Dispersion of electron-hole droplets in Ge

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The dispersion of electron-hole droplets in germanium is investigated under strong optical excitation at $T = 2$°K. Some dynamic characteristics of the dispersion are reported and discussed. The experimental data agree with the theoretical model wherein the droplets drift in a stream of nonequilibrium phonons {L. V. Keldysh, Pis'ma Zh. Eksp. Teor. Fiz. **23**, 100 (1976) [JETP Lett. **23**, 86 (1976)]}. The constant that characterizes the strength of the "phonon wind" in Ge is determined.

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Questions connected with the instability of an electron-hole liquid in a semiconductor and with the interaction of drops with nonequilibrium phonons were considered theoretically in [1]. It was shown that drift of the droplets can set in at definite and rather large volumes occupied by the electron-hole liquid in the crystal. The electron-hole droplets (EHD) can disperse in this case over macroscopic distances with initial velocities close to that of sound. We have investigated experimentally the expansion of EHD by using for their observation a direct method based on the destruction of the droplets in strong electric fields. The detectors were metal-semiconductor contacts made by dopositing silver paste on samples of pure Ge (with impurity density less than 10^{12} cm^{-3}). The droplets were registered on the face opposite to the irradiated side. The photocurrent signals produced in the measuring contacts were picked off a load connected in series with the sample and matched to the input of the receiving-amplifying system. Similar methods of droplet registration were used earlier in [2–4] to study fluctuations of the photocurrent and to determine the dimensions of the droplets. We have investigated in the present study the motion of the droplets under conditions when the carriers were generated by short intense pulses of light of duration $\tau_p = 10^{-8}$ sec and wavelength $\lambda = 5105$ Å.

Figure 1 shows the registered signals at various optical-excitation levels I indicated in the figure caption. We investigated a rectangular sample measuring $2 \times 2 \times 2$ mm. It was observed that the photocurrent pulses were delayed relative to the exciting light pulse. The delay time τ_d was determined by the optical-excitation level and decreased when the latter increased. At the same time, the photocurrent signals became narrower and the leading front became steeper. The photocurrent pulses were registered at $T \leq 2$ °K. The pulse waveform and the regularities that manifest themselves when the optical-excitation level changes could be due to the spatial distribution of the droplets and to their motion in the crystal lattice.

The dependence of the time τ_d, of registration of the leading fronts of the investigated signals on the distance R, between the focused light spot scanning the surface of the sample and received by the contact is shown in Fig. 2. We

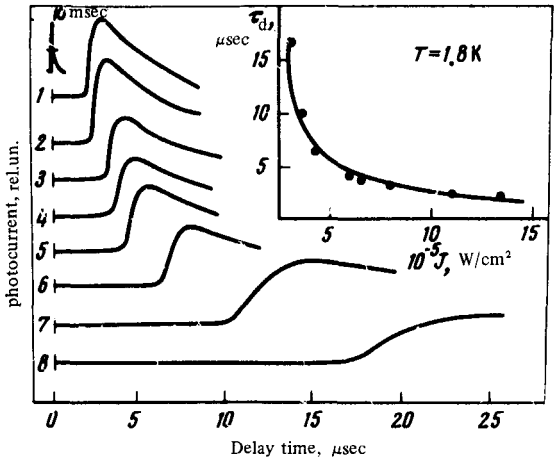

FIG. 1. Photocurrent signals recorded at various optical excitation levels I (W/cm^2): 1—$1.4 \cdot 10^6$; 2—$1.1 \cdot 10^6$; 3—$8 \cdot 10^5$; 4—$6.7 \cdot 10^5$; 5—$6 \cdot 10^5$; 6—$4.3 \cdot 10^5$; 7—$3.3 \cdot 10^5$; 8—$3 \cdot 10^5$. Upper right—dependence of the droplet time of flight τ_d on I.

used in the experiment samples of 15 mm length and thickness $d = 1$ mm. As seen from Fig. 2, the delay times of the photocurrent pulses varied little in the vicinity of the point $R = d$ and increased appreciably with increasing distance R at $R > d$.

According to [1], the motion of each droplet detached from the main volume at the point R_0 (if the initial volume of the electron-hole liquid was a sphere) or L_0 (in the case of a flat layer) is described by one of the equations

$$L(t) = L_0[1 + \lambda(1 - e^{-t/\tau_0})], \qquad L_0 \leqslant L(t), \tag{1}$$

and

$$R(t) = R_0[1 + \lambda\,(1 - e^{-t/\tau_0})]^{1/3}, \qquad R_0 \leqslant R(t). \tag{2}$$

Here

$$\chi = \frac{4\pi\rho^2\tau_0}{Mn_0\gamma},$$

where ρ_0 is a constant that characterizes the force of the phonon wind produced in the electron-hole liquid, τ_0 is the carrier lifetime in the drops; Mn_0 is the effective-mass density of the electron-hole liquid, and γ is a coefficient characterizing the friction of the droplets as they move in the crystal lattice. [5]

Formulas (1) and (2) are valid so long as the droplet velocity is $V \leq S$, where S is the velocity of sound.

It was shown in [3] that the quantity ρ, which determines the volume forces produced in the electron-hole liquid by the "phonon wind," is a characteristic of the given semiconductor. The constant ρ depends on the parameters of the

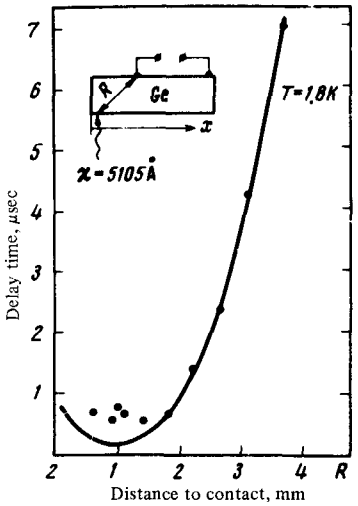

FIG. 2. Dependence of the time of registration τ_d of the photocurrent pulses on the distance R to the light spot scanning the sample surface. The solid curve is calculated and the points are experimental.

band structure, on the concentration, and of the lifetimes, of the electrons and the holes in the droplets. So far, the estimates of the possible velocities and flight times of EHD in Ge[1] turned out to be for the most part approximate because of the uncertainty in the choice of ρ. Our measurements have made it possible to determine experimentally the strength of the phonon wind.

In the experiment represented by curves 1—8 of Fig. 1 the time of travel of the droplets to the recording contact was $\tau_d < \tau_0$. In this case the intensity of the optical generation and the times τ_d should, in accord with (1) and (2), be connected by a relation close to $I\tau_d = \text{const}$. Figure 1 shows a plot of Eq. (1), using $\rho = 290\ \text{g}^{1/2}\text{cm}^{-3/2}\text{sec}^{-1}$, calculated by averaging eight experimental points that yield ρ with a scatter not larger than 5% of the averaged value. Figure 2 shows another calculated $\tau_d(R)$ curve, which is practically equal to the experimental one, except for those points which were obtained by illuminating surface sections located opposite to the measuring contacts. The point is that formulas (1) and (2) are valid for infinite crystals and no account is taken in them of effects due to the finite dimensions of the samples. The reflection of the phonon streams, and hence the deceleration of the EHD, may be among the causes of the difference between the experimental and calculated curves at $R \approx d$. The interaction of the reverse phonon streams with the cloud of dispersing droplets is greatly attenuated for the points for which $R \gg d$. The value of ρ determined for them is $320\ \text{g}^{1/2}\text{cm}^{-3/2}\text{sec}^{-1}$. It is this value which was used to plot the calculated curve (Fig. 2). The role of the reflected phonon streams is particularly large in the case of one-dimensional motion of the droplets in a crystal with plane-parallel faces, as was the case, to a certain degree, in the experiment represented by Fig. 1. To determine the characteristic quantity ρ_0 in this case it is necessary to introduce corrections. The value $\rho = 320$

$g^{1/2}cm^{-3/2}sec^{-1}$ is also an underestimate and is not equal to ρ_0, since it is impossible to account for all the losses of the exciting radiation in the calculations.

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