Journal of Electronic Research and Application, 2025, Volume 9, Issue 1
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Comparative Study of the Hexagonal Structure of the SiC JBS Source Region

Yili Xu*, Xin Li

Hangzhou Puxi Optoelectronic Semiconductor Technology Co., Ltd., Hangzhou 31700, Zhejiang Province, China

***Corresponding author:** Yili Xu, 3543798@qq.com

Abstract: Silicon carbide (SiC) junction barrier Schottky (JBS) diode has been widely used in power electronic systems due to its excellent physical characteristics and electrical performance, and the structural design of its source area has a particularly significant impact on the performance. This study provides a comparative analysis of the SiC JBS diode performance of different hexagonal structures, aiming to provide theoretical support and practical guidance for the optimization of JBS diode performance. Through theoretical derivation, experimental verification and data processing, the paper deeply analyzes the influence of hexagonal structure on JBS diode current distribution and breakdown voltage, and proposes a targeted optimization strategy.

Keywords: SiC; JBS diode; Hexagon structure; Performance comparison

1. Foreword

Since the discovery of SiC materials, its unique physical and chemical properties have attracted much academic attention. With the rapid development of power electronics technology, SiC material, with its excellent physical characteristics and electrical properties, shows great application potential under extreme working conditions such as high pressure, high frequency, and high temperature, and is increasingly used in the field of power electronics [1–4]. In SiC devices, the JBS diode, as one of the key representatives, has been widely used in power electronic systems with its advantages of low reverse leakage current, high breakdown voltage, and excellent switching characteristics. The structural design of the JBS diode has undergone an evolution from basic to complex and from single to multivariate [5–8]. However, the performance of the JBS diode is largely affected by the structural design of its source region, and the systematic comparative study on the impact of different structures on device performance is still insufficient. Therefore, this study focuses on the comparative analysis of the hexagonal structure of the SiC JBS diode source region, aiming to provide new research perspectives for further optimization of device performance. The hexagon structure of the diode source region is shown in **Figure 1**.

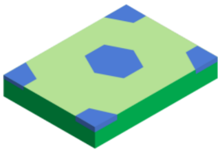


Figure 1. Schematic diagram of the hexagonal structure cells in the SiC JBS source region

2. Experiment and testing

2.1. Experimental design

The SiC material, with its physical characteristics such as wide forbidden bandwidth, excellent hardness, and high thermal conductivity, gives SiC devices the ability to show excellent performance in high-pressure, high-frequency, and high-temperature environments. The JBS diode successfully achieves the balance of low reverse leakage current and high breakdown voltage by combining the composite structure of Schottky and P-N junction barriers. As a kind of special geometry, the hexagonal structure can affect the current distribution and electric field distribution in the JBS diode source area, thus having a significant effect on the overall performance of the device [9–12]. Based on the physical characteristics of SiC material and the working mechanism of the JBS diode, this study aims to explore the specific influence of hexagonal structure on the performance of the JBS diode [13–16]. In the experiment, the opposite side length of the hexagon in the p + injection region was set to 1.5 μm, while the interval was set to 2.5 microns and 2 microns, respectively, as shown in **Table 1**.

Table 1. Control table of the device structure conditions

Device number	The hexagonal side	The hexagon interval	The Schottky contact ratio
1	1.5	2.5	0.8594
2	1.5	2	0.8163

2.2. Test results

In the stage of experimental verification and result analysis of exploring the influence of silicon carbide JBS active area on device performance, the measurement and comparison of performance parameters constitute the key link to evaluate its effect. In this study, the B1505A advanced test equipment of KEYSIGHT company and the Kelvin test method were used to comprehensively determine the current transmission characteristics of the silicon carbide JBS active area [17–19].

2.2.1. Forward high-current conduction characteristics

The test conditions are: 0–10 V step voltage and a current limit of 25 A. The forward voltage drop is taken at 20 A, and the on resistance is at 20 A. The test results of the device are shown in **Figure 2** and **Table 2**.

Table 2. Comparison of pressure drop and on resistance of different devices.

Device number	The Schottky contact ratio	V_F(V) @ 20 A	on resistance (mΩ)
1	0.8594	1.2601	15.93
2	0.8163	1.3964	20.94

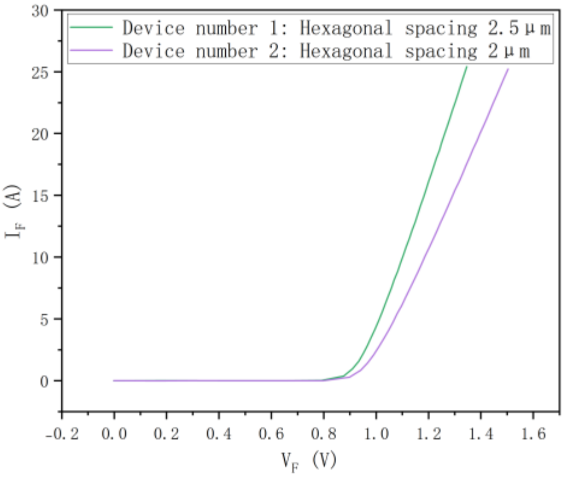


Figure 2. Forward I-V curve diagram.

2.2.2. Forward small current conduction characteristics

The test conditions are 0–1 V step voltage and a current limit of 25 A of 1 mA. The ideal factor *n* is used to measure whether the device is close to the ideal diode. When *n* = 2 is the composite current (SRH composite), *n* = 1 is the diffusion current (no defect has the PN junction). In fact, in practice, there is always a composite center in the PN junction barrier region, so generally, *n* is between 1 and 2. The closer to 1 indicates less non-radiative recombination and less defect density. The ideal factor *n* is calculated as follows [20,21]:

$$n = (q/kT) * (dV/d(\ln I))$$

Where q/kT is constant, when T = 300 K, q/kT = 25.85 mV, dV/d(lnI) can be obtained by the slope of the IV characteristic curve of the PN junction. The test results of the device are shown in **Figure 3** and **Table 3**.

Table 3. Comparison of the ideal factors of different devices.

Device number	dV/d(lnI)	Ideal factor *n*
1	39.02928	1.00898
2	39.03236	1.00906

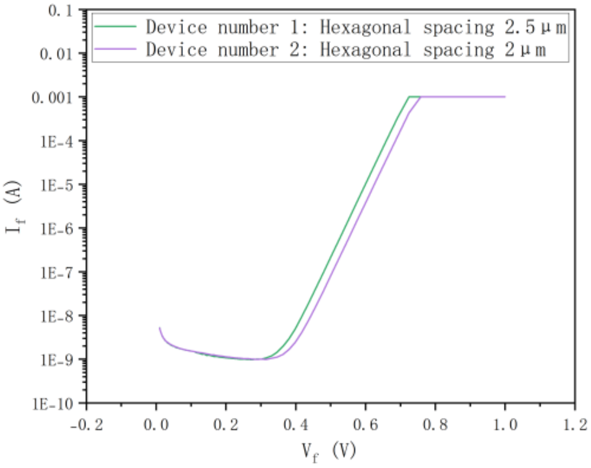


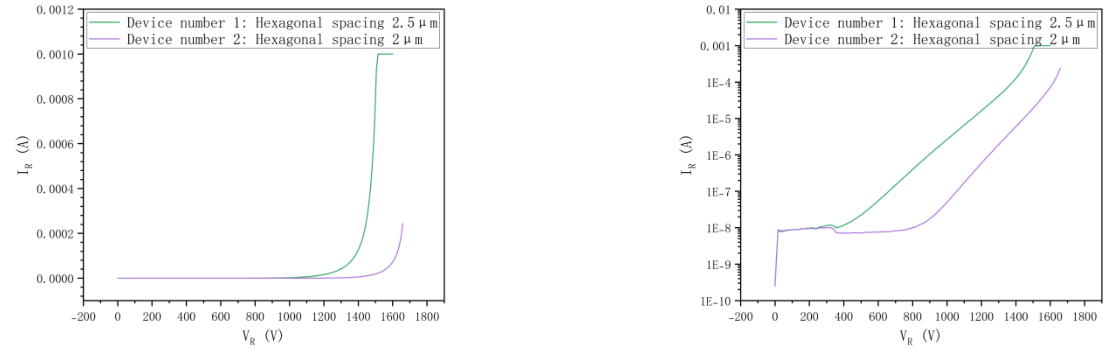
Figure 3. Forward small current lgI-V curve diagram.

2.2.3. Reverse breakdown characteristics

The test conditions of the device are 0–1700 V step voltage and a current limit of 1 mA. The test results are shown in **Figure 4** and **Table 4**. In the reverse blocking state, the current around 1 × 10^{-8} A should be the minimum accuracy of the test equipment to test the current. Although the leakage current of different structures has different degrees, any structure has no advance breakdown trace before reaching 1 mA, and the leakage current is caused by the large tunneling current. In the industry standard, 200 µA condition also reached the standard greater than 1200 V.

Table 4. Reverse leakage current of different devices

Device number	The Schottky contact ratio	I_R(A) @ 1200 V	V_R(V) @ 200 µA
1	0.8594	1.72×10^{-5}	1426.7
2	0.8163	6.41×10^{-7}	1648.0



(a) (b)

Figure 4. Reverse characteristic plot: (a) Reverse I-V plot, (b) Reverse lgI-V plot

3. Conclusion

After a thorough analysis of the experimental data, we show that different hexagonal structures have significant effects on the performance of the JBS diode. Specifically, when the Schottky contact ratio increases by 5.3%, the forward pressure drop VF decreases by 10.8% and the on resistance by 31.5%. However, at 1200 V, the reverse current reached 200 µA.

Nevertheless, by optimizing the device structure design, the increase of the reverse leakage current can be effectively controlled, which can further improve the overall performance of the device without sacrificing the pressure resistance. In addition, the experiment also found that the fine regulation of the device conduction characteristics and blocking characteristics can be realized by adjusting the Schottky contact ratio, which provides a new idea for the optimal design of the SiC JBS diode. Future studies will focus on further reducing the reverse leakage current and improving the pressure resistance of the device to meet the requirements of industrial applications.

In this study, by comparing the performance of different hexagonal structures in the SiC JBS source region, the following conclusions are drawn. The hexagonal structure has a significant impact on the performance of the JBS diode and optimizing the hexagonal structure can further improve the breakdown voltage and reduce the conduction loss. When preparing a JBS diode, suitable hexagon structure should be selected according to specific application requirements. Meanwhile, the influence of other shape geometry on device performance can be further explored to expand the application range of the JBS diode.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Sheng K, Ren N, Xu H, 2020. Overview and Prospect of Silicon Carbide Power Devices. Chinese Journal of Electrical Engineering, 40(06): 1741–1753.

[2] Zhang B, Deng X, Chen W, et al., 2009, Wide-Band-Power Semiconductor Device Technology. Journal of University of Electronic Science and Technology, 38(5): 618–623.

[3] Nie YH, 2024, "Core" to the Future of the Industry Rookie to Lead the Car Regulation Level Chip Localization. Securities Times, A06, published November 5, 2024.

[4] Zhang C, Hao Y, Zhao T, et al., 2002, SiC New Semiconductor Devices and their Applications. Journal of Xidian University, 29(2): 157–162.

[5] Wu L, Zhang T, Zhang M, et al, 2024, Study of a 1200 V SiC JBS Diode with a Circular P + Region. Journal of Changsha University of Science and Technology (Natural Science Edition), 21(4): 168–175187.

[6] Cheng S, Zhang J, Zhang Y, et al., 2024, SiC Progress in the Study of Power Module Packaging Materials. Scientific and Technological Innovation and Application, 14(3): 106–109.

[7] Xu N, 2024, To the "New" Breakthrough, Planting the New Advantages of Industrial Strong City. Nanjing Daily, A01, published September 25, 2024.

[8] Xue A, Huang R, Bai S, et al., 2018, Development of the 6500 V 15 A 4H-SiC JBS diodes. Micro-nano electronic Technology, 55(3): 161–165177.

[9] Hui C, 2023, Design and Experimental Study of High Reliability High Voltage Diode SiC JBS, thesis, Xidian University; He Y, Gu J, Yuan Q, et al., 2023, Design and Analysis of the 650V50A SiC JBS. Integrated Circuit Application, 40(04): 52–53.

[10] Zhuo W, 2022, Research on Key Processes for 4H-SiC JBS Device Preparation, thesis, Xidian University.

[11] Xin W, Yue R, Zhang L, 2013, Improvement and Performance Optimization of the POP-type SiC JBS Diode Structure. Research and Progress in Solid State Electronics, 33(5): 415–419.

[12] Wu H, Yang F, Yu K, 2013, 1000V 4H-SiC JBS Power Diode Cells. Micro-Nano Electronic Technology, 50(11): 695–700.

[13] Jiang Y, Zhou H, Zhao L, et al., 2021, Study on the Breakdown Characteristics of 4H-SiC JBS Diodes. Microelectronics, 51(6): 918–922.

[14] Ni W, Li Y, Li Z, et al., 2010, 1200V-5A 4H-SiC JBS Diode Resistant to 250°C. Research and Progress in Solid State Electronics, 30(4): 478–480549.

[15] Tang Y, Li C, Shi J, et al., 2018, Development of 1200 V / 100 A High Temperature High Current 4H-SiC JBS Device. Semiconductor Technology, 43(4): 266–273.

[16] Huang RH, Li R, Chen G, et al., 2012, A 2.7 kV 4H-SiC JBS Diode. Power Electronics Technology, 46(12): 72–73.

[17] Li X, 2017, STMicroelectronics Released a 2-40 A 1200 V SiC JBS Diode. Electrons and Packaging, 17(6): 40.

[18] Huang R, Tao Y, Cao P, et al., 2014, Development of 10 kV 4H-SiC JBS Diode with FGR Termination. Journal of

Semiconductors, 35(7): 56–59.

[19] Ni W, Li Y, Li Z, et al., 2011, 2700V 4H-SiC Junction Barrier Schottky Diode. Research and Progress in Solid State Electronics, 31(3): 223–225232.

[20] Yang T, Yang X, Huang R, et al., 2018, Design and Implementation of 6500 V SiC Field Limit Loop Terminal. Research and Progress in Solid State Electronics, 38(1): 1–5.

[21] Qi H, Zhang X, Xie X, et al., 2014, Assessment of a Bipolar Transistor Storage Life Based on Ideal Factor Degradation. Journal of Sichuan War Engineering, 35(8): 141–145.

[22] Feng X, Qiu S, Zhang J, et al., 2020, Study on the Ideal Factor Extraction Method of Base Current Based on Matlab. Microelectronics, 50(2): 267–271.