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DRAG OF ELECTRON-HOLE DROPLETS IN GERMANIUM BY LASER INDUCED DEFORMATION PULSE

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It was shown experimentally that electron-hole droplets (EHD) may be dragged by deformation pulse and move together with it along the crystal at sound velocity.

1. Introduction

Observation of EHD high mobility in nonuniform external fields [1] stimulated a number of publications reviewed in detail in [2]. Under nonuniform static stress conditions the maximum EHD velocity V was experimentally found to be $\sim 10^3$ m/ sec [3]. This value proved to be only somewhat less than sound velocity S in Ge for the corresponding crystallographic direction. However, the case when $V \geq S$ is the one of great interest presently. The motion of EHD at velocities $V \geq S$ was discussed theoretically in [4,5]. The "polaron"-like effect resulting in dependence of EHD mass upon it's velocity as well as the flattening of a droplet along it's velocity direction together with various instabilities, which may be followed by the decay of droplet - all these predicted phenomena endow experimental efforts to obtain EHD velocities $V \geq S$ with great interest. The possibility of EHD complete capture and drag at $V \geq S$ by an acoustic wave of appropriate amplitude was predicted in [6].

High values of deformation and strain gradients required for achievement of $V \gtrsim S$ may be probably attained by producing in a sample a deformation pulse; the latter can be generated by illumination of the sample with a laser pulse [7]. Neglecting the effects arising at $V = S$, $S = F\tau / M$, where F - a force per a EH pair in a droplet, τ -EHD carrier momentum relaxation time, M - effective mass of EH pair. For the carriers in a deformation field $S \sim D \cdot \epsilon \cdot \tau / LM$ or $S \sim D \cdot P\tau / E L M$; here, D - deformation potential, ϵ - deformation, L- linear dimension of deformed region, E- Young's modulus. Therefore, $P/L \sim M \cdot S \cdot E / D\tau \sim M\rho S^3 / D\tau$, where P- pressure and ρ - density. Then $P/L \sim$

$$\frac{10^{-27} \cdot 10 \cdot 3 \cdot 10^{16}}{3 \cdot 10^{-11} \cdot 10^{-8}} \sim 2 \cdot 10^{9}\ dn/cm^3 = 2 \cdot 10^3\ kg/\ cm^3$$

The main aim of this work was to investigate the interaction of EHD and excitons at 1.7-4.2K with perturbation induced in Ge crystal illuminated by a "giant" laser pulse. Particular attention was paid to the proper realization of experimental conditions when EHD velocity might reach that of the sound.

2. Experimental

Measurements were carried out on pure Ge samples with residual impurity concentration of $n_0 \sim 10^{12}$ cm^{-3}. The samples had a shape of cylinder of $8 \div 10$ mm length or of elongated parallelepiped $2.5x2.5x8 \div 10$ mm^3 size. (Fig. (1).) The side of the sample illu-

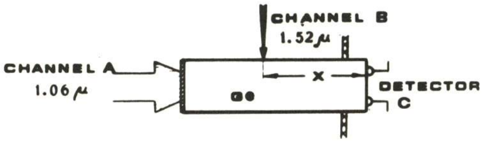

Fig. 1 Geometry of photoexcitation of Ge sample while investigating the interaction of deformation pulse with the system of nonequilibrium carriers (EHD, excitons)

minated with the laser pulse (channel A) was coated either (usually) with a vacuum evaporated metal film (0.5 + 3 mcm Au or Al) or by glued metal foil. Depending on the kind of laser induced crystal perturbation the signal detection was provided either by alloyed p-n junction or by a thin film electroacoustic transducer CdS or by superconducting Al bolometer [8]. Detectors were mounted on the side of the sample opposite to the channel A. YAG - laser was used as a source of intense pulsed light in the channel A. The laser produced "giant" pulses with λ = 1.06 μm, $\tau_p \sim 10$ nsec with repetition rate of 12.5 + 25 cps. The maximum energy of a pulse was 2×10^{-3} J and could be attenuated by filters. The special optical system allowed to adjust the laser beam with respect to the proper region of the sample within the accuracy of 0.1 mm and to vizualize the injuries of the surface. The excitation of nonequilibrium carriers was produced by means of He-Ne laser with λ = 1.52 μm and power up to 8 mW (channel B). The amplitude and profile of detected signals were measured and analyzed by an oscillograph or by a boxcar integrator PAR-160 followed by X-Y recorder. Time-resolution of the system was of $\sim$ 15 nsec.

3. Resuslts and Discussions

It was observed by means of CdS transducer that the illumination of pure or metallyzed Ge surface gave rise to deformation wave propagation along the sample.(Fig. (2a).) The first and the second groups of signals correspond to the arrival at the CdS transducer of longitudinal and shear deformation waves with S_l= 5530 m/sec and S_t = 3200 m/sec respectively that exactly coinsides with the values of longitudinal and transverse sound velocities for [111] in Ge [9].

A number of processes may be considered being responsible for the laser induced deformation pulse in crystal. Several check experiments and numerical evaluations made it possible to exclude: a) Lebedev light pressure, b) deformation, arising from a sharp increase of free carrier concentration, c) deformation, produced by an abrupt evaporation of liquid helium away from the heated sample surface. Thus, in our case, i.e. when the density of absorbed energy was of order of $10^{-5} \div 10^{-1}$ J / cm^2, the deformation pulse arose due to two mechanisms: 1) local heating of the crystal surface with the subsequent nonuniform thermal expansion followed by strain gradients

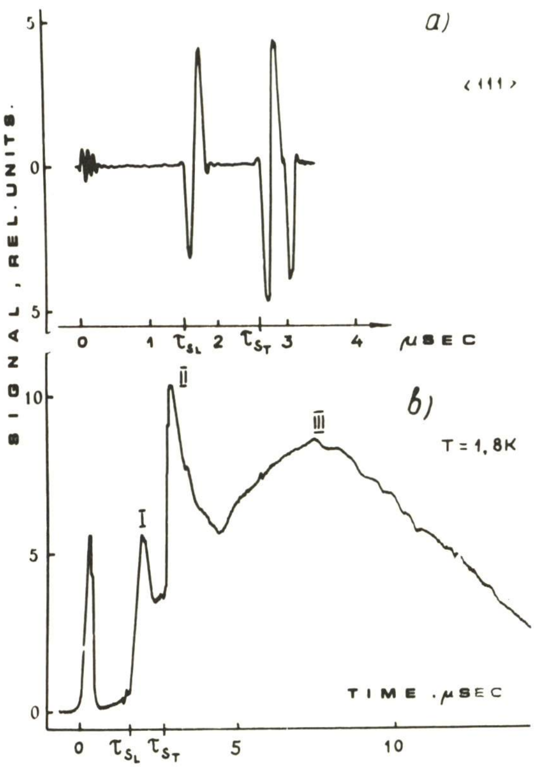

Fig. 2
a) Groups of signals arising at the acoustoelectric transducer CdS after propagation of deformation pulse across Ge sample: The path of propagation ~ 8.2 mm
b) The shape of the signal arising at p-n junction as a result of interaction of deformation pulse, propagating along [111] direction of Ge with EHD and excitons:
The length of the sample 8.3 mm

up to ~ 10 kb/cm and 2) evaporation of sample surface caused by incident laser pulse (for the densities of absorbed energy of 10^{-3} -10^{-1} J/ cm^2).

Under condition of simultaneous action of channel A and channel B lasers the p-n junction detected a signal of a rather complex shape, shown in Fig. (2b). It is of importance that in absence of channel B action no signals were detected. Therefore, the signals appeared to be caused by the existence of nonequilibrium carriers in the vicinity of p-n junction. The carriers were dragged there by the perturbation, propagating from the region of interaction of channel A laser light with the crystal surface. Let us put forward an important argument in advance of this supposition: signal I and II in Fig. (2b) were delayed by the times required the longitudinal and transverse sound to pass across the sample. In other words the carriers produced by the channel B light beam were dragged by the longitudinal and transverse deformation pulse and arrived at the detector exactly with the velocities of the sound. It should be noted that the channel B could be displaced with respect to p-n junction and the largest distance x which still allowed to detect signals I and II was ~ 4 mm.

An important question arises - in what kind of state the nonequilibrium carriers were dragged? The sharp temperature dependence of amplitudes of signals I and II near 2K, shown in Fig. (3) is common for the change of number of particles in liquid phase (owing to phase diagram of EHD) near the condensation threshold at excitation level employed in our experiments and provides us with unambigious answer.

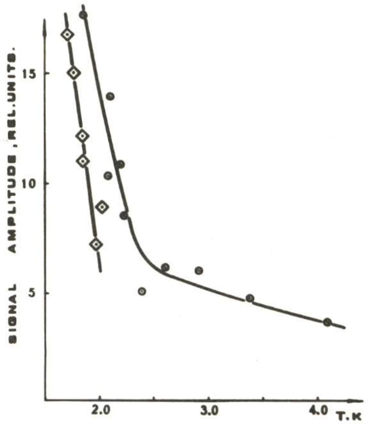

Fig. 3 The temperature dependence of amplitudes of signals I and II (◈ - curve 1) and of signal III (⊙ - curve 2): The power in channel B ~2 mW

The temperature dependence of signal III was not so sharp and the latter could be discerned up to 4.2K. It's behaviour (profile, duration, position of the maximum) as a function of the pulse energy in channel A was similar to that of bolometer signal, while detecting high-frequency acoustic phonons [8]. It is possible, that signal III was due to EHD (the steep part of curve 2 Fig.(3)) as well as to excitons (the smooth part of curve 2 above 2.5K) existing in the vicinity of p-n junction as a result of their drag by the flux of nonequilibrium phonons at the velocities less than those of the sound ($\sim 10^4$ cm /sec) [10].

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