CONCERNING THE TRANSITION OF DIAMOND INTO THE METALLIC STATE

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It is shown experimentally that at pressures on the order of 1 megabar, in the temperature interval from 77 to 600°K, $\partial T/\partial P$ is negative on the equilibrium curve of the dielectric and metallic phases of diamond.

We have reported earlier [1] that when a pressure on the order of 1 megabar ($P \sim 10^6$ kg/cm^2) is applied, the electric resistivity of diamond decreases jumpwise by several orders of magnitude. When the pressure is removed, the electric resistance also returns jumpwise to the initial value. These facts have allowed us to suggest that a transition to a new, metallic phase takes place in diamond. Similar transitions were observed in germanium and in silicon at 115 - 120 kbar and 190 kbar, respectively [2, 3].

We have attempted to determine qualitatively the course of the dielectric-metal equilibrium line on the (P, T) phase diagram of carbon. To this end, we investigated the dependence of the electric resistivity of the sample on the applied force at different temperatures. The experiments were performed in the temperature interval 77 - 600°K.

Figure 1a shows a typical plot of the resistance R against the force F, including the jump in R. It is observed that when the temperature is increased the transition occurs at lower forces (the loop on Fig. 1a shifts to the left) and vice versa.

It should be noted that in experiments with a thin layer of powder, the force necessary to turn the diamond into a metal depends on the thickness of the powder layer, and also on the anvils between which it is placed. In our experiments the dielectric-metal transition was observed at forces ranging from 20 to 200 kg.

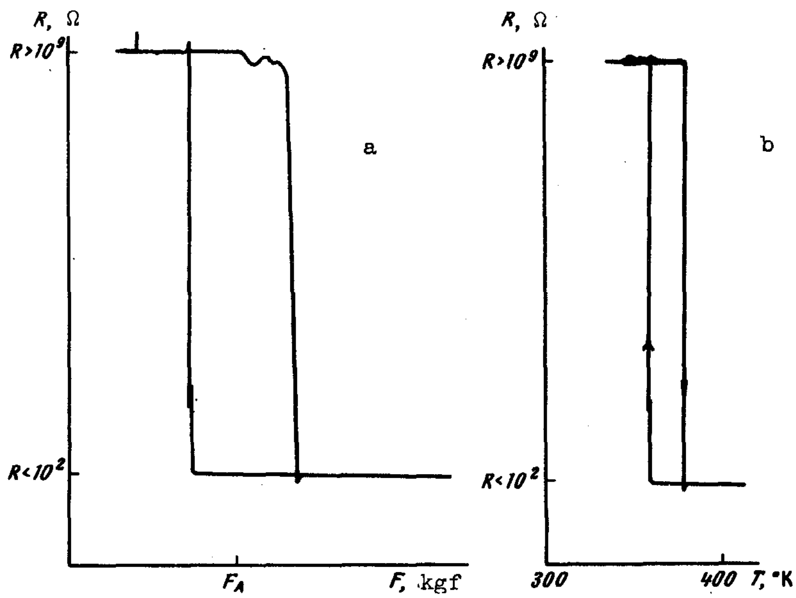

Fig. 1. Electric resistivity of diamond vs. the stress (a) and the temperature (b).

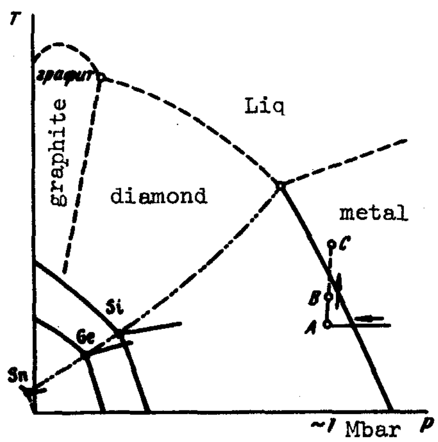

Fig. 2. Phase diagram of carbon (after Bundy [4]). The state A was reached by slowly removing the force applied to the initially metallic diamond sample. The metal - dielectric transition and dielectric - metal transitions occur at the points B and C, respectively.

Figure 1b shows a plot of R(T) at a fixed force. The observed jump of R confirms that the dielectric - metal equilibrium line has a negative slope. As expected, with decreasing force a higher temperature is needed to obtain the transition (the loop on Fig. 1b shifts to the right).

By way of example we indicate the forces at which the transition takes place for one of the experimental runs performed at room and nitrogen temperatures:

$$F = 110,\ 114,\ 112\ \text{kgf}$$

at room temperature and

$$F = 152 \text{ and } 140\ \text{kgf}$$

after cooling to $\sim 77°K$.

Although these data do not make it possible to determine the numerical value of $(\partial T/\partial P)_{equil}$ on the dielectric - metal equilibrium curve, we can nevertheless conclude on their basis that $(\partial T/\partial P)_{equil} < 0$.

We note that metastable states can exist in the region adjacent to the phase-equilibrium line. In particular, the metallic phase can exist in the region where the dielectric phase is stable (Fig. 2). In this case the metal should become "unfrozen" when heated and turn into a dielectric.

We have observed a transition of the metal into a dielectric with increasing temperature in experiments performed in the following manner. We first plotted R(F) (Fig. 1a). At a force F_A (Figs. 1a and 2) the system was heated. During the rise of the temperature we observed a jumplike increase of the electric resistance of the system to the value corresponding to the dielectric phase.

If the heating is then continued, a transition into the metallic phase is again observed (Fig. 2).

The negative slope of the line of phase equilibrium between the semiconducting and metallic phases is typical of elements of the fourth group of the periodic system [4] (Fig. 2). Experiments performed by us with diamond show that carbon is no exception.

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