Magnetogyration in the CdS and $(Ga_x In_{1-x})_2Se_3$ Crystals in the Spectral Range of Interband Absorption

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Abstract

The paper is devoted to the study of induced magnetic field gyration in CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) crystals in the spectral range of interband absorption. The dispersion of the magnetogyration effect is experimentally obtained. It was found the magnitude of magnetogyration depends on the value of absorption coefficient and that the circular dichroism appears with the approach of the wavelength of absorption edge. Contrary to the wide band semiconductors CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) the $Li_2B_4O_7$ do not possess magnetogyration as well as SiO_2 crystals do not possess the magnetogyration effect due to the symmetry conditions. The observed phenomenon is explained as the result of the presence absorption, spatial dispersion and the existence of the external magnetic field. In such a case the found effect is not contradiction to the Onzager principle.

Key words: magnetogyration, interband absorption, dichroism, Faraday effect

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Introduction

In our previous report [1] it was shown that magnetogyration phenomena exist in noncentrosymmetrical crystals that possess strong absorption. For example in CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3; 0.4) crystals on the wavelength of He-Ne laser radiation (λ=632.8nm) the magnetogyration coefficients are found to be $\delta_{333}=5.7\times10^{-11}Oe^{-1}$ and $\delta_{333}=2.45\times10^{-10}Oe^{-1}$ (x=0.3), $\delta_{333}=2.43\times10^{-10}Oe^{-1}$ (x=0.4), respectively. At the same time the Faraday effect coefficients for these crystals are of the order larger than magnetogyration one: $\alpha_{33}=5.05\times10^{-9}Oe^{-1}$ (CdS), $\alpha_{33}=9.27\times10^{-9}Oe^{-1}$ ($[Ga_{0.3}In_{0.7}]_2Se_3$), $\alpha_{33}=9.29\times10^{-9}Oe^{-1}$ ($[Ga_{0.4}In_{0.6}]_2Se_3$). It was also shown that magnetogyration rotation of the polarization plane is absent in transparent $Li_2B_4O_7$ as well as in SiO_2 crystals and $CdS_{0.22}Se_{0.78}$ and $CdS_{0.4}Se_{0.6}$ nanocrystals embedded in a borosilicate glass matrix due to the point symmetry limiting. In order to confirm our assumption that the magnetogyration effect, as an effect of the spatial dispersion induced by the magnetic field in non magnetic crystals appears only due to absorption we have conducted a spectral study of magnetogyration and the absorption coefficient in the above mentioned crystals the result of which is reported in the present paper.

Theoretical consideration

Let us consider the dielectric permitivity ε_{ij} of absorption media that consist on real $\varepsilon_{ij}^{(o)}$ and imaginary $i\varepsilon_{ij}`$ parts

$$\varepsilon_{ij}=\varepsilon_{ij}^{(o)}+i\varepsilon_{ij}`. \quad (1)$$

The expansion of the real and imaginary parts of dielectric permitivity by wave vector k_k (taking into account the spatial dispersion) lead to the relation

$$\varepsilon_{ij}=\varepsilon_{ij}^{(o)}+i\varepsilon_{ij}`=\varepsilon_{ij}^{(o1)}+i\gamma_{ijk}k_k+i\varepsilon_{ij}`^{(1)}-\gamma`_{ijk}k_k. \quad (2)$$

where γ_{ijk} – is antisymmetrical by i, j - indices third rank polar tensor, described gyration in dissipate media; $\gamma`_{ijk}$ – is symmetrical by $i$, $j$ - indices third rank tensor, described non reciprocity of refractive indices in dissipate media; $\varepsilon_{ij}^{(o1)}$ and $i\varepsilon_{ij}`^{(1)}$ – real and imaginary parts of dielectric permitivity, described refraction and absorption, respectively. In the presence of an external magnetic field eq.(2) can be rewritten as:

$$\begin{aligned}\varepsilon_{ij}&=\varepsilon_{ij}^{(o)}+i\varepsilon_{ij}`=\varepsilon_{ij}^{(o1)}+i\gamma_{ijk}k_k+i\varepsilon_{ij}`^{(1)}-\gamma`_{ijk}k_k=\\&=\varepsilon_{ij}^{(o2)}+i\varepsilon_{ij}`^{(2)}+i\alpha_{ijm}H_m-\alpha_{ijm}`H_m+\\&+i\gamma^{(o)}_{ijk}k_k-\gamma`^{(o)}_{ijk}k_k-\delta_{ijkm}k_kH_m-i\delta`_{ijkm}k_kH_m,\end{aligned} \quad (3)$$

where the first two terms $\varepsilon_{ij}^{(o2)}$ and $i\varepsilon_{ij}`^{(2)}$ describe refraction and absorption; the third $i\alpha_{ijm}H_m$ and the fourth term $\alpha_{ijm}`H_m$ – describe the Faraday effect and change of refractive indices linearly proportional to the magnetic field in the dissipate media; $i\gamma^{(o)}_{ijk}k_k$ and $\gamma`^{(o)}_{ijk}k_k$ terms describe the gyration and non reciprocity of refractive indices in dissipate gyrotropic media and finally the term $\delta_{ijkm}k_kH_m$ describes non reciprocity of refractive indices in gyrotropic, dissipate media in the presence of a magnetic field as well as the term $-i\delta`_{ijkm}k_kH_m$ describes the magnetogyration effect. Thus the magnetogyration can be considered as the addition to the effect of non reciprocity of refractive indices in gyrotropic media on the application of a magnetic field in the spectral range of sufficient absorption. Coefficient $\delta`_{ijkm}$ is axial fourth rank tensor antisymmetrical by i, j indices that can be rewritten according to duality condition as $\delta`_{ijkm}=e_{ijr}\eta_{rkm}$, where e_{ijr} - Levi-Civit unit tensor and η_{rkm} - is a third rank polar tensor with symmetry V^3 (about the tensors symmetry see [2]). On other hand (see [3]):

$$2n_o^2\kappa_{ij}=\varepsilon`^{(2)}_{ij}+\eta_{rkm}k_kH_m \quad (4)$$

where n_o - is refractive index, κ_{ij} - absorption coefficient. The specific rotation of the polarization plane in the case of magnetogyration (if to neglect the circular dichroism) can be written as

$$\rho=\pi\eta_{rkm}H_m/\lambda n_o, \quad (5)$$

where λ - wavelength. In such a case one can

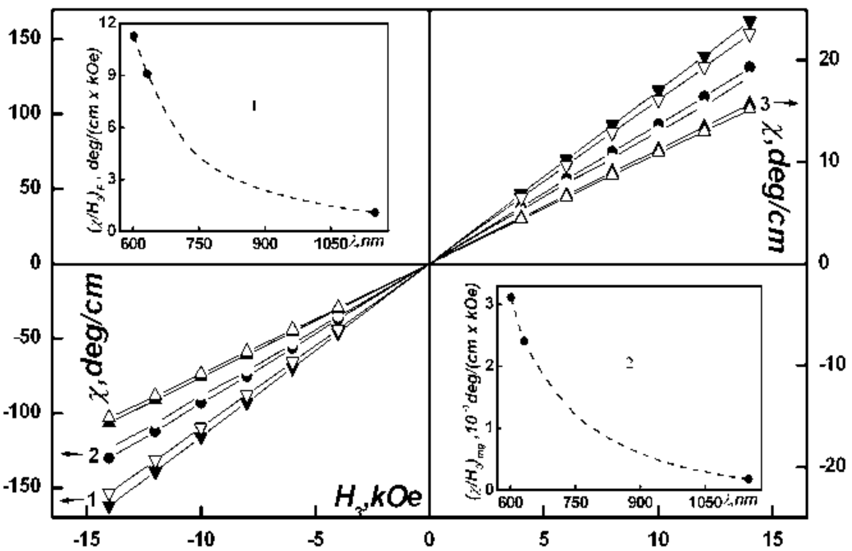

Fig. 1. The specific angle of rotation of the azimuth of polarization ellipse χ versus magnetic field H_3 in $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) crystals: 1-602nm, 2-632.8nm, 3-1150nm (full and open circuits and triangles correspond to the different sign of wave vector). Insert 1: Dispersion of χ/H_3 due to the Faraday effect; Insert 2: Dispersion of χ/H_3 due to the magnetogyration effect.

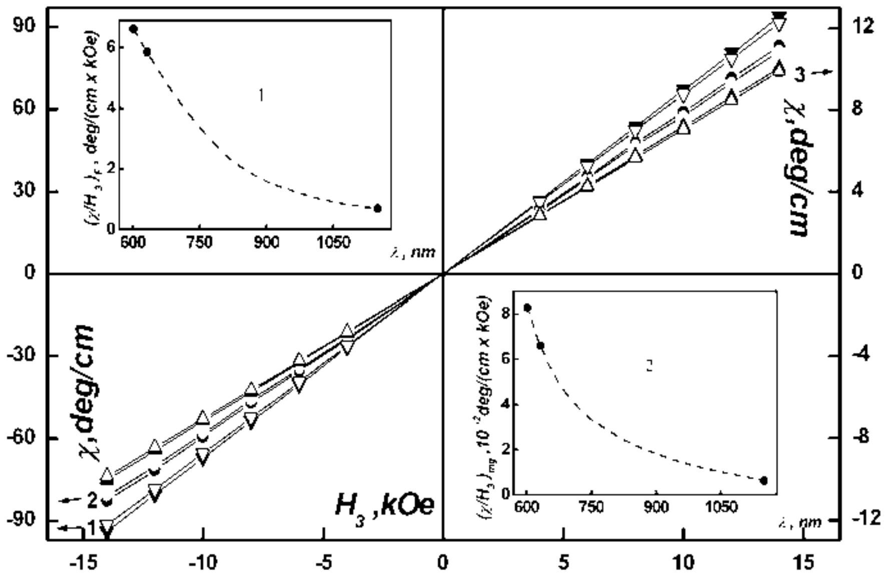

Fig. 2. The specific angle of rotation of the azimuth of polarization ellipse χ versus magnetic field H_3 in CdS crystals: 1-602nm, 2-632.8nm, 3-1150nm (full and open circuits and triangles correspond to the different sign of the wave vector). Insert 1: Dispersion of χ / H_3 due to the Faraday effect; Insert 2: Dispersion of χ / H_3 due to the magnetogyration effect.

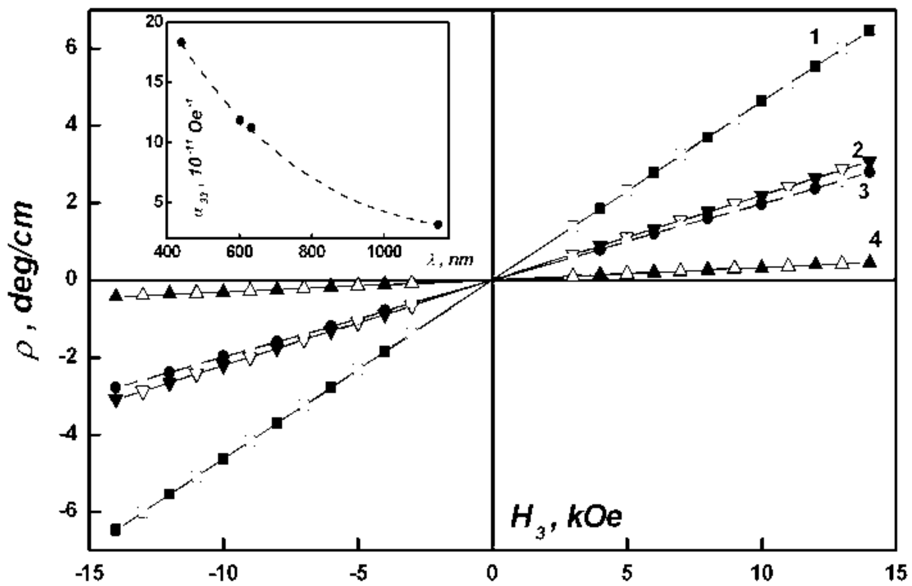

Fig. 3. The specific angle of rotation of the polarization plane versus magnetic field in $Li_2B_4O_7$ crystals: 1-440nm, 2-602nm, 3-632.8nm, 4-1150nm (full and open circuits, squares and triangles correspond to the different sign of the wave vector). Insert: Dispersion of Faraday effect coefficient.

obtain a relation between the rotation of the polarization plane and the absorption coefficient

$$\rho \propto \frac{2n_O\kappa\pi}{\lambda}, \qquad (6)$$

or

$$\chi \propto \frac{2n_O\kappa\pi}{\lambda}, \qquad (7)$$

where χ - is the turning of the azimuth of the ellipse of the polarization in the presence of circular dichroism. In conditions of the existence of sufficient absorption, eigen circular waves will possess different amplitudes due to the circular dichroism. It means that the value ρ has to be considered as rotation of the azimuth of the polarization ellipse but not as a plane of polari-

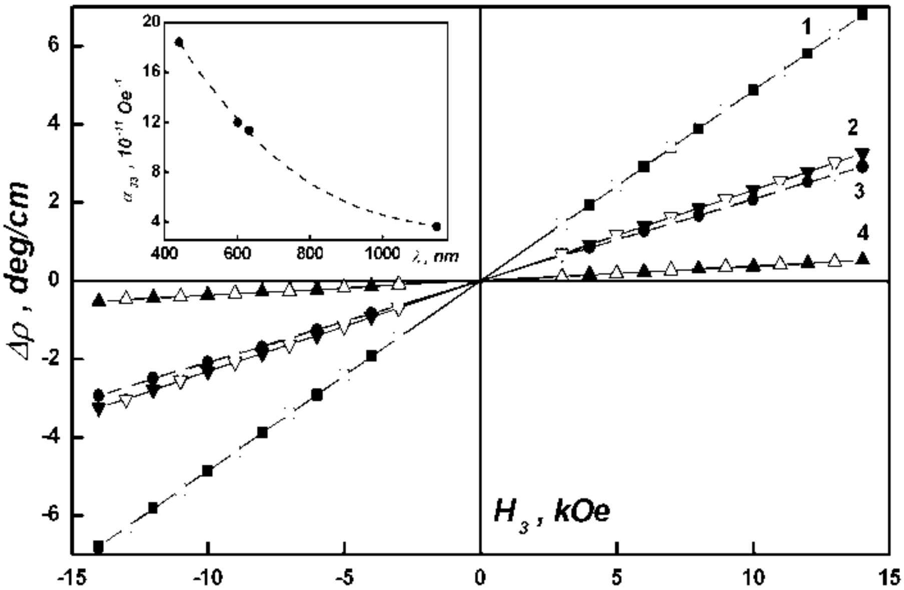

Fig. 4. The specific angle of rotation of the polarization plane versus magnetic field in SiO_2 crystals: 1-440nm, 2-602nm, 3-632.8nm, 4-1150nm (full and open circuits, squares and triangles correspond to the different sign of wave vector). Insert: Dispersion of Faraday effect coefficient

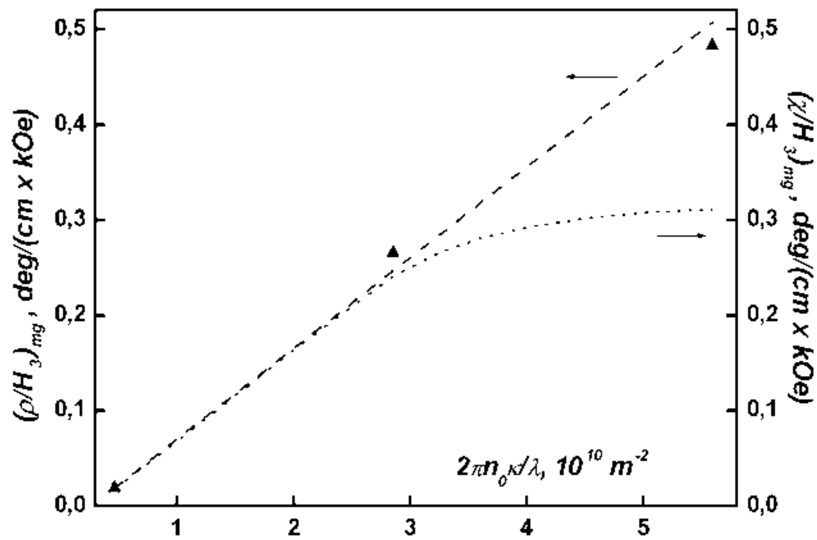

Fig. 5. The dependencies of $(\chi / H_3)_{mg}$ versus $2n_0\kappa\pi/\lambda$ for $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) crystals (open circuits, dot line). Dash line correspond to the ρ - value (full triangles) calculated with accounting of the circular dichroism.

zation. Thus the azimuth of rotation of the ellipse of polarization and ellipticity of the emergent wave can be described by the formula [4]:

$$\tan 2\chi = e^{-\delta}\tan\Delta , \tag{8}$$

$$\sin 2\phi = -\frac{1}{2}\left[\frac{1-e^{2\delta}}{1+e^{2\delta}}\right], \tag{9}$$

respectively, where $\phi=\arctan(b/a)$ - ellipticity, δ - circular dichroism coefficient and $\Delta=2\pi d(n_r-n_l)/\lambda$, n_r and n_l - refractive indices of right and left circular waves, respectively.

From eq.(7) it follows that

$$\tan 2\chi = e^{-\delta}\tan 2\rho , \tag{10}$$

since δ approaches 0 then χ approaches to ρ. But when $\delta \neq 0$ the angle of the azimuth of polarization ellipse turning will be smaller than ρ.

Experimental

The separation of the magnetogyration from the Faraday rotation was conducted by turning the sample 180° around the axis that is perpendicular to the optical axis and in such way changing the sign of η_{nlk} tensor. During the described operation the magnetogyrational rotation of the polarization plane $\rho_l \sim \eta_{nlk} H_l k_k$ will change the sign while the Faraday rotation should not do so.

The study of the Faraday effect and magnetogyration was conducted by the polarimetric setup that permits to determine the polarization plane rotation with the accuracy not more than 15″ and the application of magnetic field up to 15kOe. The optical radiation of He-Ne laser with the wavelength 602.0nm, 632.8nm and 1150.0nm and He-Cd laser with the wavelength 440nm was propagated along the optical axis of uniaxial crystals and the magnetic field was applied along the same direction.

The study of the ellipticity of an emergent wave was conducted by the direct measurement of intensities of light in extinction and transmission positions.

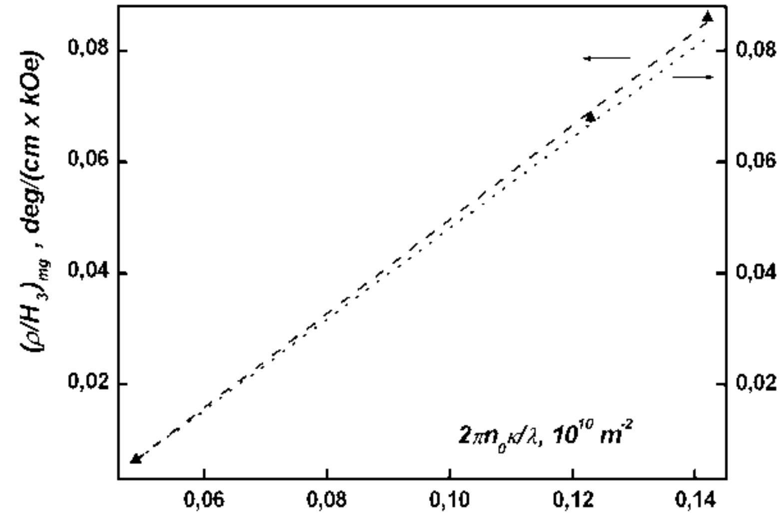

Fig. 6. The dependencies of $(\chi / H_3)_{mg}$ versus $2n_o\kappa\pi/\lambda$ for CdS crystals (open circuits, dotted line). Dash line corresponds to the ρ - value (full triangles) calculated taking into account the circular dichroism.

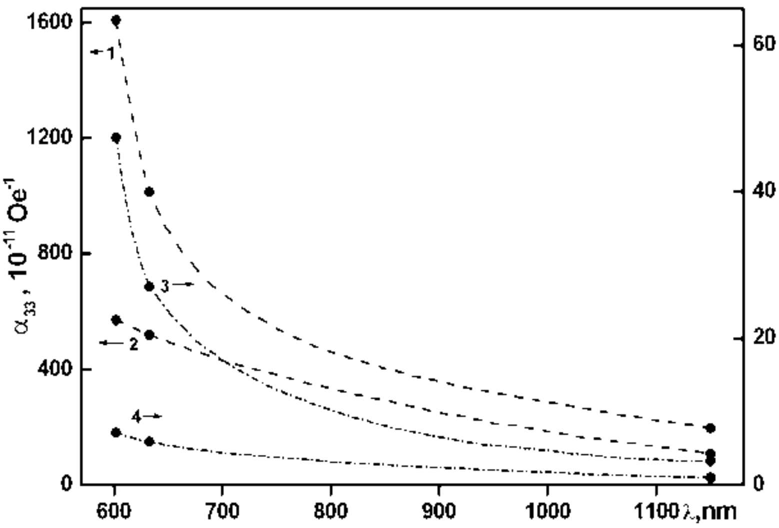

Fig. 7. The dispersion of Faraday effect and magnetogyration coefficients: 1,2-Faraday effect coefficient for $(Ga_{0.3}In_{0.7})_2Se_3$ and CdS crystals, respectively; 3,4-magnetogyration coefficient for $(Ga_{0.3}In_{0.7})_2Se_3$ and CdS crystals, respectively.

Results and discussion

The magnetic field dependencies of the rotation of polarization plane at different wavelength are presented in Figures 1-4. As it is visible from Figures 1,2 the magnetogyration exists in $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) and CdS crystals i.e. the change of the sign of the wave vector (or η_{nlk} tensor) leads to a different value of polarization plane rotation.

Contrary to $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) and CdS crystals the $Li_2B_4O_7$ and SiO_2 crystals do not exhibit the magnetogyration effect (Figures 3,4). It is necessary to note that quartz crystals can not possess longitudinal magnetogyration ($H_3 || k_3$) due to the symmetry limiting that leads to the η_{333} =0.

Since in the region of the absorption of $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) and CdS crystals circular dichroism exist one can discuss the dispersion of a specific angle of polarization azimuth rotation (Figures 1,2 (inserts 2)). In Figures 5,6 the dependencies of $(\chi / H_3)_{mg}$ versus $2n_o\kappa\pi/\lambda$ are presented for $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) and CdS, respectively. As it is clear these dependencies are not linear due to the existence of a circular dichroism.

The dependence of the measured values of the circular dichroism coefficient at the wavelength λ=1150nm, 632.8nm, 602nm are equal δ = 0.044; 0.097; 0.440 respectively for $(Ga_{0.3}In_{0.7})_2Se_3$ crystals and δ = 0.019; 0.032; 0.035 respectively for CdS crystals . With the help of eq.(10) one can calculate the values of the specific rotation of polarization plane taking into account the circular dichroism and determine the dispersion of magnetogyration and Faraday effect coefficients (Figure 7).

Conclusion

The dispersion of the magnetogyration effect is experimentally obtained in CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) crystals. It was found that magnitude of magnetogyration depend on the value of absorption coefficient and that the circular dichroism appeared with approaching to the wavelength of absorption edge. In the contrary to the wide band semiconductors CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3) the $Li_2B_4O_7$ do not possess magnetogyration as well as SiO_2 crystals do not possess the magnetogyration effect due to the symmetry condition. The observed phenomena is explained as the result of presence of absorption, spatial dispersion and existing of external magnetic field. In such a case the founded effect is not in contradiction to Onzager principle.

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