Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Test element for high voltage SiC Schottky diodes quality control

To cite this article: S V Sedykh *et al* 2020 *J. Phys.: Conf. Ser.* **1695** 012153

Test element for high voltage SiC Schottky diodes quality control

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Abstract. The test element for quality control of SiC Schottky type high voltage diodes has been constructed at first in this study. It is shown that proposed test element give possibility for determination of important parameters for testing diode before Schottky contact formation and therefore can be decrease production costs in production of SiC Schottky type high voltage diodes.

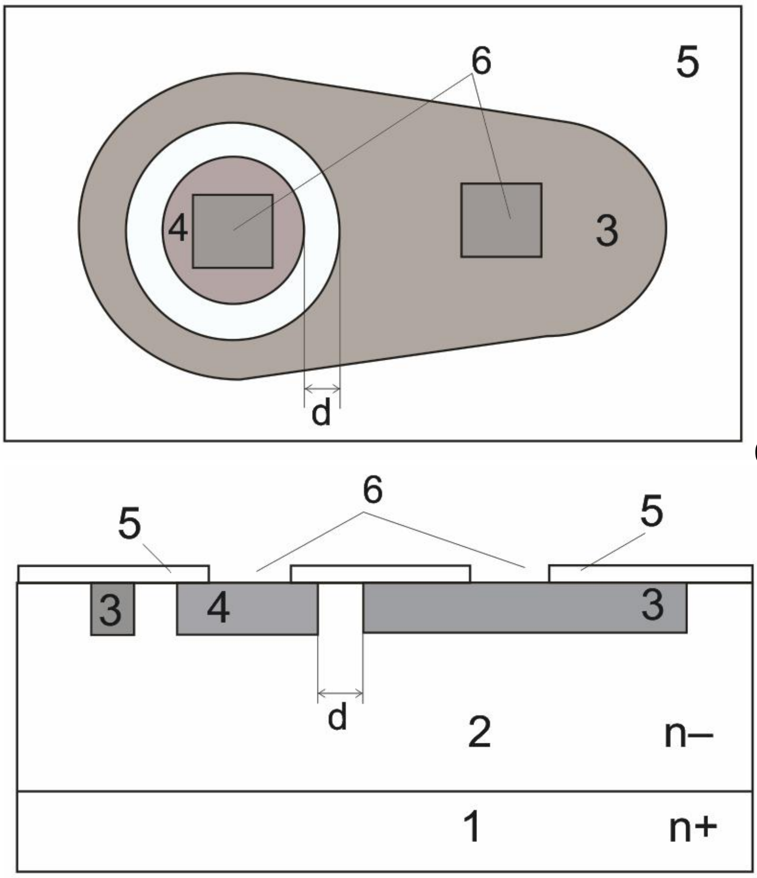
1. Introduction
The Schottky type diodes on the base of silicon carbide (SiC) have several advantages over traditional diodes because of high values of breakdown voltage and now are key components of power electronics [1]. In our previous studies it is established that SiC Schottky diodes produced by company the AO «GRUPPA KREMNY EL» (Bryansk, Russia) demonstrate good characteristics by *dV/dt* parameter [2]. However, one of some problems is determination of quality of produced diodes during their manufacturing procedure. Early was proposed test element for quality control of the manufacture of GaAs Schottky diodes, consisting of a Schottky diode formed on an epitaxial structure of one type of conductivity [3], but the main disadvantage of this test element is increased leakage currents of the Schottky diode because of higher field strength at the boundary of the metallization edge of the Schottky contact and the semiconductor. Therefore, structure 4H-SiC diode proposed in paper [4] is more preferable. Therefore the main goal of this study is to construct test element for quality control of SiC Schottky type diodes based on proposed in paper [4] Schottky structure diode.

2. Materials and methods
The proposed test element (see Figure 1) has the following structure: on the silicon carbide substrate of n^+-type conductivity from 4H-SiC (1), an n^--type epitaxial layer with 13 μm thick (2) with an impurity concentration of 5×10^{15} cm^{-3} is formed. Further, for increasing of breakdown voltage was carried out implantation with boron ions (doses of 3×10^{15} cm^{-2} and 6×10^{15} cm^{-2}) with energies of 150 keV and 350 keV, respectively (depth of ≈0.67 μm), then *p*-type planar working junction 3 and a *p*-type dividing ring were formed (4) by annealing at a temperature of 1580 °C. Then, a silicon oxide layer SiO_2 (5) is formed two contact windows 6 were etched in oxide layer SiO_2.

3. Results and discussion
The one of main problems in power microelectronics industry is quality control for produced devices, especially for of SiC Schottky type diodes. For instance, for GaAs Schottky diodes early was proposed test element [3] for quality control that is consist from Schottky diode formed on an epitaxial structure

of one type of conductivity, but the main disadvantage of this test element is increased leakage currents of the Schottky diode because of higher field strength at the boundary of the metallization edge of the Schottky contact and the semiconductor.

It is known that the basic technology for obtaining of planar *p-n* junction in silicon carbide is implantation of impurities (depth ~0,5-1,5 μm) and therefore the breakdown voltage of planar junction is defined by concentration of impurity in epitaxial layer, thickness epitaxial layer and radius *p-n* junction curvature radius [1,4-9]. Breakdown voltage of planar *p-n* junction in 3-5 times is less, than breakdown voltage of plane-parallel junction. With aim to increase of breakdown voltage of *p-n* junction in SiC apply system of dividing rings which raises *p-n* junction curvature radius at applying of reverse voltage. The gap between the basic *p-n* junction and the first ring and also between rings are identical and choose so that the space charge regions of the main and dividing junctions was closed up in process when voltage increase at the anode. For power semiconductor devices on SiC a gaps between dividing rings as a rule choose identical from 0,5 up to 5 μm. In case when impurity is aluminum (Al) the gap is 0,5-1 μm micron and 2-5 μm when impurity is boron (B). As it was established earlier in SiC the width of space charge regions is 6-7 μm under voltage of 600 V and 15-16 μm under voltage of 1700 V [1,4].



(a)
(b)

Figure 1. General view of test element: (a) – view from above; (b) – cross-sectional view. The structure of the test element: 1 – n^+-type substrate; 2 – n^--type epitaxial layer; 3 – *p*-type planar working junction (collector); 4 – *p*-type dividing ring (emitter); 5 – layer of SiO_2 silicon oxide; 6 – contact windows; *d* – is the gap between the emitter and the collector.

Moreover, because of parameter spread of annealing conditions, concentration of impurity in epitaxial layer and technological errors of photolithographs, actual values of breakdown voltages can be less calculated values before space charge regions of dividing rings can not be closed up on calculated voltages (for example, at -60^{o}C the breakdown voltage can be decreased ~300-400 V [1]). In the presence of a charge in SiO_2 also increase of reverse currents and therefore difficult to determine the cause of increasing of reverse voltages for prevention of these processes.

It is important that above-mentioned deviations of breakdown voltage parameters can be found only after completion of formation process of Schottky contact.

Also failure of diode can take place before increase of reverse voltage amplitude *dV/dt* (>50 V/ns) so called as "*dV/dt* effect" where diode's breakdown is cause of broken of space charge regions in area beyond the bounds of metallurgical boundary of the *p-n* junction in dividing rings space because of increase of eclectic field in this place [2,10-12].

In respect of power SiC Schottky type diodes for test element was selected the 4H-SiC Schottky type diode with six guard-ring-terminated planar 4H-SiC *p-n* junctions and with a breakdown voltage of 1800 V [4]. The structure of the test element is shown in Figure 1. If voltage is applied between the planar working junction (3) and the dividing ring (4) (see Figure 1) we can determine the pinch-off potential of ring after the formation of the dividing rings before the step when Schottky contact is formed. Then, based on the obtained value of the ring potential, we can draw conclusions about the correct choice of the gap and the annealing mode, which increases the efficiency of control. As a rule, if pinch-off voltage $U_{p.o.}$ is high (>150 V) [1,4] there is possibility redistribute of boron by mean of impulse annealing, but in case if $U_{p.o.}$ is small (<70 V) it lead to rejection of testing diode before Schottky contact formation that can be decrease production costs. Some test results of diode with various gap between emitter and collector are shown in Table 1.

Table 1. The measurement results of the two test elements and Schottky diodes with different gaps *d*, fabricated on the same epitaxial structures and technological conditions.

No.	*d* (μm), gap between emitter and collector	Number of rings in testing diode	$U_{p.o.}$ (V), pinch-off voltage of emitter–collector for test cell	*U* (V), breakdown voltage (25°C)	*U* (V), breakdown voltage (60°C)	*dV/dt* (V/ns), speed of reverse voltage increase before failure
1	2.5	5	130	1550	1540	200
2	1.0	5	50	1150	1140	200

As follows from obtained data the optimal gap is 2.5 μm when breakdown voltage (~1550 V) is more then in case of 1.0 μm (~1150 V).

4. Conclusions

Test elements for quality control of high-voltage SiC Schottky type diodes that allows preliminary obtain information about quality of diodes before Schottky contact formation for the first time was constructed. As important result, the proposed test element allows to choose optimal parameters for SiC Schottky type high voltage diodes before Schottky contact formation operation and spare production costs.

Acknowledgements

This work was carried out with financial support of the Russian Ministry of Science and High Education within the framework of complex project by creation of highly technological industry «Creation of highly technological industry of silicon and silicon carbide microelectronic technics products in small-sized metal-polymeric packages of the SOT, SO and QFN types» (agreement of 29 November No. 075-11-2019-035)) at the organization of the leading performer of RDDTE (Research and Development Design and Technological Engineering) the Bryansk State Technical University.

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