MAGNETO-OPTICAL KERR SPECTRA FOR AMORPHOUS RE-Co ALLOY FILMS

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The magneto-optical Kerr spectra(λ=250~700nm) of amorphous RE-Co(RE=Ce, Nd, Pr, Gd, Tb, Er, Ho) are compared with those of Y-Co films. It has been found that the Kerr rotation of RE-Co is mainly due to Co in the long wavelength region, whereas at short wavelength Ce, Pr, Nd, and Gd contribute positively, and Tb, Ho, and Er contribute negatively to the Kerr rotation of RE-Co amorphous films. In the interesting energy region(1.5~5.0 eV), the magneto-optical contribution of Pr and Nd are thought to be related with 4f↑ → 5d↑ interband transition, and the contribution of Ce and Gd might be concerned with d→ p interband transition. The magneto-optical effect of Tb in the short wavelength region might be related with 4f↓ → 5d↓ and/or 5d↓ → 4f↓, and that of Ho and Er can be explained by 4f↓ → 5d↓ magneto-optical interband transition.

I. INTRODUCTION

Amorphous rare earth-transition metal (RE-TM) alloy films have been used quite successfully as magneto-optical(MO) recording medium[1, 2]. MO effects of these materials, however are still relatively low for wide application such as vedio recording with high quality[3]. It is well known that transition metals play a major role in MO coefficients in these alloys, but early studies showed that rare earth such as Gd or Tb plays only minor role in determining the MO effects at least in visible part of the spectrum[4,5]. However, as discussed in the previous report, Gd[6] and Nd[7] contribute significantly to the MO effects of Gd-TM and Nd-TM alloys in the short wavelength region. In order to enhance the MO effects of RE-TM alloys, it is important to investigate the MO behavior of rare earth elements in these amorphous alloys.

In this report, the wavelength dependence of the Kerr rotations for amorphous RE-Co(RE=Ce, Nd, Pr, Gd, Tb, Er, Ho) alloy films is studied. Futhermore the magneto-optical Kerr rotations of rare earth elemants in amorphous state are evaluated by comparing the Kerr rotation spectra of RE-Co with those of Y-Co, and their origins are estimated using the model of the magneto-optical interband transition described in the previous report[7, 8].

II. EXPERIMENTAL

Amorphous RE_xCo_{1-x} and Y_xCo_{1-x} ($x=0.02\sim0.48$) alloy films were prepared by means of dual source e-beam evaporation onto quartz substrates. The vacuum system is evacuated to a pressure of 3×10^{-7} Torr before film deposition, and the back ground pressure during evaporation is $5\sim8\times10^{-7}$ Torr. The total deposition rate is typically 1.5 Å/sec, and the deposited films are about 1000 Å thick. Before being exposed to air, films are passivated with SiO of 600-Å-thickness.

The magnetic measurements were made by a VSM with an applied magnetic field parallel and perpendicular to the film plane. The polar Kerr rotation angle has been measured from the substrate side at room temperature using an automatic null type kerr spectrometer with an applied field of 13 KOe. The Faraday rotation of the substrate is subtracted from the measured value. Sample com

position was determined by EPMA and film thickness was obtained by the mechanical step technique. The amorphous state was checked by conventional X-ray diffraction measurements.

Ⅲ. RESULTS AND DISCUSSION

The compositional dependece of the saturation magnetization(M_s) at room temperature is shown in Fig. 1 for various RE-Co and Y-Co films. In Gd-Co and Tb-Co films, the magnetic compensation occurs at almost the same RE content of 22 at. %, and the compensation composition of Ho-Co film at room temperature was 27 at. % of Ho. In case of Er-Co, the apparent magnetic compensation composition is not seen in Fig. 1, in spite that Er is one of the members of heavy rare earth elements and this phenomenon is also seen in other literature [9]. The compositional dependence of light RE-Co and Y-Co shows almost the same trend in respect that M_s is simply decreasing with increasing light RE or Y content.

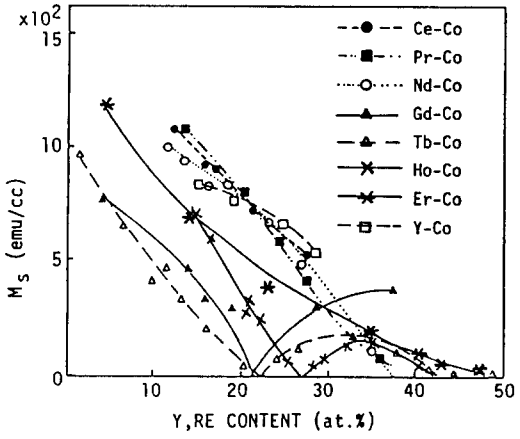

Fig. 1 Compositional dependence of saturation magnetization(M_s) at room temperature for RE-Co films.

Fig. 2 shows the compositional dependence of absolute value of the Kerr rotation(θ_K) measured at room temperature using He-Ne laser, and it is noted that all the RE-Co films between 12 and 29 at. % of RE show almost the same tendency. This fact suggests that the Kerr rotation at the wavelength of 633 nm is mainly determined by Co subnetwork.

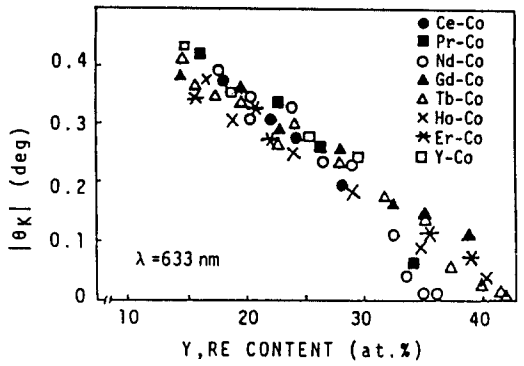

Fig. 2 Magneto-optical Kerr rotation(θ_K) at the wavelength of 633 nm for amorphous RE-Co and Y-Co alloy films as a function of Re and Y content.

In Fig. 3, the Kerr rotation spectra for RE-Co and Y-Co are shown in the wavelengh range from 250 to 700 nm. Most of the films shown in this figure have almost the same Co content of about 80 at. %. It is noted that in the short wavelength re-

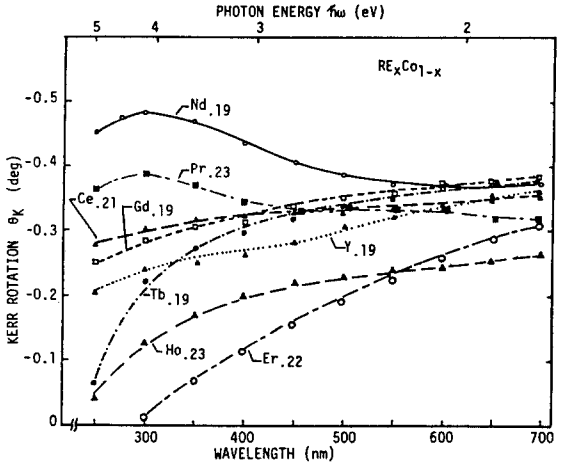

Fig. 3 Magneto-optical Kerr rotation(θ_K) spectra for amorphous RE-Co and Y-Co alloy films whose Co content is 77～81 at. %.

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gion the Kerr rotation shows much difference depending on the species of RE in contrast to that in the long wavelength region. The shape of the Kerr spectra of $Gd_{.19}Co_{.81}$ and $Ce_{.21}Co_{.79}$ is very similar to that of $Y_{.19}Co_{.81}$ in respect of the monotonous decrease of Kerr rotation with decreasing wavelength. The Kerr spectra of Tb-Co, Ho-Co and Er-Co decrease with decreasing wavelength more rapidly than that of Y-Co in the short wavelengh region, whereas those of Nd-Co and Pr-Co increase with decreasing wavelength and show a peak at about 300 nm.

Assuming that the Kerr rotation of Y-Co totally come from Co subnetwork and the 3d electron state of Co in RE-Co is quite similar to that of Y-Co [8, 10], the magneto-optical Kerr spectra of amorphous RE subnetwork $\theta_K(RE_x)$ is estimated by the following equation and shown in Fig. 4.

$$\theta_K(RE_x)=\theta_K(RE_xCo_{1-x})-\theta_K(Y_{.19}Co_{.81})\frac{M_s(Y_xCo_{1-x})}{M_s(Y_{.19}Co_{.81})} \quad (1)$$

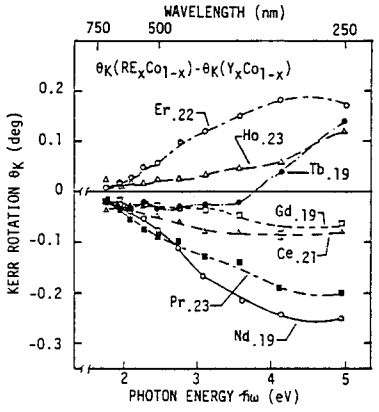

Fig. 4 Magneto-optical Kerr rotation (θ_K) spectra contributed by RE subnetwork in amorphous RE-Co films at room temperature.

It is noted from Fig. 4 that the magnitude of RE contribution in the high energy region is significantly larger than those of low energy region. The negative Kerr rotation means the additive conribution to that of Co subnetwork and positive sign is subtractive to Co, since the sign of the MO effect of Co is treated as negative in the interesting energy region. It is already discussed in previous reports that the large MO effects of Nd and Gd in the high energy region are originated from the f→d and p→d MO interband transition, respectively [6, 7]. The origins of MO effect can be attributed to Ce, Pr, Tb, Ho and Er on the basis that the Kerr rotation spectra are closely related with the joint-density-of-states which is presumed from the XPS and BIS data for RE elements reported by Lang et al [11], on reference to the model described in previous reports [7,8].

In case of Ce, the trivalent Ce ion has one 4f electron below Fermi energy level. According to the XPS and BIS for Ce shown in Fig. 5(a), one electron and six holes of 4f up-spin (4f↑) are thought to be distributed at about 2 eV below and 4 eV above the Fermi level, respectively. If we assume that 5d band of most of RE is located around the Fermi level, then 4f↑→5d↑ and 5d↑→4f↑ interband transition are possible in the interesting energy region. According to these interband transitions, the Kerr spectra of Ce is supposed to show a broad peak at around 2 eV or 4 eV. But these peaks are not seen in the Kerr rotation spectra for Ce in Fig. 4. This is understandable considering that highly polarized 4f band of Ce is so close to the Fermi level that some of Ce atom has no magnetic moment, and also the Ce-TM exchange interaction is too weak and the single ion anisotropy is too strong to align the magnetic moment of Ce atom at the room temperature [12]. The Kerr spectrum of Ce in Ce-Co film has a resemblance to that of Gd as seen from Fig. 4, and therefore might be closely related with p→d interband transition.

The trivalent Pr ion has two 4f↑ electrons below the Fermi level. The locations of 4f↑ are assumed to be 3. 3 eV below for filled band and 2 eV above the Fermi level for vacant band, respectively as from the XPS and BIS for Pr shown in Fig. 5(b). In Pr, 4f↑→5d↑ and /or 5d↑→4f↑ interband transitions are thought to be possible in the interesting energy region, and the significantly

large MO effects are expected at about 4 eV by 4 f↑→5d↑ and 2 eV by 5d↑→4f↑ interband transition. However, any large MO effects are not seen around 2 eV in Kerr rotation spectrum of Pr in Fig. 4. Therefore the origin of MO effect of Pr in amorphous Pr-Co alloys is thought to be 4f↑→5 d↑ transition and this is just the same case as that of Nd [7].

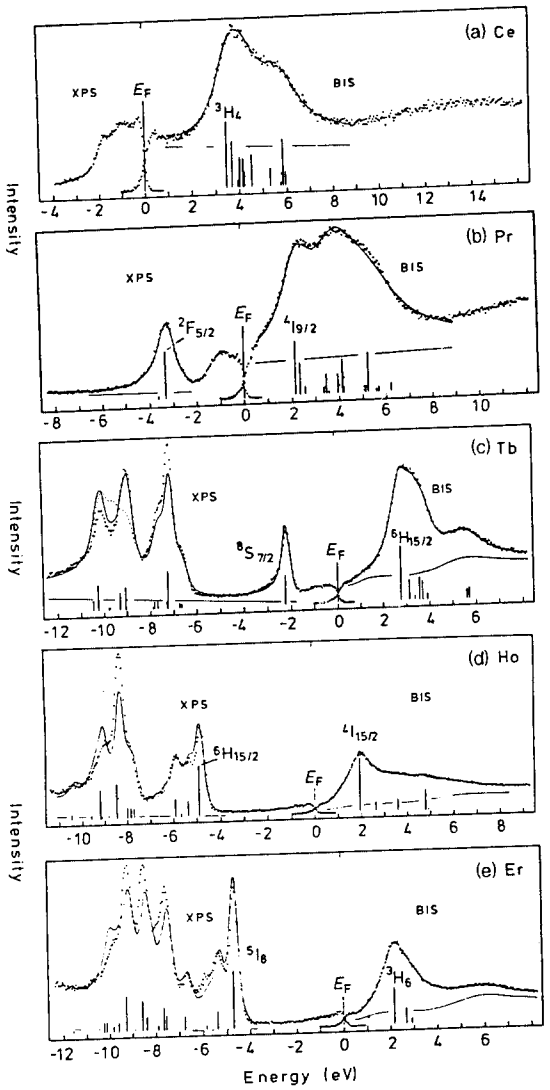

Fig. 5 XPS and BIS data for (a) Ce, (b) Pr, (c) Tb. (d) Ho and (e) Er [11].

The trivalent Tb ion has eight 4f electrons below Fermi level. The distributions of these 4f electrons are divided into two groups, that is, seven up-spin group and the one down-spin group. As seen from XPS and BIS data for Tb in Fig. 5(c), seven up-spin electrons and one down-spin electron seem to be located at about 7 eV and 2.3 eV below Fermi level, respectively, and 4f down-spin holes are thought to be distributed around 2.8 eV above the Fermi level. If we assume that 5d band is located near the Fermi level, considerably large MO effects are expected at about 2~3 eV in the interesting energy region for 4f↓→5d↓ and/or 5d↓→4f↓ transitions, but the measured Kerr spectrum of Tb shown in Fig. 4 shifted to the higher energy region than that estimated from Lang et al's data [11]. This might be due to the fact that, as shown in the Connell's data of XPS and BIS for amorphous Tb-Fe alloy [13], 4f states of electrons and holes of Tb are located farther from the Fermi level than those reported by Lang et al [11].

The trivalent Ho ion has ten 4f electrons below the Fermi level. Seven electrons are up-spins and other three electrons are down-spins. According to the XPS and BIS data for Ho shown in Fig. 5(d), it is noted in the interesting energy region that the filled and the vacant 4f↓ band are located at 5 eV below and 2 eV above the Fermi level, respectively. If we assume that 5d band is located near the Fermi level, the MO effects are expected at 5 eV for 4f↓→5d↓ and 2 eV for 5d↓→4f↓ interband transition. The peak position of the Kerr rotation spectra for Ho in Fig. 4 might therefore be due to the 4f↓→5d↓ interband transition.

Finally, in case of Er, the trivalent Er ion has eleven 4f electrons below the Fermi level. Seven electrons are up-spins and other four electrons are down-spins. XPS and BIS data for Er shown in Fig. 5(e) are very similar to those of Ho, and 4f down-spin electrons and holes are thought to be located at about 4.8 eV below and 2.2 eV above the Fermi level, respectively. The magneto-optical effects of Er in the interesting energy region is assumed to be related to the interband transition

between the 4f down band and 5d band which is located near the Fermi level as the case for other rare earths. The large magneto-optical effects of Er are expected at about 5 eV for $4f\downarrow \rightarrow 5d\downarrow$ and at about 3 eV for $5d\downarrow \rightarrow 4f\downarrow$ interband transition. The Kerr rotation spectra for Er shown in Fig. 4 can be explained by $4f\downarrow \rightarrow 5d\downarrow$ magneto-optical interband transition.

Ⅳ. CONCLUSION

The Kerr rotations for RE_xCo_{1-x} $(0.19 < x < 0.23)$ in the short wavelength region exhibit much different values depending on the kind of RE elements in contrast to those in the long wavelength region. These differences in the short wavelength region is thought to be related with the magneto-optical effects of RE elements.

Comparing the Kerr rotation spectra for RE-Co with that for Y-Co, it is found that Ce, Pr, Nd and Gd contribute additively, but Ho and Er contribute subtractively to the Kerr rotation of Co in amorphous RE-Co alloy films in the energy region from 2 to 5 eV. In case of Tb, its magneto-optical effect is additive in the lower energy region than 3.5 eV but subtractive in the higher region than 3.5 eV to that of Co. In the interesting energy region, the magneto-optical contribution of Pr and Nd are thought to be related with $4f\uparrow \rightarrow 5d\uparrow$ interband transition, and the contribution of Ce and Gd might be concerned with d→p interband transition. The positive magneto-optical effect of Tb in the high energy region might be related with 4 $f\downarrow \rightarrow 5d\downarrow$ and/or $5d\downarrow \rightarrow 4f\downarrow$, and that of Er and Ho can be explained by $4f\downarrow \rightarrow 5d\downarrow$ magneto-optical interband transition.

REFERENCES

[1] N. Imamura and C. Otha, Jpn. J. Appl. Phys., **19**, L737 (1982)

[2] Y. Togami, K. Kobayashi, M. Kajimura, K. Sato and T. Teranishi, J. Appl. Phys., **53**, 2335 (1982)

[3] T. Nomura, K. Yokoyama, S. Nakagawa and K. Kimoto, Res. Rep. of Electronics and Commu. Soc. Jpn., **MR86**, 33 (1986)

[4] S. Tsunashima, S. Masui, T. Kobayashi and S. Uchiyama, J. Appl. Phys., **53**, 8175 (1982)

[5] K. Sato and T. Togami, J. Mag. Magn. Mat., **35**, 181 (1983)

[6] Y. J. Choe, S. B. Park, E. S. Leem, O. S. Choe, S. Y. Kim and T. K. Kim, New Phys., **32**, 507 (1992)

[7] Y. J. Choe, New Phys., **31**, 622 (1991)

[8] Y. J. Choe, S. Tsunashima and S. Uchiyama, J. de Physique, **C8**, 1953 (1988)

[9] A. G. Dirks, J. W. M. Biesterbos and K. H. J. Buschow, Physica, **86-88B**, 761 (1977)

[10] K. H. J. Buschow and P. G. Van Engen, Philips J. of Research, **39**, 1 (1984)

[11] J. K. Lang, Y. Bear and P. A. Cox, J. Phys. F: Metal Phys., **11**, 121 (1981)

[12] K. N. R. Taylor, Advan. Phys., **20**, 649 (1971)

[13] G. A. N. Connell, J. Mag. Magn. Mat., **54-57**, 1561 (1986)

비정질 RE-Co 합금막의 자기광학 스펙트럼

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비정질 RE-Co(RE＝Ce, Nd, Pr, Gd, Tb, Er, Ho) 합금막의 자기광학 스펙트럼(λ＝250~700 nm)을 Y-Co의 그것과 비교하여 RE 부격자에 의한 자기광학효과를 추정하였다. RE에 의한 자기광학효과는 단파장 영역에서 크게 기여하는 것으로 나타났으며, Ce, Pr, Nd 및 Gd은 Co의 자기광학효과에 더해지는 방향으로 일어나고, Tb, Ho 및 Er은 Co와 반대방향으로 일어난다. 자기광학 천이 모델에 의하면, Pr과 Nd은 $4f\uparrow \rightarrow 5d\uparrow$, Ce과 Gd은 d→p, Tb은 $4f\downarrow \rightarrow 5d\downarrow$ 또는 $5d\downarrow \rightarrow 4f\downarrow$ 그리고 Ho과 Er은 $4f\downarrow \rightarrow 5d\downarrow$ 밴드간 천이에 의한 것으로 각각의 자기광학효과를 설명할 수 있다.