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EFFECT OF WEAK MAGNETIC FIELD ON THE PARAMETERS OF TERAHERTZ RADIATION EMITTED BY HOT CARRIERS IN *p*-Ge

Experimental results are reported on the influence of a weak magnetic field on the intensity and the polarization of a terahertz radiation (∼100 μm*) emitted by hot carriers in p-Ge specimens with the (111) or (100) crystallographic direction at a temperature of 5 K and heating electric fields of 300–600 V/cm.*

К л ю ч о в і с л о в а: weak magnetic field, terahertz radiation, *p*-Ge.

In work [1], we studied the influence of a weak magnetic field (WMF) on the polarization characteristics of radiation (∼100 μm) emitted by hot carriers in n-Ge at a temperature of 5 K. As a "weak" magnetic field, we consider the field H, for which $\hbar\omega_c \ll kT$, $\omega_x\tau \ll 1$, and $g_e\mu_{\rm B}H \ll kT$, where $\omega_c = eH/(m^*c)$ is the cyclotron frequency, k the Boltzmann constant, $\mu_{\rm B}$ the Bohr magneton, e the electron charge, c the speed of light, and τ the momentum scattering time of charge carriers. It was found that the action of such a field reduces the terahertz (TGz) radiation intensity by almost an order of magnitude. It was also observed experimentally that the polarization dependences (i.e. the change of the radiation intensity with the variation of the polarizer rotation angle) are inherent not only to n-Ge specimens with the crystallographic direction (111) (when the heating electric field induces a non-uniform distribution of charge carriers over the valleys), but also in the case of the crystallographic direction (100), when all the valleys are populated identically. The results obtained were unclear and demanded an explanation.

P.M. Tomchuk showed that those phenomena cannot be described in the framework of the traditional diffusion approximation, when only the first two terms in the series expansion of the distribution function are taken into account. He proposed a more complicated approach, in which the third term in the series expansion, which includes information concerning finer characteristics of radiation, is also made allowance for. This phenomenon was explained, and the corresponding theoretical analysis and the estimation calculations were carried out, the results of which satisfactorily coincided with experimental data. In this connection, it is of interest to check the existence of similar polarization dependences for the p-Ge semiconductor characterized by a complicated band structure. In it, the insignificant amount of light holes (2%) is responsible, when being heated up, for a substantial influence on the electric properties.

By analogy with our previous researches of n-Ge, we selected a high-resistance p-Ge from various manufacturers, but with one common feature: a specific resistance of 45 $\Omega\cdot$cm. The specimens were fabricated following the elaborated technology [1]. The specimen length was 7 mm, and the transverse cross-section was 1×1 mm^2. In some of the specimens, it was the crystallographic direction (111) that was oriented along the specimen length (Figs. 1 to 4), whereas in others it was the crystallographic direction (100) (Fig. 5). In the course of experiments, we measured the dependences of the follo-

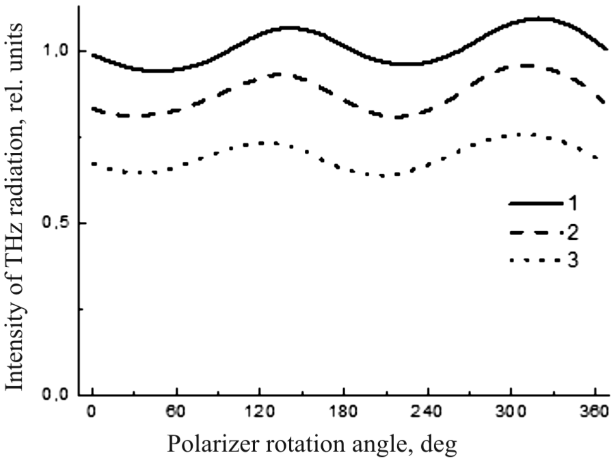

Рис. 1. Polarization dependences of the THz radiation signal emitted by hot charge carriers in the p-Ge specimens with a specific resistance of 45 Ω·cm and the crystallographic direction (111): (*1*) no WMF, (*2*) WMF in parallel to the current, and (*3*) WMF perpendicular to the current. The heating electric field strength is 9 V/cm, the measurement temperature is 5 K

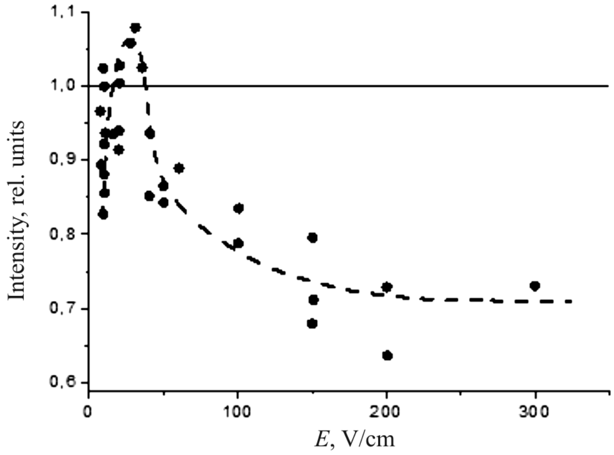

Рис. 3. Dependence of the relative intensity of THz radiation emitted by hot charge carriers in the p-Ge specimens with a specific resistance of 45 Ω · cm, the crystallographic direction (111) on the heating electric field in the case of the WMF applied in parallel to the current. A relative intensity of 100% corresponds to the THz radiation intensity in the absence of WMF

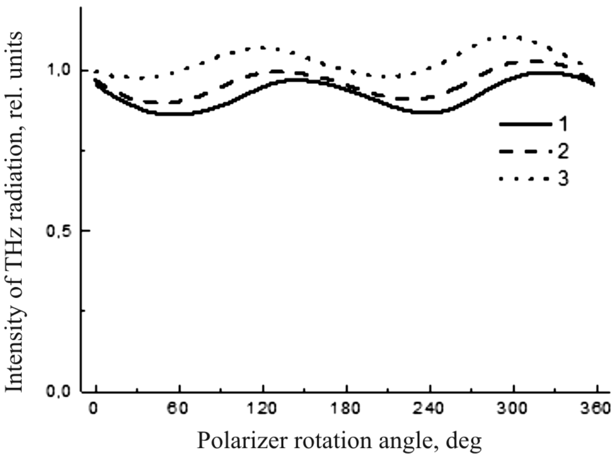

Рис. 2. The same as in Fig. 1, but for a heating electric field strength of 20 V/cm

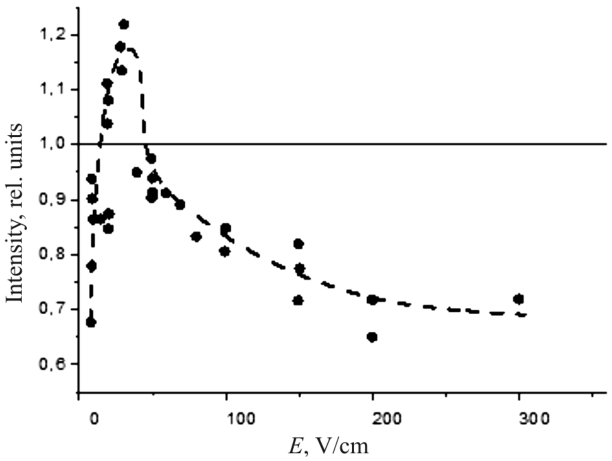

Рис. 4. The same as in Fig. 3, but for the WMF applied perpendicularly to the current

wing parameters on the heating electric field strength: the emitted signal polarization degree, the signal shift along the abscissa axis, and the signal intensity change under the action of the transverse or longitudinal WMF (300 Gs in strength), for which the weak-field criteria given above are satisfied in p-Ge at $T = 5$ K. We also took the crystallographic direction of specimens along its large size into account: in Figs. 1 to 4, this is the direction (111), and in Fig. 5 the direction (100).

The measurement procedure was as follows. The amplitude in the maximum of the polarization dependence measured without a WMF was fixed. Then, the WMF was switched on, and the variation in the signal level with respect to the previously measured value was registered. The detailed characteristics of measurements are given in the figure captions. All experiments were carried out at a temperature of 5 K. Note that the WMF oriented in parallel to the specimen axis acts more weakly on THz radiation,

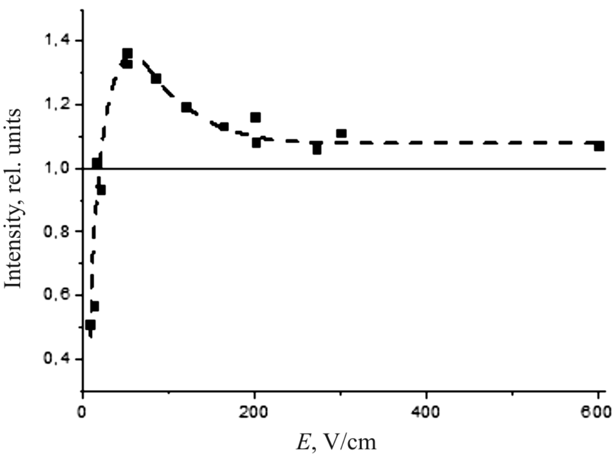

Рис. 5. The same as in Fig. 3, but for the p-Ge specimens with the crystallographic direction (100)

whereas the action of the WMF directed perpendicularly to the specimen axis (perpendicularly to the crystallographic direction (111)) is much stronger. Note that every point in the plots in Figs. 3 to 5 was obtained after two scanning of the polarization dependence of THz radiation. From the presented results, one can see that the signal polarization dependences demonstrate larger or smaller phase shifts of their curves (Figs. 1 and 2) depending on the heating electric field, with the relative influence of the WMF being much stronger at low heating electric fields than at high ones (150, 300, and 600 V/cm).

In order to explain the influence of the WMF on the phase shift and the amplitude of THz radiation emitted by hot carriers in p-Ge, the estimations have to be carried out with regard for the features in the band structure and the influence of the WMF on it, the role of light and heavy holes, the increase in the number of light holes at the carrier heating using the electric field, and the transition of holes into the third band located below the first twos by 0.29 eV. This task is extremely difficult. Therefore, we report only experimental facts and propose some assumptions concerning the dependences that were observed experimentally. In addition to the phase shift of the polarization parameters of the THz radiation under the influence of a WMF, the following characteristic features were also detected.

1. At low electric fields (7–20 V/cm), the application of the WMF induced a substantial reduction of the amplitude of the polarization signal for specimens with the crystallographic direction (111) – let us conditionally call this phenomenon the "negative" influence of WMF (Figs. 3 and 4). As the heating electric field increased from 20 to 30 V/cm, the growth in the intensity of polarization signal (the "positive" influence of WMF) was observed. If the heating electric field increased further, the "negative" influence of the WMF was observed again.

2. For specimens with the crystallographic direction (100), the behavior of analogous dependences was qualitatively different. Namely, after the growth of the THz radiation intensity (at 20 V/cm), the influence of the WMF remained "positive" up to 600 V/cm, although it decreased by absolute value.

3. The WMF directed perpendicularly to the heating electric field had the largest influence on the phase shift of THz-radiation polarization curves and the THz radiation intensity.

We did not found works dealing with the influences of the WMF on the THz radiation emitted by hot charge carriers in p-Ge. Since the WMF affects the specimen resistance (the magnetoresistance phenomenon [7]), the relationship between the THz radiation intensity and the magnetoresistance is to be found. However, the difficulty consists in that the magnetoresistance of p-Ge was mainly studied under the weak electric fields (1–2 V/cm), when the charge carriers are not heated up, and within the interval of magnetic fields 7–9 T, where a strong dependence on the crystallographic direction manifests itself at weak electric fields [2–5]. At the same time, our measurements concern weak magnetic fields and strong electric ones (up to 600 V/cm), where we have a very complicated picture of three interrelated valence bands [6], with this interdependence varying as the charge carriers are heated up.

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ВПЛИВ СЛАБКОГО МАГНІТНОГО ПОЛЯ НА ПАРАМЕТРИ ТЕРАГЕРЦОВОГО ВИПРОМІНЮВАННЯ В ОКОЛІ 100 мкм ГАРЯЧИМИ НОСІЯМИ З *p*-Ge

Р е з ю м е

У роботі наведено експериментальні результати вимірювання впливу слабкого магнітного поля на поляризаційні характеристики терагерцевого випромінювання в околі 100 мкм гарячих носіїв у *p*-Ge для зразків кристалографічного напрямку (111) і (100) при температурі 5 K і розігріваючих електричних полях до 300–600 В/см.