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# Characteristics of High Current 4H-SiC Schottky Barrier Diodes

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**Keywords:** 4H-SiC, SBD, High Current, Large-area, Temperature.

**Abstract.** Silicon carbide (SiC) Schottky barrier diodes (SBDs) have become critical components in power electronics due to their excellent high-voltage, high-temperature tolerance, and fast switching capability. However, increasing the device area to improve current-carrying capability increases the total number of defects, which leads to an increase in reverse leakage current and a reduction in wafer yield. To improve current distribution uniformity within SiC module packaging, reduce system size and weight, and enhance the current-carrying capacity and high-temperature stability of a single SBD, this paper develops 750V/100A and 1200V/100A SiC SBDs on 6-inch wafers. For the 750V/100A device, the corresponding forward voltage drop ($V_F$) at forward current ($I_F$) of 100 A is 1.68 V. For the 1200V/100A device, the corresponding $V_F$ is 1.75V. Calculation based on the current voltage characteristics shows that the ideal factors of 750V/100A and 1200V/100A devices are 1.01 and 1.04, respectively, which are very close to 1. It demonstrates excellent Schottky contact and a high-quality interface. The devices exhibit high-temperature stability, meeting the demands of high-temperature applications.

## Introduction

In industrial power applications, there is a demand for 4H-SiC SBDs with the capability for a high current [1, 2]. These devices have a great potential in fields such as new energy vehicles, switching power supplies, and industrial motor drives [3-5]. Considering the usage scenarios of these applications, enhancing power density is a key issue that assists in improving the system's efficiency. In a high-current module, using the high-current SiC SBDs contributes to the reduced number of chips, and it can increase the uniformity of the current distribution within the module packaging [6]. However, a challenge for high-current SiC SBDs is that increasing the active area to maintain high currents increases the likelihood of encountering material defects. This leads to an increase in reverse leakage current ($I_R$) and ultimately reduces wafer yield [7, 8]. Therefore, this paper investigates the fabrication of two high-current SiC SBDs with specifications (750V/100A and 1200V/100A).

In contrast to conventional ion implantation techniques, this paper proposes a design that employs an epitaxial etching process to fabricate the terminal P+ region. This method not only achieves excellent junction terminal protection but also significantly reduces manufacturing costs[9]. Consequently, the device ensures enhanced reverse blocking voltage capability and reduced $I_R$. Static characteristic tests of 750V/100A and 1200V/100A SiC SBDs on 6-inch SiC wafers were conducted in the temperature range from room temperature to 240 °C. The devices present superior properties, including high current, low $I_R$, and favorable capacitance characteristics. They maintain stable operation even under high-temperature conditions, thereby meeting the urgent demand for high-performance SiC power diodes in high-temperature and high-frequency power modules.

## Experimental

The schematic diagram of the 4H-SiC SBDs is shown in Fig. 1(a). The devices in this study were fabricated on 6-inch n-type 4H-SiC single-crystal epitaxial wafers of high quality. The p-type terminal region was patterned by photolithography and inductively coupled plasma (ICP) etching, with its cross-sectional view shown in Fig. 1(b). The terminal protection was accomplished by employing polyimide/silicon nitride (SiN). A nickel (Ni) metal layer was deposited on the rear side of the wafer, followed by high-temperature annealing to form an ohmic contact with the SiC substrate. The titanium (Ti) and aluminum (Al) metal layers were deposited on the n-type SiC epilayer to establish the Schottky contact. Based on the aforementioned process, two large-area single-chip SiC SBDs with different specifications were successfully fabricated. The active region areas were 21.5 mm$^2$ and 38.9 mm$^2$ for the 750V/100A and 1200V/100A devices, respectively. Photographs of the fabricated samples are shown in Fig. 1(c) and 1(d). The yield of the 750V/100A and 1200V/100A SiC SBD is 85.4 % and 76.4 %.

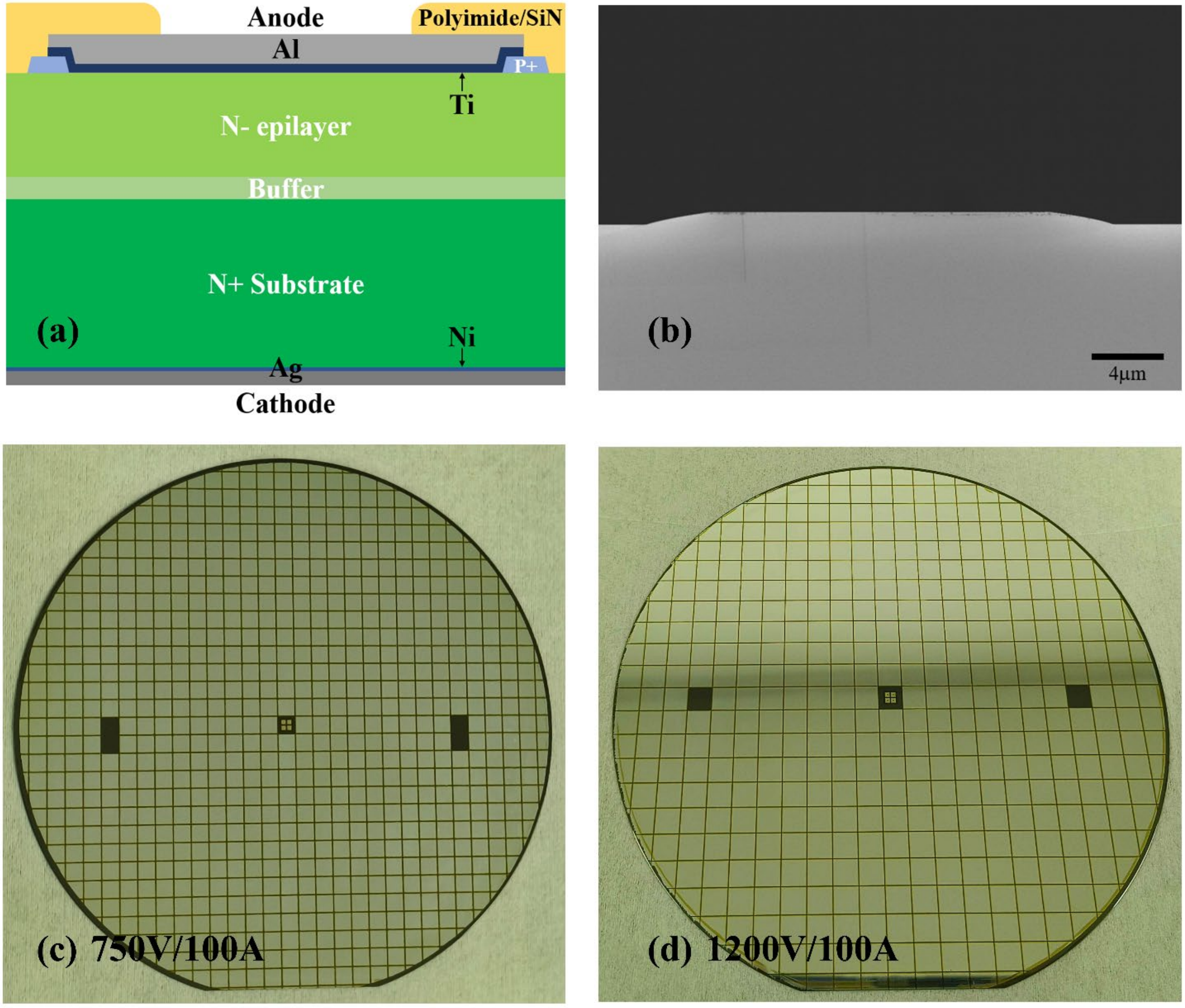

**Fig. 1.** (a) The schematic cross-section of the 4H-SiC SBD structure. (b) The cross-sectional view of the epitaxial etching termination area. (c) 750V/100A SiC SBD and (d) 1200V/100A SiC SBD fabricated in the 6-inch SiC wafers.

## Result and Discussion

### Forward characteristics at different temperatures

The static characteristics and temperature stability of the devices are evaluated at various temperatures from 30 °C to 240 °C. The forward characteristic curves of the 750V/100A and 1200V/100A devices at low current are shown in Fig. 2(a) and 3(a), respectively. Test results indicate that under lower forward current ($I_F$), the forward voltage ($V_F$) of the device decreases with increasing temperature, exhibiting a negative temperature coefficient. This behavior is primarily attributed to the thermionic emission mechanism of the Schottky barrier, where electrons at higher temperatures possess greater energy and can more easily overcome the Schottky barrier. At low forward current, the current-voltage (I-V) characteristics of the SBD typically follow thermionic emission theory. Thus, the forward I-V characteristics can be used to derive the key parameters of SBDs. Calculations show that the Schottky barrier heights (SBH) of 1.31 eV and 1.14 eV for the 750V/100A and 1200V/100A devices, respectively, with ideal factors (n) of 1.01 and 1.04, respectively, both very close to 1. This indicates that current conduction in both devices is almost entirely dominated by thermionic emission, with the effects of interface states or tunneling effects being negligible, confirming the excellent quality of the Schottky contacts and interfaces.

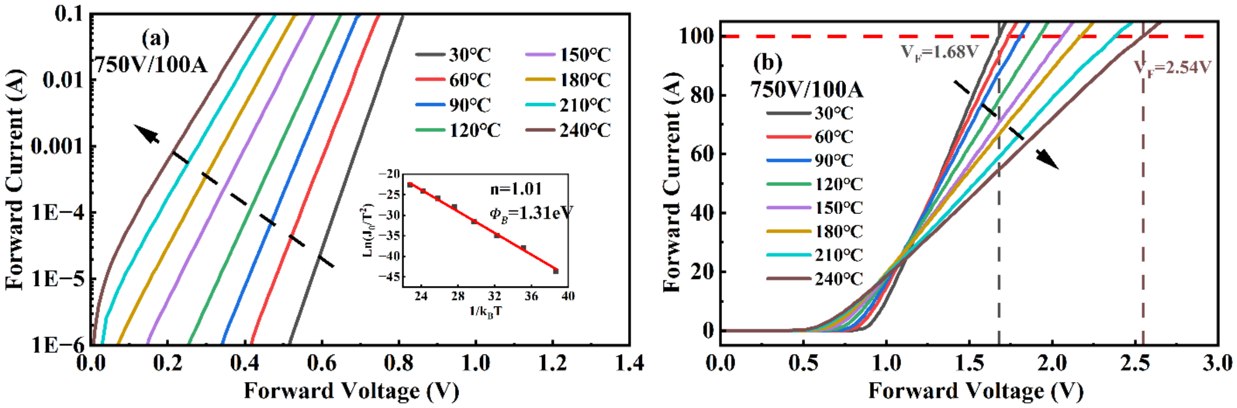

**Fig. 2.** Forward characteristic curves of 750V/100A SiC SBD at (a) low forward current, and (b) high forward current.

The forward characteristic curves of the 750V/100A and 1200V/100A devices at high current are shown in Fig. 2(b) and 3(b), respectively. When $V_F$ = 1.7 V, the forward current density of the 750 V/100 A SBD decreases from 476 A/cm$^2$ at 30 °C to 259 A/cm$^2$ at 240 °C. The forward current density of the 1200 V/100 A SBD decreases from 240 A/cm$^2$ at 30 °C to 111 A/cm$^2$ at 240 °C. Meanwhile, under the same $I_F$, $V_F$ shows significant positive temperature coefficients, rising to 2.54 V ($\Delta V_F$ = 0.86 V) for the 750V/100A device and 3.19 V ($\Delta V_F$ = 1.44 V) for the 1200V/100A device at 240 °C. This phenomenon is primarily attributed to the increase in the intrinsic resistance of the SiC material and the significant decrease in carrier mobility with rising temperature. Calculation results indicate that at 30 °C, the 750V/100A SiC SBD exhibits a specific on-resistance ($R_{on\text{-}sp}$) of 1.6 mΩ·cm$^2$, while the $R_{on\text{-}sp}$ of the 1200V/100A SiC SBD is 3.3 mΩ·cm$^2$. However, as the temperature increases from 30 °C to 240 °C, the $R_{on\text{-}sp}$ of the 750V/100A device significantly increases to 4.1 mΩ·cm$^2$, while the $R_{on\text{-}sp}$ of the 1200V/100A device increases to 10.4 mΩ·cm$^2$.

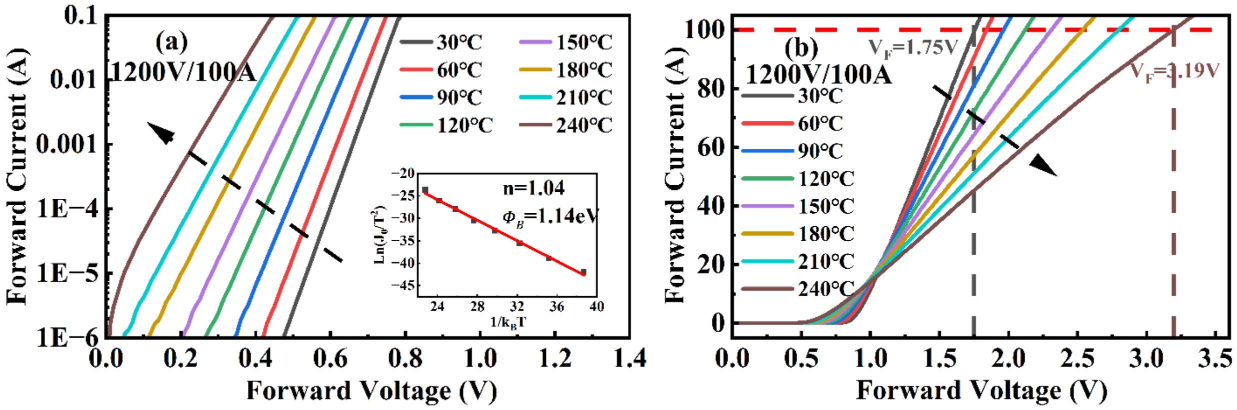

**Fig. 3.** Forward characteristic curves of 1200V/100A SiC SBD at (a) low forward current, and (b) high forward current.

### Reverse characteristics at different temperatures

Fig. 4(a) and 4(b) show the reverse characteristics of 750V/100A and 1200V/100A SiC SBD devices at different temperatures. Test results indicate that the $I_R$ of devices is positively related to temperature. Under a reverse voltage ($V_R$) of 750 V and room temperature, the $I_R$ of the 750V/100A device is 13.5 μA. As the temperature increases to 240 °C, the $I_R$ of the 750V/100A device increases to 1.3 mA. For the 1200V/100A device, $I_R$ is 14.8 μA at $V_R$ = 1200 V and 30 °C; after the temperature rose to 240 °C, the $I_R$ increased to 1.8 mA. The increase in $I_R$ at high temperatures is primarily influenced by the combined effects of thermionic emission current, barrier height lowering, and tunneling current.

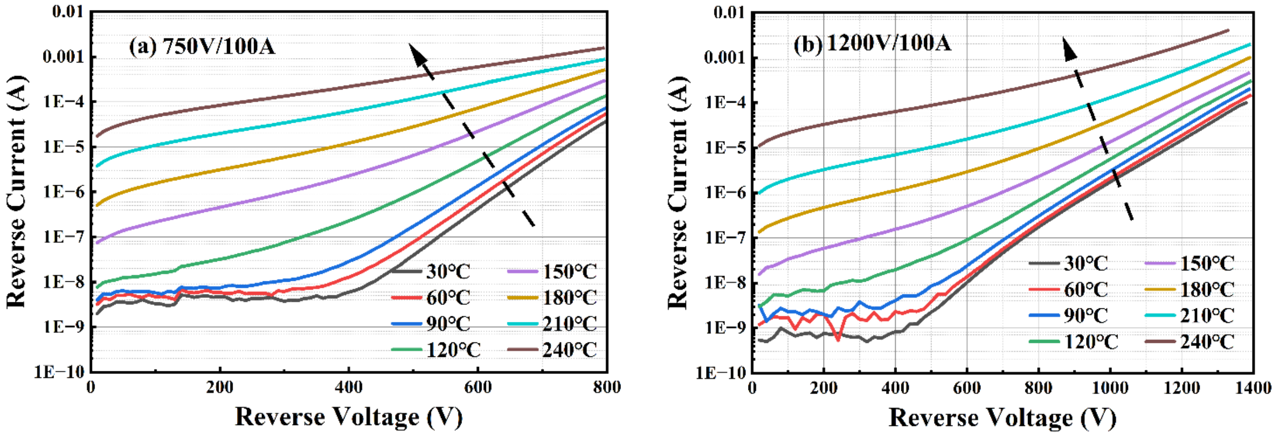

**Fig. 4.** Reverse characteristic curves at different temperatures of (a) 750V/100A SiC SBD and (b) 1200V/100A SiC SBD.

### Capacitance characteristics

One of the main advantages of SiC SBDs is their ultra-fast switching speed and extremely low switching losses. This study conducted a detailed analysis of their capacitance characteristic. This characteristic is crucial for calculating and predicting the switching losses of the device in actual circuits. Capacitance characteristics are measured at a frequency of 1 MHz, and the results are shown in Fig. 5(a).

Capacitive charge ($Q_C$) and capacitance stored energy ($E_C$) are core electrical parameters of SiC SBDs. $Q_C$ quantifies the total charge stored under reverse bias in SiC SBDs, which directly determines reverse recovery losses and dynamic turn-on response speed. $E_C$ quantifies the magnitude of energy stored through capacitive effects. It is used to evaluate capacitive discharge losses during switching cycles and the risks of circuit surge. Based on the integration results of the capacitance-voltage characteristics, Fig. 5(b) and 5(c) show the characteristic curves of $Q_C$ and $E_C$ versus voltage for the

750V/100A and 1200V/100A devices, respectively. The corresponding $Q_C$ and $E_C$ values for specific $V_R$ are summarized in Table 1.

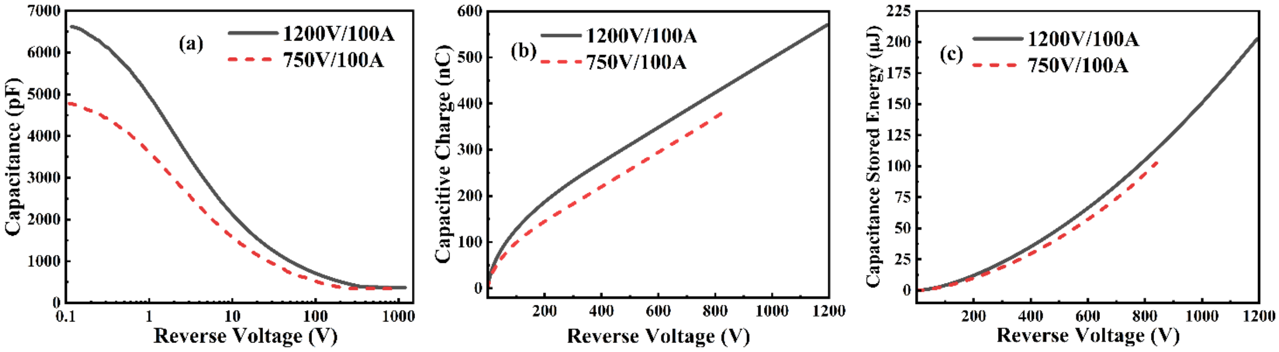

**Fig. 5.** (a) Capacitance-voltage characteristics; (b) Capacitive charge curve; (c) Capacitance stored energy curve.

**Table 1.** Capacitance, $Q_C$, and $E_C$ at specific voltages of 750V/100A and 1200V/100A devices.

| Devices | Capacitance [pF] | $Q_C$ [nC] | $E_C$ [μJ] |
|---|---|---|---|
| 750V/100A (@$V_R$ = 400 V) | 347 | 220 | 29 |
| 1200V/100A (@$V_R$ = 800 V) | 374 | 423 | 105 |

## Summary

This study successfully produces high-current SiC SBD devices rated at 750V/100A and 1200V/100A. Their electrical characteristics are analyzed in the temperature range of 30 °C to 240 °C. Test results indicate that the fabricated 4H-SiC SBDs exhibit excellent static characteristics, with an ideal factor approaching 1, demonstrating superior interface quality. They maintain good thermal stability even at elevated temperatures. Consequently, these SiC SBDs show significant application potential in high-voltage, high-power, high-temperature, and high-frequency fields.

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