smaller than the wavelength of light. We think that the results show that the plasma resonance enhancement of $\theta_K$, which has been reported on TmS, etc.[9], can be realized in the multilayer films.

Although we are interested in the possibility of $\theta_K$ enhancement originated from a spin polarization effect of the band near the Fermi level of non-magnetic elements, it is concluded that the above mentioned $\theta_K$ enhancement is ascribed to the modification of the optical constants due to the plasma resonance effect. As an attempt of finding

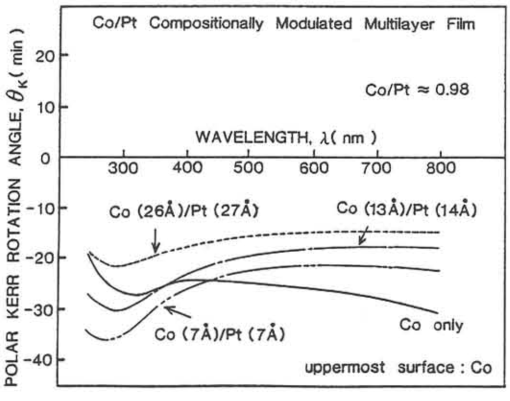


Fig.5 $\theta_K$ spectra in Co/Pt CMF's with different D.

of new $\theta_K$ enhancement due to spin polaization of non-magnetic metals such as Pt, Pd, we measured the $\theta_K$ spectra of Co/Pt, Co/Pd etc. As an example, in Fig.5 are shown the $\theta_K$ spectra in several Co/Pt CMF's with almost constant layer thickness ratio. $\theta_K$ peaks are located around 290nm and its magnitude becomes larger with the decreasing D contrary to that of the CMF's such as Fe/Cu, Co/Ag, etc. Moreover, the magnitude of $\theta_K$ peak is somewhat larger than that of the alloys with the same composition. In Fe/Pt CMF's, it is found that $\theta_K$ peak moves slightly to the shorter wavelength side. Until now, however, it is not confirmed yet that the $\theta_K$ peaks are originated from the polarization of Pt near interfaces.

We believe that the phenomena described here will provide a promising method for enhancement of $\theta_K$ in magneto-optical storage media.

## 5. CONCLUSION

The structure and the $\theta_K$ spectra of magnetic CMF's contaning 3d transition and noble metals have been investigated. It is found that, though the $\theta_K$ spectra is simple in cases of relatively small D, a new $\theta_K$ peak appears around the wavelength which corresponds to the plasma edge of noble metals with the increase of D. There are optimum values of both layer thicknss ratio and D in CMF's for the enhancement of $\theta_K$. Moreover, the enhancement of $\theta_K$ depends on the species of the top surface, namely, whether it is magnetic or non-magnetic. A similar $\theta_K$ enhancement occurs also around the plasma edges of noble metals in the bilayered films. All these $\theta_K$ behaviors can be explainable principally by the numerical calculation using a virtual optical constants. The $\theta_K$ enhancement is observed around 290nm in CMF system containing Pt.

## REFERENCES

1) J.Kwo, E.M.Gyorgy, et al.; Phys. Rev. Lett., 55, (1985) 1402.
2) P.F.Carcia, A.D.Meinhaldt, et al.; Appl. Phys. Lett., 47, (1985) 178.
3) T.Katayama, H.Awano, et al.; J. Phys. Soc. Jpn., 55, (1986) 2539.
4) T.Katayama, H.Awano, et al.; J. Appl. Phys., 61, (1987) 4329.
5) T.Katayama, H.Awano, et al.; IEEE Trans. Magn., MAG-23, (1987) 2949.
6) T.Katayama, Y.Suzuki, et al.; Phys. Rev. Lett., 60, No.14, (1988) 1426.
7) K.Sato, H.Kida, et al.; Jpn. J. Appl. Phys., 27, (1988) L237.
8) H.Feil and C.Haas ; Phys. Rev. Lett., 58, (1987) 65.
9) W.Reim, J.Schoenes, et al.; Phys. Rev., B-29, (1984) 3252.