Research and Development of 1200V 4H-SiC Trench JBS Diode

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Abstract. This paper introduces the design and fabrication process of 1200V SiC trench Junction Barrier Schottky (JBS) diode, and tests the performance of the diode. The cell and terminal of diode structure both adopt trench structure, by simulation and early stage, the structural parameters of device cell and terminal structure are determined, and the fabrication of 1200V SiC trench JBS diode is completed through an intact technological process. The test results show that the leak current of the device under 1200V at room temperature is about 0.36uA, when the current is 20A, the forward voltage drop is 1.53V.

1. Introduction

The material of SiC has advantages of wide band gap, high breakdown field, high heat conductivity, high electron drift velocity etc., SiC is an ideal semiconductor material for fabrication of power device, since SiC devices have significant advantages in aspects of high voltage, high power, heat resistance, radiation resistance, and compared with silicon-based diode, SiC diode can be of smaller size and save area [1-5].

SiC diode device is mainly classified into three type, including Schottky Barrier Diode (SBD), pin diode, and SiC Schottky diode which contains Junction Barrier (JBS). Compared with the silicon-based PN diode, SiC Schottky Barrier Diode (SBD) has great advantages, among which the SiC Schottky diode with Junction Barrier (i.e. SiC JBS device) has both PN junction and metal semiconductor contact, it has the advantages of small threshold voltage, high withstand voltage, and small leakage current, it combines the advantages of PiN diode and Schottky diode and is suitable for fabricating devices of medium and high voltage [6-8]. Currently, the mainstream of SiC device factories in the market are mostly foreign enterprises, so the domestic research of SiC devices is of great significance.

This paper designs a kind of 1200V/20A trench JBS diode, introduces the process and outcomes of design and simulation, and conducts tape-out and tests on it. The test results indicate that, when the current of device is 20A, the forward voltage drop is 1.53V, and the reverse breakdown voltage can reach about 1.5kV.
2. Design and Simulation

2.1. Cell Structure Design and Simulation

Figure 1 shows the sectional diagram of cell structure, it adopts JBS structure, the conductivity modulation effect of PN junction decreases the forward voltage drop of device, and the pinch-off effect of P+ injection region also can decrease the electric field of the Schottky contact surface, so as to decrease the reverse leakage current. In order to reduce the processing steps, inject the etching ion into the covering film and make the etch aligned to the mark simultaneously and adopts trench JBS diode cell structure. Since there are trenches in the p+ area due to etching, conduct the etching process of trenches before injection, the p+ injected position become more deep so that the high electric field position is further from the Schottky contact surface and the surface electric field at the Schottky electrode is smaller, which can effectively reduce the leakage current, the depth of trench is 0.4μm. The doping concentration of substrate is $1 \times 10^{19} \text{ cm}^{-3}$, according to the theoretical calculation and simulation in early stage, adopt the depth $H$ of drifting layer to be 12.2μm, the doping concentration $N_D$ is $7.8E+15 \text{ cm}^{-3}$, according to the simulation results of planar diode in early stage, select the separation distance of P+ area $S$ to be 3.1μm, the width of P+ area $W$ to be 1.3μm and its depth $d$ to be 0.8μm.

![Sectional Diagram of 1200V SiC Trench JBS Diode Cell](image)

Figure 1. Sectional Diagram of 1200V SiC Trench JBS Diode Cell

Adopt Sentaurus TCAD software to simulate the forward and reverse characteristics of the device, the simulation outcomes are depicted in figure 2. From the simulation results, it can be seen that when the current is 20A, the forward voltage drop is about 1.4V and the reverse withstand voltage is about 2250V.

![Forward Conducting Characteristic](image)

(a) Forward Conducting Characteristic
2.2. Design and Simulation of Terminal Structure

Terminal structure is an important factor of determining the withstand voltage of device, diode needs the protection of terminal structure to reduce crowding effect. Generally, field-limiting ring structure and junction termination extension structure are adopted for the structure of terminal, since the terminal extension structure is too sensitive to the doping concentration, and the main advantage of field-limiting ring structure is simple, it can be formed simultaneously with the P+ injection in the cell to reduce processing steps, in this paper, the field-limiting ring structure is selected as the terminal structure of diode. The trench field-limiting ring is also adopted and its structure is shown in figure 3. The selected field-limiting ring structure has 14 rings in total, by comparing the simulation of reverse characteristics of trench junction terminal and not trench junction terminal, the comparison diagram of reverse characteristic curves is depicted in figure 4. It can be seen in figure 4 that adopting trench structure for device terminal has little impact on the outcome of reverse withstand voltage of device, and even better than the not trench structure. The reverse withstand voltage is approximately 2020V, it can be seen in figure 5 that the distribution of electric field intensity is uniform, all the field-limiting rings are utilized with a high utilization rate, and due to processing requirements, the trench and trench etching in cell are formed simultaneously, which reduces processing steps and saves costcons, consequently, the trench terminal structure is adopted as the terminal structure and the selection of terminal structure parameters is reasonable.
3. Fabrication and Preparation of Devices

Based on the simulation results in early stage, the adopted main technological processes are as follows: first process the surface of samples, rinse the device and start growing the injection of covering film, then etch the injected covering film and aligned mark. Adopt an injected photomask, make the etch aligned to the mark and form the injected covering film simultaneously, and form an etching trench above the injected area of p+ strip at the same time. Conduct ion implantation of high energy and high temperature at 500°C, implant to form the P+ doping and field-limiting ring terminal in the cell of the device, and adopt the protection of carbon film formed by sputtering to annealing, which protect the surface from rough during annealing, anneal in the argon atmosphere at a temperature of 1850°C, the after-sputtering metal Ni implements the fabrication and preparation of rear ohmic contact electrode, and anneal for 3
minutes at the temperature of 1000 ℃, then conduct the fabrication and preparation of the frontal Schottky electrode, and finally adopt SiO₂ layer and polyimide to fabricate the passivating layer on the surface. Produce the 1200kV 4H-SiC JBS trench diode. Figure 6 shows the photo of the final completed 6-inch wafer.

![Figure 6. 1200V Trench Diode Wafer](image)

4. Test and Analysis
In order to verify the performance of device, this paper adopts Agilent 1505A Power Device Analyzer to test the characteristics of device, figure 7 shows the curves of forward and reverse characteristics tests, the pulse width of forward test is 1ms, the result shows that the device threshold voltage is 0.9V, when the current of device is 20A, the forward voltage drop is 1.53V and the reverse breakdown voltage of device is about 1.5kV, when 1200V, the leakage current is about 0.36uA.

![a) Forward Characteristic](image)
5. Conclusion
Through design and optimization of devices, adopting the design and fabrication of 1200V 4H-SiC Trench Junction Barrier Schottky Diode with field-limiting ring terminal completed in this paper, the threshold voltage of device is 0.9V, when the current in device is 20A, the forward voltage drop is 1.53V, the reverse breakdown voltage of device can reach a maximum value of 1.5kV approximately, compare the reverse withstand voltage with designed value, the transformation rate is only 75%,the subsequent plan is to modify the simulation method according to the actual situation of technology and optimize process,The device adopts trench structure which saves processing steps and reduces the current leakage. The adopted field-limiting ring structure terminal prohibits the problem of reduced voltage withstand ability of terminal caused by the large variation of effective empty hole concentration generated by JTE terminal due to technical reasons, and increases the efficiency of terminal protection.

Acknowledgement
The authors thank for the state key laboratory of advanced power transmission technology and the support from State Grid Science and Technology Project, China (Research on channel self alignment of silicon carbide MOSFET, No. 5455 GB190011).

6. References
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