Threshold effects in the electron-hole drops—superfluid helium system

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As a result of studying the properties of the electron-hole drops (EHD) in a germanium crystal as a function of optical pumping, we were able to establish a correlation between the threshold appearance of plasma and helium at the crystal surface.

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In this paper we studied the EHD system at $T < T_\lambda = 2.17$ K in a wide range of optical pumping. We investigated the noise associated with electrical conductivity and absorption of microwave radiation with a wavelength $\lambda = 2$ mm in germanium crystals, focusing particular attention on the effect of the coolant, superfluid helium-HeII, on the EHD system. We measured super-heating of the germanium sample relative to the helium bath and controlled the intensity of the exciting light scattered by the crystal surface.

The experimental setup is shown in Fig. 1. The concentration of the residual

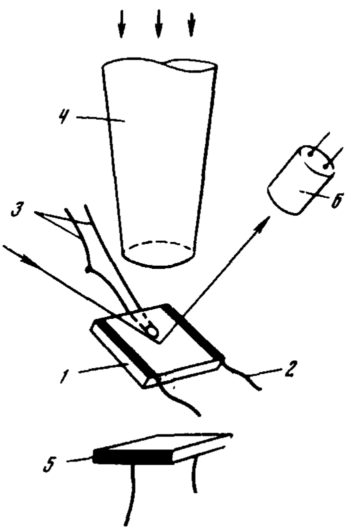

FIG. 1. Experimental setup.

impurities in the $4\times5\times0.3$-mm³ germanium sample 1 with contacts 2 was $N \leqslant 10^{12}$ cm^{-3}. A miniature differential Ag-Au thermocouple 3 with a sensitivity of 12 μW/deg was soldered to the center of the hot illuminated surface of the crystal. The microwave radiation from a backward-wave tube was focused on the sample through a light pipe 4. A n-InSb crystal 5 was used as a microwave receiver. The electron-hole drops were produced as a result of stationary irradiation of the sample by a LT-2 neodymium laser light with a maximum exposure rate of 10 W. The light scattered on the sample's surface was detected by a high-speed germanium photodiode 6. The ac components of the electrical conductivity signals, of the microwave absorption, and of the scattered light, after being amplified at a frequency of 2 kHz in the 90-Hz frequency band and detected, were conducted to the Y input of the X-Y recorder. The X coordinate of the recorder received a signal proportional to the intensity of the exciting light.

The results of the experiment are given in Fig. 2. It can be seen in Fig. 2a that

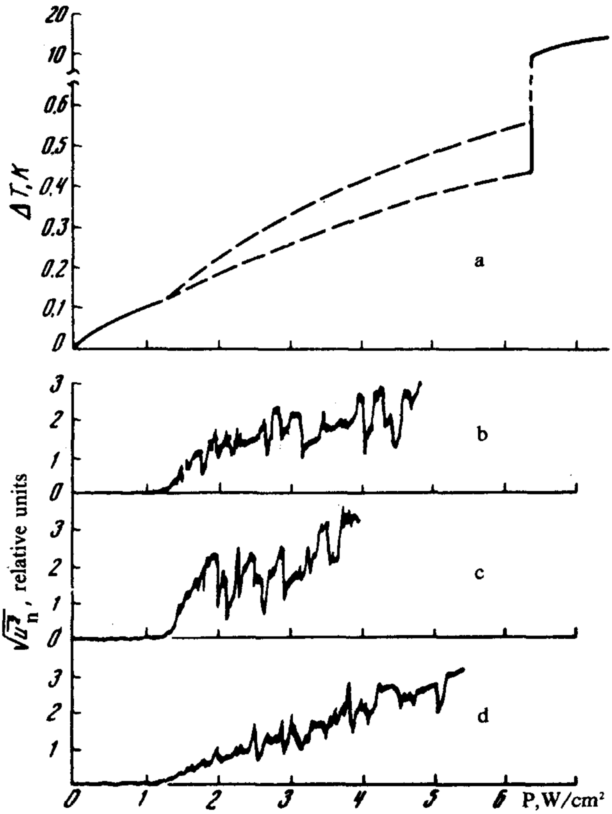

FIG. 2. Dependence on the intensity of the exciting light: a of the superheating of the germanium crystal relative to the helium bath, $T_B = 2.07$ K; b of the noise of the scattered light; c of the noise of the electrical conductivity, $E = 1$ V/cm; d of the noise due to absorption of the microwave radiation with $\lambda = 2$ mm. The immersion depth of the sample in the helium bath is 15 cm.

when the density of the optical excitation is ~ 6 W/cm^2 the temperature of the sample increases sharply to 10 K relative to the helium bath. This is the well-known effect of film boiling of helium,[1] which causes the helium to break away from the surface of the crystal and form a gas blanket around it. However, the temperature fluctuations of the crystal occur long before the onset of film boiling at a pumping density of ~ 1.2 W/cm^2. The temperature fluctuations could not be measured because of thermal inertia of the thermocouple. It is important to note that we observed simultaneously a scattering of exciting light from the illuminated surface of the crystal (curve b), a threshold onset of noise in the electrical conductivity (curve c), and in the absorption of microwave radiation (curve d), which indicate the appearance of electron-hole plasma in the crystal.

We attribute the observed effects to the formation of helium gas bubbles at the surface of the crystal.

By scanning the surface of the sample with an ~20-mW laser beam, ~1 mm in diameter, we determined that bubbles had formed on the microcracks and scratches, which almost always remain on the surface after mechanical polishing and subsequent etching of the sample in a peroxide etching agent. The structural defects near the surface of the sample can also conceivably play an important role in the formation of gas bubbles. This assumption, however, requires further study.

We performed additional experiments on recording of EHD in a *p-n* transition by the technique described in Ref. 2, which showed that the drops from the excitation region begin to disperse simultaneously with the appearance of plasma. An analogous effect of dispersal of EHD by the phonon "wind" was initially observed by Bagaev *et al.*[3] and Astemirov *et al.*[4] In these experiments the excited surface of the crystal was not in direct contact with the helium bath. Thus, the experimental facts allow us to surmise that the basic reason for the threshold phenomenon of the aforementioned characteristics in the effects of photoconductivity, uhf absorption, and phonon drag of EHD are attributable primarily to the local superheating of the surface of the sample due to the break of the thermal contact between the crystal and the liquid helium.

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