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Abstract

Full Text

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CHANGE IN THE ELECTRICAL RESISTANCE OF CERTAIN SEMICONDUCTORS AT PRESSURES UP TO 300,000 kg/cm^2

Measurement of the electrical resistance of certain chemical elements (^1) possessing semiconductor properties (C, Si, Ge, Se, Te) was carried out by Bridgman (^2) up to a pressure of 100,000 kg/cm^2.

The authors, continuing the study of the electrical resistance of elements of the periodic system ([3]-5), measured the electrical resistance of B, C, Si, P, Ge, Te, I. All measurements in the present work were performed at room temperature.

In Fig. 1a the change in the electrical resistance of a boron specimen, R/R_{30}, is presented as a function of pressure, where R_{30} is the electrical resistance of boron at $P = 25\,600$ kg/cm^2 (reference point Bi_I—Bi_{III}). The value of the electrical resistance R_{30} is taken as the initial value, since at lower pressures a strong change in the electrical resistance of the specimen occurs owing to changes in its geometrical dimensions, caused by the outflow of the pressure-transmitting substance from the working volume of the chamber. The electrical properties of pure boron have as yet been investigated insufficiently in detail, but its belonging to the class of semiconductors is beyond doubt. This is confirmed by the sharp decrease in the electrical resistance of a boron specimen upon its heating (from 27 to 300° by more than $2 \cdot 10^6$ times) (^7). From the curve in Fig. 1a it is seen that the electrical resistance of boron, when the pressure is changed from 25,600 to 250,000 kg/cm^2, decreases by a factor of 2.6, passing through a maximum at 35,000 kg/cm^2.

Fig. 1. Change in electrical resistance: *a*—boron under pressure up to 250,000 kg/cm^2; *b*—graphite up to 250,000 kg/cm^2; *c*—silicon up to 150,000 kg/cm^2

Figure 2 and Figure 3: plots of electrical resistance versus pressure

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We also carried out an investigation of a specimen of polycrystalline graphite (spectrally pure). When the pressure was changed from 25,600 to 250,000 kg/cm^2, the electrical resistance of graphite (see Fig. 1b) decreased by 20.7%. It should be noted that the initial portion of the curve up to 100,000 kg/cm^2 coincides with Bridgman' s data. The comparison was verified by calculating the ratio R_{100}—the resistance at 100,000 kg/cm^2—to R_{30}—the resistance at 25,600 kg/cm^2. According to Bridgman' s data $R_{100}/R_{30} = 0.843$; according to the data obtained by us $R_{100}/R_{30} = 0.845$.

In Fig. 1b the dependence of the electrical resistance of silicon on pressure is presented. The sample was made from preliminarily pressed powder. As can be seen from the curve, as the pressure changes from 25,600 to 150,000 kg/cm^2, the resistance smoothly decreases by 17.7%. These data agree in order of magnitude with Bridgman' s data, who measured the electrical resistance of samples of *p*-type and *n*-type silicon up to a pressure of 100,000 kg/cm^2. For the *p*-type, the resistance from 36,000 to 100,000 kg/cm^2 decreases by 6%; for the *n*-type, from 30,000 to 100,000 kg/cm^2, by approximately one third.

Fig. 2. Change in electrical resistance:
a—germanium under pressure up to 250,000 kg/cm^2 (*I*—*p*-type curve, *II*—*n*-type curve);
b—black phosphorus under pressure up to 200,000 kg/cm^2

Fig. 3. Change in electrical resistance;
a—iodine under pressure up to 300,000 kg/cm^2;
b—selenium under pressure up to 250,000 kg/cm^2;
c—tellurium under pressure up to 250,000 kg/cm^2

The change in the electrical resistance of germanium at high pressures is so large that, in order to plot the dependence of electrical resistance on pressure, it is necessary to use semilogarithmic coordinates.

In Fig. 2a, curve 1, the dependence of the electrical resistance of *p*-type germanium with high specific electrical resistivity ($\rho \sim 40\ \Omega \cdot \mathrm{cm}$) on pressure is presented. From the curve it is seen that, when the pressure changes from 25,600 to 250,000 kg/cm^2, the electrical resistance of germanium smoothly decreases by $4.85 \cdot 10^3$ times.

The electrical resistance of *n*-type germanium (Fig. 2a, curve *II*) from 25,600 to 250,000 kg/cm^2 decreases by $0.77 \cdot 10^3$ times; curve *II* passes through

maximum at 30,000-35,000 kg/cm^2. A maximum in the electrical resistance of *n*-type germanium was found by Bridgman at 50,000 kg/cm^2. The difference from our data can apparently be explained by a difference in the degree of purity of the starting materials. It is interesting to note that the strongest resistance of n- and p-type germanium is observed at pressures above 100,000 kg/cm^2.

Phosphorus, as is known, has a number of modifications. White phosphorus, which is an insulator with a forbidden-band width of 2.1 eV ($\rho \sim 1 \cdot 10^{11}\ \Omega \cdot$cm), at a pressure of 13,000 kg/cm^2 and 200° transforms into black phosphorus, whose forbidden-band width is 0.33 eV ($\rho = 0.439\ \Omega \cdot$ cm). Red phosphorus also transforms into black phosphorus at a pressure of 45,000 kg/cm^2 and room temperature. With increasing pressure, the specific resistance of black phosphorus decreases and at 23,000 kg/cm^2 is $3700 \cdot 10^{-6}\ \Omega \cdot$ cm ([7]), i.e., it decreases by a factor of 100. From Fig. 2b it is evident that the electrical resistance of black phosphorus from 25,600 to 90,000 kg/cm^2 decreases by a factor of 27.5, and with further increase in pressure it does not change.

These data, in order of magnitude and in the character of the dependence of electrical resistance on pressure, agree with the data of one of the authors. In work ([8]) the electrical resistance of red phosphorus was measured up to 200,000 kg/cm^2. The method of producing high pressure and measuring electrical resistance in that work made it possible to obtain roughly quantitative results, which explains the small discrepancy.

The electrical resistance of selenium up to 100,000 kg/cm^2 was measured by Bridgman, who found that at 100,000 kg/cm^2 the resistance of a selenium specimen is 10^4 times less than the initial value. We found that from 25,600 to 250,000 kg/cm^2 (Fig. 3b) the resistance of selenium decreases by $2 \cdot 10^5$ times, passing through a maximum at 40,000 kg/cm^2. A maximum in the electrical resistance of selenium was also noted by Bridgman, but at 56,000 kg/cm^2.

Figure 3b gives the dependence of the electrical resistance of tellurium on pressure. When the pressure is increased from 30,000 to 45,000 kg/cm^2, the electrical resistance decreases by a factor of 8.6. In the region of 45,000 kg/cm^2 a step-like drop in resistance by a factor of 11 is observed. With further increase in pressure it decreases comparatively slowly. At pressures from 30,000 to 250,000 kg/cm^2 the electrical resistance of the tellurium specimen decreases by a factor of 1200 and amounts to thousandths of an ohm, approaching the electrical resistance of metals. If it is taken into account that, according to Bridgman' s data, the electrical resistance of tellurium from 0 to 30,000 kg/cm^2 decreases by a factor of 600, then from 0 to 250,000 kg/cm^2 it decreases by $\sim 10^6$ times.

Iodine was also studied by one of the authors and E. V. Zubova ([8]). Iodine has a high specific resistance at atmospheric pressure and room temperature (from $6.7 \cdot 10^7$ to $1.3 \cdot 10^9\ \Omega \cdot$ cm) ([7]). Under the action of high pressures, the resistance of an iodine specimen decreases sharply and at 250,000 kg/cm^2 is only 85 Ω. With further increase in pressure to 300,000 kg/cm^2, the resistance of iodine decreases by a factor of two.

From Fig. 3a it is evident that the electrical resistance of iodine from 45,000 to 300,000 kg/cm^2 decreases by $\sim 5 \cdot 10^3$ times. Knowing approximately the dimensions of the iodine specimen after the experiment and its specific electrical resistance, one can calculate that the resistance of iodine from 0 to 300,000 kg/cm^2 decreases by 6–8 orders of magnitude. These data, in order of magnitude, agree with the literature data ([8], [9]).

In the present work the authors did not take contact resistance into account, since the aim of the work was to determine the direction and order of magnitude of the change in electrical resistance at high pressures. The absence of a substantial influence of contact resistance on the course of the change in electrical resistance is confirmed by the fairly good agreement of our data with Bridgman' s data up to 100,000 kg/cm^2, in whose experiments the contact conditions were different.

Analyzing the data obtained, one can note a general tendency toward a decrease in the electrical resistance of the elements studied under

pressure, and the order of magnitude of the decrease increases with increasing atomic number of the element. Indeed, the resistance of boron, carbon (graphite), and silicon decreases within one order of magnitude; that of phosphorus (black modification) and germanium (*p*- and *n*-types) by $\sim 10^3 \div 10^4$ times; and that of Se and Te by $10^5 \div 10^6$, iodine by $\sim 10^6 \div 10^8$.

In further investigations the temperature dependence of the electrical resistance of these substances on pressure will be determined.

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REFERENCES

1. *Semiconductors in Science and Technology*, ed. A. F. Ioffe, 1957.
2. P. W. Bridgman, Proc. Am. Acad. Arts and Sci., **81**, 165 (1952).
3. L. F. Vereshchagin, A. A. Semerchan et al., DAN, **136**, No. 2 (1961).
4. L. F. Vereshchagin, A. A. Semerchan et al., DAN, **138**, No. 1 (1961).
5. L. F. Vereshchagin, A. A. Semerchan, S. V. Popova, DAN, **138**, No. 5 (1961).
6. L. F. Vereshchagin, A. A. Semerchan, S. V. Popova, DAN, **139**, No. 3 (1961).
7. M. P. Slavinskii, *Physicochemical Properties of the Elements*, Moscow, 1952.

8. L. F. Vereshchagin, E. V. Zubova, *Fiz. tverd. tela*, **2**, 11 (1960).

9. R. E. Harris, R. J. Vaisny et al., *Progress in Very High Pressure Research*, 1960, p. 165.

Note: Figure translations are in progress. See original paper for figures.