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MAGNETOOPTICAL PROPERTIES OF ORTHOFERRITES AND GARNETS IN INFRARED

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Résumé. — Les propriétés magnéto-optiques de YFeO₃, EuFeO₃, DyFeO₃ et DyIG sont étudiées dans l'infrarouge. La rotation Faraday de YFeO₃ est estimée à partir de |ε₁|. La valeur calculée de cette rotation est 700 °/cm à λ = 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 Iron libre. On utilise l'équation de mouvement du moment magnétique avec un facteur g anisotrope pour interpréter la rotation Faraday à 25 °K.

Abstract. — Magneto-optical properties of the YFeO₃, EuFeO₃, DyFeO₃ and DyIG were investigated in infrared. The non-diagonal component |ε₁| of the dielectric constant are large enough. Faraday Rotation (F. R.) along optical axis of YFeO₃, was estimated from the value |ε₁|. The calculated value of this rotation is equal to 700 °/cm at λ = 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 YFeO₃, EuFeO₃ and DyFeO₃ [5]. The single crystals orthoferrites were grown by means of the technique of zone melting with optical heating [6]. Figure 1 gives ratio 2δ/Ido(λ) in YFeO₃ plate 102 μ thickness cut in the {001} plane. Here 2δ 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 2δ/Ido 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 χ = δ/2Ido which defines the orientation of the major axis of the ellipse with respect to direction of polarization of the incident light, can be written in the following form [8].

\[ \tan 2\chi = -2k \sin \Delta = \frac{2\pi \Delta n}{\lambda} \]  \( \Delta n \) = birefringence,

\[ G_{33} = \frac{\epsilon_{33}}{\epsilon_0}, \quad \epsilon_{12} = -i(\epsilon_1 - i\epsilon_2), \]

\( \epsilon_{12} \) is the non-diagonal component of the dielectric constant tensor, \( \epsilon_0 \) is the diagonal component, \( d \) is the thickness of the plate, \( \lambda \) is the wavelength. From the « period » of the changing \( \chi \) we get

\[ \Delta n = (3.6 \pm 0.3) \times 10^{-2} \text{ at } \lambda = 1.15 \mu, \]

\[ \Delta n = (3.5 \pm 0.3) \times 10^{-2} \text{ at } \lambda = 1.8 \mu, \]

\[ \Delta n = (2.9 \pm 0.3) \times 10^{-2} \text{ at } \lambda = 6 \mu. \]

Birefringence of YFeO₃ is large comparable with birefringence of the CaCO₃.

The inset figure 1 shows |ε₁| of YFeO₃, obtained with the help of (1). The values of |ε₁| are large 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 YFeO₃ 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 |ε₁| and the angle between the optical axis and <001>. For example, F. R. is equal to 700 °/cm at λ = 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 \( \chi \) is small; \( \chi = 0.4° \) and 1.3° at \( \lambda = 1.15 \mu \) 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 orthoromobically distortions. For example, in EuFeO₃ at

![Fig. 1. — Relative change in the intensity of the radiation 2δ/I passing through the YFeO₃ of thickness 102 μ when the current in the electromagnet is switched as function of the wavelength.](image-url)
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\[ \lambda = 1.15 \mu \Delta n = (2.2 \pm 0.2) \times 10^{-2} \text{ and } \chi = 0.60. \]

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 \( \alpha_{F0} \) which exists due to the magnetic permeability in the optical frequency. It was shown that the F. R. in DyIG at 80-293 K is isotropic [11] and the values \( \alpha(\lambda) \) may be written in the form [10-12]:

\[
\alpha_p = \frac{\pi \sqrt{g_\text{e}}}{m e^2} (g_{R1} I_{R1} + g_{R2} I_{R2}) + \frac{k}{\lambda^2} \cdot (2)
\]

Here the first member is \( \alpha_{F0} \); \( g_{R1}, g_{R2}, I_{R1}, I_{R2} \), are the g-factor and the magnetizations of \( \text{Fe}^{3+} \) and \( \text{Dy}^{3+}, \)

\[ \sqrt{g} = n \text{. The } g\text{-factor of } \text{Dy}^{3+} \text{ ion obtained from the value } \alpha_{F0} \text{ equals its free ion value.}
\]

The result of the investigation of the F. R. of oriented DyIG single crystals at 25 K in magnetic field \( H = 12 \text{ kOe} \) is represented in figure 2. From these results and (2) we obtain:

\[
\begin{align*}
\alpha_{F0}^{111} & = 180 \pm 10^9 \text{cm;} \\
\alpha_{F0}^{100} & = 120 \pm 10^9 \text{cm;} \\
\alpha_{F0}^{<100} & = 140 \pm 10^9 \text{cm}.
\end{align*}
\]

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 \text{ up to } \Delta n = 0.95 \times 10^{-3} \text{ at } \lambda = 6.6 \mu \text{. In this case the value } \alpha_{F0} < 110 > \text{ was calculated using (1).}

From the values \( \alpha_{F0} \) and (2), using the magnetization data [15], may be determined \( g_{R1} < 111 > = 1.55 \pm 0.1, g_{R2} < 100 > = 1.8 \pm 0.1, g_{R3} < 110 > = 1.4 \pm 0.1. \)

To obtain these values \( \alpha_{F0} \), the values \( \alpha_{F0} = 1, \sqrt{2}, \sqrt{3} \) were introduced in (2) for the \( <111>, <110>, \) and \( <100> \) directions respectively. It is not excluded that anisotropic \( \alpha_{F0} \) is due to the difference of values of \( \alpha_{F0} \) from those mentioned above. In this case it must vanish in the high magnetic fields.

The interpretation \( \alpha_{F0} \) at 80-293 K mentioned above is based on using the Landau-Lifshitz equations with anisotropic 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 Yshumahetov’s equations [16] and taking account of the six non-equivalent positions of the rare-earth ions in the unit cell, one obtains:

\[
g_{R} = \frac{g_{11}^2 g_{22}^2 + g_{12}^2 g_{33}^2 + g_{11} g_{33}^2}{3 g_{11} g_{22} g_{33}} \cdot (3)
\]

along over all directions of the crystal. In (3) the \( g_{11}, g_{22}, g_{33} \) are the principal values of g-tensor. When \( g_{11} = g_{22} = g_{33} = g_{R} \) then \( g_{R} = g_{R} \). If \( g_{11} \neq g_{22} \neq g_{33}, g_{R} \neq g_{R} \) 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 \( \alpha_{F0} \) under condition of the equal magnetic moments of the rare-earth ions in unequalvivalent positions.

References