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Temperature Dependence of Magneto-Optical Spectra in EuO Epitaxial Films

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Abstract- Ferromagnetic EuO films were epitaxially grown on MgO substrate. The Curie temperature Tc of the obtained film was 69K. Spectra of magneto-optical polar Kerr rotation and Kerr ellipticity were measured from the substrate side of the MgO/EuO/Ag structure using the photoelastic modulator technique for photon energies between 1.2 and 4 eV under the magnetic field of 1T. Huge magneto-optical effect was obtained. A few spectral structures were observed for photon energies between 1.2 and 2.6eV, which undergo strong temperature dependence.

Key words: EuO, magneto-optical, thin film, flux monitor

1. Introduction

Europium chalcogenides (EuO, EuS, EuSe and EuTe) attracted attention of physicists in late 1960's and early 1970's as typical examples of magnetic semiconductors, in which various physical phenomena arise as a consequence of exchange interaction between localized magnetic moments and conduction-electron spins, for example the magnetic red shift of the absorption edge, the large magneto-optical (MO) effect and the huge magneto-resistance effect in the vicinity of Curie temperature.[1] Among these europium chalcogenides, the highest Curie temperature (69 K) was observed in EuO. Since EuO crystal shows Kerr rotation as large as 6 deg, the compound was studied as a material for MO storage media.[2] The MO storage was operated immersing the MO media in liquid-nitrogen. Although magneto-optical Kerr spectra at 2K in a bulk single crystal was reported by ETH group,[3] no reliable data were available on the temperature dependence of MO spectra in a well-defined film.

Recently, one of the authors (N. Iwata) has succeeded in preparation of epitaxial thin films of ferromagnetic EuO on MgO substrates.[4] Fig. 1 shows an X-ray diffraction pattern of the film. Only the diffraction lines indexed to 002 and 004 of cubic EuO lattice are observed in addition to the 002 line of the MgO substrate, suggesting a good epitaxial relationship. From the magnetic measurements, the magnetic moment per europium atom was determined as $6.9 \pm 0.3 \mu_B$ and the Curie temperature 69K.

This film was employed as a MO layer for monitoring the flux penetration in high-temperature superconductors. For monitoring, a silver film of 0.5μm in thickness was deposited on the EuO film as a reflection and protection layer. Placing the MgO/EuO/Ag film on top of the $NdBa_2Cu_3O_{7-\delta}$ single crystal superconductor, the MO images of the spatial distribution of magnetic flux were observed at 5 K with the magnetic field up to 5.5 T and at 60 K up to 2.2 T.[5] Use of EuO proved to be superior to

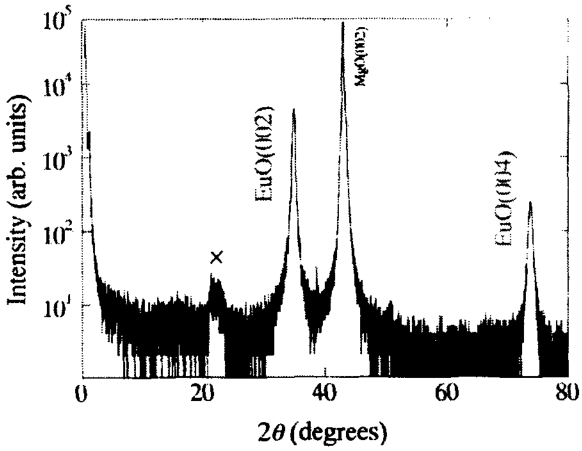

Fig. 1 XRD spectra for film on MgO substrate. The peak marked × is due to impurities in the substrate. (From ref.4)

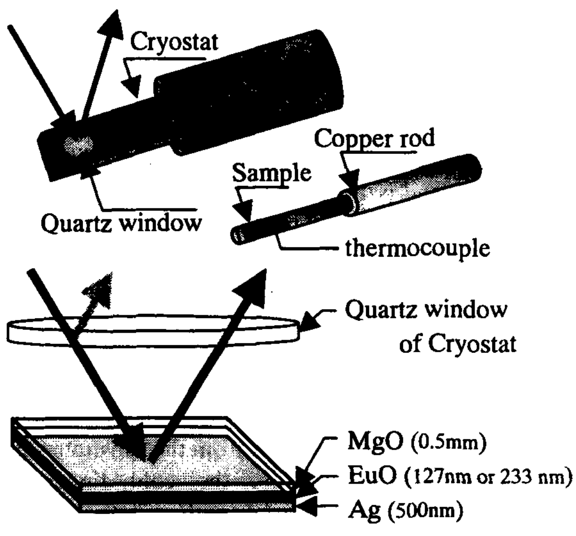

Fig. 2 Experimental schematic for measuring MO Kerr rotation and ellipticity spectra. Spectra were measured from the substrate side of the MgO/EuO/Ag structure.

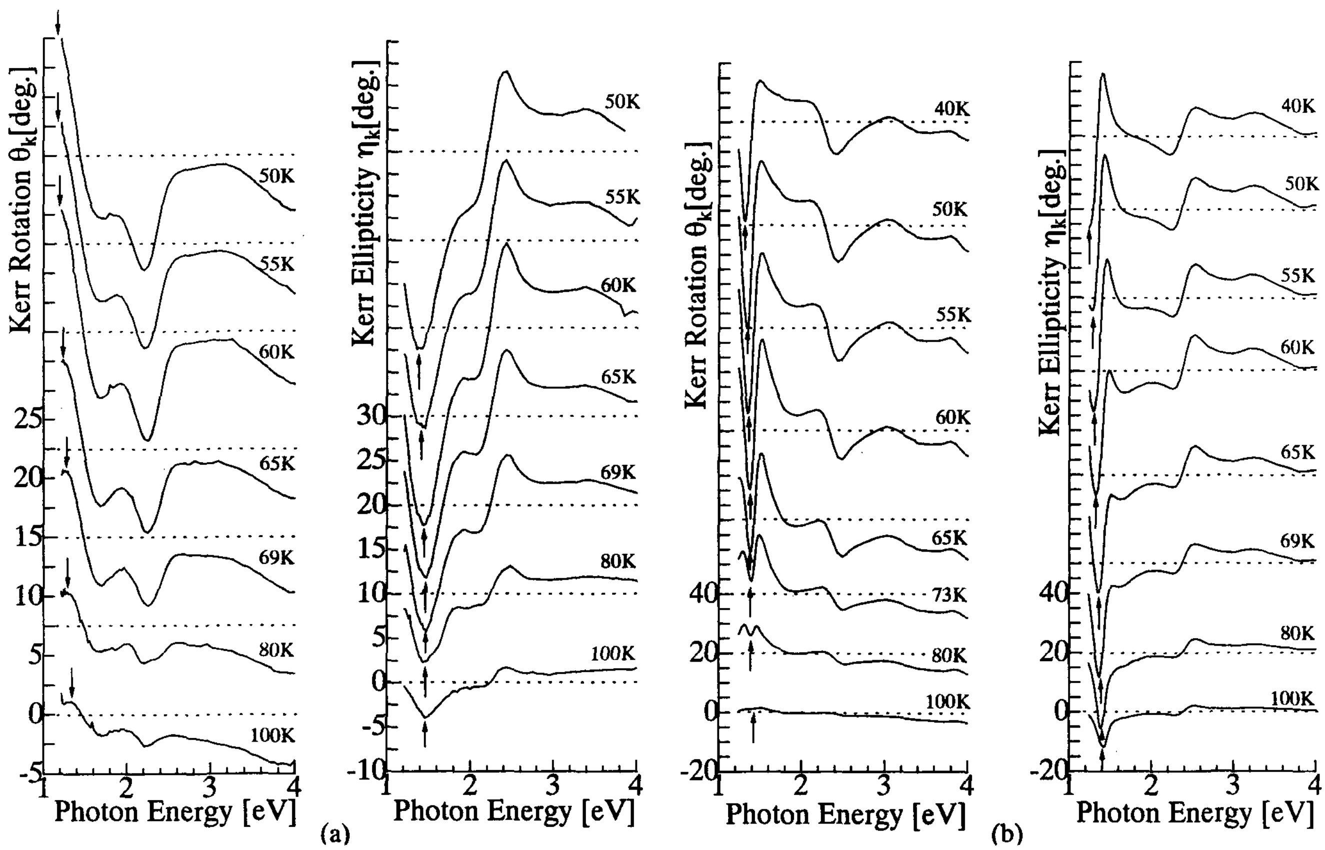

Fig. 3 Temperature dependence of Kerr rotation and Kerr ellipticity spectra in MgO/EuO/Ag structure measured with the magnetic field of 1 T. The thickness of EuO layer is (a) 127 nm and (b) 233 nm.

magnetic garnets that are conventionally employed as a flux monitor, since saturation magnetization is much higher in EuO than magnetic garnets.

It is meaningful to measure MO spectra at different temperatures in our EuO film, since no reliable temperature dependent MO spectra have been published in good quality single crystalline films of EuO.

2. Experimental methods

The MgO/EuO/Ag structures were prepared at ISTEC. The substrates are single crystals of MgO cut along the (100) plane and polished for both sides. EuO films of 127 and 233 nm in thickness were deposited on the substrates in a MBE chamber. As a reflecting layer Ag film of 500 nm in thickness was deposited.

Spectra of MO Kerr rotation and Kerr ellipticity were measured for photon energies between 1.2 and 4 eV by the polarization modulation technique using a photoelastic modulator (PEM).[6] Magneto-optical measurements were carried out for a light incident from the substrate side.

Sample was placed on the cold finger of the He-refrigerator type cryostat with quartz windows as shown in Fig. 2.

The cryogenic system was inserted between the pole pieces of a perforated electromagnet, which can apply the magnetic field normal to the film plane (polar Kerr configuration). The applied field was 1 T, which was not sufficient to saturate the sample magnetization. Due to this experimental configuration, the measured MO signal is subjected to the superposition of Faraday rotation of window and substrate materials.

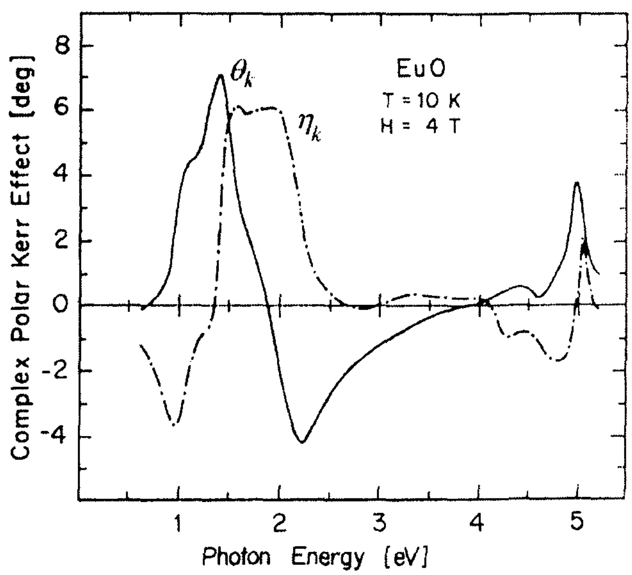

Fig. 4 Polar Kerr rotation and .Kerr ellipticity spectra of cleaved EuO single crystals reported by Wang et al. (From ref. 3)

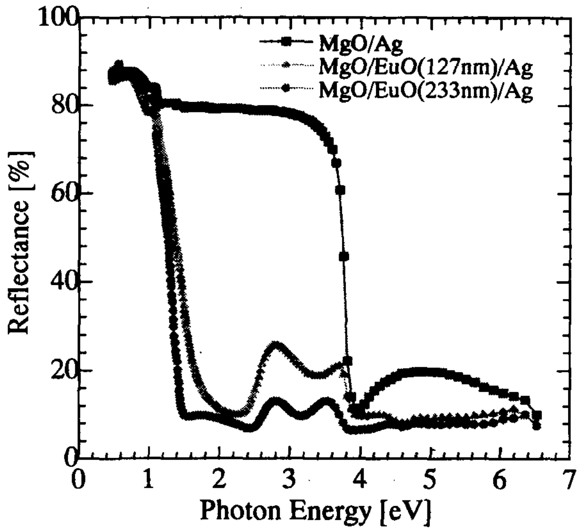

Fig. 5 Reflectance spectra of MgO/Ag, MgO/EuO(127 nm)/Ag and MgO/EuO(233 nm)/Ag at room-temperature.

3. Results and Discussions

Spectra of the MO Kerr rotation and ellipticity are shown in Figs. 3(a) and 3(b), for two different values of EuO thickness, 127 nm and 233 nm, respectively. Huge MO effect was obtained. The data has not been corrected for nonlinearity of the apparatus that would be necessary for such a large MO effect. The data also includes spurious MO effects of the window and substrate materials, which make rotation increased in the negative side for higher photon energies.

The obtained spectra are considerably different from those reported in the literature (Fig.4).[3] A lot of spectral structures were observed for photon energies between 1.2 and 2.6 eV. The 2.4-eV structure appears at the same position for two samples with different EuO thickness. For this structure temperature dependence of the peak position is not obviously observed. On the other hand, the structure below 1.5 eV is different depending on the thickness, suggesting a presence of interference effect.

The room-temperature reflectivity spectra of the MgO/EuO/Ag structures with the different thickness of EuO are given in Fig. 5, together with that of the MgO/Ag as a reference. Reflectivity spectrum of the MgO/Ag is quite similar to Ag itself. The sharp decrease in the reflectivity around 1.1-1.4 eV is due to the onset of absorption at the band edge of EuO.

Since thickness of the measured EuO film is only 127 and 233 nm, considerable interference effect is expected. Taking into account that the absorption coefficient of EuO near the absorption edge is about 5×10^4 cm^{-1}, the optical transmittance of the thinner sample is estimated to be e^{-1}, which is sufficient to be subjected to the interference effect.

Since the thicker sample undergoes much less influence of the interference, we focus on the MgO/EuO(233 nm)/Ag specimen in further discussion.

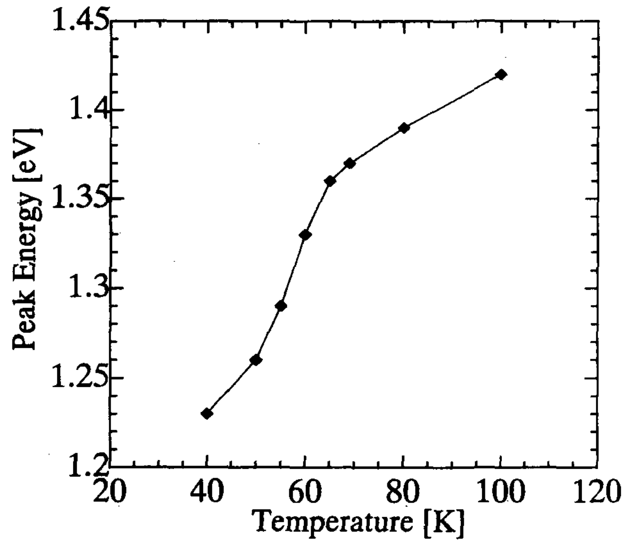

Fig. 6 Temperature dependence of peak position of ellipticity near the absorption edge in the MgO/EuO (233 nm)/Ag sample.

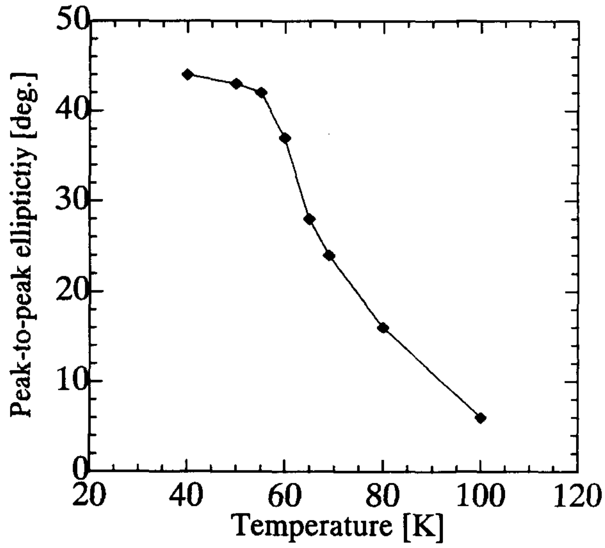

Fig. 7 Temperature dependence of the peak-to-peak value of ellipticity in the MgO/EuO(233 nm)/Ag sample.

As shown in Fig. 6, the sample with EuO thickness of 233 nm exhibits a prominent red shift of the peak position of ellipticity (marked by arrows in Fig. 2) with the decrease of the temperature. This peak may be associated with the absorption edge of the crystal.

The peak-to-peak value of the Kerr ellipticity of the red-shifting structure is plotted against temperature as shown in Fig. 7. The peak intensity of MO signal decreases as temperature is raised. However, the intensity does not vanish even above Curie temperature Tc=69 K. This is partly because the measurement was carried out under the magnetic field of 1 T. It is known that temperature dependence of the absorption edge of ferromagnetic semiconductors does not follow the magnetization curve, but obey the curve that is expected for the system with a short-range spin-spin correlation.[7]

Optical analysis is underway to separate the interference effect and to get MO spectra inherent to the EuO film.

4. Conclusion

MO Kerr rotation and ellipticity spectra were measured in the MgO/EuO/Ag film from 40 K to room temperature. A prominent structure of Kerr effect was observed around the absorption edge of the magnetic semiconductor, which undergoes prominent magnetic red shift as the temperature is lowered.

Acknowledgments

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