Original Research Article

Study on the voltage withstand design of 4H-SiC schottky barrier diode terminal area

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Abstract: This study successfully designed a 4H-SiC Schottky diode. To understand the performance of the device, the forward and reverse breakdown characteristics by changing its terminal structure. By comparing the device performance under different terminal structures, a new terminal design method is found, and its experimental results successfully verify the effectiveness of this design. It is shown that the dense to sparse field-limiting loop structure arranged from the main junction is better than that in the terminal design. At the same time, the positive guide pass feature is almost unaffected in the terminal injection structure. This study provides a new idea for the design of the device terminals.

Keywords: Silicon carbide; Diode; Terminal structure

1. Introduction

In the field of semiconductor devices, terminal voltage design has been one of the research hotspots. With the rapid development of power electronics technology, the global demand for high voltage, high frequency and high efficiency semiconductor devices is increasing day by day, providing an important guarantee for the development of new energy, smart grid, energy storage, automobile and other fields[1-3], 4H-SiC (4H type silicon carbide) Schottky barrier diode as a new semiconductor device with excellent performance, its terminal voltage withstand design is particularly important. Terminal withstand voltage design is directly related to the reliability, stability and service life of the device, and is the key to ensure the normal operation of the device in the complex working environment. However, in the problem of pressure resistance design in practical application, the terminal resistance often becomes the bottleneck restricting its performance. Therefore, the in-depth study of 4H-SiC Schottky barrier diode terminal voltage design has important theoretical value and practical significance.

In the current semiconductor industry, 1200V grade products generally use 10 μm thick epitaxial wafer, its actual pressure resistance capacity is about 1500V, which is lower than the theoretical pressure limit. Therefore, there is still a potential to improve the pressure resistance of products. In order to further enhance the properties of silicon carbide materials and improve the reliability[4], Initiated the following research projects.

In this study, we explored the withstand voltage design of 4H-SiC Schottky barrier diode terminal, analyzed the influencing factors, and proposed the optimization strategy. By introducing a new terminal structure, we successfully improved the pressure resistance by 21.4%, providing a solid technical support for the improved performance of the 4H-SiC Schottky barrier diode. At the same time, with the improvement of the pressure resistance of silicon carbide material, the thickness of the epitaxial layer can be reduced accordingly, which helps to reduce the production cost.

2. Design considerations of the silicon carbide JBS diodes

The Junction Barrier Schottky diode (JBS) is a high-performance semiconductor device that combines the advantages of the Schottky diode and the PN junction diode. The Schottky barrier and the PN junction are arranged alternatively to form a composite structure. This structure enables the JBS diode to have the low conduction pressure drop characteristic of a Schottky diode at the positive guide, and also has the high blocking ability of a PiN junction diode at the reverse cutoff. Moreover, due to the interaction between the Schottky barrier and the PiN junction, the JBS diode also has a lower reverse recovery charge and reverse recovery loss, which is suitable for high frequency and high efficiency application scenarios[5-8].

The design of JBS mainly consists of two aspects: source area design and terminal design.

2.1. Source Area design

The design of the source area mainly considers the aspects of the contact metal type, annealing temperature, Al ion injection concentration, Al ion injection depth and injection interval.

(1) The choice of metal types in Schottky contact has a significant impact on the contact characteristics. The following are the main aspects: Schottky barrier height, interface resistance, rectification characteristics, frequency response, temperature stability.

(2) The main effects of Schottky contact annealing temperature mainly include the following aspects: positive guide current and forward body resistance, Schottky base height and ideal factor, reverse leakage current density and breakdown voltage, Ohm contact and Schottky contact transition.

(3) The concentration of Al ion injection in silicon carbide Schottky diode is related to many aspects, specifically: device performance, drift zone injection concentration, through-state resistance, and voltage resistance of the device.

(4) The depth of Al ion injection in silicon carbide JBS diode mainly affects the following aspects: doping concentration and distribution, PN junction characteristics, conductance modulation effect, and reverse recovery performance of the device.

(5) The injection interval of silicon carbide JBS diode is mainly related to its design and working principle. The following main characteristics of silicon carbide JBS diode injection interval can be summarized: P zone interval injection, positive guide pass and reverse pressure bearing mechanism.

For all the above reasons, Ti was used as the Schottky contact metal, and the mature Al ion injection conditions were used for the source region production.

2.2. Terminal design

In the implementation process of the terminal design, the main focus is on the pressure resistance of the terminal, which is the key factor to ensure its normal operation. In the design process, the distribution of the electric field near the source area must be carefully considered and evaluated to prevent the electric field outside the source area, as this situation may cause serious damage to the terminal and may even cause the terminal to not work properly.

Therefore, in order to avoid this situation, a series of measures, such as JTE (Junction Terminal Extension) / FLR (Field Limiting Ring), are required to ensure that the terminal is not damaged by the steep drop of the electric field during operation.

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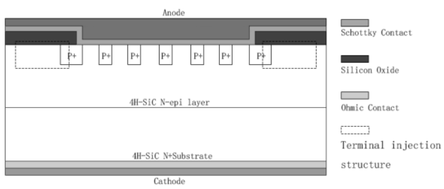
The existing device terminal structure is mainly FLR, mainly in the same ring, the same spacing, the same ring spacing, the depth and deep ring, the depth and deep ring spacing, etc., the ring injection, the spacing is the middle interval of the field limit ring.

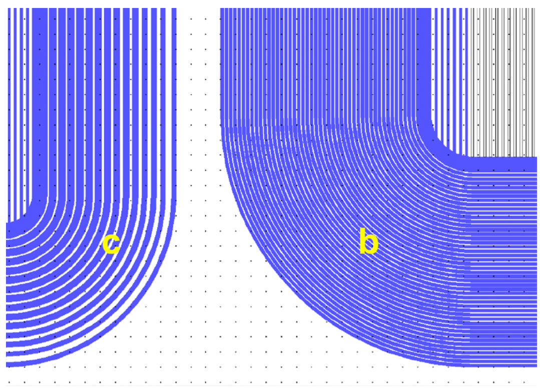
These terminals have their own advantages, but also have disadvantages. Take the increasing spacing of the same ring and the increasing spacing of the deep ring as an example: the increasing spacing of the same ring will increase the width of the same ring and the overall width of the increasing ring will be smaller, but the additional shallow or deep ring injection increases the risk of device process manufacturing, which is greatly influenced by etching and injection equipment and process fluctuation.

This paper uses a “ring reduction increase” terminal structure, greatly improve the efficiency of the terminal.”Ring reduction increase” is a terminal structure with high cost performance. As the name implies, “ring reduction increase” refers to the decrease of the number and width of the terminal injection area, and the increase of injection spacing. This structure can greatly reduce the width of the terminal area, improve the terminal voltage resistance, and increase the terminal efficiency.

The “ring reduction increase” structure and the existing terminal structure are shown in Figure 1 (b):



(a)



(b)

Figure 1. Schematic diagram of the junction barrier controlled Schottky diode and terminal injection structure in 4H-SiC.

(a) Schematic diagram of the junction barrier controlled Schottky diode in 4H-SiC.

(b) terminal diagram, where b is the schematic diagram of the existing device terminal structure, and c is the schematic diagram of the "ring reduction and increase" terminal injection structure proposed in this paper.

3. Collection and analysis of the experimental data

Sample data collection The electrical characteristics of the samples used the B1505A power device analyzer of KEYSIGHT company, and was tested and collected with the semi-automatic probe table. The Kelvin test method was used to accurately test the samples. The test conditions are:

(1) Forward test: Apply a voltage of 0-10V to the anode, measure the current, and limit the current by 25A.

(2) Reverse test: apply a voltage of 0-1750V to the cathode, measure the current, and limit the current by 1 mA.

The reverse test curve of the produced device samples is shown in Figure 3. Both terminal structures can meet the withstand voltage requirements of the device 1200V, and are more than 200V higher than the typical value of the device 1200V. The design of "ring reduction increase" of the terminal reaches about 1700V at the upper limit of 1 mA, which is about 300V higher than the existing terminal voltage of 1400V, and the terminal has obvious advantages.

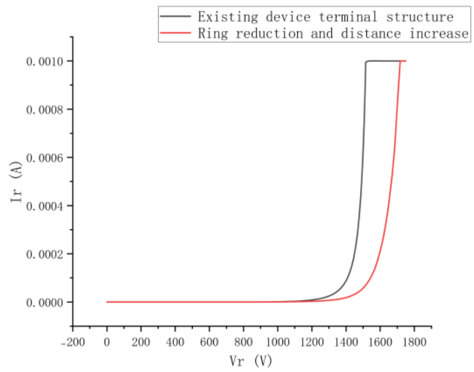


Figure 3. The reverse I-V curve diagram of the device.

The forward test curve of the device sample is shown in Figure 4. It can be seen that the terminal of the two structures have no effect on the forward characteristics of the device.

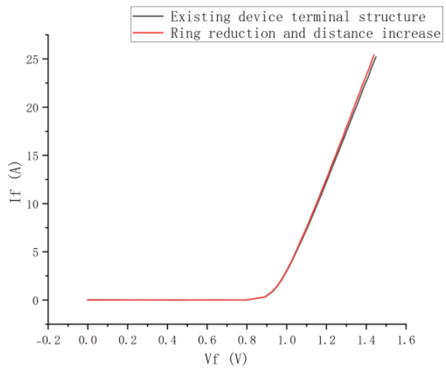


Figure 4. Forward I-V curve diagram of the device.

4. Conclusion

Compared with the existing terminal structures, the device terminal structures designed here have obvious advantages:

As shown in Figure 1, the width of designed terminal structure is significantly smaller than that of existing device terminal;

As shown in Figure 3, the voltage resistance value of this design terminal structure is about 300V higher than that of the existing terminal structure;

The voltage resistance effect of the device is mainly related to the terminal structure and the thickness of the epitaxial layer. Since the terminal structure designed in this paper improves the voltage resistance value of the device, the thickness of the epitaxial layer can be appropriately reduced if the device can meet the basic voltage resistance requirements, and the thickness of the epitaxial layer can reduce the conduction resistance of the device. The designed terminal structure can be applied to SiC MOSFET devices, which can reduce the conduction resistance of the device while the voltage resistance is constant.

The design of 4H-SiC Schottky barrier diode. First, the key impact of terminal structure optimization design on pressure resistance was successfully verified through fine experimental steps and operation procedures. The experimental data show that after adopting the new terminal structure, the pressure resistance capacity of the diode has been improved, reaching the leading level of the industry. This result not only verifies the feasibility of the design idea, but also provides a strong support for the subsequent product development.

In conclusion, this study has achieved remarkable results in the terminal withstand voltage design of the 4H-SiC Schottky barrier diode. We have successfully improved the voltage resistance of the diode and made an important contribution to the development of semiconductor devices.

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