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Abstract

Full Text

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PHYSICS

Academician L. F. VERESHCHAGIN, O. G. REVIN, V. N. SLESAREV,
I. N. SENFI-KHUSAĪNOV, A. S. CHMYKHOV

ELECTRICAL CONDUCTIVITY OF ARTIFICIAL SEMICONDUCTING DIAMOND

The production of artificial diamonds has made it possible to begin a systematic study of many of their properties, including physical ones. However, the electrical properties of such diamonds have not yet been studied.* It is known that natural—

Fig. 1. Appearance of artificial semiconducting diamonds

—diamonds are insulators, but among them there are crystals characterized by relatively low electrical resistance (down to $50 \text{ ohm} \cdot \text{cm}$ at room temperature, in contrast to the majority of diamonds, whose resistance is $10^{11}–10^{16} \text{ ohm} \cdot \text{cm}$). These diamonds have been assigned ⁽³⁾ to

* As far as we know, only in works ^(1,2), and also by L. V. Lezheiko (Institute of Semiconductors, USSR Academy of Sciences, on diamond obtained at the Institute of High-Pressure Physics, USSR Academy of Sciences), has the electrical conductivity of synthetic diamond been investigated.

a special group and are called type IIb.* Type IIb diamonds exhibit semiconductor properties; studies have shown that they are all *p*-type semiconductors with an impurity activation energy of $0.35 \div 0.38 \text{ eV}$.**

Semiconducting diamonds can also be synthesized by special doping under conditions of high pressures and temperatures. Measurement of the electrical conductivity of artificial diamonds doped with aluminum gave activation-energy values of 0.32 eV (1) and 0.37 eV (2).

We obtained and studied single crystals of diamond doped with aluminum (Fig. 1), colorless, well-faceted octahedra and

Fig. 2. Apparatus for determining the electrical conductivity of diamond as a function of temperature: 1 —LATR; 2 —heating transformer; 3 —millivoltmeter

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Figure 2: Fig. 2. Apparatus for determining the electrical conductivity of diamond as a function of temperature: 1 –LATR; 2 –heating transformer; 3 –millivoltmeter for measuring thermal emf; 4 –junction of a chromel-alumel thermocouple; 5 –movable contact; 6 –crystal; 7 –nichrome heater; 8 –silver core

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cubeoctahedra with linear dimensions of 0.5–1 mm. Measurements of the electrical properties of the crystals were carried out on a special apparatus (Fig. 2), comprising a cylindrical nichrome heater 7 with a silver core 8, a chromel-alumel thermocouple 4, and a movable head with a micrometer screw 5, also made of silver. The specimen was placed on the end of the core near the thermocouple junction and was pressed by opposite faces to the electrodes. Leads from the core and the movable contact were connected to the measuring instrument. To reduce heat removal through the movable contact, the latter was made in the form of an alundum tube, inside which a nichrome wire 0.2 mm in diameter and 40 mm long was placed. The core itself was thermally insulated from the base on which it was mounted by an asbestos-cement casing. To exclude the influence of air currents on the temperature regime, the entire device was covered with an organic-glass cap. Temperature regulation was carried out by means of the LATR 1 feeding the heating transformer 2. The time for temperature stabilization at each measurement was 10 min. The resistance of the specimen was measured with a VK7-9 vacuum-tube voltmeter; if the resistance value exceeded its measurement limits, with an E6-3 teraohmmeter. The total error of the temperature and resistance measurements did not exceed 5%.

In the course of the measurements, the contacts between the electrodes and the diamond did not break down; this testifies to their ohmic character, which is a consequence of

* In terms of their optical and electrical behavior, natural diamonds are divided into three types: I, IIa, and IIb.

** In (4) an acceptor activation energy of ~ 0.7 eV is given.

low concentration of surface defects that do not impede the penetration of excess electrons into the diamond.

The type of conductivity of diamond is determined from the rectification effect at a point metal–semiconductor contact; for this purpose the movable contact was replaced by a steel needle. The indication of rectification was carried out

Fig. 3. Current-voltage characteristic of a diamond diode

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by an oscillographic method. The current-voltage characteristic of the resulting diode was reproduced on the oscilloscope screen (Fig. 3), changing its form depending on the type of semiconductor.

Fig. 3. Current-voltage characteristic of a diamond diode

The artificial diamond specimens we investigated exhibited *p*-type conductivity up to a temperature of 500°C. However, because of the instability of the point contact, especially at high temperatures, it was not possible to carry out precise measurements of the current-voltage characteristic.

The diamond crystals under consideration had, at room temperature, a resistivity of 10^5 – $10^4 \Omega \cdot \text{cm}$. The dependence of the logarithm of the resistivity on reciprocal temperature for one such specimen is shown in Fig. 4. The temperature was measured from 293 to 793°K; the resistivity decreased from $3 \cdot 10^4$ to $5 \Omega \cdot \text{cm}$. It is seen from the graph that the dependence of $\lg R$ on T^{-1} deviates only weakly from a straight line. From measurement of the temperature dependence by means of the relation

$$\sigma = \sigma_0 \exp(-\Delta E_a/2kT)$$

the activation energy of the acceptors was determined to be 0.34 eV.*

Fig. 4. Dependence of the logarithm of the resistance of diamond on reciprocal temperature

However, it is known [5] that diamond can exhibit semiconductor properties in a surface layer of small thickness, of the order of several microns. In order to prove that the diamonds investigated by us are semiconductors throughout their entire volume, several specimens were split, and the same measurements were carried out on the fragments. The temperature dependence of the resistance in this case did not change, within an accuracy of up to 8%.

For comparison, we investigated the electrical conductivity of diamond crystals synthesized under analogous conditions but not doped with aluminum. All of them were insulators with a resistivity at room temperature of 10^9 – $10^{10} \Omega \cdot \text{cm}$. This con—

* For different specimens the activation energy varied from 0.34 to 0.36 eV.

confirms that it is precisely the aluminum acceptor centers that are responsible for the semiconducting properties of diamond.

The current-voltage characteristic of a diamond diode at 450°C, shown in Fig. 3, demonstrates the possibility of using such devices as high-temperature nonlinear

elements.

Institute of High-Pressure Physics
Academy of Sciences of the USSR
Academgorodok settlement, Podolsk district, Moscow region

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