Magnetogyration in Absorbing Cubic $Bi_{12}GeO_{20}$ Crystals

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Abstract

The results for the Faraday effect and magnetogyration in non-centrosymmetric, non-polar $Bi_{12}GeO_{20}$ crystals are presented. Those phenomena are studied for the magnetic field applied along <111> direction and the light wavelengths of 632.8nm and 602nm. The values of the determined coefficients are equal to $\alpha_{11}=329.5\times10^{-11}$Oe^{-1}, $\delta_{321}=10.6\times10^{-11}$Oe^{-1} ($\lambda$=602nm) and $\alpha_{11}=321.3\times10^{-11}$Oe^{-1}, $\delta_{321}=3.5\times10^{-11}$Oe^{-1} ($\lambda$=632.8nm) for the Faraday effect and the magnetogyration, respectively.

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Key words: magnetogyration, absorption, $Bi_{12}GeO_{20}$ crystals

Introduction

In our previous studies [1,2] we have reported the first observations of magnetogyration (MG) effect in CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3; 0.4) crystals. The appearance of MG effect, manifested as an optical rotation additional to the Faraday one, in those non-ordered magnetic crystals has been explained by existence of essential absorption of light in CdS and $(Ga_xIn_{1-x})_2Se_3$ at the wavelength of measurements. Both CdS and $(Ga_xIn_{1-x})_2Se_3$ crystals are polar, wide-band semiconductor crystals. CdS crystals belong to the point group of symmetry 6mm, while $(Ga_xIn_{1-x})_2Se_3$ to the group 6. In frame of our approach, the possibility for the MG has followed from the expansion of dielectric permitivity tensor in magnetically non-ordered crystals in the external magnetic field, with taking spatial dispersion and absorption into account,

$$\begin{aligned}\varepsilon_{ij} = \varepsilon_{\iota j}^{(0)} + i\varepsilon_{ij}' = \varepsilon_{ij} + i\varepsilon_{ij}' + \\ +i\alpha_{ijm}H_m - \alpha_{ijm}'H_m + i\gamma_{ijk}k_k - \quad , \\ -\gamma_{ijk}'k_k - \beta_{ijkm}k_kH_m - i\delta_{ijkm}'k_kH_m\end{aligned} \qquad (1)$$

where the first two terms ε_{ij} and $i\varepsilon_{ij}$` describe ordinary refraction and absorption, the third ($i\alpha_{ijm}H_m$) and the fourth ($\alpha_{ijm}$`H_m) ones, respectively, the Faraday effect and the change of refractive indices in dissipative media proportional to the magnetic field, $i\gamma_{ijk}k_k$ and γ`$_{ijk}k_k$ refer respectively to the gyration and non-reciprocity of the refractive indices in dissipative gyrotropic media, the term $\beta_{ijkm}k_kH_m$ corresponds to non-reciprocity of refractive indices in dissipate gyrotropic media in the presence of magnetic field and, finally, the term $-i\delta$`$_{ijkm}k_kH_m$ produces the MG effect. Thus, the changes in the specific optical rotation ρ_n and the gyration tensor g_{nk} due to the MG may be written as

$$\rho_n=\delta_{nkm}k_kH_m, \quad g_{nk}=\delta_{nkm}H_m, \qquad (2)$$

with $\delta'_{ijkm} = e_{ijn}\delta_{nkm}$ and e_{ijn} being the Levi-Civit pseudo-tensor. The tensor δ_{nkm} in the relations (2) represents a third-rank polar tensor that can be non-zero only in non-centrosymmetric crystals.

Let us remind that in some early papers [3,4] the MG effect has been explained as a so-called "pseudogyration", the effect with the point symmetry ∞ that appears due to a combined influence of magnetic field and polarization P_l in pyroelectric crystals:

$$g_{nk} = A_{nklm}P_lH_m. \qquad (3)$$

At present, it is understood that the above approach for description of the additional optical rotation in magnetic field is incorrect from many points of view (on the other side, it is a change in the Faraday rotation, but not the gyration tensor, that has been really observed in [3,4] under the effect of electric field and spontaneous polarization in ferroelectric crystals, and the latter interpretation seems to be correct). Nevertheless, all of the experimental results for the MG obtained up to now concern the polar crystals only. The only exception, probably, is the experiments with SiO_2 crystals [2]. However, there is more to the quartz crystals than their non-polarity. They cannot manifest the MG since it is symmetry forbidden (in case of the light propagation and the magnetic field directed along *Z* axis) and the absorption in the visible spectral range is weak enough. Eventually, the MG effect has not been found in SiO_2 crystals.

The goal of the present work is to study the MG effect in non-centrosymmetric (but not pyroelectric or ferroelectric), absorbing crystals and therefore solve finally the problem of MG origin in non-ordered magnetic crystals, at least on the phenomenological level. From our viewpoint, one of the best choices would be $Bi_{12}GeO_{20}$ crystals that possess essential absorption in the visible spectral range [5]. They are non-centrosymmetric (the point symmetry group 23), though not polar.

Experimental

The Faraday effect and the MG have been studied using the polarimetric set-up that allowed us to apply magnetic fields up to 15kOe and determine the optical rotation with the accuracy not worth than 20″. The optical radiation of He-Ne laser with the wavelengths 602.0nm and 632.8nm propagated along <111> axis and the magnetic field has been applied along the same direction. With such a longitude experimental geometry, the field-induced Cotton-Mouton birefringence is not interfering with the optical rotation.

The separation of MG from the Faraday rotation has been carried out with rotating sample by 180° around the axis perpendicular to <111> direction in the cubic $Bi_{12}GeO_{20}$ crystal, thus changing the sign of the δ_{nkm} tensor. Under the described operation, the MG rotation of polarization plane would change its sign,

	H_1	H_2	H_3			H_1	H_2	H_3
g_{11}	0	0	0		g_{11}	0	0	0
g_{22}	0	0	0		g_{22}	0	0	0
g_{33}	0	0	0	→	g_{33}	0	0	0
g_{32}	δ_{321}	0	0		g_{32}	$-\delta_{321}$	0	0
g_{31}	0	δ_{321}	0		g_{31}	0	$-\delta_{321}$	0
g_{21}	0	0	δ_{321}		g_{21}	0	0	$-\delta_{321}$

while the Faraday rotation should remain invariant, i.e.

	H_1	H_2	H_3			H_1	H_2	H_3
ρ_1	α_{11}	0	0		ρ_1	α_{11}	0	0
ρ_2	0	α_{11}	0	→	ρ_2	0	α_{11}	0
ρ_3	0	0	α_{11}		ρ_3	0	0	α_{11}

.

The total rotation of the polarization plane due to the Faraday rotation ρ_F and the MG rotation ρ_{mg} in cases of light propagation along <111> and $<\bar{1}\bar{1}\bar{1}>$ directions may be written as

$$\rho = \rho_F + \rho_{mg}, \tag{4}$$

$$\rho = \rho_F - \rho_{mg}, \tag{5}$$

respectively. The MG and the Faraday coefficients have been calculated respectively with the formulae

$$\delta_{321} = \frac{\lambda n_0 \sqrt{3}}{\pi} \times \frac{\rho_{mg}}{H_{<111>}}, \tag{6}$$

$$\alpha_{11} = \frac{\lambda n_0}{\pi} \times \frac{\rho_F}{H_{<111>}}. \tag{7}$$

In order to avoid the photorefractive effect in $Bi_{12}GeO_{20}$ crystals, the duration of the exposition has been reduced to Δt=1min at the power of laser radiation equal to $P_{632.8nm}$=15mW and P_{602nm}=10mW.

Results and discussion

The change in the specific rotatory power produced with the magnetic field for $Bi_{12}GeO_{20}$ crystals is presented in Figure 1.

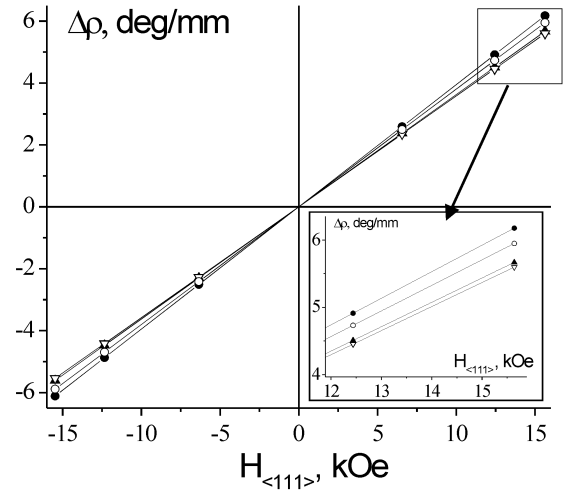

Fig. 1. Optical rotatory power versus magnetic field due to the Faraday effect and the MG for $Bi_{12}GeO_{20}$ crystals (full and open circles correspond to <111> and $<\bar{1}\bar{1}\bar{1}>$ directions of light propagation at λ=602nm; full and open triangles to <111> and $<\bar{1}\bar{1}\bar{1}>$ propagation directions at λ=632.8nm).

As seen from Fig. 1, the rotation of sample by 180° around the axis perpendicular to <111> direction or, what is the same, a sign change of the *k* vector, leads to different rotation angles for the same values of the magnetic field. This difference corresponds to the MG effect (Figure 2).

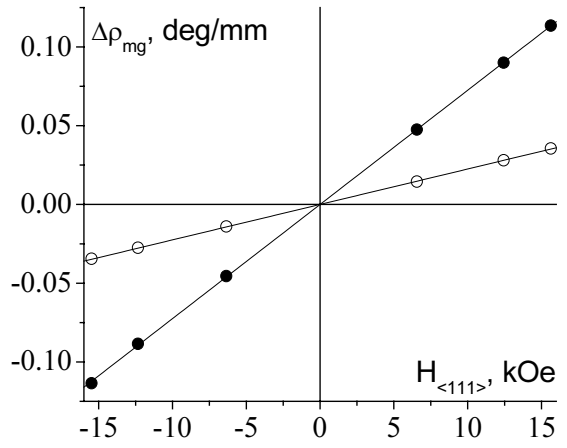

Fig. 2. Specific rotatory power due to MG versus magnetic field for $Bi_{12}GeO_{20}$ crystals (full and open circles correspond to the wavelengths λ=602nm and λ=632.8nm, respectively).

The calculated values of the Faraday and MG coefficients are $\alpha_{11}=329.5\times10^{-11}Oe^{-1}$, $\delta_{321}=10.6\times10^{-11}Oe^{-1}$ for the λ=602nm and $\alpha_{11}=321.3\times10^{-11}Oe^{-1}$, $\delta_{321}=3.5\times10^{-11}Oe^{-1}$ for λ=632.8nm. As we have earlier shown [2], the MG optical rotation increases linearly with increasing absorption coefficient. In order to make sure of this fact in our case, we have measured the absorption coefficient of $Bi_{12}GeO_{20}$ crystals (see Figure 3).

It has been found that the values of those coefficients are κ=0.249cm^{-1} and κ=0.215cm^{-1} for λ=602nm and λ=632.8nm, respectively. Basing on the said above, one can expect that the relation

$$\frac{\delta_{321}^{\lambda=602nm}}{\delta_{321}^{\lambda=632.8nm}}=\frac{\kappa^{\lambda=602nm}}{\kappa^{\lambda=632.8nm}} \qquad (9)$$

should be valid. However, obtain that $\frac{\delta_{321}^{\lambda=602nm}}{\delta_{321}^{\lambda=632.8nm}}=3.03$, while $\frac{\kappa^{\lambda=602nm}}{\kappa^{\lambda=632.8nm}}=1.15$.

Conclusions

1. The existence of the MG effect in non-polar crystals is established for the first time on the example of $Bi_{12}GeO_{20}$ crystals.
2. It is proven that the MG effect appears in non-ordered magnetic crystals owing to the

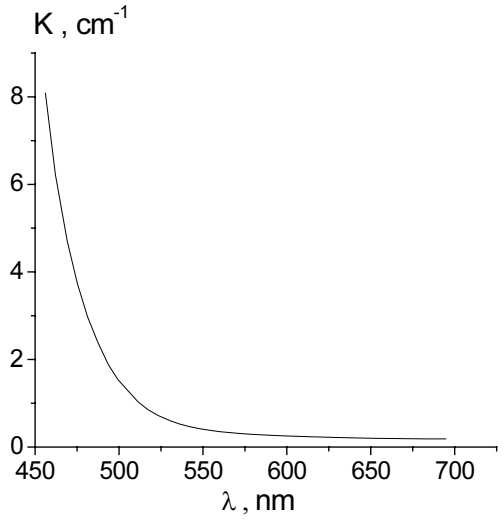

Fig. 3. Spectral dependence of the absorption coefficient for $Bi_{12}GeO_{20}$ crystals.

spatial dispersion and essential absorption.

3. The determined values of the Faraday and MG coefficients for $Bi_{12}GeO_{20}$ crystals are as follows:

a) $\alpha_{11}=322.6\times10^{-11}Oe^{-1}$, $\delta_{321}=3.5\times10^{-11}Oe^{-1}$ for the wavelength $\lambda=632.8$nm;

b) $\alpha_{11}=333.1\times10^{-11}Oe^{-1}$, $\delta_{321}=10.7\times10^{-11}Oe^{-1}$ for the wavelength $\lambda=602$nm.

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