Hall effect for bulk photovoltaic current in the piezoelectric ZnS

V. M. Fridkin, V. G. Lazarev, Yu. É. Levin, and A. I. Rodin
Institute of Crystallography, Academy of Sciences of the USSR, State University at Rostov-on-Don and Pedagogical Institute at Rostov-on-Don

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The temperature dependence of the mobility of nonequilibrium carriers, which are responsible for the bulk photovoltaic effect (BPE), is measured for the first time. In contrast to the usual photo-Hall mobility, the mobility of holes responsible for BPE does not depend on temperature.

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The bulk photovoltaic effect (BPE) can be described as follows. Uniform illumination of a homogeneous crystal lacking an inversion center by a linearly or circularly polarized light produces a stationary current, whose magnitude and direction depend on the illumination direction and on the orientation of the polarization plane of light.[1] For linearly polarized light, the BPE is described by a tensor of rank 3 α_{ijk}

$$J^{i}_{\text{pv}} = \alpha_{ijk} E_j E^*_k \quad , \tag{1}$$

where J^{i}_{pv} is the stationary photovoltaic current, and E_j and E_k are the projections of the polarization vector of the light. The components of the photovoltaic tensor α_{ijk} differ from zero for 20 point groups in which there is no inversion center.

The microscopic theory indicates two possible mechanisms for the BPE. The first ("ballistic") mechanism is related to the asymmetry of the momentum distribution function of nonequilibrium carriers.[2] This asymmetry arises due to the asymmetry of excitation, recombination, and scattering of nonequilibrium carriers lacking an inversion center. The second ("displacement") mechanism is related to the inclusion of nondiagonal (in the band numbers) elements of the density matrix in piezoelectrics and pyroelectrics.[3–6]

As shown in Ref. 7, in a magnetic field a Hall photovoltaic current J_{pvx}, which

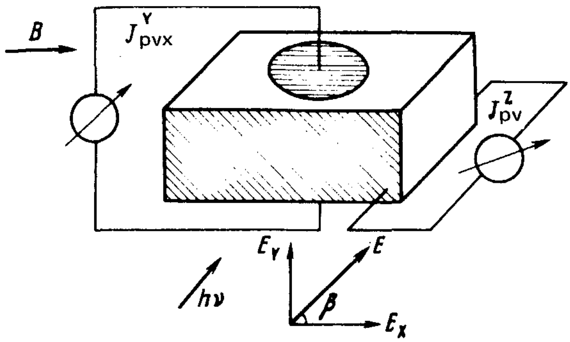

FIG. 1. Diagram illustrating the measurements of photovoltaic current J^z_{pv} and the Hall component of the photovoltaic current J^y_{pvx}. B is the magnetic field.

depends linearly on the magnetic field B, arises for both of these mechanisms. The mobility of nonthermalized carriers μ_{pv} and its temperature dependence can be determined from the Hall experiment.

The temperature dependence of μ_{pv} was first obtained in the present work from measurements of impurity BPE in cubic piezoelectric crystals of ZnS (symmetry $\bar{4}3\ m$). The procedure for the Hall measurements of the bulk photovoltaic current was described in Refs. 8 and 9. According to (1) and the $\bar{4}3\ m$ symmetry group, when a ZnS crystal is illuminated along the direction of the fourth-order axis z with linearly polarized light in the absence of a magnetic field, a photovoltaic current J^z_{pv}

$$J^z_{pv} = \frac{1}{2}\alpha_{14} I \sin 2\beta , \tag{2}$$

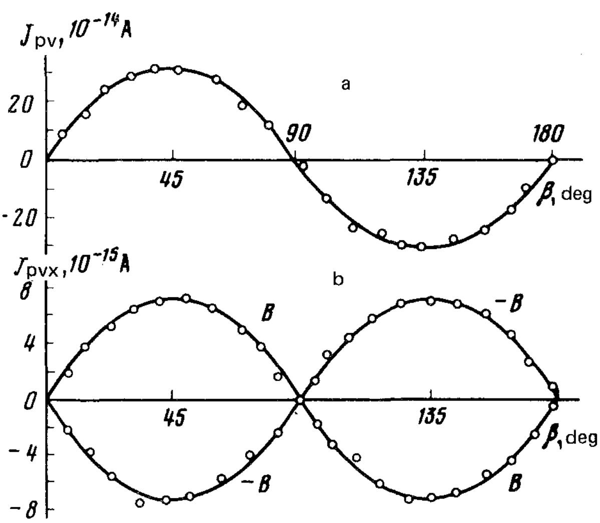

FIG. 2. (a) Orientational dependence of the photovoltaic current $J^z_{pv}(B=0)$ at $T=300$ K and $\lambda=600$ nm. (b) Orientational dependence of the Hall component of the photovoltaic current J^y_{pvx} for $B=1.25$ T, $T=300$ K and $\lambda=600$ nm. The light intensity is $I=1.2\times10^{-3}$ W · cm^{-2}.

where β is the angle between the polarization plane of the light and the x axis, and I is the intensity of the light, flows in this direction (Fig. 1). The observed dependence, which corresponds to (2), is shown in Fig. 2a. In the impurity region, $500<\lambda<800$ nm, $\alpha_{14}\simeq(3–4)\times10^{-8}$ A·W^{-1}, and correspondingly, $K_{14}=\alpha_{14}/\alpha^*\simeq(3–4)\times10^{-8}$ A·W^{-1} cm^{-1} ($\alpha^*\simeq1$ cm^{-1} is the absorption coefficient). When a magnetic field is switched on (Fig. 1), a Hall current J^y_{pvx}

$$J^y_{pvx} = \mu_{pv} J^z_{pv} B. \tag{3}$$

flows along the y axis. The angular dependence of the Hall current for two opposite orientations of the magnetic field B is shown in Fig. 2b. The Hall current (3) is linear in B up to values $B=1.4$ T.

Parallel measurements of the mobility μ_{pv} in the BPE regime and of the usual Hall mobility μ at temperatures ranging from room temperature down to $T\simeq150$ K were performed. The mobility of carriers μ_{pv} responsible for BPE was determined from (3). The usual Hall mobility μ was measured using the usual procedure by applying an external electric field E along the z axis and measuring the photocurrent J^z and the photo-Hall current J^y

$$\mu = \frac{1}{B}\frac{J^y}{J^z}. \tag{4}$$

The photocurrents J^z and J^y depended linearly on the field E, changed sign with a change in the direction of the field E, and did not depend on the polarization of the light.

These measurements show that in ZnS crystals in the spectral region $500\lesssim\lambda\lesssim800$ nm, the carriers responsible for impurity BPE are holes. At the same time, the holes are responsible for photoconductivity in the region $600\lesssim\lambda\lesssim800$ nm and electrons are responsible for photoconductivity in the region $500\lesssim\lambda\lesssim600$ nm.

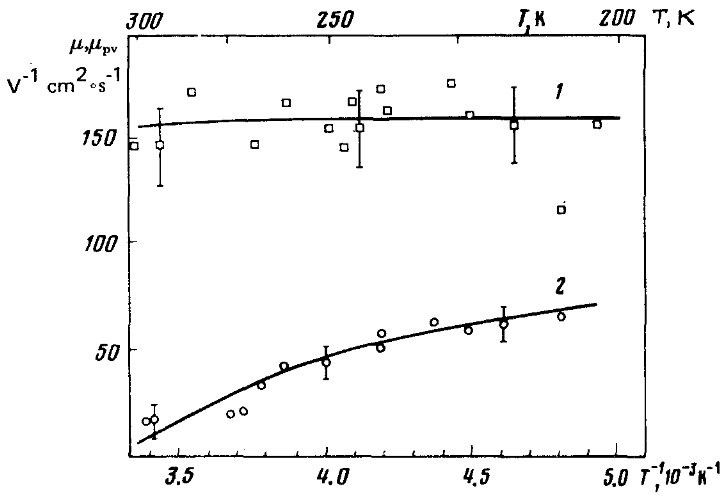

FIG. 3. Temperature dependence of hole mobilities μ_{pv} (1) and μ (2) for $\lambda=600$ nm.

Figure 3 shows the temperature dependence of μ_{pv} (curve 1) and μ (curve 2) for holes in the spectral region $\lambda \simeq 600$ nm. On the other hand, in the low-temperature region $\mu \sim T^{-2}$, the mobility μ_{pv} of holes responsible for BPE does not depend on temperature in the entire interval studied. This situation leads to the fact that at $T = 300$ K, $\mu_{pv} \gg \mu$, and at $T \simeq 150$ K, $\mu_{pv} \simeq \mu \simeq 100$ $cm^2 \cdot V^{-1} \cdot s^{-1}$.

Thus the results of measurements of BPE in ZnS have indicated the presence of a Hall effect for BPE, linear with respect to the magnetic field, as well as a difference in the temperature dependence of thermalized and nonthermalized carriers.

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