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Polarization of far-IR radiation from *p*-type germanium under uniaxial pressure and strong electric field

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Experimental results on the polarization of the far-IR radiation ($\lambda = 80$–120 μm) from *p*-type germanium under strong uniaxial pressure and heating electric field at liquid-helium temperature are reported. The directions of the polarization and the electric field are shown to be mainly coaxial for samples under pressure and perpendicular to each other for unstrained samples. The possible reasons of this phenomenon are discussed.

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Introduction

As is well known, a strong electric field disturbs the cubic symmetry of the carrier distribution of a semiconductor in *k*-space. This results in anisotropic optical properties connected with free carriers. In particular, the electromagnetic radiation from a semiconductor must be polarized [1,2]. Indeed, polarization of the far-IR radiation ($\lambda = 80$–120 μm) from Ge and Si was observed and studied in [3–5]. It was proposed that in *p*-Ge the polarization is caused by asymmetry of the distribution function of heavy holes (by the second spherical harmonic in the development of the distribution function in a strong electric field). On the other hand, there is a theoretical model of radiation polarization that takes into account the possible intersubband transitions in the *p*-material [1]. Uniaxial pressure splits the light and heavy subbands and must change the intersubband transitions. In view of this, the main goal of the present is to investigate the influence of uniaxial pressure (up to 8 kbar/cm^2) on the polarization and intensity of the far-IR radiation from *p*-Ge under strong electric fields at liquid-helium temperature.

Experimental details

The samples of *p*-Ge with resistivity at room temperature 5 Ohm·cm and 1×1×7 mm dimensions were used in our experiments. The sides were well parallel (up to 20″). The samples were oriented along <100> axis. To improve the mechanical strength of the samples at liquid-helium temperature, Pb–In contacts were utilized. Injection of minor carriers from the contacts started when the value of the applied field reached 200–250 V/cm. This injection was controlled by the form of the current pulse and did not exceed ~ 10%. To cut off the short-wavelength part of the IR emission spectrum, black polyethylene was used as a filter. The strong electric field was provided by a pulse generator with 0.8 μs pulse duration and repetition rate 6 Hz. The measurements were carried out at temperature 4.2–5 K. A Ge–Ga photodetector with a range of sensitivity of 80–120 μm was employed. The results were reproducible (correctness up to 95%) and corresponded to elastic deformation, as after having been released from the maximal pressure (7–8 kbar/cm^2) the samples gave the same signals as did the original unstrained states.

Results and discussion

Figure 1 presents the dependences of the far-IR signal intensity on the angle between the <100> axis and transmission direction of the polarizator when the directions of the electric field and pressure coincide with the <100> axis. Without pressure the radiation is partly polarized, and the degree of polarization reached nearly 10%. The maximum intensity of the radiation is observed for zero angle of rotation of the polarizator. Under weak pressure (up to around 0.7 kbar/cm^2) the intensity dependence on the angle of rotation of the polarizator is almost a straight line (curve *3*). Increasing the applied pressure causes a change of the polarization direction to 90°, which remains constant up to 6 kbar/cm^2.

We can propose at least two reasonable explanations of this phenomenon. The first one is a significant role of the intersubband transitions, which play the main role in the emission of IR light from *p*-Ge under a heating electric field without applied pressure. It has been shown [1] that in this case the radiation will be partly polarized in the direction perpendicular to the electric field. The degeneracy of the valence band vanishes under uniaxial pressure, and the role of the intersubband transitions decreases. Under strong pressure and not so strong a heating electric field the intersubband transitions do not play any role at all in the light emission. On the other hand, the isoenergetic surfaces under strong pressure are known to be ellipsoids with different hole populations [6]. The effective mass of the holes in a more populated ellipsoid is less along the field direction than in the perpendicular one. In this case the radiation should be oriented along the electric field.

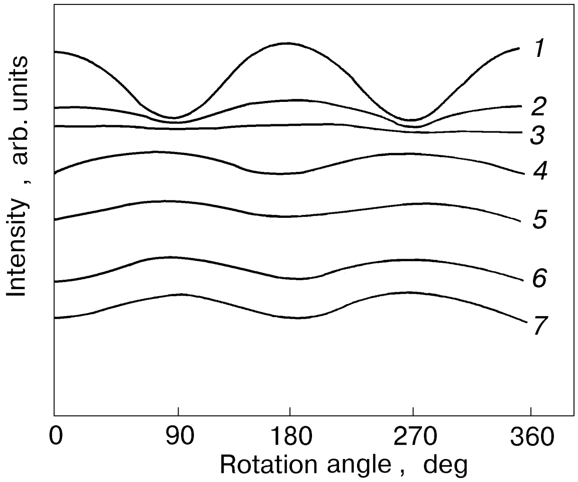

Fig. 1. Dependence of the direction of radiation polarization upon the angle rotation of the polarizer. Uniaxial pressure, kbar/cm^2: 0 (*1*); 0,25 (*2*); 1 (*3*); 2 (*4*); 3 (*5*); 4 (*6*); 6 (*7*). The value of electric field $V = 100$ V/cm.

The second probable explanation derives from the different scattering probability of a hole on an acoustic phonon and an ionized impurity. The effective mass of the majority of the holes along the field direction is considerably less in the strained samples than in the unstrained ones. As a result of the effective mass reduction, the carrier scattering from the ionized impurities is expected to be less efficient in the strained samples than in the unstrained ones. On the other hand, the scattering on acoustic phonons is assumed to be essentially unaffected by the applied pressure. The temperature dependences of the degree of polarization could be helpful to test this hypothesis.

It should be noted that the same change of the polarization with respect to the applied heating electric field and pressure was observed for *n*-Ge samples with different resistivities: for pure samples the polarization is oriented along the field direction, while for heavily doped samples it is perpendicular to the field.

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