Effect of a magnetic field on the circular photovoltaic current in germanosillenite single crystals

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It has been discovered that a magnetic field affects the circular bulk photovoltaic effect. The results confirm an earlier suggestion that the thermalization of carriers may be accompanied by a transition from a band conductivity to a hopping conductivity.

The uniform illumination of homogeneous crystals without a symmetry center in a magnetic field generates a steady-state magnetophotovoltaic current[1] $J_i^{B_j}$ given by

$$J_i^{B_j} = S_{ijkl} B_j E_k E_l^* + Q_{ijk} B_j i(\mathbf{E}\times\mathbf{E}^*)_k . \tag{1}$$

Here E_k and E_l are the components of the light polarization vector, B_j is the magnetic field, and $i(\mathbf{E}\times\mathbf{E}^*)$ determines the degree of circular polarization of the light (σ):

$$i(\mathbf{E}\times\mathbf{E}^*) = \sigma \frac{\mathbf{q}}{|\mathbf{q}|} I , \tag{2}$$

where $\mathbf{q}$ is the photon wave vector. The first term on the right side of (1) describes the magnetophotovoltaic effect for linearly polarized light (the linear magnetophotovoltaic effect), while the second term describes the magnetophotovoltaic effect for circularly polarized light (the circular magnetophotovoltaic effect). The magnetophotovoltaic effect can be obtained from the bulk photovoltaic effect[2,3] by expanding the bulk photovoltaic current J_i in the magnetic field. The elementary mechanism for the magnetophotovoltaic effect involves both the Hall component of the ballistic photovoltaic current and the magnetically induced asymmetry of the photoexcitation of carriers.[4,5]

The linear magnetophotovoltaic effect was detected experimentally for $LiNbO_3$:Fe and ZnS in Refs. 6–8. In the present letter we report a circular magnetophotovoltaic effect in single crystals of the piezoelectric $Bi_{12}GeO_{20}$. A circular bulk photovoltaic effect has been observed previously[9] in $Bi_{12}GeO_{20}$. To observe the circular effect, we used a modulation procedure for measuring the photovoltaic current[9,10] and its Hall component in a magnetic field $B_y \lesssim 1$ T.

We studied single-crystal wafers with dimensions of 6.3×5.7×1.7 mm along the x, y, and z axes, which coincide with $\langle 100 \rangle$ directions. Semitransparent nickel electrodes A where deposited on a (001) face for measurements of the circular photovoltaic current J_z, while electrodes B were used to measure its Hall component $J_x^{B_y}$ (Fig. 1). The crystal is illuminated with the beam from a He-Cd laser, 4 ($\lambda = 440$ nm, $I = 3.6\times 10^{-3}$ W), through an electrooptic modulator 3, whose path difference is adjusted by a voltage with a meander waveform with a frequency of 19.3 Hz and an amplitude equal to the half-wave voltage. At the same time, a static voltage is applied from source 9 through switch 6 to modulator 3. This static voltage shifts the working

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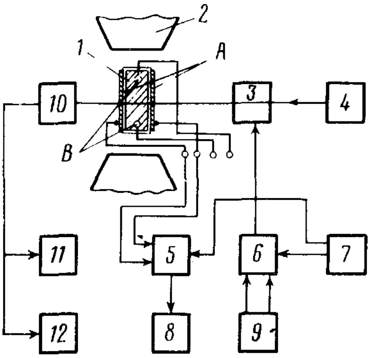

FIG. 1. The measurement arrangement. 1—Crystal with semitransparent (*A*) and Hall (*B*) contacts; 2—electromagnet; 3—electrooptic modulator; 4—He-Cd laser; 5—synchronous nanovoltmeter; 6—switch; 7—reference-signal oscillator; 8—recording potentiometer; 9—static voltage source; 10—photodetector; 11—tuned amplifier; 12—dc amplifier.

point of the modulator in such a way that the positive and negative half-periods of the meander correspond to positive (σ^+) and negative (σ^-) circular polarizations of the light or to a linear polarization of the light with a mutually perpendicular direction of the polarization vector **E**. By varying the bias voltage, we can change the sign of the circular polarization with respect to the reference voltage from an oscillator.[7] Our pulsed-modulation procedure simplifies the task of distinguishing the circular and linear effects and also reduces the effect of the parasitic amplitude modulation of the light. The polarization of the light is studied with a photodetector and analyzer 10. The depth of the parasitic intensity modulation does not exceed 0.1%. The currents J_z and $J_x^{B_y}$ are measured by a Unipan 232 B synchronous nanovoltmeter with an input impedence of 50 MΩ.

According to the symmetry point group of the crystal, 23, the circular photovoltaic current J_z and its Hall component $J_x^{B_y}$ are given by

$$J_z = I\gamma_{zz}\sigma\,, \tag{3}$$

$$J_x^{B_y} = IB_y Q_{xyz}\sigma\,, \tag{4}$$

where γ_{zz} and Q_{xyz} are the only nonvanishing components of the tensor of the circular bulk photovoltaic effect and that of the circular magnetophotovoltaic effect, and I is the light intensity. The value that we find, $\gamma_{zz} \simeq 3\times10^{-10}$ A·cm/W (for an absorption coefficient $\alpha^* \simeq 14$ cm^{-1}) agrees satisfactorily with the result given in Ref. 9. Figure 2

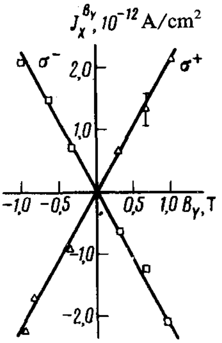

FIG. 2. $J_x^{B_y}$ versus the magnetic field B_y for different signs of the circular polarization of the light.

shows the results of the $J_x^{B_y}$ measurements, which can be summarized as follows. In accordance with (4), the sign of the Hall current $J_x^{B_y}$ changes when the sign of the circular polarization of the light (σ) or that of the magnetic field B_y is changed. The Hall current depends linearly on B_y at $B_y \leqslant 1$ T. The unthermalized carriers are electrons. According to Refs. 6–8, the mobility of unthermalized electrons, μ_H, can be determined from (3) and (4):

$$\mu_H = \frac{1}{B} \frac{J_x^{B_y}}{J_z} = \frac{Q_{xyz}}{\gamma_{zz}} . \tag{5}$$

Substituting $J_z \simeq 1.5 \times 10^{-11}$ A/cm^2 and the value of $J_x^{B_y}$ from Fig. 2 into (5), we find $\mu_H \simeq 1400 \pm 200$ cm^2/(V·s). According to Refs. 11 and 12, the thermalized electron mobility in $Bi_{12}GeO_{20}$, determined by a time-of-flight method, depends strongly on the filling of traps and varies over the range $\mu_T \simeq 10^{-6}$–10^{-2} cm^2/(V·s). Such low values of μ_T are associated with the hopping-conductivity mechanism which has been reliably established in these crystals. Consequently, during the thermalization of electrons in $Bi_{12}GeO_{20}$, their mobility decreases by more than five orders of magnitude, confirming Malinovskiĭ's suggestion[13] that the thermalization of carriers is accompanied by a transition from a band conductivity to a hopping conductivity.

[1] E. L. Ivchenko and G. E. Pikus, in: Problemy sovr. fiziki (Problems of Modern Physics), Nauka, Moscow, 1980, p. 275.

[2] V. M. Fridkin and B. N. Popov, Usp. Fiz. Nauk **126**, 657 (1978) [Sov. Phys. Usp. **21**, 981 (1978)].

[3] V. I. Belinicher and B. I. Sturman, Usp. Fiz. Nauk **130**, 415 (1980) [Sov. Phys. Usp. **23**, 199 (1980)].

[4] E. L. Ivchenko, Yu. B. Lyanda-Geller, G. E. Pikus, and R. Ya. Rasulov, Fiz. Tekh. Poluprovodn. **18**, 93 (1984) [Sov. Phys. Semicond. **18**, 55 (1984)].

[5] E. L. Ivchenko, G. E. Pikus, and R. Ya. Rasulov, Fiz. Tverd. Tela (Leningrad) **26**, 3362 (1984) [Sov. Phys. Solid State **26**, 2020 (1984)].

[6] V. M. Fridkin and B. N. Popov, Dokl. Akad. Nauk SSSR **256**, 63 (1980) [Sov. Phys. Dokl. **26**, 45 (1981)].

[7] A. P. Levanyuk, A. R. Pogosyan, and E. M. Uyukin, Dokl. Akad. Nauk SSSR **256**, 60 (1980) [Sov. Phys. Dokl. **26**, 43 (1981)].

[8] V. M. Fridkin, V. G. Lazarev, Yu. É. Levin, and A. I. Rodin, Pis'ma Zh. Eksp. Teor. Fiz. **38**, 159 (1983) [JETP Lett. **38**, 186 (1983)].

[9] M. P. Petrov and A. I. Grachev, Fiz. Tverd. Tela (Leningrad) **22**, 1671 (1980) [Sov. Phys. Solid State **22**, 975 (1980)].

[10] S. K. Esayan, V. V. Lemanov, and A. Y. Maksimov, Ferroelectric Lett. **2**, 93 (1984).

[11] R. V. Lenzo, J. Appl. Phys. **43**, 1107 (1972).

[12] V. Kh. Kostyuk, A. Yu. Kudzin, and G. Kh. Sokolyanskiĭ, Fiz. Tverd. Tela (Leningrad) **22**, 2454 (1980) [Sov. Phys. Solid State **22**, 1429 (1980)].

[13] V. K. Malinovskiĭ and B. I. Sturman, Fiz. Tverd. Tela (Leningrad) **22**, 3678 (1980) [Sov. Phys. Solid State **22**, 2153 (1980)].

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