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THE ELECTRON AND PROTON IRRADIATION EFFECTS ON THE PROPERTIES OF HIGH-VOLTAGE 4H-SiC SCHOTTKY DIODES WITHIN THE OPERATING TEMPERATURE RANGE

V. V. Kozlovski [1] ✉, A. A. Lebedev [2], R. A. Kuzmin [2],
D. A. Malevsky [2], M. E. Levinshtein [2], G. A. Oganesyan [2]
[1] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia;
[2] Ioffe Institute, St. Petersburg, Russia
✉ kozlovski@physics.spbstu.ru

Abstract. In the paper, the effects of type, dose and temperature of irradiation with stable elementary particles (0.9 MeV electrons and 15 MeV protons) on the properties of the high-voltage 4H-SiC Junction Barrier Schottky diodes at room temperature (23°C) and the limiting operating one (175°C) have been compared. The electron irradiation of the objects with equal doses at 23°C и 175°C was found to cause a significant increase in its base differential resistance in the former case and the absence of this effect in the latter. However, in the latter, DLTS spectra exhibited a noticeable increase in the concentration of deep levels in the upper half of the band gap. The proton irradiation resulted in a noticeable rise in the mentioned resistance even at 175°C. The results obtained make it possible to evaluate the radiation resistance of the studied devices to proton and electron irradiation within the framework of any given requirements.

Keywords: silicon carbide, Schottky diode, irradiation, DLTS spectrum, current–voltage characteristic, annealing

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ВЛИЯНИЕ ЭЛЕКТРОННОГО И ПРОТОННОГО ОБЛУЧЕНИЯ НА СВОЙСТВА ВЫСОКОВОЛЬТНЫХ 4H-SiC ДИОДОВ ШОТТКИ В РАБОЧЕМ ТЕМПЕРАТУРНОМ ДИАПАЗОНЕ

В. В. Козловский [1] ✉, А. А. Лебедев [2], Р. А. Кузьмин [2],
Д. А. Малевский [2], М. Е. Левинштейн [2], Г. А. Оганесян [2]
[1] Санкт-Петербургский политехнический университет Петра Великого,
Санкт-Петербург, Россия;

[2] Физико-технический институт им. А. Ф. Иоффе РАН, Санкт-Петербург, Россия

✉ kozlovski@physics.spbstu.ru

Аннотация. В работе сопоставлено влияние вида, дозы и температуры облучения стабильными элементарными частицами (электронами и протонами с энергиями 15 и 0.9 МэВ соответственно) на свойства высоковольтных 4H-SiC интегрированных диодов Шоттки (JBS) при комнатной (23°C) и предельно допустимой рабочей (175°C) температурах. Установлено, что электронное облучение объекта одинаковыми дозами при температурах 23°C и 175°C приводит к существенному росту дифференциального сопротивления базовых слоев в первом случае и отсутствию этого эффекта во втором. Однако во втором случае DLTS-спектры демонстрируют заметный рост концентрации глубоких уровней в верхней половине запрещенной зоны. Протонное же облучение даже при 175°C приводит к существенному росту указанного сопротивления. Исследовано влияние отжига на облученные протонами структуры. Полученные результаты позволяют оценивать устойчивость исследованных приборов к протонному и электронному облучению в рамках любых заданных требований.

Ключевые слова: карбид кремния, диод Шоттки, облучение, спектр DLTS, вольт-амперная характеристика, отжиг

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Introduction

High-voltage 4H-SiC Schottky diodes are important components of automotive and space-based electronics, nuclear power plant equipment, reactive power compensators, photovoltaic cells, etc. The radiation resistance of such components to electron and proton irradiation is an essential criterion for the possibility of using them in nuclear reactor equipment and aerospace electronics [1 – 4].

The effect of electron irradiation on the properties of SiC-based devices has been studied in a number of papers (see, for example, Refs. [5 – 7] and references therein). In these papers, irradiation was carried out only at room temperature. In Ref. [8], for 1700 V 4H-SiC integrated junction barrier Schottky diodes (JBS), the influence of the electron irradiation temperature at very high temperatures T_i (300°C and 500°C) was studied. These temperatures are much higher than the limit operating temperature of high voltage SiC industrial JBS diodes (175°C).

The effect of 100 keV–60 MeV proton irradiation on the properties of the 4H-SiC devices has also been studied in a number of papers. In the vast majority of papers, irradiation was carried out at room temperature (see, for example, references in Ref. [9]). In Ref. [10], the T_i irradiation temperature was within 100–400 K. In Ref. [11], the maximum irradiation temperature T_i was 500°C.

Studies of the irradiation effect at high (up to 500°C) temperatures have shown that the radiation resistance of SiC devices increases monotonically with the irradiation temperature growth. It has been demonstrated that high-temperature ("hot") irradiation produces defects that are absent during irradiation at room temperature. As shown earlier, when studying the defect creation in the silicon and gallium arsenide, it is very important to pay attention to high-temperature investigations specifically, due to the possibility of formation of secondary defects [12, 13].

However, as a practical matter, of prime importance is analyzing the effect of electron and proton irradiation and subsequent annealing on the properties of high-voltage Schottky diodes in the range from the room temperature to the limiting operation temperature of 175°C (CPW3-1700S010 Datasheet | Silicon Carbide Schottky Diode Chip. (n.d.), Accessed November 20, 2023), because 4H-SiC diodes are elements of power industrial electronics including automotive electronics, power converters, solar cells drives, and numerous other applications [14 – 17].

The goal of this study was to compare the effects of electron and proton irradiation carried out at room temperature and the maximum operating temperature, as well as post-irradiation annealing, on the parameters of high-power 4H-SiC JBS.

This study allows us to suggest some practical recommendations for improving their radiation resistance.

In this paper, we have compared the effect of irradiation with 0.9 MeV electrons and 15 MeV protons at T_i = 23°C and 175°C on the parameters of 4H-SiC high-voltage 4H-SiC JBS diodes with 600 and 1700 V blocking voltage U_b.

Materials and methods

4H-SiC Schottky diodes (JBS structures) with blocking voltage U_b = 600 V (CPW3-0600S002.0)[1] and U_b = 1700 V (CPW3-1700SO10)[2] were investigated [14]. The concentration of uncompensated impurity ($N_d - N_a$) in the base of structures with U_b = 600 V was $1 \cdot 10^{16}$ cm^{-3}; this value for the diodes with U_b = 1700 V was $3.4 \cdot 10^{15}$ cm^{-3}. At small forward bias, in the region of the exponential part of forward current–voltage characteristic, the I–V characteristics of both types of diodes were very well described by the dependence [11, 18]:

$$I = I_0 \exp(qU/\beta kT),$$

where I_0 is the saturation current, $I_0 = 10^{-12} - 10^{-11}$ A; β is the ideality factor, $\beta = 1.02 - 1.05$; q is the elementary charge; k is the Boltzmann constant.

Irradiation by electrons with an energy of 0.9 MeV was carried out in a pulsed mode (the pulse repetition rate was 490 Hz; its duration was 330 µs). The irradiation was carried out in a target chamber in air, where the temperature was maintained with an accuracy of ±5°C.

Irradiation by protons with an energy of 15 MeV was carried out at the MGTs-20 cyclotron in a pulsed mode (the pulse repetition rate was 100 Hz; its duration was 2.5 ms). The current density of the proton beam did not exceed 100 nA/cm^2.

The path lengths of electrons with an energy of 0.9 MeV and protons with an energy of 15 MeV in SiC were about 1.0 mm [19]. Thus, at base thicknesses $L \approx 10$ µm for 600 V diodes and $L \approx 20$ µm for diodes with U_b = 1700 V, defects were introduced uniformly over the sample volume.

The structures were subjected to post-irradiation annealing in the atmosphere of dry nitrogen at 300°C for 120 min. The I–V characteristics of the diodes were measured at 23°C in a pulsed mode, which ensured the isothermal nature of the measurements. The parameters of the formed radiation defects were determined by the method of non-stationary capacitance spectroscopy (DLTS). The measurements were carried out both in the initial samples and after each irradiation and/or annealing.

Results and discussion

The forward I–V characteristics of a diode with U_b = 600 V for an unirradiated structure (curve *1*) and those irradiated with electrons at temperatures T_i = 23°C and 175°C are compared in Fig. 1.

At small forward biases U_f, less than the cutoff voltage $U_c \approx 0.8$ V, i.e., in the region of the exponential part of the I–V curve, the electron irradiation has only a slight effect on the parameters of the current – voltage characteristics [8]. At $U_f \geq U_c$, the I–V curves are characterized by a linear forward current dependence on the forward voltage.

In an unirradiated diode, the differential resistance R_d of the base is 0.075 Ω. Irradiation with a fluence $\Phi_e = 1 \cdot 10^{16}$ cm^{-2} at room temperature leads to an increase in R_d by 1.9 times, to the value of $R_d \approx 0.142$ Ω. Irradiation with a fluence $\Phi_e = 2 \cdot 10^{16}$ cm^{-2} leads to an increase in R_d by approximately 4.6 times, to the value of $R_d \approx 0.345$ Ω. The concentration in the base of the

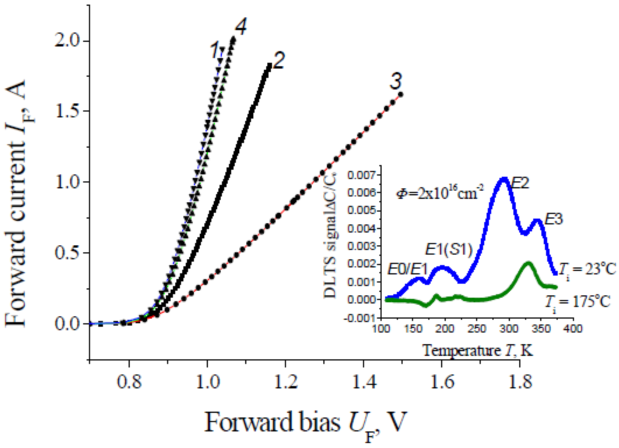

Fig. 1. A comparison of forward current – voltage characteristics of a diode (the blocking voltage is 600 V) obtained before (*1*) and after (*2* – *4*) its electron irradiation with fluences $\Phi_e = 1\cdot10^{16}$ cm^{-2} (*2*) и $2\cdot10^{16}$ cm^{-2} (*3*, *4*) at T_i = 23°C (*2*, *3*) and 175°C (*4*).
The data was obtained in the region of biases exceeding the cut-off voltage; T_i = 23°C (*1*).
In the inset: the DLTS spectra of the sample irradiated with electrons with fluence $\Phi_e = 2\cdot10^{16}$ cm^{-2} at two temperatures. The rate window was 51 s^{-1}

non-irradiated structure n_0 approximately equals to 10^{16} cm^{-3} [20]. Assuming that the change in the mobility under the influence of irradiation can be neglected [21] and that the change in the base resistance is due to a decrease in the electron concentration only, it is easy to calculate that, for the both fluence values, the removal rate η_e of electrons under the influence of irradiation is

$$\eta_e = (n_0 - n)/\Phi_e \approx 0.40 \text{ cm}^{-1}, \quad (1)$$

where n is the electron concentration after irradiation.

The η_e value obtained is less than that of 1.67 cm^{-1} specified in Ref. [6], and slightly more than that of 0.25 cm^{-1} reported in Ref. [22].

After electron irradiation with fluence $\Phi_e = 2\cdot10^{16}$ cm^{-2} at T_i = 175°C, the differential resistance of the base R_d is 0.085 Ω (see curve *4* in Fig. 1), i. e. the value of R_d increases as a result of irradiation by only approximately 13 %. It is quite obvious that an increase in the irradiation temperature T_i, even within the permissible operating temperature, radically increases the radiation resistance of the devices.

Inset in Fig. 1 shows the DTLS spectra describing the levels in the upper half of the band gap after electron irradiation of diodes with fluence $\Phi_e = 2\cdot10^{16}$ cm^{-2} at T_i = 23°C and 175°C. The temperature position of the DLTS peaks at T_i = 23°C agrees satisfactory with the data of Ref. [7], in which the DLTS spectra were studied after irradiation of JBS structures with U_b = 1700 V by electrons with an energy of 1.05 MeV. The concentrations of acceptor levels N_t determined from the position of the peaks in the inset (see Fig. 1) are $N_t^{E0/E1} = 2.35\cdot10^{13}$ cm^{-3}, $N_t^{E1/S1} = 3.70\cdot10^{13}$ cm^{-3}, $N_t^{E2} = 1.40\cdot10^{14}$ cm^{-3}, and $N_t^{E3} = 1.02\cdot10^{14}$ cm^{-3} for the E_0/E_1, E_1/S_1, E_2, and E_3 peaks, respectively.

It is well known that electron irradiation creates also EH6/7 acceptor level, which corresponds to a maximum in DTLS spectra at a temperature of ~ 570 K [6]. When measuring the samples (see the data in Fig. 1), the maximum temperature did not exceed 400 K in order to avoid spontaneous annealing [5]. The DLTS spectra measured up to temperature of ~ 630 K on control samples showed that the EH6/7 level with concentration of about 10^{14} cm^{-3} corresponds to fluence $\Phi_e = 2\cdot10^{16}$ cm^{-2} at T_i = 23°C.

Thus, the total concentration of acceptor centers in the upper half of the forbidden zone after electron irradiation with fluence $\Phi_e = 2\cdot10^{16}$ cm^{-2} at a temperature of T_i = 23°C is approximately $4\cdot10^{14}$ cm–3. At the initial electron concentration $n_0 = 10^{16}$ cm^{-3}, one would expect an increase in the resistance of the diode base by ≈ 10 %. Meanwhile, the experiment shows that the resistance increases by ~ 4.6 times. It should be assumed that electron irradiation creates acceptor levels in the lower half of the band gap as well. However, to the best of our knowledge, data on the concentration and parameters of the acceptor centers created by electron irradiation in 4H-SiC in the lower half of the band gap are not available in the literature.

Under irradiation at T_i = 175°C (see inset in Fig. 1), the peak with the maximum amplitude at $T \approx 330$ K (peak E_2) corresponds to the $Z1/Z2$ level. Its concentration $N_t^{Z1/Z2}$ is $5.0 \cdot 10^{13}$ cm^{-3}. The peaks observed at T = 171 K, 185 K, and 220 K correspond to the concentration of $N_{t171} \approx 9.0 \cdot 10^{12}$ cm^{-3}, $N_{t185} \approx 4.2 \cdot 10^{12}$ cm^{-3}, and $N_{t220} \approx 5.0 \cdot 10^{12}$ cm^{-3}, respectively. Assuming that the concentrations of the EH6/7 and $Z1/Z2$ levels are equal [23], the total concentration of acceptor levels generated by fluence $\Phi_e = 2 \cdot 10^{16}$ cm^{-2} in the upper half of the band gap at T_i = 175°C can be considered equal to $1.2 \cdot 10^{14}$ cm^{-3}. An increase in resistance due to irradiation expected from such data should be ~1.2 %. Meanwhile, as can be seen from a comparison between curves *1* and *4* in Fig. 1, the resistance R_d increases in this case by about ~13%, i.e., about an order of magnitude stronger.

The forward I–V characteristics of a diode with U_b = 600 V for an unirradiated structure (curve *1*) and those irradiated with protons at temperatures T_i = 23°C and 175°C, as well as the structures after subsequent annealing (see inset in Fig. 2), are compared in Fig. 2.

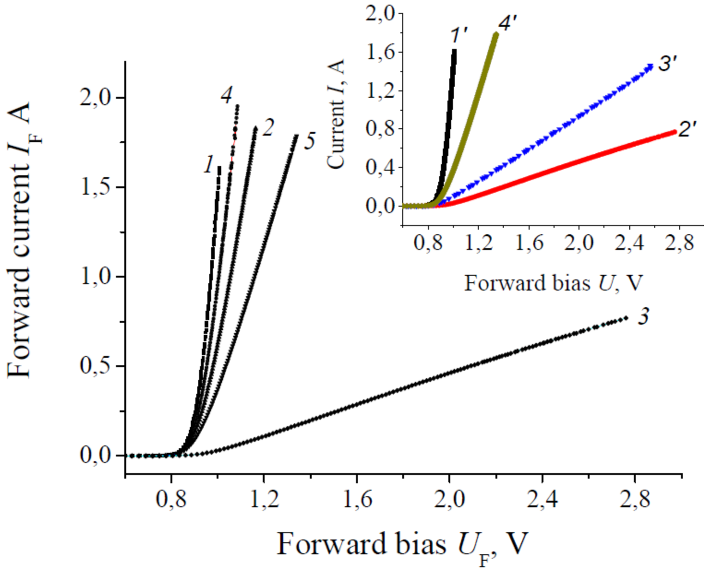

Fig. 2. A comparison of forward current – voltage characteristics of a diode (the blocking voltage is 600 V) obtained before (*1*, *1′* in the inset) and after (*2*, *2′* in the inset, *3* – *5*) its proton irradiation with fluences $\Phi_p = 5 \cdot 10^{13}$ cm^{-2} (*2*, *2′*, *4*) and $1 \cdot 10^{14}$ cm^{-2} (*3*, *5*) at T_i = 23°C (*2*, *2′*, *3*) and 175°C (*4*, *5*).

In the inset: the I–V curves of the diode irradiated ($5 \cdot 10^{13}$ cm^{-2}, 23°C) without subsequent annealing (*2′*); irradiated ($1 \cdot 10^{14}$ cm^{-2} , 23°C) and then annealed at 300°C for 2 hrs (*3′*), irradiated ($5 \cdot 10^{13}$ cm^{-2}, 175°C) and then annealed twice at 300°C for 2 hrs in the both cases (*4′*). All the data was obtained in the region of biases exceeding the cut-off voltage

After irradiation with protons at room temperature with fluence $\Phi_p = 5 \cdot 10^{13}$ cm^{-2} (see curve *2* in Fig. 2), the differential base resistance R_d was 0.15 Ω.

In a similar manner (see Eq. (1)), the electron removal rate

$$\eta_p = (n_0 - n)/\Phi_p \approx 100 \text{ cm}^{-1}, \tag{2}$$

where n is the electron concentration after irradiation.

Note that approximately the same increase in R_d results from electron irradiation with fluence $\Phi_e = 1 \cdot 10^{16}$ cm^{-2} (see curve *2* in Fig. 1).

After proton irradiation with fluence $\Phi_p = 1 \cdot 10^{14}$ cm^{-2}, the R_d value was about 2.3 Ω, i. e., it increased by a factor of 30 compared to the R_d value in the nonirradiated diode. However, at $n_0 = 1.0 \cdot 10^{16}$ cm^{-3}, $\eta_e \approx 100$ cm^{-1}, and $\Phi_p = 1 \cdot 10^{14}$ cm^{-2}, the electron concentration in the base n would have to be equal to zero. Such a discrepancy between the estimate established from the value of η_e determined at $\Phi_p = 5 \cdot 10^{13}$ cm^{-2} and the experimental result presented by curve *3* in Fig. 2 can be explained by the “flattening” of the dependence $n(\Phi)$ when approaching the situation of full compensation ($n = 0$).

At $T_i = 175$°C and irradiation with fluence $\Phi_p = 5 \cdot 10^{13}$ cm^{-2} (see curve *4* in Fig. 2), the R_d value becomes equal to ≈ 0.09 Ω, i. e., it increases by only 1.2 times compared to the differential resistance of the nonirradiated diode. After irradiation with fluence $\Phi_p = 1 \cdot 10^{14}$ cm^{-2}, the R_d value is 0.24 Ω (see curve *5*), i.e., an order of magnitude less than that after irradiation with the same fluence at room temperature.

The inset in Fig. 2 shows the results of post-irradiation annealing (proton irradiation of the diodes had fluence $\Phi_p = 1 \cdot 10^{14}$ cm^{-2} at $T_i = 23$°C and 175°C). Annealing at 300°C for 120 min led to a noticeable decrease in the base differential resistance for the diode irradiated at $T_i = 23$°C (compare curves *2′* and *3′*). However, even after annealing, the value of R_d (see curve *3′*) significantly exceeds the value of R_d in an unirradiated diode (see curve *1′*). After irradiation at $T_i = 175$°C, the diode was twice subjected to subsequent annealing at 300°C. The duration of each annealing was 120 min. However, annealing did not have any noticeable effect on the current–voltage characteristic of the diode irradiated at $T_i = 175$°C (see curve *4′*).

It should be noted that an increase in the annealing temperature to a value significantly exceeding 300°C can lead to degradation of devices even in the absence of a voltage applied to the device. As noted in Ref. [24], heating to temperatures $T > 370$°C leads to partial melting of nickel into the silicon carbide surface.

The results of the study of electron and proton irradiation effects on the parameters of JBS devices with blocking voltage $U_b = 1700$ V qualitatively correlate well with the above results for diodes with $U_b = 600$ V.

Fig. 3 shows the forward current–voltage characteristics of a diode with a blocking voltage of 1700 V in the region of biases exceeding the cut-off voltage.

In the unirradiated diode, the differential resistance of the base R_d is 0.082 Ω. Electron irradiation at room temperature with fluence $\Phi_e = 5.0 \cdot 10^{15}$ cm^{-2} leads to an increase in R_d by a factor of 1.8, up to $R_d \approx 0.15$ Ω. After irradiation with fluence $\Phi_e = 1.5 \cdot 10^{16}$ cm^{-2}, the

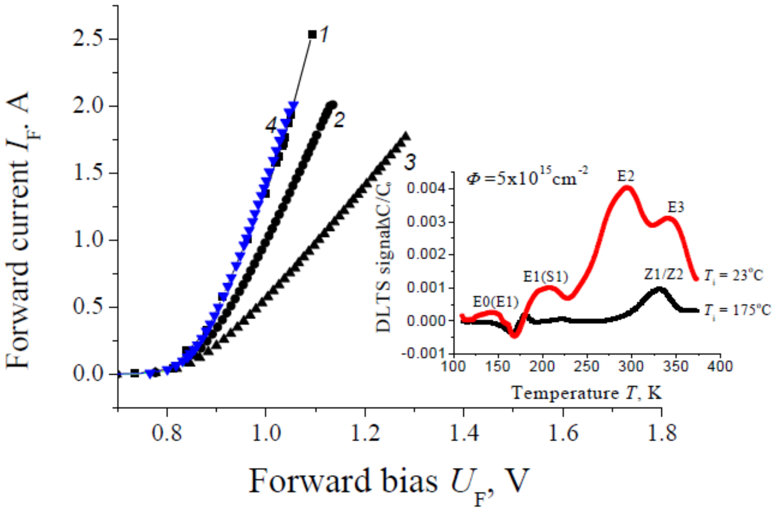

Fig. 3. A comparison of forward current–voltage characteristics of a diode (the blocking voltage is 1700 V) obtained before (*1*) and after (*2* – *4*) its electron irradiation with fluences $\Phi_e = 5.0 \cdot 10^{15}$ cm^{-2} (*2*, *4*) and $\Phi_e = 1.5 \cdot 10^{16}$ cm^{-2} (*3*) at $T_i = 23$°C (*2*, *3*) and 175°C (*4*).
The data was obtained in the region of biases exceeding the cut-off voltage.
In the inset: the DLTS spectra of the sample irradiated with electrons with fluence $\Phi_e = 5.0 \cdot 10^{15}$ cm^{-2} at two temperatures. The rate window was 51 s^{-1}

value of R_d was ≈ 0.23 Ω, i.e. increased approximately 2.8 times. At the initial concentration $n_0 = 3.4 \cdot 10^{15}$ cm^{-3}, this result corresponds to the electron removal rate $\eta_e \approx 0.15$ cm^{-1}. This value agrees well with that one found for similar diodes in Ref. [7] upon irradiation with electrons with an energy of 1.05 MeV.

After electron irradiation of the sample with a fluence $\Phi_e = 5.0 \cdot 10^{15}$ cm^{-2} at $T_i = 175$°C (see curve *4* in Fig. 3), the *I*—*V* curve precisely coincides with the corresponding one of the unirradiated sample. However, as can be seen from the inset in Fig. 3, the DLTS spectra corresponding to the levels in the upper half of the band gap demonstrate changes in the amplitudes of the peaks not only after irradiation at room temperature, but also after irradiation at $T_i = 175$°C. One can see in Fig 3 that at $\Phi_e = 0$, the amplitudes of the maxima of the DLTS spectra are negligible compared to the amplitudes of the DLTS spectra of irradiated ones.

Comparing the results shown in the inset in Fig. 3 with those shown in the inset in Fig. 1, it is easy to see that in both cases DLTS registers almost identical maxima. A small difference in the positions and widths of the maxima is explained by the inevitable change in these parameters with a significant change in fluence.

For the DLTS spectrum at $T_i = 175$°C, the maximum at $T = 317$ K was identified as $Z1/Z2$ level with a concentration of $N_{Z1/Z2} \approx 1.2 \cdot 10^{13}$ cm^{-3}. The total concentration of all levels observed in the upper half of the band gap corresponding to the irradiation temperature $T_i = 175$°C, taking into account the concentration of the EH6/7 level, taken equal to the concentration of the $Z1/Z2$ level, is $N_t^{\Sigma} \approx 2.6 \cdot 10^{13}$ cm^{-3}, i. e. less than one percent on the electron concentration $n_0 = 3.4 \cdot 10^{15}$ cm^{-3} in the nonirradiated sample. Thus, as in the discussion of the data shown in Fig. 1, it should be assumed that acceptor levels with a considerable concentration are created by electron irradiation also in the lower half of the band gap.

Fig. 4 shows the effect of proton irradiation at temperatures $T_i = 23$°C and 175°C as well as subsequent annealing on forward *I*—*V* characteristics of a diode with $U_b = 1700$ V.

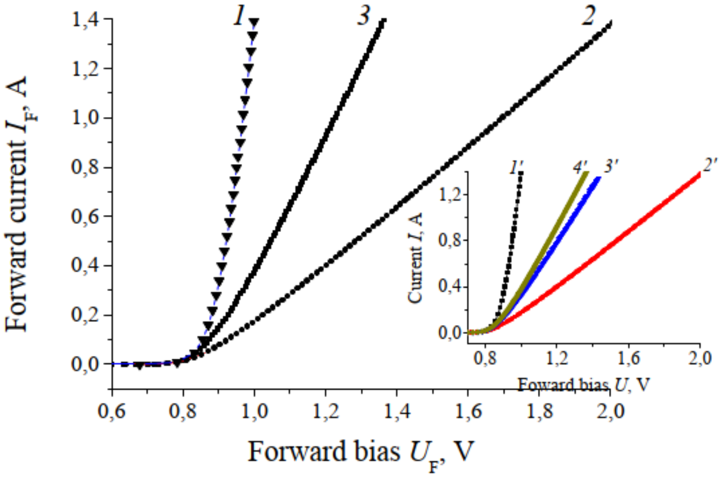

Fig. 4. A comparison of forward current — voltage characteristics of a diode (the blocking voltage is1700 V) obtained before (*1*, *1′* in the inset) and after (*2*, *2′* in the inset, *3*) its proton irradiation with fluence $\Phi_p = 3 \cdot 10^{13}$ cm^{-2} (*2*, *2′*, *3*) at $T_i = 23$°C (*2*, *2′*) and 175°C (*3*, *3′*).

In the inset: the *I*—*V* curves of the diode irradiated ($3 \cdot 10^{13}$ cm^{-2}, 23°C) without subsequent annealing (*2′*); irradiated ($3 \cdot 10^{13}$ cm^{-2}, 23°C) and then annealed at 300°C for 2 hrs (*3′*), irradiated ($3 \cdot 10^{13}$ cm^{-2}, 175°C) and then annealed twice at 300°C for 2 hrs in the both cases (*4′*). All the data was obtained in the region of biases exceeding the cut-off voltage

After proton irradiation with fluence $\Phi_p = 3 \cdot 10^{13}$ cm^{-2} at $T_i = 23$°C, the base differential resistance R_d increased from 0.082 to 0.812 Ω, which corresponds to an order of magnitude decrease in the electron concentration in the base. Thus, the removal rate of electrons due to the generation of acceptor centers by protons is in this case

$$\eta_p = (n_0 - n)/\Phi_p \approx 100\ \text{cm}^{-1}, \qquad (3)$$

which agrees with the data obtained above for diodes with U_b = 600 V very well (see Eq. (2)).

At the same fluence $\Phi_p = 3\cdot10^{13}$ cm^{-2}, but at the irradiation temperature T_i = 175°C, the value of the base differential resistance after irradiation was R_d = 0.38 Ω, i. e., about 2.1 times less than that after irradiation with the same fluence at room temperature (23°C). Annealing for two hours at 300°C reduces the differential resistance R_d of the diode irradiated at 23°C from 0.812 to 0.420 Ω, i. e., almost two times (compare curves *2′* and *3′* in the inset in Fig. 4). However, this value is still greater than the R_d value after irradiation with the same fluence at T_i = 175°C (R_d = 0.38 Ω, curve *4′*). On the other hand, annealing in the same mode (120 min at 300°C) has practically no effect on the R_d value of the diodes irradiated at T_i = 175°C. This result turns out to be partly expected, since some of the defects introduced during irradiation were annealed at 200 – 350°C [25].

Conclusions

The effects of 0.9-MeV-electron and 15-MeV-proton irradiation on the parameters of the high-voltage 4H-SiC Schottky diodes with blocking voltages U_b = 600 V and 1700 V were studied at irradiation temperatures T_i = 23°C (room temperature) and 175°C (limiting operating temperature). Removal rate η_e under electron irradiation for diodes with U_b = 600 V was found to be 0.40 cm^{-1} for T_i = 23°C. For diodes with U_b = 1700 V, the value of η_e was found to be $\eta_e \approx$ 0.15 cm^{-1}. Electron irradiation at T_i = 175°C practically does not affect the resistance of the base. Thus, heating during irradiation even to a relatively low temperature significantly increases the radiation resistance of devices with respect to electron irradiation. Both for T_i = 23°C and 175°C, a comparison of the DLTS spectra describing the levels in the upper half of the band gap with the data on the changes in the base resistance leads to the assumption that acceptor levels with a noticeable concentration are created during electron irradiation also in the lower half of the band gap. Under proton irradiation, both for the diodes with U_b = 600 V and 1700 V, the removal rate η_p for T_i = 23°C was found to be about 100 cm^{-1}. Annealing for 120 min at 300°C after irradiation with fluence $\Phi_p = 1\cdot10^{14}$ cm^{-2} at T_i = 23°C leads to a noticeable decrease in the differential resistance of the base. Double annealing for 120 min at 300°C after irradiation with the same fluence at T_i = 175°C practically does not change the current–voltage characteristic of the diodes.

In summary, it may be said that the radiation hardness of high-voltage SiC Schottky diodes subjected to electron irradiation, can be significantly improved if they are heated to a relatively low temperature during irradiation. As for the proton irradiation, the radiation resistance of these devices also increases noticeably with increasing the irradiation temperature. At relatively low irradiation doses, even a relatively short-term post-irradiation annealing at a temperature of 300°C can significantly reduce the differential resistance of the diode base.

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THE AUTHORS

KOZLOVSKI Vitali V.
Peter the Great St. Petersburg Polytechnic University
29 Politechnicheskaya St., St. Petersburg, 195251, Russia
kozlovski@physics.spbstu.ru
ORCID: 0000-0002-1752-6

LEBEDEV Alexander A.
Ioffe Institute of RAS
26 Polytekhnicheskaya St., St. Petersburg, 194021, Russia
shura.lebe@mail.ioffe.ru
ORCID: 0000-0003-0829-5053

KUZMIN Roman A.
Ioffe Institute of RAS
26 Polytekhnicheskaya St., St. Petersburg, 194021, Russia
kuzminra@mail.ioffe.ru
ORCID: 0000-0001-6681-7046

MALEVSKY Dmitry A.
Ioffe Institute of RAS
26 Polytekhnicheskaya St., St. Petersburg, 194021, Russia
dmalevsky@scell.ioffe.ru
ORCID: 0000-0002-9337-4137

LEVINSHTEIN Mikhail E.
Ioffe Institute of RAS
26 Polytekhnicheskaya St., St. Petersburg, 194021, Russia
melev@nimis.ioffe.ru
ORCID: 0000-0002-9712-7387

OGANESYAN Gagik A.
Ioffe Institute of RAS
26 Polytekhnicheskaya St., St. Petersburg, 194021, Russia
Gagik.Oganesyan@mail.ioffe.ru
ORCID: 0000-0001-7111-6316

СВЕДЕНИЯ ОБ АВТОРАХ

КОЗЛОВСКИЙ Виталий Васильевич – *доктор физико-математических наук, профессор кафедры физики Санкт-Петербургского политехнического университета Петра Великого, Санкт-Петербург, Россия.*
195251, Россия, г. Санкт-Петербург, Политехническая ул., 29
kozlovski@physics.spbstu.ru
ORCID: 0000-0002-1752-6

ЛЕБЕДЕВ Александр Александрович — *доктор физико-математических наук, профессор, заведующий лабораторией и Отделением твердотельной электроники Физико-технического института им. А. Ф. Иоффе Российской академии наук, Санкт-Петербург, Россия.*
194021, Россия, г. Санкт-Петербург, Политехническая ул., 26
shura.lebe@mail.ioffe.ru
ORCID: 0000-0003-0829-5053

КУЗЬМИН Роман Алексеевич — *инженер лаборатории твердотельной электроники Физико-технического института им. А. Ф. Иоффе Российской академии наук, Санкт-Петербург, Россия.*
194021, Россия, г. Санкт-Петербург, Политехническая ул., 26
kuzminra@mail.ioffe.ru
ORCID: 0000-0001-6681-7046

МАЛЕВСКИЙ Дмитрий Андреевич — *научный сотрудник ООО «Научно-технический центр тонкопленочных технологий в энергетике при Физико-техническом институте им. А. Ф. Иоффе» Российской академии наук, Санкт-Петербург, Россия.*
194021, Россия, г. Санкт-Петербург, Политехническая ул., 26
dmalevsky@scell.ioffe.ru
ORCID: 0000-0002-9337-4137

ЛЕВИНШТЕЙН Михаил Ефимович — *доктор физико-математических наук, главный научный сотрудник Отделения твердотельной электроники Физико-технического института им. А. Ф. Иоффе Российской академии наук, Санкт-Петербург, Россия.*
194021, Россия, г. Санкт-Петербург, Политехническая ул., 26
melev@nimis.ioffe.ru
ORCID: 0000-0002-9712-7387

ОГАНЕСЯН Гагик Араратович — *кандидат физико-математических наук, старший научный сотрудник Отделения твердотельной электроники Физико-технического института им. А. Ф. Иоффе Российской академии наук, Санкт-Петербург, Россия.*
194021, Россия, г. Санкт-Петербург, Политехническая ул., 26
Gagik.Oganesyan@mail.ioffe.ru
ORCID: 0000-0001-7111-6316

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