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MAGNETO-OPTIC STUDY OF CHROMIUM DOPED $BI_{12}SIO_{20}$

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ABSTRACT *Faraday rotation in $Bi_{12}SiO_{20}$:Cr (BSO:Cr) has been investigated on (100) direction at room temperature using refractive index data in the spectral region 700 – 850 nm. Verdet constant (V) spectrum is determined in the same spectral region for this crystal. The Verdet constant spectrum of pure BSO can be described by the linear dependence V^{-1} (λ^{2}) (λ is the wavelength of the light). The Cr-ions in the sillenite crystal lattice cause a deviation of Verdet constant from the mentioned linear dependence in the spectral region of the absorption impurity structure. The magneto-optic anomaly factor γ is also investigated.*

KEY WORDS: *3d transition metals, Faraday rotation, Verdet constant, magneto-optic anomaly factor*

INTRODUCTION

Bismuth oxide compounds such as the sillenite-type $Bi_{12}MO_{20}$ (BMO, where M = Si, Ge, Ti) crystals are being extensively studied because of their potential applications including dynamic holography, optical information processing, optical phase conjugation and real-time interferometry [1–5]. The defect identification, including the dopant ions involved, their valence and local symmetry is essential because this information may guide the efforts for optimization of the synthesis conditions to obtain the intended material properties. The dopants in the sillenite crystals form the subband of the deep or shallow impurity levels in the forbidden band. This fact leads to the manifestation of paramagnetic or diamagnetic properties of the doped sillenite in magnetic field.

In this paper, we present a detailed magneto-optic study of the paramagnetic behavior of Cr ions in doped $Bi_{12}SiO_{20}$ in the spectral region 700 – 850 nm.

MATERIALS AND SAMPLES PREPARATION

$Bi_{12}SiO_{20}$ crystals belong to the sillenite family of materials with the space symmetry I23 with a body centered cubic unit cell (a = 10.102 Å), which contains 24 Bi^{3+} ions, 2 Si^{4+} ions and 40 O^{2-} ions (nominal valences). Two structural elements can be distinguished, the SiO_4 regular tetrahedron and the BiO_7 polyhedron [6]. The former exists at the corners and at the center of the cubic unit cell. In the BiO_7 polyhedron, each of the Bi^{3+} ions is surrounded by 7 oxygen atoms and is coordinated in a pseudo-octahedral configuration, in which the oxygen atom at one corner is replaced by two atoms at somewhat larger distance. BSO single crystals were grown in air by the Czochralski method from a melt containing a mixture of high purity (99.9999%) oxides including Bi_2O_3 and SiO_2 in a 6:1 molar ratio [7]. Platinum crucibles of 60 mm in diameter and 80 mm in height were used as containers. The crystals were grown in a <001> direction under conditions of low temperature gradient over the solution (5–7 ^{o}C/cm), at a growth rate of 0.7 mm/h and a rotation rate of 20 rpm. Fully facetted and optically homogeneous crystals of 35 mm in diameter and 50 mm in height were obtained. The starting chromium dopant was introduced into the melt solution in the form of the oxide Cr_2O_3. The analysis by atomic absorption spectrometry shows that they are present in the crystal at concentration of [Cr] = 4.9×10^{18} cm^{-3}. This corresponds to relative concentration [Cr]/[Si] = 0.25%.

EXPERIMENTAL RESULTS AND DISCUSSION

The magneto-optic Faraday effect presents the connection between optics, magnetism and atomic physics. The effect occurs when the rotation of a linearly polarized wave passes through a thickness of a transparent medium. However, rotations of polarized light are not only limited to optically active materials, but also including some optically inactive materials exposed to high magnetic field. In magnetized medium the refractive indices for right- and left-handed circularly polarized light are different. The precession of the angular momentum of an electron orbiting the nucleus leads to different indices of refraction for rightly or leftly polarized light. This leads to a rotation of plane polarized light. The rotation angle φ and refractive index n are related by the formula [8]:

$$\varphi = \frac{\pi\varepsilon_2}{\lambda n} d. \qquad (1)$$

The magneto-optic anomaly factor γ can be taken as a measure of the degree of covalency that exists in the bonds connecting the ions and atoms [9].

$$\gamma = \frac{\varphi}{\frac{e}{2mc^2}\lambda D} \qquad (2)$$

In the paramagnetic materials, the anomaly factors γ can vary with the wavelength of the incident light, even if there is only one a absorption frequency contributing to dispersion. The dispersivity of the investigated crystal can be presented by the following equation:

$$D = -\frac{\lambda}{c}\frac{d^2n}{d\lambda^2}. \quad (3)$$

The magneto-optic rotation in many crystals, glasses and solutions is expressible by the Becquerel's formula [10]:

$$V = \gamma\frac{e}{2mc^2}\lambda\frac{dn}{d\lambda}. \quad (4)$$

Equation (2) is substituted in equation (4) after the substitution of formulas (1) and (3) in (2). The final result is formula (5):

$$V = -\frac{cd\alpha}{2\lambda\frac{d^2n}{d\lambda^2}}\frac{dn}{d\lambda}. \quad (5)$$

The anomaly factor γ_{ion} for the chromium ions is calculated from the equation [10]:

$$\gamma_{ion} = \frac{[\Omega_i]_M}{\frac{e}{2mc^2}\lambda[D_i]_M}. \quad (6)$$

The equation (7) is obtained from formulas (4) and (6).

$$\frac{[\Omega_i]_M}{[D_i]_M} = \left[\frac{V}{\frac{dn}{d\lambda}}\right] \quad (7)$$

The spectral dependence $n(\lambda)$ of chromium doped BSO is presented in figure 1. The dependence $1/\varphi(\lambda^2)$ is shown in figure 2. The Verdet constant as a function of wavelength λ is obtained in figure 3. The magneto-optic anomaly factor γ and the dependence $[\Omega_i]_M/[D_i]_M(\lambda)$ are presented respectively in figures 4 and 5. All values of the Verdet constant are negative in the investigated spectral region. This is the proof for the manifestation of paramagnetism of the chromium in doped $Bi_{12}SiO_{20}$ [11]. The covalency of the bonds Cr-O in the oxygen substructures of doped crystal changes constantly in the spectral region 700-850 nm. The attitude $[\Omega_i]_M/[D_i]_M$ as a function of wavelength λ shows the anisotropy of chromium rotativity and dispersivity.

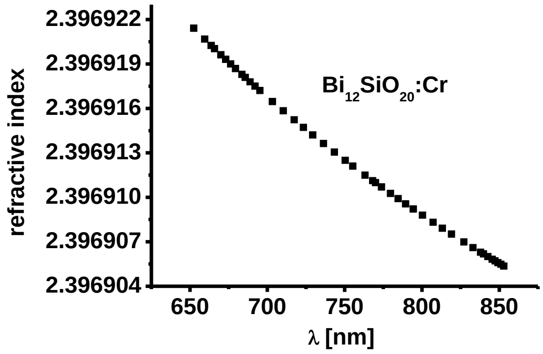

Figure 1 The refractive index n of $Bi_{12}SiO_{20}$:Cr in the spectral region 700 – 850 nm.

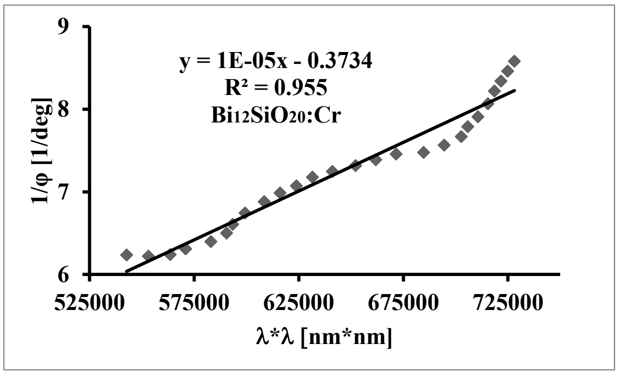

Figure 2 The linear dependence 1/φ [deg^{-1}] for $Bi_{12}SiO_{20}$:Cr in the spectral region 700 – 850 nm.

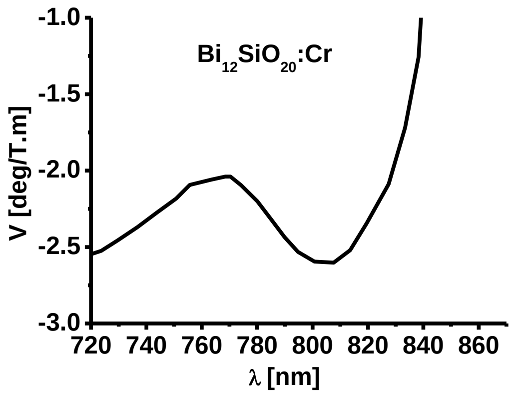

Figure 3 The Verdet constant for $Bi_{12}SiO_{20}$:Cr in the spectral region 700 – 850 nm.

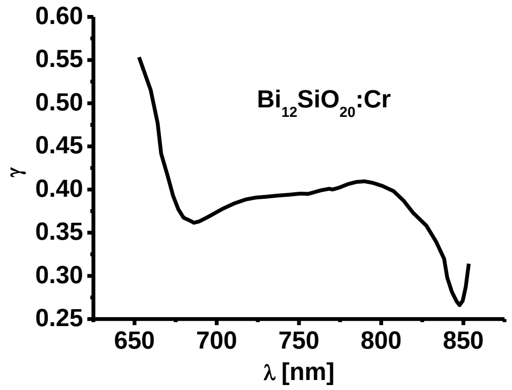

Figure 4 The magneto-optic anomaly factor γ for $Bi_{12}SiO_{20}$:Cr in the spectral region 700 – 850 nm.

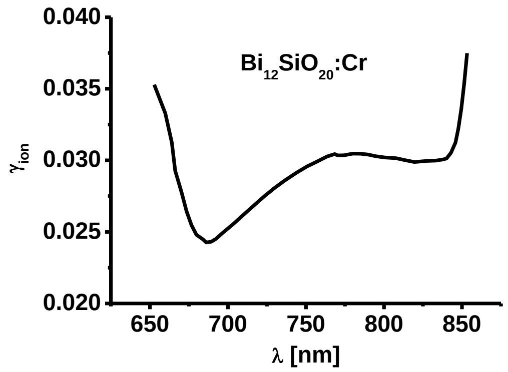

Figure 5 The attitude of the molecular rotativity $[\Omega_i]_M$ and the molecular dispersivity $[D_i]_M$ as a function of wavelength λ for $Bi_{12}SiO_{20}$:Cr.

CONCLUSIONS

In this work, we have been obtained the anomaly dispersion of magnetic rotation (ADMR) of chromium ions in doped $Bi_{12}SiO_{20}$. As it is known, ADMR is connected with the nature of electron levels of ions and their configuration and conformation. In this connection, the next step of our investigation is in this direction. As it is known, the Faraday effect due to paramagnetic ions is much stronger than that of diamagnetic lattice with the size of the effect strongly dependent on the choice of the paramagnetic ions and their density in the material. This choice is very important for the future applications of the investigated doped materials. Therefore we will continue to study their magneto-optical properties.

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