Conductivity of plastically deformed germanium at superlow temperatures

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It is shown that the temperature dependence of the conductivity of germanium samples subjected to strong plastic deformation has a power characteristic down to 40 mK, in which the exponent depends on the deformation.

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1. It is known that a semiconductor-metal (S-M) transition occurs as a result of increasing the concentration of impurities in doped semiconductors.[1] On the metallic side of the transition the conductivity is almost independent of the temperature, while on the semiconductor side the temperature dependence of the conductivity is exponential to the transition. Investigation of the conductivity of germanium doped with impurities in the region of superlow temperatures showed[2] that the activation energy decreases with temperature, which is attributable to the mechanism of jump conductivity "with a variable length of jump." [1] Nevertheless, the activation energy decreases slower than the temperature, and the exponential conductivity can be traced to 0.1 –0.05 K. Such electrical conductivity is described well by an expression of the form

$$\sigma(T) = \sigma_0 \exp\left[-\left(\frac{T_0}{T}\right)^x\right] , \tag{1}$$

where $x = \frac{1}{4} - \frac{3}{4}$, depending on the impurity concentration.

The exponential nature of $\sigma(T)$ with decreasing activation energy is displayed clearly on the logarithmic scale, where the corresponding curves have a characteristic "concave" shape (see Fig. 1, curves a, b, and c, which correspond to curves 2, 3, and 4 in Fig. 2. of Ref. 2 and also that of Ref. 3).

2. The S-M transition was also observed in "pure" germanium that was subjected to strong plastic deformation. A model for the conductivity "along the dislocations" was developed to explain the charge-transfer process in such material. [4,5] However, in contrast to the conductivity "in the impurities," in our case there is a definite range of deformations D ($\approx$30–50%) in which a power temperature dependence of the conductivity is observed at low temperatures ($T \leqslant 30$ K)

$$\sigma(T) \sim T^y . \tag{2}$$

Usually $y \lesssim 1$, and it decreases in proportion to the increase of D. Such dependence for most of the samples of plastically deformed germanium was traced to 1.7 K.[5]

3. A question arises whether the power temperature dependences of the conduc-

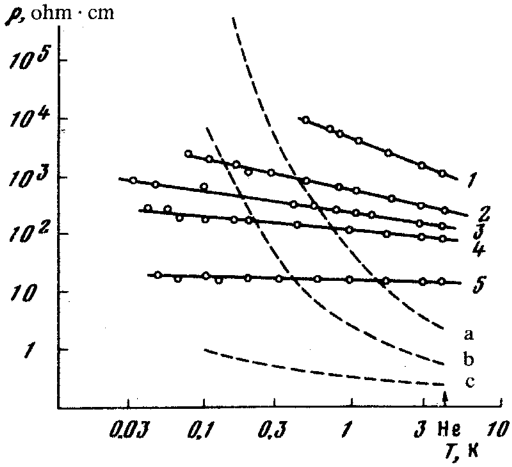

FIG. 1. Temperature dependence of the resistivity of the germanium samples doped by impurities (a,b,c) and subjected to strong plastic deformation (1–5). Parameters of the deformed samples: 1—$N = 2\times10^{13}$ cm^{-3}, $D = 30\%$; 2—$N = 2\times10^{16}$ cm^{-3}, $D = 43\%$; 3—$N = 5\times10^{17}$ cm^{-3}, $D = 28\%$; 4—$N = 2\times10^{13}$ cm^{-3}, $D = 41\%$; 5—$N = 5\times10^{17}$ cm^{-3}, $D = 47\%$.

tivity are a reflection of a fundamentally different charge-transfer mechanism connected with the specific properties of the "dislocation band," or whether they are transition regions which are replaced by the usual activation dependences with further decrease of temperature.

To obtain the answer to this question, we investigated the dependence $\sigma(T)$ of a number of samples of plastically deformed germanium with $D \geqslant 30\%$ in the region of superlow temperatures. The measurements were performed in a cryostat with a He^3–He^4 solution.[6] The starting material was n-type germanium both "pure" (with an impurity concentration $N \approx 2\times10^{13}$ cm^{-3}) and doped ($N \approx 2\times10^{16}$ and 5×10^{17} cm^{-3}). The technique of plastic deformation and contact deposition was described elsewhere.[5] The results of the investigation, shown in Fig. 1, indicate that there is no evidence of a transition to the activation conductivity in the region 0.03 –0.04 K.

Therefore, taking into account the results of Ref. 5, we can assume that there is a power temperature dependence in plastically deformed germanium in a very broad temperature range (from 40 to 0.04 K). This leads us to conclude that the power dependence is characteristic for the conductivity "along the dislocations."

It should be noted that several papers[7,8] devoted to experimental study of the conductivity "in impurities" reported that in some cases the activation nature of the conductivity with decreasing temperature was replaced by a weaker temperature dependence (specifically, a linear dependence $\sigma \sim T$ was observed in heavily doped and compensated n-InSb[8]). We can assume that this effect is connected with the dislocation structure of the doped samples investigated in this paper.

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