MAGNETOOPTICAL PROPERTIES OF ORTHOFERRITES AND GARNETS IN INFRARED

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Résumé. — Les propriétés magnéto-optiques de $YFeO_3$, $EuFeO_3$, $DyFeO_3$ et DyIG sont étudiées dans l'infra-rouge. Le terme non diagonal $|\varepsilon_1'|$ du tenseur $|\varepsilon|$ et la biréfringence des orthoferrites sont assez grands. Dans la direction de l'axe optique λ la rotation Faraday de $YFeO_3$ est estimée à partir de $|\varepsilon_1'|$. La valeur calculée de cette rotation est 700 °/cm à $\lambda = 1.15$ μ. Le résultat expérimental est en accord avec cette estimation. La rotation Faraday du DyIG est isotrope entre 80 et 293 °K et le facteur g du Dy^{3+} est égal à la valeur pour l'ion libre. On utilise l'équation du mouvement du moment magnétique avec un facteur g anisotrope pour interpréter la rotation Faraday à 25 °K.

Abstract. — Magnetooptical properties of the $YFeO_3$, $EuFeO_3$, $DyFeO_3$ and DyIG were investigated in infrared. The nondiagonal components $|\varepsilon_1'|$ of tensor $|\varepsilon|$ are large enough. Faraday Rotation (F. R.) along optical axis of $YFeO_3$ was estimated from the value $|\varepsilon_1'|$. The calculated value of this rotation is equal to 700 °/cm at $\lambda = 1.15$ μ. The experimental value is — 600 °/cm. The F. R. in DyIG is isotropic at 80-293 °K and g-factor Dy^{3+} equals its free ions value. The equation of motion of the magnetic moment with anisotropic g-factor is used for interpretation F. R. at 25 °K.

Orthoferrites, like ferrite garnets, have a transparency window in the infrared [1]. The transparency of the orthoferrites has been used for observing the domain structure [1, 2]. The polar Kerr effect of orthoferrites in the visible was investigated in [3, 4]. Using the transparency of the single crystals, we have investigated magnetooptical properties of orthoferrites $YFeO_3$, $EuFeO_3$ and $DyFeO_3$ [5]. The single crystals orthoferrites were grown by means of the technique of zone melting with optical heating [6]. Figure 1 gives ratio $2\,\delta/I_0(\lambda)$ in $YFeO_3$ plate 102 μ thickness cut in the { 001 } plane. Here $2\,\delta$ is the change in intensity of radiation I passing through the system when the current in the electromagnet is switched. The electrical field of the incident radiation coincides with the axis < 100 >. The analyser was rotated by 45° from < 100 >.

For all thicknesses of the specimen the quantities $2\,\delta/I_0$ are the same for the same value of wavelength. In birefringent crystals the Faraday rotation can only occur along the optical axis [7]. In the directions which do not coincide with the optic axis the angle $\chi = \delta/2\,I_0$ which defines the orientation of the major axis of the ellipse with respect to direction of polarisation of the incident light, can be written in the following form [8].

$$\text{tg}\, 2\,\chi = -\,2\,k \sin \Delta = \frac{G_{33}\,\varepsilon_0^{3/2}}{\Delta n} \sin \frac{2\,\pi\, d\Delta n}{\lambda} \qquad (1)$$

where Δn-birefringence,

$$G_{33} = \frac{\varepsilon_{12}}{\varepsilon_0^2}, \quad \varepsilon_{12} = -\,i(\varepsilon_1 - i\varepsilon_2)\,,$$

ε_{12} is the nondiagonal component of the dielectric constant tensor, ε_0 is the diagonal component, d is the thickness of the plate, λ is the wavelength. From the « period » of the changing χ we get

$$\Delta n = (3.6 \pm 0.3)\,10^{-2} \quad \text{at} \quad \lambda = 1.15\,\mu\,,$$
$$\Delta n = (3.5 \pm 0.3)\,10^{-2} \quad \text{at} \quad \lambda = 1.8\,\mu\,,$$
$$\Delta n = (2.9 \pm 0.3)\,10^{-2} \quad \text{at} \quad \lambda = 6\,\mu\,.$$

Birefringence of $YFeO_3$ is large comparable with birefringence of the $CaCO_3$.

The inset figure 1 shows $|\varepsilon_1|$ of $YFeO_3$, obtained with the help of (1). The values of $|\varepsilon_1|$ are large

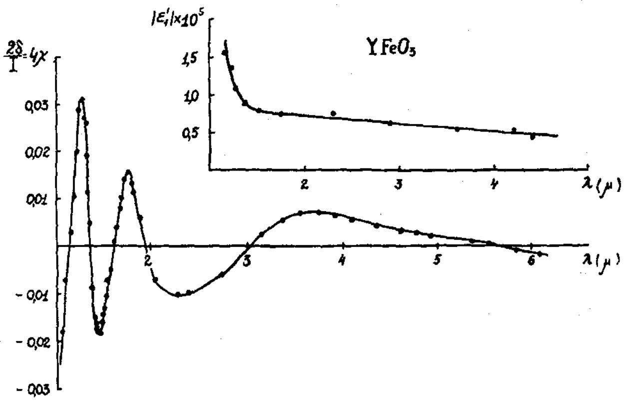

FIG. 1. — Relative change in the intensity of the radiation $2\,\delta/I$ passing through the $YFeO_3$ of thickness 102 μ when the current in the electromagnet is switched as function of the wavelength.

enough, as in visible [3, 4]. The orthoferrites crystallize in an orthorombically distorted perovskite structure belonging to the two-axis crystals. The optical axis of $YFeO_3$ lies in the { 100 } plane and makes with the axis < 001 > the angle of 40°. That is very convenient to receive large F. R. The value of F. R. may be estimated from $|\varepsilon_1|$ and the angle between the optical axis and < 001 >. For example, F. R. is equal to 700 °/cm at $\lambda = 1.15$ μ. The experimental value is − 600 °/cm. This F. R. is higher than in YIG. In direction that doesn't coincide with the optical axis, the value χ is small; $\chi = 0.4°$ and 1.3° at $\lambda = 1.15$ μ and 0.63 μ respectively. Curves similar to those of figure 1 were obtained for other orthoferrites. Birefringence of the orthoferrites is proportional to its orthorombical distortions. For example, in $EuFeO_3$ at

$\lambda = 1.15\ \mu\ \Delta n = (2.2 \pm 0.2)\ 10^{-2}$ and $\chi = 0.6^o$. The curves $\chi(\lambda)$ in the vicinity of the absorption bands have some peculiarities [9].

In papers [10] was found the frequency independent Faraday effect α_{F_0} which exists due to the magnetic permeability in the optical frequence. It was shown that the F. R. in DyIG at 80-293 °K is isotropic [11] and the values $\alpha_F(\lambda)$ may be written in the form [10-12]:

$$\alpha_F = \frac{\pi\sqrt{\varepsilon e}}{mc^2}(g_{Fe} I_{Fe} - g_R I_R) + \frac{k}{\lambda^2}. \quad (2)$$

Here the first member is α_{F_0}; g_{Fe}, g_R, I_{Fe}, I_R are the g-factor and the magnetizations of Fe^{3+} and Dy^{3+}, $\sqrt{\varepsilon} = n$. The g-factor of Dy^{3+} ion obtained from the value α_{F_0} equals its free ion value. The result of the investigation of the F. R. of oriented DyIG single crystals at 25 °K in magnetic field $H = 12$ kOe is represented in figure 2. From these results and (2) we obtains:

$$\alpha_{F_0}^{<111>} = 180 \pm 10\ ^o/\text{cm};$$

$$\alpha_{F_0}^{<110>} = 120 \pm 10\ ^o/\text{cm};$$

$$\alpha_{F_0}^{<100>} = 140 \pm 10\ ^o/\text{cm}.$$

Along the $< 110 >$ direction was found the birefringence [13, 14] which varies from $\Delta n = 1.1 \times 10^{-3}$ at $\lambda = 3.5\ \mu$ up to $\Delta n = 0.95 \times 10^{-3}$ at $\lambda = 6.6\ \mu$. In this case the value $\alpha_{F_0} < 110 >$ was calculated using (1). From the values α_{F_0} and (2), using the magnetization data [15], may be determined $g_R < 111 > = 1.55 \pm 0.1$, $g_R < 100 > = 1.8 \pm 0.1$, $g_R < 110 > = 1.4 \pm 0.1$. To obtain these values α_{F_0} the values $\cos \alpha_i = 1, \sqrt{2/3}, \sqrt{1/3}$ were introduced in (2) for the $< 111 >$, $< 110 >$ and $< 100 >$ directions respectively. It is not excluded that anisotropic α_{F_i} is due to the difference of values of $\cos \alpha_i$ from those mentioned above. In this case it must vanish in the high magnetic fields.

The interpretation α_{F_0} at 80-293 °K mentioned above is based on using the Landau-Lifshitz equations with isotropic g-factor. At low temperature one must take into account that local symmetry of rare-earth ions is not cubic. In this case we must employ the equations of motion of magnetic moment with anisotropic g-factor. Using the Vlasov's and Yshmuhametov's equations [16] and taking account of the six non-equivalent positions of the rare-earth ions in the unit cell, one obtains

$$g_R = \frac{g_{11}^2 g_{22}^2 + g_{22}^2 g_{33}^2 + g_{11}^2 g_{33}^2}{3\, g_{11}\, g_{22}\, g_{33}} \quad (3)$$

along over all directions of the crystal. In (3) the g_{11}, g_{22}, g_{33} are the principal values of g-tensor. When $g_{11} = g_{22} = g_{33} = g_J$, then $g_R = g_J$. If $g_{11} \neq g_{22} \neq g_{33}$, $g_R \neq g_J$ and this is observed on the experiment for $< 111 >$ direction.

Allowance for non-colinear sublattices [17] within the Wolf's model [18] doesn't lead to anisotropic α_{F_0} under condition of the equal magnetic moments of the rare-earth ions in unequivalent positions.

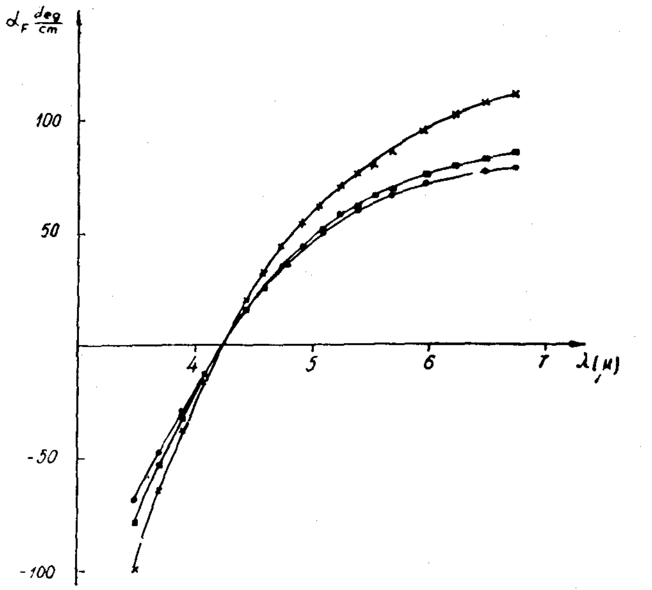

FIG. 2. — The Faraday Rotation $\alpha_F(\lambda)$ in oriented single crystals DyIG at 25 °K in magnetic field $H = 12$ kOe. (● — $\alpha_F < 110 >$; ■ — $\alpha_F < 100 >$; × — $\alpha_F < 111 >$).

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