PHOSPHORESCENCE AND THERMOLUMINESCENCE OF ARTIFICIAL DIAMONDS WITH A BORON IMPURITY

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Fig. 1 and Fig. 2

Figure 1: Fig. 1 and Fig. 2

Abstract

Full Text

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A. V. NIKITIN, G. N. BEZRUKOV, V. S. VARAGIN

PHOSPHORESCENCE AND THERMOLUMINESCENCE OF ARTIFICIAL DIAMONDS WITH A BORON IMPURITY

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It is known that the introduction into diamond, under certain conditions, of boron and aluminum impurities, which play the role of acceptors, gives rise to p-type conductivity in diamond ([1,2]). In the present work it is shown that a boron impurity can also exert a substantial influence on the thermoluminescence of synthetic diamonds.

The samples were synthesized by the technology repeatedly described in the literature ([3–5]), in which an alloy of several metals was used as the solvent for graphite, and boron was additionally introduced into it. Measurements of thermoluminescence were carried out over the temperature interval 20—400° by the standard method ([6]), at a sample-heating rate of 1°/sec.

After one hour of irradiation at room temperature from an x-ray tube with a tungsten anode, voltage 37 kV, current 15 mA, phosphorescence was observed, decaying according to an exponential law. The duration of the decay period was sometimes more than 2 hours. The dependence of $\lg I$ on time is shown in Fig. 1. The luminescence was passed through a filter selecting the principal wavelength $\lambda = 436$ mμ and was stopped by a filter selecting the principal wavelength $\lambda = 579$ mμ.

Fig. 1. Decay of phosphorescence of artificial diamonds with a boron impurity, excited by x-rays. I is the intensity of luminescence, t is the time after cessation of excitation.

Fig. 2. Thermoluminescence curves of artificial diamonds with a boron impurity (1) and without a boron impurity (2). The intensity of curve 2 is increased by a factor of 50.

After the phosphorescence had decayed, thermoluminescence curves were recorded, of the form shown in Fig. 2, 1. The observed luminescence peak in the region of 115° was represented, like the phosphorescence, by a blue emission band (filter 436 mμ). For comparison, Fig. 2 also gives the thermoluminescence curve 2 of nonphosphorescing diamonds without a boron impurity, obtained under analogous crystallization conditions. The introduction of boron leads to a considerable increase in the luminescence intensity, without noticeably affecting the "color" or the position of the thermoluminescence peak near 115°. Calculations carried out by the known method ([7]) showed that

the thermoluminescence of diamonds with a boron impurity is governed by first-order processes. Therefore the trap depth E_0 and the probability of thermal transitions p_0 were calculated from formulas (8)

$$E_0 = \frac{kT_m^2}{\delta_m}, \qquad p_0 = \frac{\beta_0}{\delta_m} \exp\left(\frac{T_m}{\delta_m}\right)$$

(k is Boltzmann' s constant, T_m is the temperature of the maximum in °K, δ_m is the half-width of the peak, β_0 is the heating rate). The following values were found: $E_0 = 0.49$ eV, $p_0 = 2.7 \cdot 10^4$ s^{-1}. Calculation of E_0 from the formula

$$\ln I = C - E_0/kT$$

gives the value 0.37 eV.

Thus, the introduction of boron causes the appearance of long-lived phosphorescence and an intensification of the luminescence peak at 115°. If, moreover, one takes into account the identical "color" of the phosphorescence and of the thermoluminescence peaks shown in Fig. 2, it may be concluded that localization of excitation electrons in the studied diamonds with and without a boron impurity occurs at metastable levels of one and the same type of centers ([9], [10]).

Since the presence of a luminescence peak at 115° has also been established for boron-free diamonds, and the luminescence intensity of the latter depends on the content of substitutional nitrogen ([6]), it may be concluded that, also in the case of the presence of boron impurity, nitrogen participates in the formation of luminescence centers. The role of boron in crystals containing nitrogen is, consequently, that boron atoms under certain conditions facilitate the entry of nitrogen atoms into the structure. In this case a covalent bond is formed between nitrogen and boron atoms, realized by an electron pair whose total spin is zero (we note that the total valence of nitrogen and boron is equal to the valence of two carbon atoms). As a result, nitrogen in the presence of substitutional boron in diamond cannot be detected by the EPR method, which is also confirmed experimentally ([11]). The proposed model is also supported by the fact that diamonds with a boron impurity, in their optical properties, belong to nitrogen-containing crystals, although on the basis of EPR data they should rather be assigned to the group of nitrogen-free diamonds ([11]).

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