Surface tension of electron-hole liquid in germanium

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The coefficient of surface tension of an electron-hole liquid in germanium, $\sigma = 1.6 \times 10^{-4}$ erg/cm^2, was measured by the light-scattering method.

The surface-tension coefficient of an electron-hole liquid was calculated in a number of papers,[1–4] but was never heretofore determined experimentally. We have estimated the coefficient of surface tension by measuring the temperature dependence of the concentration of electron-hole drops (EHD).

If the nuclei of the liquid phase are produced as a result of fluctuations of exciton density, then the probability of the appearance of a nucleus having a "critical" radius R^* (i.e., a nucleus in unstable equilibrium with the exciton gas) is determined by the formula[5]

$$W \sim \exp\left(-\frac{4\pi\sigma R^{*2}}{3kT}\right). \tag{1}$$

When the vapor-liquid phase transition begins at a given vapor density, which is maintained constant while the temperature is varied, then

$$R^* = \frac{2\sigma}{n_0 \epsilon_0 \ln(T_0/T)}, \tag{2}$$

where n_0 is the carrier density in the EHD, ϵ_0 is the binding energy per pair of particles in a drop, reckoned from the exciton level, and T_0 is the threshold temperature at a given generation rate. Substituting (2) in (1), we obtain

$$W \sim \exp\left[-\frac{16\pi\sigma^3}{3n_0^2\epsilon_0^2 kT \ln^2(T_0/T)}\right]. \tag{3}$$

It can be assumed that the EHD concentration in the crystal is directly proportional to the probability of production of nuclei of "critical" dimension; therefore, by measuring the temperature dependence of the concentration of the drops and using expression (3), we can find the surface-tension coefficient.

The measurements were performed with the setup described in detail in[6]. The excitation source was a helium-neon laser of 12 mW power, operating at the wavelength 1.52 μ. The exciting radiation was modulated at a frequency 1 kHz and focused on the front face of the sample into a spot of ~0.35 mm diameter (Fig. 1). Exciting pulses with rise time shorter than 3 μsec were used in the experiments. We investigated the scattering of helium-neon laser radiation at 3.39-μ wavelength. The beam of the laser was focused onto the sample into a spot of ~0.3 mm diameter in such a way that the beams of both lasers were superimposed. Owing to the near equality of the beam diameters, they had to be aligned with particular care, for otherwise diffraction by the edge of the excitation region is observed[7] and hinders the quantitative measurements. The light scattered by the EHD was amplified by a helium-neon

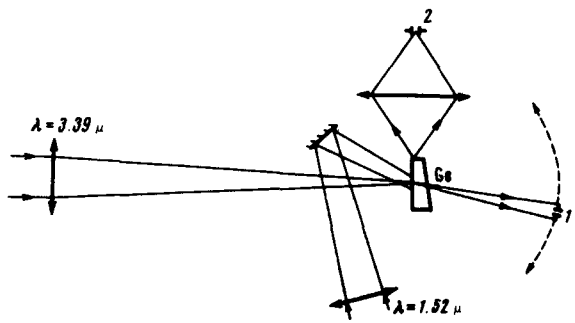

FIG. 1. Experimental setup: 1—quantum-amplifier entrance diaphragm, 2—monochromator slit.

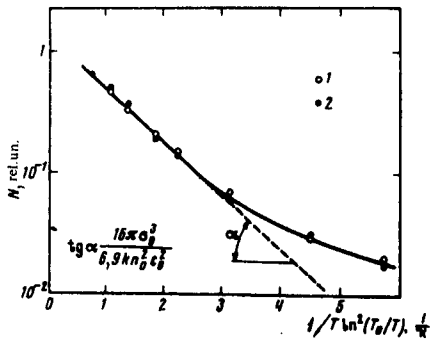

FIG. 2. Plot of EHD concentration against $[\ln(T_0/T)]^{-2}T^{-1}$ (threshold temperature $T_0=4.4$ °K): 1—recombination radiation; 2—scattering.

quantum amplifier and was registered with a PbS receiver cooled to ~100 °K.

The angular distribution of the intensity of the scattered light was recorded automatically. The measurements were performed with germanium samples having a residual-impurity concentration not higher than 10^{12} cm^{-3}.

The EHD concentration was calculated from data obtained by measuring the scattered-light intensity, in the same manner as in[8]. In addition, the EHD concentration was determined from the line intensity of the drop luminescence, which was observed simultaneously with the scattering. Since the EHD recombination-radiation line intensity is directly proportional to the volume of the liquid phase, it is possible to determine the EHD concentration in relative units by determining the radius of the drops from the angular distribution of the scattered-light intensity.

Figure 2 shows a plot of the EHD concentration, obtained from data on scattering and recombination radiation, against $[\ln(T_0/T)]^{-2}T^{-1}$. It is seen from the plot that at low temperature the experimental points fit well a straight line. As seen from (3), the slope of this line can yield the surface-tension coefficient. If we assume $\epsilon_0=2.1$ meV and $n_0=2\times10^{17}$ cm^{-3}, then we get $\sigma=1.6\times10^{-4}$ erg/cm^2. Theoretical calculations[1-4] yield for σ values from 0.8×10^{-4} to 1.5×10^{-4} erg/cm^2. It should be noted that the experimentally determined threshold temperature is apparently smaller than the true thermodynamic equilibrium temperature. The finite rise time of the exciton density when the illumination is turned on also introduces an error in the determination of σ. The assumption that W and N are proportional was not verified by us with sufficient rigor. However, the reasonable agreement between our estimate of σ and the theoretical calculations gives grounds for hoping that this value does not deviate greatly from the true one.

It can be concluded from the obtained data that under the conditions of our experiment, at temperatures below ~3 °K, the fluctuation mechanism of the production of the liquid-phase nuclei is in operation. At higher temperatures, when the probability of formation of "critical" nuclei, determined by formula (3), is greatly decreased, the concentration of the EHD is determined by the number of condensation centers.

We note in conclusion that the observed temperature dependence of the EHD concentration explains the increase, observed in[9], of the drop dimension within increasing temperature. Further investigations of the dependences of the dimensions and concentration of the EHD on the experimental condition have made it possible to trace the kinetics of the growth of the EHD and its dependence on the condition of their nucleation.[10]

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