Faraday effect in $AgGaGe_3Se_8$ crystals

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Abstract. We have studied experimentally the Faraday effect in $AgGaGe_3Se_8$ crystals. The Verdet constant V_F and the effective Faraday coefficient F'_{11} are determined at the light wavelength $\lambda = 632.8$ nm under the normal conditions. They are equal to $V_F = (69.5\pm2.8)$rad/(T×m)and $F'_{11} = 0.96F_{11}+0.04F_{33} = (8.36\pm0.33)\times10^{-13}$m/A, respectively. We have shown that, among magnetically non-ordered substances, $AgGaGe_3Se_8$ represents an efficient magnetooptic material.

Keywords: Faraday effect, Verdet constant, $AgGaGe_3Se_8$ crystals

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1. Introduction

Complex chalcogenide $AgGaGe_3Se_8$ belongs to the acentric point symmetry group mm2 [1]. It is an optically biaxial single crystal. Its calculated principal refractive indices are equal to $n_a = 2.769$, $n_b = 2.761$ and $n_c = 2.602$ at the light wavelength $\lambda = 632.8$ nm [1]. The crystalline lattice of $AgGaGe_3Se_8$ can be represented as a cluster formed by Se atoms surrounding a statistical mixture 0.25Ga +0.75Ge, with Ag atoms being located in the voids of the clusters [2]. In general, the $AgGaGe_3Se_8$ crystals are transparent in the spectral range from 600 to 16000 nm, although they manifest a number of absorption peaks located at 2844.1, 10020.0, 12853.5 and 13297.9 nm [3, 4].

A number of earlier studies have suggested that AgGaGe3Se8 represents the material that can be used in various optical industries. So, the electric, optical and thermoelectric properties of $AgGaGe_3Se_8$ indicate that it may find its practical applications in the nonlinear optics and fabrication of heterojunctions, along with wide-gap II–VI chalcogenides that are typically of *n*-type [5]. The studies of mixed crystals $Ag_xGa_xGe_{1-x}Se_2$ have shown that $AgGaGe_3Se_8$ occupies a special position in this family and deserves further attention, especially in relation to its composition stability in the growth process [1]. The investigations of photoinduced anisotropy in the $AgGaGe_3Se_8$:Cu crystals at $\lambda = 532$ and 1300 nm have revealed the photoinduced changes proper for disordered materials, although the irreversible background is less than that observed for the disordered substances and, moreover, $AgGaGe_3Se_8$:Cu crystals are more stable to the laser irradiation [2]. The spectral kinetics induced in $AgGaGe_3Se_8$:Cu with an infrared laser ($\lambda = 10600$ nm) can be used for controlling the power density of CO_2 lasers [6]. The reversible piezoelectric effect photoinduced in $AgGaGe_3Se_8$ at $\lambda = 532$ nm can also be applied in laser-operated piezotronic devices [7].

The studies of acoustic anisotropy in the $AgGaGe_3Se_8$ crystals [8] have given some reasons to believe that $AgGaGe_3Se_8$ can turn out to be one of the best acoustooptic materials for the infrared spectral range. At the same time, the other optical properties of $AgGaGe_3Se_8$ are studied in a much less detail. The aim of the present work is to investigate the Faraday rotation in these crystals.

2. Experimental conditions and procedure

Single crystals of $AgGaGe_3Se_8$ were obtained with a Bridgman–Stockbarger method. The process was performed in a vertical two-zone furnace, using a gradual growth of crystal onto a single-crystalline seed formed in a specially-shaped bottom part of container under prescribed conditions. The technology was described in detail in Ref. [9]. In our experiments the rate of lowering of the container in the steady-temperature profile of the furnace was 3 mm/day. The temperatures of the growth zone (1200 K) and the annealing zone (710 K), and use of a steel disk between them created the temperature gradient of 4.8 K/mm at the solid-melt interface. After completion of crystallization of the melt, its content was moved to the bottom zone of the furnace and annealed for 100 hrs. The process ended in synchronous cooling of both zones of the furnace down to the room temperature at the rate of 10 K/hr. An example of as-grown single-crystalline boules of $AgGaGe_3Se_8$ is shown in Fig. 1.

Fig. 1. As-grown $AgGaGe_3Se_8$ single crystal illuminated from below by white light.

Under normal conditions and at the light wavelength $\lambda = 632.8$ nm, the plane containing the optic axes of $AgGaGe_3Se_8$ coincides with the crystallographic plane *ca*. The *c* axis represents the acute bisector of the angle 2θ between the optic axes. The calculated angle θ between the optic axes and the *c* axis is equal to 11.6 deg [1].

It is known that the Faraday effect manifests itself in rotation of polarization plane when a linearly polarized light propagates along an optically isotropic direction (i.e., along one of the optic axes) and a magnetic field is applied in the same direction. Under these conditions the magnetically perturbed optical-frequency dielectric impermeability tensor B_{jk}, the specific optical rotation angle $\Delta\rho_l$ and the Verdet constant V_F are given by the following relations:

$$B_{jk} = B_{jk}^0 + ie_{jkl}F_{lm}H_m, \tag{1}$$

$$\Delta\rho_l = \frac{\pi n_b^3}{\lambda} F_{lm}H_m, \tag{2}$$

$$V_F = \frac{\pi \bar{n}^3}{\lambda} F_{lm}. \tag{3}$$

Here B_{jk}^0 implies the impermeability tensor in the absence of any external magnetic field H_m, e_{jkl} the unit antisymmetric axial Levi-Civita tensor, n_b the refractive index for the light propagating along the optic axis, $\bar{n}$ the mean refractive index along the given propagation direction, and F_{lm} the Faraday tensor. For the point group mm2 this tensor is as follows:

$$\begin{array}{c|ccc} & H_1 & H_2 & H_3 \\ \hline \Delta\rho_1 & \frac{\pi\bar{n}^3}{\lambda}F_{11} & 0 & 0 \\ \Delta\rho_2 & 0 & \frac{\pi\bar{n}^3}{\lambda}F_{22} & 0 \\ \Delta\rho_3 & 0 & 0 & \frac{\pi\bar{n}^3}{\lambda}F_{33} \end{array} . \tag{4}$$

where the crystallographic axes *a*, *b*, *c* correspond respectively to the principal axes *Z*, *Y*, *X* of the Fresnel ellipsoid (abbreviated as the axes 3, 2, 1). Application of the magnetic field along the optic axis induces the two nonzero filed components, $H_1 = H\cos\Theta = 0.9796H$ and $H_3 = H\sin\Theta = 0.2011H$.

Suppose that the light wave vector and the magnetic field are parallel to the optic axis. Then the magnetically induced rotation of the polarization plane reduces to

$$\Delta\rho_{X'} = \frac{\pi n_b^3}{\lambda} F_{11}^{'} H_{X'} , \tag{5}$$

where $F_{11}^{'}$ denotes the effective Faraday coefficient corresponding to the rotated coordinate system, of which $X^{'}$ axis coincides with the optic axis:

$$F_{11}^{'} = F_{11}\cos^2\Theta + F_{33}\sin^2\Theta = 0.96F_{11} + 0.04F_{33} = \frac{\lambda}{\pi n_b^3}\left(\frac{\Delta\rho_{X'}}{H_{X'}}\right). \tag{6}$$

Hence, one can readily determine the combined Faraday coefficient $0.96F_{11} + 0.04F_{33}$ for the $AgGaGe_3Se_8$ crystals, using a simple direct technique for measuring the optical rotatory power for the light propagating along one of the optic axes.

To measure the Faraday rotation, we employed a single-ray polarimetric technique. In our experiment, a He-Ne laser with the wavelength of $\lambda = 632.8$ nm was used as a light source. The longitudinal magnetic field was applied using an electromagnet. A crystal sample thickness was $d = 1.63$ mm . A plane-parallel crystalline plate was placed in between the poles of electromagnet. Finally, the sample was oriented such that the centre of the conoscopic rings was aligned with the light beam centre.

3. Results and discussion

The dependence of specific optical rotation upon the external magnetic field measured for the $AgGaGe_3Se_8$ crystals is presented in Fig. 2. This dependence is indeed linear, as it should be for the case of Faraday rotation. The combined (effective) Faraday coefficient $F_{11}^{'}$ calculated with a standard linear fitting of the experimental data is equal to $(8.36 \pm 0.33)\times 10^{-13}$ m/A , while the appropriate Verdet constant V_F amounts to (69.5 ± 2.8) rad/(T×m) .

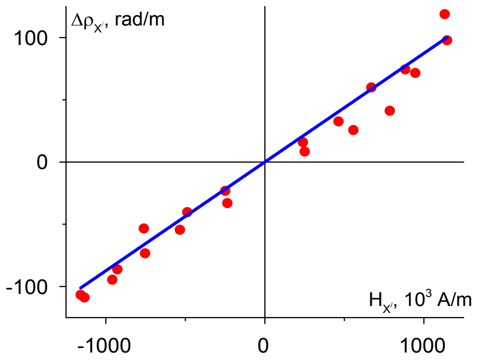

Fig. 2. Dependence of specific rotatory power for $AgGaGe_3Se_8$ on the magnetic field, as obtained experimentally at $\lambda = 632.8$ nm : circles correspond to experimental data and straight line to linear fitting.

Our experimental results are to be compared with the data reported earlier for the known magnetooptic materials. For instance, the Verdet constant is equal to 82 $\mathrm{rad/(T\times m)}$ for Tl_3AsS_4 crystals [10] and 115 $\mathrm{rad/(T\times m)}$ for $Sn_2P_2S_6$ crystals [11]. Hence, $AgGaGe_3Se_8$ should be classified as an efficient magnetooptic material, at least among magnetically non-ordered crystalline substances.

4. Conclusion

We have experimentally determined the effective Faraday coefficient $F_{11}^{'} = 0.96F_{11} + 0.04F_{33}$ and the Verdet constant V_F for the $AgGaGe_3Se_8$ crystals at the laser wavelength $\lambda = 632.8\ \mathrm{nm}$ under the normal conditions. Our experimental geometry corresponds to light propagation and magnetic field directions parallel to one of the optic axes. The parameters mentioned above are equal to $F_{11}^{'} = (8.36 \pm 0.33)\times 10^{-13}$ m/A and $V_F = (69.5 \pm 2.8)\ \mathrm{rad/(T\times m)}$. Following from these values, which are close to the parameters of Tl_3AsS_4 and $Sn_2P_2S_6$, the $AgGaGe_3Se_8$ crystals can be regarded as an efficient non-ordered magnetooptic crystalline material.

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Анотація. *Експериментально досліджено ефект Фарадея в кристалах* $AgGaGe_3Se_8$. *На довжині хвилі оптичного випромінювання* $\lambda = 632{,}8$ нм *і за нормальних умов визначено сталу Верде і ефективну компоненту тензора ефекту Фарадея. Вони дорівнюють* $V_F = (69{,}5 \pm 2{,}8)$ рад/(Тл×м) *і* $F'_{11} = 0{,}96F_{11} + 0{,}04F_{33} = (8{,}36 \pm 0{,}33) \times 10^{-13}$ м/А, *відповідно. Показано, що кристали* $AgGaGe_3Se_8$ *є досить ефективними магнітооптичними матеріалами поміж магнітно невпорядкованих середовищ.*