JOULE HEATING OF GERMANIUM AND GALLIUM ARSENIDE IN LIQUID NITROGEN

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Data have been obtained on values of the maximum dissipated power for germanium and gallium arsenide in liquid nitrogen.

In the experiments small rectangular bars of p-Ge and n-GeAs ($p \sim 10^{14}$ cm^{-3}, $n \sim 10^{17}$ cm^{-3}) with different surface areas (0.2–7.5 cm^2) were investigated. A thermocouple was placed between two similar samples; electrical contact was made with fused indium.

Germanium. The degree of additional heating of the samples was determined from the current-voltage characteristic, the resistance curve, and directly from the temperature rise due to the power released. At low powers up to 0.01 watt the samples remain at liquid nitrogen temperature, and Ohm's law is satisfied ($\mu_1 p$ = const). With further power increase the temperature of the samples increases monotonically up to 80°–83° K (Fig. 1). At the same time the resistance increases. According to Hall effect data p = const; the dissipation is determined by lattice vibrations and $\mu \sim T^{-2.1}$. In this case the relative change in resistance

$$\frac{\rho_T}{\rho_{78}} = \frac{\mu_{78}}{\mu_T} = \left(\frac{T}{78}\right)^{2.1},$$

which agrees with experiment. In this region the heating is not directly proportional to the surface area of the samples. At the critical power of 13 ± 3 W/cm^2 a sharp jump in temperature to 100°–120° K occurs, at the same time the resistance abruptly increases by a factor of 2–3 (owing to the decrease in mobility), and the current falls (Fig. 2). Again when the critical power is attained, the temperature jumps to 400° K, and the current increases (band-band thermal ionization).

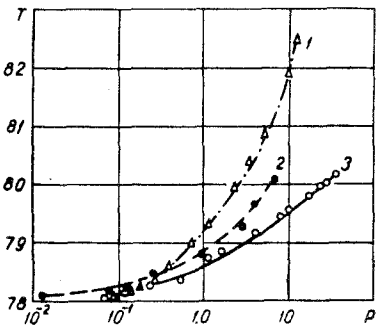

Fig. 1. Dependence of temperature of samples on power released in them: 1) S = 1.6 cm^2; 2) 0.6; 3) 5.2.

The critical power for samples with a smaller area is bigger than the average (13 W/cm^2) owing to the influence of the conductors and thermocouple leads. The hysteresis of the current-voltage characteristics shows that the power required for onset of the temperature jump is less than the power required for sustaining the "breakdown" state.

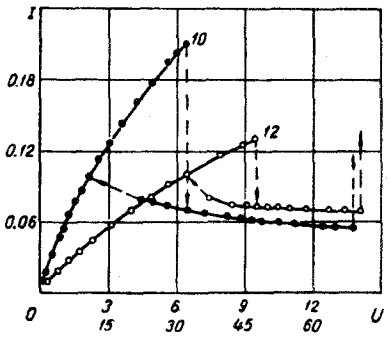

Fig. 2. Current-voltage characteristics for germanium samples 10 (S = 0.45 cm^2)—lower voltage scale, and 12 (S = 1.1 cm^2)—upper voltage scale.

Gallium arsenide. The results are analogous to those for germanium. However, after the critical power of 13 W/cm^2 is attained the temperature rises directly to ~450° K (which is connected with the constancy of n and μ in the interval 80°–450° K).

The coincidence of the critical powers for Ge and GaAs shows that the temperature jump is connected with the behavior of the liquid nitrogen, namely, with the formation of a gaseous film around the sample and a sharp decrease in heat transfer. This phenomenon was observed in helium [1] and is analogous to the formation of a "vapor lock" in boilers [2]. The considerable superheating of the samples at low powers is apparently connected with superheating of the liquid phase and also with decrease in heat conductivity with increase in temperature [3, 4].

NOTATION

T—temperature; n, p—carrier density; μ—mobility; S—area; ρ—resistivity.

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