TEMPERATURE DEPENDENCE OF THE ELECTRICAL RESISTANCE OF p-TYPE GERMANIUM AT PRESSURES UP TO 90 kbar

N. N. KUZIN and A. A. SEMERCHAN

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The temperature dependence of the electrical resistance of p-type germanium with $\rho = 27$ ohm-cm is investigated at pressures up to 90 kbar and temperatures ranging from room temperature to 152°C. The width of the forbidden band E_g at 127–152°C is determined as a function of the pressure.

In 1952 Bridgman[1] investigated the pressure dependence of the electrical resistance of germanium up to 100,000 kg/cm^2 at room temperature. The resistance differed qualitatively in germanium samples with carriers of different signs. The resistance of n-type germanium with $\rho = 19$ ohm-cm increased with pressure up to 50,000 kg/cm^2 (40 kbar according to the scale of Kennedy and La Mori), decreasing thereafter. The resistance of p-type germanium with $\rho = 3.35$ ohm-cm decreased smoothly in the entire investigated range of pressures. In spite of the considerable number of papers concerning investigations of electrical and galvanomagnetic properties of germanium under pressure,[2–9] no clear explanation of this phenomenon has so far been given. This paper is an attempt to clarify this problem somewhat.

It has been stated previously[10] that in n-type germanium with $\rho = 39.4$ ohm-cm at pressures up to 90 kbar at room and higher temperatures the main role is played by the intrinsic conductivity; for this reason at constant temperature the resistance of the samples varies with the pressure P in the same direction as the width of the forbidden band E_g, since the number of intrinsic charge carriers is proportional to $\exp(-E_g/2kT)$, where k is the Boltzmann constant and T the absolute temperature. Thus the resistance has, just as E_g, a maximum at a pressure of 40 ± 2.5 kbar.

In the present work we investigated the temperature dependence of the resistance of p-type germanium with $\rho = 27$ ohm-cm at pressures up to 90 kbar. An electrical current flowing through a coil wound on the lateral surface of the high-pressure apparatus provided the heating. The temperature was measured with a chromel-alumel thermocouple placed in the high-pressure chamber in such a way that its bead was in direct proximity of the sample. The accuracy of the temperature determination was $\pm 2\%$, and of the pressure— $\pm 5\%$. The sample resistance was measured with a PPTV-1 potentiometer by the method of four probes, introduced into the high-pressure chamber by means of special electrical leads. As is seen from Fig. 1, in p-type germanium at room temperature throughout the investigated range of pressures impurity conductivity predominates with complete (or almost complete) impurity ionization. The ln R(P) curve has at room temperature no characteristic maximum at 40 kbar (Fig. 2, curve I). A maximum is observed at higher temperatures when the intrinsic conductivity begins to play the dominant role (Fig. 2, curve II).

The different nature of the R(P) curves for germanium is explained in the first place by the unequal ratio of the intrinsic and impurity conductivity which depends on P, T, and the number and type of impurities. When intrinsic conductivity

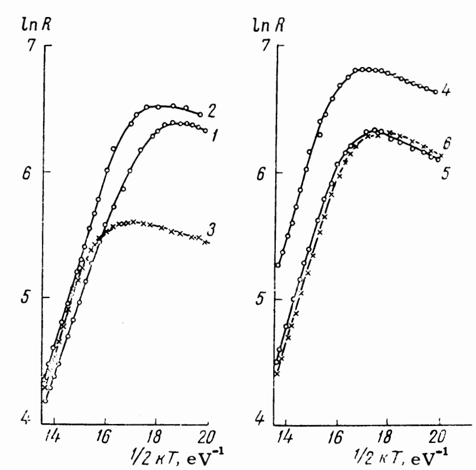

FIG. 1. The temperature dependence of the electrical resistance of p-type germanium with $\rho = 27$ ohm-cm at pressures: Curve 1 – 20, 2 – 30, 3 – 40, 4 – 60, 5 – 75, and 6 – 90 kbar. k – Boltzmann's constant, and T – absolute temperature. Samples 1 – 6 have different dimensions.

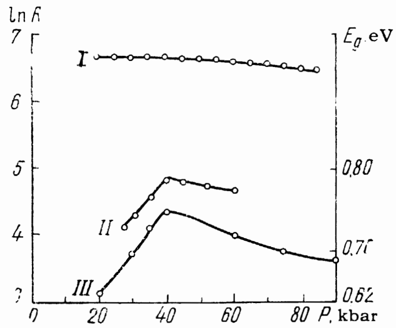

FIG. 2. The change of the electrical resistance of p-type germanium with pressure: I – at room temperature, II – at 156°C. III – pressure dependence of the forbidden band E_g of p-type germanium.

predominates, the curve has a maximum at 40 kbar. In the region of impurity and, particularly, mixed conductivity the situation becomes considerably more complicated. The form of the R(P) curve with changing pressure is then determined not only by E_g but by such quantities as E_{imp} and u, where E_{imp} is the activation energy of the impurity atoms and u is the mobility of the intrinsic and impurity carriers.

The value of E_g, equal to the slope of the straight-line portions of the curves, has been obtained from the data shown in Fig. 1 by least squares in the range of $1/2\,kT$ values from 14.5 (127°C) to 13.49 (152°C). The accuracy of the determination was ±2%. It must be noted that the $E_g(P)$ curve for p-type germanium (Fig. 2, curve III) is somewhat lower than the same curve for n-type germanium.[10] This can apparently be explained by a difference in the temperature intervals within which we determined E_g for n and p-type germanium (it is known[11] that E_g of germanium decreases with increasing temperature). In addition, the method of determining E_g from the temperature dependence of the resistance is not altogether accurate, since in doing so one does not take into account the change in the mobility of the carriers with temperature, which depends on the number and type of the impurities.

In conclusion it should be noted that with increasing pressure a temperature shift of the maximum is observed on the temperature dependence of the resistance in the direction of the change of E_g (see Fig. 1 and Fig. 2, curve III).

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