Light scattering in n-Ge following bulk excitation of nonequilibrium carriers

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Results are presented of experiments on the scattering of CO_2-laser radiation by density fluctuations of the nonequilibrium carriers around defects. The average statistical dimension of the defect is determined ($r \sim 8\ \mu$).

Light scattering in optically-pumped single-crystal Ge samples was observed by a number of workers[1,2] at temperatures below 4.2 °K and was attributed to the formation of electron-hole drops (EHD). Our experiments on scattering have shown that scattering by nonequilibrium density fluctuations takes place in n-Ge in a wide temperature interval, 10—300 °K.

The experiments were performed on Ge samples with impurity-center density from 10^{11} cm^{-3} to several times 10^{11} cm^{-3}. The working part of the crystal measured 5×5×5 cm. The crystal surface was polished with optical accuracy.

The volume excitation of the nonequilibrium carriers was effected by the two-photon absorption method[3] by exposing the Ge samples to radiation from a dysprosium laser ($\lambda = 2.36\ \mu$) operating in the giant-pulse mode ($\tau = 40$ nsec) at a frequency 300—400 Hz.[4]

By focusing the dysprosium-laser radiation with a cylindrical lens of $F = 70$ mm onto the end face of the crystal we were able to produce a nonequilibrium-carrier region measuring 5×5×2 mm.

The scattered light was measured with a heterodyne receiver operating in the 10-μ band.[5] We used in the experiment a CO_2 laser with output power 1 W, operating in the cw regime at the fundamental mode TEM_{00q}. The CO_2-laser sounding beam, of 3 mm diameter, was perpendicular to the large dimension of the nonequilibrium-carrier region (5×5 mm), so that the effect of refraction phenomena could be eliminated.

The assembled experimental setup has made it possible to plot the scattering diagram both in the forward and in the backward direction in an angle range 2—30° relative to the sounding beam. The diagram was plotted by displacing and rotating one of the mirrors in the arm of a Mach-Zander interferometer, directing part of the scattered radiation through a diaphragm to a Ge-Hg photoresistor. The use of the method of optical heterodyning has made it possible to obtain a high angular resolution, 10^{-4} rad, and a sensitivity 10^{-16} W/Hz.

Figure 1 shows the diagram of the scattered CO_2-laser radiation, measured in the direction of the sounding beam at a sample temperature 300 °K and a nonequilibrium carrier density 10^{15} cm^{-3}. An analysis of the scattering curve has shown that the observed diagram is quite well approximated by the curve calculated in the Rayleigh-Gans approximation[6] for spherical particles with characteristic dimension 8 μ (this radius should, of course, be regarded as a certain approximation corresponding to the value statistically-averaged over inhomogeneities of various dimensions and of different shapes).

Figure 2 shows the temperal dependences of the scattered CO_2-laser radiation (Fig. 2a) and the signal due to absorption of this radiation by nonequilibrium carriers (Fig. 2b). It is seen from the oscillograms that the scattered signal duplicates the absorption signal. To assess the nature of the scattering, a number of additional experiments were performed. Thus, in the absence of excitation and at 100% modulation of the sounding radiation, it was impossible to observe scattering within the sensitivity limits of our setup. The scattering can be registered at a nonequilibrium carrier density 10^{14} cm^{-3}. No significant changes of the angular distribution of the scattering with changing excitation level were observed, whereas the scattering intensity increased in nonlinear fashion with increasing carrier density.

When the temperature is lowered from 300 to 10 °K, the intensity of the scattered light increases by approxi-

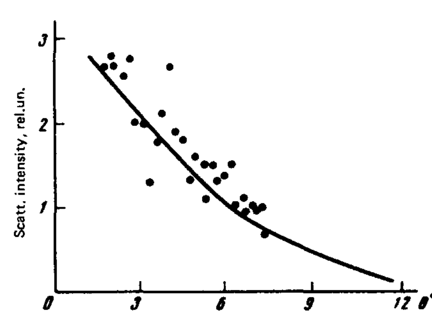

FIG. 1. Scattering diagram of CO_2-laser radiation by nonequilibrium carrier density fluctuations in n-Ge (solid curve-calculated in the Rayleigh-Gans approximation, $r = 8\ \mu$).

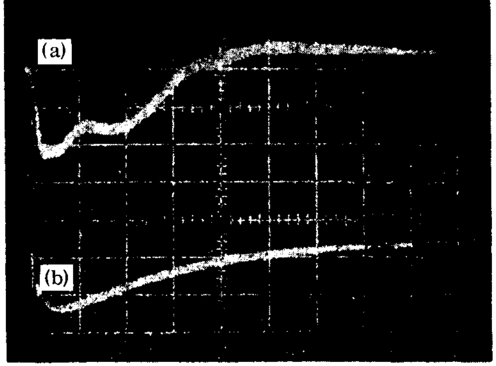

FIG. 2. Time dependence of the scattered and absorbed CO_2-laser radiation signal: a) scattering signal; b) absorption signal (sweep 50 μsec/division).

mately by one order of magnitude, without appreciable changes in the angular distribution.

It can be proposed on the basis of the presented data that the scattering of the light is due to fluctuations in the density of the nonequilibrium carriers at different types of defects in Ge crystals. The possibility of the presence of such defects in the crystals was indicated in[7]. According to the presented data, the density of defects with dimensions from 1 to 10 μ is 10^4-10^6 cm^{-3}.

It is still difficult to draw any definite conclusions concerning the nature of these defects. Since no scattering was observed in the absence of excitation, it can be assumed that for these effects the deviation Δn of the refractive index from its average value in Ge is smaller than 10^{-4}. This value of Δn may be connected with the presence in the crystal of local stresses or of intruded amorphous Ge.

The value of Δn that causes scattering upon excitation can be estimated from the scattering intensity, assuming that the number of scattering centers does not change and corresponds to 10^4-10^6 cm^{-3}. Estimates based on the scattering diagram plotted at 300 °K and at an excitation level 10^{15} cm^{-3} yield a value on the order of 10^{-4} for Δn. If this change of the refractive index is attributed to density fluctuations in the electron-hole gas, then the value of Δn determined by Drude's theory should correspond to a concentration larger than the average by 4–6 times. It appears that to explain the existence of such density fluctuations it must be assumed that potential wells (barriers) amounting to several dozen meV are present.

Within the framework of this assumption, we can attribute the increased scattering intensity, observed in the experiments at 10 °K, to an increase of the excess carrier density with decreasing temperature. For a detailed calculation of this dependence, however, it is necessary, besides taking the screening into account, to know the nature and amount of the defects.

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