Dislocation conductivity of germanium

Yu. A. Osip'yan and S. A. Shevchenko

Institute of Solid State Physics, USSR Academy of Sciences

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An experimental study was made of the temperature dependence of the resistivity of plastically deformed p germanium in the range 4.2–300 °K, and electric conductivity attributed to conductivity along the dislocation lines has been observed.

In the study of the influence of dislocations on the electric properties of p-germanium, we have observed an anomaly in the temperature dependence of the carrier mobility.[1,2] It turned out that at $T < 80$ °K the mobility of the holes moving perpendicular to the dislocations decreases with increasing dislocation density N_D. In samples with $N_D \approx 1\times 10^6 - 1\times 10^7$ cm^{-2}, the temperature dependence of the hole mobility has a deep minimum at $T = 16$ °K.[1] In samples with dislocation density higher than 10^7 cm^{-2}, the decrease of the Hall mobility with decreasing temperature started at even higher temperatures[2] and was more abrupt. At the same time, the Hall emf also began to decrease strongly with decreasing temperature, and at $T \lesssim 30$ °K the Hall effect in these samples practically vanished, i.e., it was impossible to measure the Hall emf by the methods used by us.

We have therefore undertaken a more detailed study of the electric properties of p-germanium with larger dislocation density. We present below results of measurements performed in the temperature interval 4.2–300 °K. Figure 1 shows the temperature dependence of

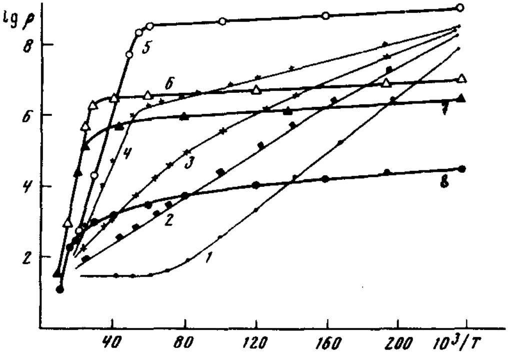

FIG. 1. Temperature dependence of the resistivity of a control sample (1) and deformed samples (2—8) of p-germanium. In samples 2—4, the dislocation density was 5×10^6, 7×10^6, and 1×10^7 cm^{-2}, respectively. The degree of deformation of samples 5—8 was 1, 3, 6 and 20%, respectively.

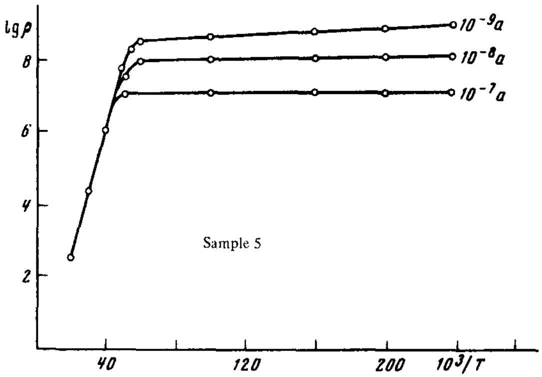

FIG. 2. Temperature dependence of the resistivity of sample 5 at different values of the electric current through the sample.

the resistivity of a control sample and of deformed samples in the temperature range 4.2–100 °K. The fact that the resistivity ρ of the control sample (differential concentration of the minute impurities is 3×10^{12} cm^{-3}, and the total concentration is 3×10^{13} cm^{-3}) depends little on the temperature in the interval 5–20 °K results from the circumstance that a small decrease in the hole density is compensated by the increase of their mobility with decreasing temperature. At $T < 20$ °K, the resistivity increases exponentially because of the freezing-out of the free carriers. At low degrees of deformation by bending (dislocation density $N_D \leq 1\times10^7$ cm^{-2}), the resistivity increases at all temperatures at $T < 80$ °K, both as a result of the decrease in the carrier density and as a result of the decrease in their mobility.[1] These data were obtained for samples for which the mobility minimum described in[1] was observed, and are shown in Fig. 1 by thin lines (samples 2–4). In samples 5–8, deformed by compression to larger degrees by the procedure described in[2], at $T = 730$–750 °C, a sharp increase of the resistivity at $80\text{ °K} \lesssim T \lesssim 25$ °K, with activation energy $\mathcal{E}_1 = 0.03 - 0.07$ eV, is followed by a transition to a rather weak temperature dependence of the resistivity at $T \lesssim 25$ °K, with an activation energy $\mathcal{E}_2$. The values of $\mathcal{E}_2$ observed by us are less than 10^{-3} eV. Therefore, the electric conductivity $\sigma(T)$ of the strongly deformed samples 5–8 in the entire temperature interval 4.2–100 °K can therefore be expressed in the form

$$\sigma(T) = \sigma_1(\mathcal{E}_1, T) + \sigma_2(\mathcal{E}_2, T). \qquad (1)$$

An investigation of the dependence of the Hall emf and of the resistivity on the magnetic field intensity has shown that the conductivity σ_1 in all the samples is due as before to the free carriers—the holes. It is typical that $\rho_1(T)$ and $\mathcal{E}_1$ increase with increasing degree of deformation, but the growth of the absolute value of $\mathcal{E}_1$ takes place only up to a value 0.07 eV.

The onset of the conductivity σ_2, characterized by a low activation energy $\mathcal{E}_2$, limits the exponential growth of the resistivity of the sample with decreasing temperature. This state of the samples is characterized by the following features: 1) no Hall emf is observed; 2) the resistivity of the samples does not increase in a magnetic field; 3) the electric conductivity increases with increasing degree of deformation, from 10^{-9} Ω-cm ($\epsilon = 1\%$) to 10^{-4} Ω-cm ($\epsilon = 20\%$); 4) the current-voltage characteristics have superlinear sections.

It is seen from the dependence of $\mathcal{E}_2$ on the electric field intensity E (Fig. 2) that the activation energy $\mathcal{E}_2$ decreases with increasing current I through the sample, and the conductivity σ_2 no longer has an activation character at $I = 10^{-7}$ A ($E \approx 60$ V/cm).

Estimates and control experiments show that the described features of σ_2 cannot be due to (a) heating of the samples in the electric field, (b) injection of the free carriers from the contacts, (c) the effect of changes in the surface states of the samples, and (d) hopping conductivity via the impurities.

We think it possible to assume on the basis of the presented data that the observed singularities of the electric properties of plastically deformed germanium are due to the presence of a unique electric conductivity along the dislocation lines, and can serve as evidence of the presence of one or several dislocation bands in the energy spectrum of the carriers.

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[2] Yu. A. Osip'yan and S. A. Shevchenko, Zh. Eksp. Teor. Fiz. **65**, 698 (1973) [Sov. Phys.-JETP **38**, 345 (1974)].