Effect of condensed phase of excitons on the absorption of ultrasound in germanium

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We investigate the absorption of ultrasound by electron-hole drops (EHD) in germanium. We observe that the temperature dependence of the absorption has resonant form with a maximum at $T \sim 2.4$°K. The width of the resonance is ~ 1°K. Extinction of the EHD luminescence was observed in the field of an ultrasonic wave.

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Since the time when Keldysh predicted theoretically the existence of a condensed phase of excitons,[1] and since the experimental observation of this phase (see, e.g., the reviews[2]), an appreciable fraction of all the subsequent studies was devoted to the properties of electron-hole drops (EHD), such as the binding energy, the equilibrium carrier density in the EHD, the formation mechanism, the charge, etc. At the same time, there are practically no data on the interaction of EHD with phonons (both equilibrium and nonequilibrium).

Ultrasound, a flux of nonequilibrium monochromatic phonons, can be absorbed by an EHD (at $\lambda_{ac} \ll R_{drop}$) by the same mechanism as in the interaction with a degenerate electron-hole plasma.[3] It appears that this phenomenon was observed in[4], but the interpretation based on the excited-phonon interaction seems unconvincing to us.[1)]

In the other limiting case $\lambda_{ac} \gg R_{drop}$, each EHD in the field of the ultrasonic wave is accelerated as a unit. As a result of this action, the EHD oscillates and dissipates energy of the sound, by interaction with the thermal phonons of the lattice.[3]

We have investigated the damping of 160-MHz ultrasound in pure germanium at temperatures 4.2–1.6°K following optical excitation of the nonequilibrium carriers. A block diagram of the setup is shown in Fig. 1. The optical-pumping source was an He-Ne laser of wavelength 1.15 μ and power up to 50 mW.

The presence of the EHD in the germanium sample was registered by means of the recombination radiation. The longitudinal acoustic oscillations were excited in the germanium sample with the aid of the thin-film electroacoustic converter based on CdS. The sound propagated in germanium in the $\langle 100 \rangle$ direction. To realize the effective interaction of the sound with the EHD, the nonequilibrium carriers were generated with the aid of a focused laser beam directly in the region of propagation of the acoustic wave (Fig. 2a). Measurement of the damping of the ultrasound with the aid of a standard echo-pulse procedure.[7]

We measured in the experiments the change of the damping of the ultrasound ($\Delta\alpha$) in optically-excited germanium in comparison with the dark damping. To this end, a strobe-integration technique was used to separate individual echo pulses (e.g., 15, 17, and 19; we observed altogether up to 40 echo pulses) and registered the change of their amplitude with changing external illumination.

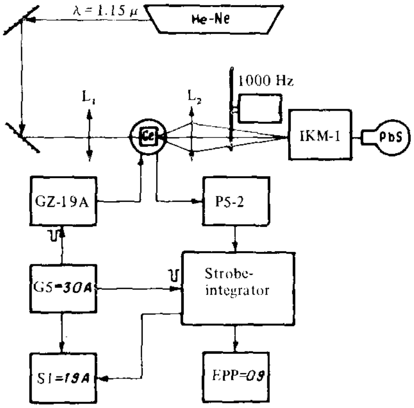

FIG. 1. Block diagram of experimental setup.

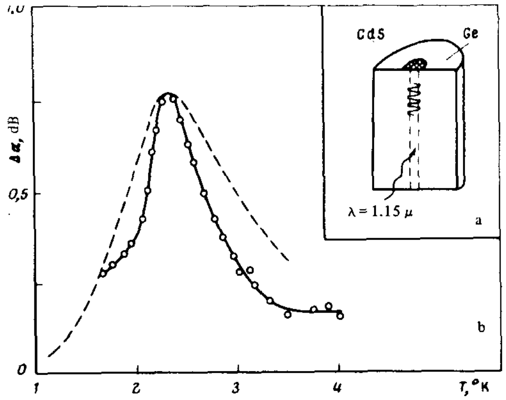

FIG. 2. a) Sample; b) temperature dependence of the change of the damping of the sound following optical illumination of the sample; dashed line—calculated theoretically in[3], solid—experimental curve.

It was observed that the temperature dependence of $\Delta\alpha$ under optical illumination of germanium has a clearly pronounced resonant character (Fig. 2b). The maximum of the curve was located at ~2.4 °K. The width of the curve is ~1 °K. The observed dependence is brought about by the presence of EHD in the sample, as determined by the appearance of the EHD emission line. When the region of EHD excitation was shifted away from the acoustic channel by an amount 1—1.5 mm (region of localization of the EHD), the effects vanished. We assume that the resonant absorption of the sound in our experiments is connected with interaction of sound with EHD.

A theoretical calculation of the absorption of ultrasound by EHD, presented in[3] for the case of a single-valley semiconductor, can be used to explain our results with account taken of the actual deformation potential.[8]

The dependence of the absorption of ultrasound by the EHD, calculated in[3] for the case[2] $\lambda_{ac} \gg R_{drop}$, is of the form

$$\Delta\alpha \sim \tilde{n}\frac{D^2}{\rho m S^5}\,\frac{\gamma\omega^2}{\gamma+\omega^2}\,, \tag{1}$$

where $\tilde{n}$ is the average density of the electrons and holes in the volume occupied by the liquid phase, m is the effective mass, and D is the total deformation potential, S is the speed of sound in the crystal, ρ is the density of the germanium, and γ is a quantity inversely proportional to the momentum relaxation time τ of the drop, which in turn has a strong temperature dependence (see Fig. 1 of[3]). Substitution in (1) of the numerical values of ω and γ obtained from experiment yield the $\Delta\alpha(T)$ curve shown in Fig. 2b.

It should be noted that we have observed also a change in the intensity of recombination radiation (by approximately 25—30%) under conditions of continuous generation of sound; this is apparently connected with the motion of the EHD and of the exciton in the field of the ultrasonic wave.

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[1] Actually, the interpretation of the experimental data of[4], which is given in[5], is valid only if the ground state of the exciton is split by ~0.1 meV, whereas the splitting amounts to 0.8—1 meV.[6]

[2] The average radius of the drops in the experiment was ~5 μ.[9]

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