appearing during crystal growth. It should be pointed out that the results obtained at 77.4 and 300°K are in good agreement.

The effective radius R_{inst} governing the recombination and at the same time of the effective potential φ_{inst} in the case when such clusters are compact should definitely be affected by temperature: an increase in the temperature from 77 to 300°K should reduce R_{inst} by a factor of about 2 and φ_{inst} by a factor of 3 (Ref. 5). Our measurements at 77.4 and 300°K showed (curves 1 and 1' in Fig. 1) that the maximum real potential at 300°K was $\varphi_{max} \approx 0.4$ eV, which was approximately 3 times as large as $\varphi_{max} \approx 0.15$ eV at 77.4°K. This temperature dependence of the experimentally observed height of the potential barriers is in good agreement with the predictions and is a serious argument in support of the proposed explanation of the quasi-point nature of clusters.

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Investigation of microplasma breakdown at a contact between a metal and a semiconducting diamond

A. V. Bogdanov, I. M. Vikulin, and T. V. Bogdanova

I. I. Mechnikov State University, Odessa

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Rectification at a contact between diamond and metal, particularly the possibility of impact ionization of carriers in diamond subjected to strong electric fields, are topics of importance in relation to potential applications of diamond in electronic technology. We investigated a contact between a synthetic diamond crystal and nickel. A second (ohmic) contact was deposited by evaporating aluminum in vacuum on diamond heated to 1000°C (Ref. 1). Our diamond crystals were cubo-octahedra with a distance of 0.6–0.8 mm between the nearest parallel faces carrying contacts; they were synthesized in the presence of impurities taken in the ratio Ti:In:As = 1:1:1 (wt.%). Thermal breakdown of diamond in strong electric fields was prevented by applying a sinusoidal voltage of 40–400 Hz. The luminescence generated in strong electric fields was recorded with an FÉU-18A photomultiplier or observed visually with a MIN-8 microscope. The experimental arrangement made it possible to determine simultaneously the current-voltage and brightness-voltage characteristics of a sample, which were displayed on an oscilloscope screen.

The forward-bias current through a diamond–nickel contact could be (for a given value of the bias) much less than under a reverse bias, which indicated a rectification of the current at this contact. Under a high reverse bias it was found that the current changed abruptly (jumps) and this was also true of the luminescence intensity, as demonstrated by the current-voltage and brightness-voltage characteristics (Fig. 1). A sudden jump of the current in the case of the current-voltage characteristic occurred at the same voltage as a sudden jump of the luminescence brightness as recorded with the aid of the brightness-voltage characteristic.

The current discontinuities ΔI in the current-voltage characteristics and the corresponding jumps of the luminescence brightness, demonstrated by the brightness-voltage characteristics, all indicate the presence of microplasmas.[2] Each microplasma in a semiconductor is usually characterized by a current discontinuity ΔI, turn-on voltage U_{to}, and a dynamic resistance R_d determined from the slope of the current-voltage characteristic of the microplasma in question. When the voltage was increased, the dynamic range of the microplasma resistance R_d decreased and the discontinuity of the current ΔI increased. When a sample was heated, the value of U_{to} of a microplasma increased, as indicated by the avalanche nature of the processes occurring in microplasmas[3] and by the reduction in the current discontinuity ΔI.

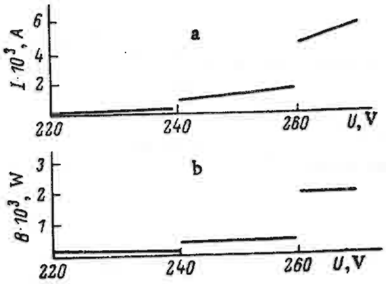

FIG. 1. Current–voltage (a) and brightness–voltage (b) characteristics of a diode.

When microplasmas were investigated visually with the aid of a microscope in the rectifying contact region, it was found that luminous green areas of 0.01-0.05 mm in diameter were observed. When the voltage across a sample was increased, the intensity and size of the first jump increased, and then at some distance from the first, a second brighter microplasma was observed and this was followed by a third one, etc.

The luminescence maximum was located, as in the case of diamonds with ohmic contacts,[4,5] in the wavelength range 510-530 nm, indicating that the luminescence was due to a donor–acceptor mechanism. In this radiative recombination case the donors were nitrogen impurities ($E_d \approx 4.0$ eV) and the acceptors were boron impurities ($E_a \approx 0.36$ eV).

The thickness of the depletion layer d and the critical field E_{cr} corresponding to the onset of impact ionization carriers in a contact region were deduced from the well-known expressions for an abrupt junction on the assumption that the space-charge density was $\rho = q(N_a - N_d)$, where N_a and N_d, are, respectively, the acceptor and donor impurity concentrations.[3] The nitrogen donors in diamond are present in concentrations of the order of 10^{18} cm^{-3} and $N_a \gg N_d$. Assuming that the main part of the voltage drop occurs in a depletion region near a rectifying contact, we find that $d = (3\text{-}4) \cdot 10^{-5}$ cm and $E_{cr} = 10^7$ V/cm. The somewhat overestimated value of E_{cr} compared with the theoretical value of the same quantity ($7 \cdot 10^6$ V/cm) – see Ref. 6 – may be explained by a drop of part of the voltage across the bulk of the semiconductor crystal.

The experimental results allow us to estimate also the geometric dimensions of the microplasmas generated by the method described above. In calculating the geometric dimensions of microplasmas in semiconductors it is usual to assume that the microplasmas are cylindrical and the height of the cylinder is equal to the thickness of the depletion layer of the rectifying contact. The volume of a microplasma can be estimated from[7]

$$\Theta_M = \frac{2\tau_\Theta U_{to}}{g N_d R_d}, \qquad (1)$$

where R_d is the microplasma resistance found graphically; $\tau_\Theta = d/v$ is the transit time of carriers across the effective impact ionization region in a microplasma; $v \approx 10^6$ cm/sec is the saturation drift velocity of carriers in diamond. Using Eq. (1), attempts were made to estimate the volume and cross section of microplasmas, which gave 10^{-11}–10^{-10} cm^3 and 10^{-7}–10^{-6} cm^2, respectively. These microplasma dimensions are in approximate agreement with those found visually.

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