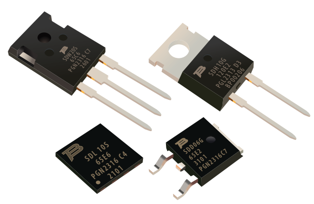
# How Silicon Carbide Power Schottky Diode Properties Provide Enhanced Application Capabilities

WHITE PAPER



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## INTRODUCTION

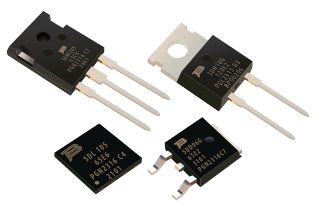
For diode applications, the ideal component would be one with no voltage drop during forward conduction and no leakage current when reverse biased. It would change instantly from conducting forward current to blocking reverse voltage. Compared to junction silicon diodes, Schottky diodes provide reduced voltage drop with decreased reverse bias recovery current.

This paper discusses the properties of Schottky diodes constructed using a silicon carbide (SiC) n- epitaxial semiconductor material layer attached to a metal contact area as opposed to diodes constructed using two differently doped silicon semiconductor materials. This construction will be further explained below.

## WHY SILICON CARBIDE IS AN IMPROVEMENT

Silicon carbide is a type of semiconductor material that maintains its useful properties at much higher temperatures than the normally used doped silicon. Using SiC to construct Schottky diodes allows them to operate at higher temperatures, up to a 175 °C junction temperature, and permits the use of smaller heat sink designs so the thermal management is simplified. Similarly, a power system designed with SiC power semiconductors can operate at a 50 °C higher ambient temperature, which is higher than what can be achieved with a silicon semiconductor that features a junction rated at a maximum of 125 °C. This is an attractive feature that allows power systems to meet automotive and other harsh environmental application thermal performance requirements.

Because SiC is a wide band gap material, it can withstand higher voltage before breakdown and at an elevated temperature compared to silicon-based devices. The expanded capabilities inherent in SiC enable SiC Schottky diodes to have reverse breakdown voltages well over 1200 volts while capable of providing several tens of amperes of forward current in a small package. Plus, smaller packages increase the power density that is achieved in power switching designs, which is the most sought-after feature in power supply requirements. In addition, a SiC Power Schottky diode's ability to operate at a higher switching frequency will allow the use of smaller inductors and capacitors that again contribute to a higher power density. The bottom line benefit of the increase in power density afforded by SiC is that it results in lower cost for a given solution.



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## WHY SILICON CARBIDE IS AN IMPROVEMENT (Continued)

Many developers of SiC Power Schottky diodes have designed them with superior avalanche performance that helps reduce the size and the cost of the snubber circuit. This again has the potential to increase the power system's power density while lowering the overall system cost.

In cases where power density is not the most critical feature, designers can opt to use fewer SiC Power Schottky diodes than silicon-based devices to achieve the same power output at a lower cost.

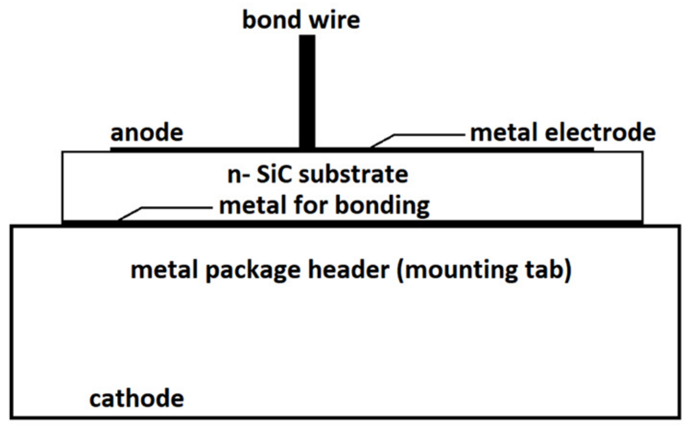


*Figure 1.* | *SiC Schottky Construction*

The construction of a SiC Schottky diode is composed of a lightly doped n-type SiC layer and a metal electrode, typically made of aluminum or platinum. The metal electrode acts as the anode and the n-type SiC substrate acts as the cathode. When forward biased, the cathode injects electrons into the n-type SiC layer, which flow out the anode, resulting in the conventional positive current flowing into the anode. Forward biasing means that the anode is at a higher potential than the cathode.

The low forward voltage drop of the SiC Schottky diode is due to the low potential barrier at the metal electrode-semiconductor substrate interface, which allows for efficient movement of electrons from the cathode to the anode. The resultant power dissipation is low and contributes to increasing the overall efficiency of the application.

When reverse biased, the metal electrode-semiconductor substrate interface sets up a depletion region at the interface. This depletion region acts as a barrier to the flow of current, and its width is determined by the reverse bias voltage applied across the diode. The reverse leakage current is reduced by using SiC, a wide band gap voltage material.

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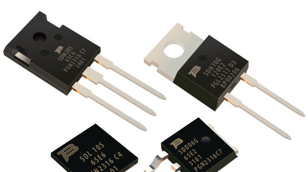

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## PEAK CURRENT HANDLING

The peak forward current and average power dissipation specifications for the SiC Power Schottky diodes limit the forward conduction pulse current. The bond wires in the diode package will act as fuses with the application of an excessive forward current. The maximum sine-wave pulse current is specified in the same manner as fuses, by the $I^2t$ rating, given in $A^2s$. This rating accounts for the heating effect of the high current pulse in the bond wires and the metal to semiconductor junction. Typically, peak current ratings are shown on the Schottky diode's data sheet for other pulse widths and measurement conditions.

Silicon carbide's high thermal conductivity enables high currents to be carried while dissipating heat efficiently. The inherent high current capability of silicon carbide semiconductor material provides very high current operation while keeping the junction temperature at a minimum. Using only one semiconductor layer, and SiC can be thinner than Si layers, making the distance from the junction to the heat sink very short. The result is that the heat produced is removed from the semiconductor layer very quickly, contributing to a very high peak current handling capability.

## REVERSE RECOVERY OPERATION

For any diode to switch from a conducting to a blocking state, the charge in the capacitor formed by the metal electrode and semiconductor region must be removed. The quantity of charge to be removed is specified in nanocoulombs. Typically, SiC Schottky diodes require removal of less than 1/10 of the charge that silicon junction diodes require. When operating at the same voltage, this indicates that SiC Schottky diodes have less than 1/10 of the capacitance than that of silicon junction diodes. On top of that, the charge in a SiC Schottky diode is constant with temperature, while the charge in the silicon junction diodes increases by about 50 percent from ambient to the highest operating temperature.

These reverse recovery effects have three important implications for SiC Schottky diodes. The first is that the time to remove the charge is constant with temperature for any specific operating condition. This provides thermal stability in the operation of the switching application. The second is that the power dissipated in the application's IGBTs (Insulated Gate Bipolar Transistors) or MOSFET (Metal Oxide Semiconductor Field Effect Transistor) switch is minimized during reverse recovery after each current conducting cycle of the switching frequency. This reduces the stress in the switching element of the power conversion application and reduces the thermal cooling requirement as well.

## REDUCED EMI (Electromagnetic Interference)

The third implication of having improved reverse recovery characteristics for power conversion applications with SiC Schottky diodes is that the EMI is reduced since no fast switching of the reverse recovery current is needed. In fact, the reverse current in power conversion applications using SiC Schottky diodes is reduced to almost zero – usually less than 1/10 of the reverse recovery current experienced using silicon junction diodes. Low reverse current reduces noise. Besides being exceptionally low, the current level and recovery time are constant with temperature. This means that the amplitude and frequency of the generated EMI will be constant over various temperature and load conditions.

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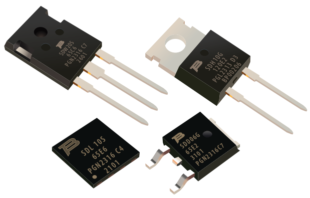

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## HIGHER EFFICIENCY BENEFITS

Adding to their advantages when switched off, there is also the benefit of less capacitance to charge when the SiC Schottky diodes are switched on at the beginning of the conducting cycle at the switching frequency. A lower current means less heat is generated in circuit resistance, which is proportional to the square of the current. When using MOSFETs, this includes the power dissipated in the channel due to its resistance. The use of IGBTs as switching elements in the power conversion applications further reduces the power generated in the switch since the power dissipated is the current multiplied by the voltage drop across the collector-emitter interface.

## TYPICAL APPLICATIONS

Industrial applications benefit from using SiC Schottky diodes due to their superior efficiency and low reverse recovery current, which reduces the resultant EMI/RFI making emission standard compliance easier. Plus, these diodes form parallel modules that can be easily implemented to enable extremely high current applications.

- Industrial high voltage AC/DC power management units
- Power Factor Correction (PFC) applications
- Motor drives for single and multiphase motors
- Air conditioner PFC compressor and fan drivers
- AC/DC management unit, high voltage power conversion, and other topologies
- Server and telecom Switched-Mode Power Supplies (SMPS)

Electric vehicle applications can be made more compact and at lower cost by applying SiC Schottky diodes in the rectifier stages because they enable increased efficiency and offer high current density. Their lower forward voltage means less voltage is lost when current is passed through these diodes.

- On-Board Charging (OBC)
- Electrical Vehicle (EV) charging stations

Domestic, consumer and many types of low power applications benefit from using SiC Schottky diodes that provide increased efficiency and offer a more compact size solution for these applications' power conversion stages. All types of switching conversion applications benefit from the enhanced performance of SiC Schottky diodes.

- Uninterruptible Power Supplies (UPS)
- Photovoltaic applications (solar boost converter, inverter topology, microinverter, etc.)
- TV and entertainment SMPS
- Desktop and PC power supplies
- White goods SMPS and motor drivers

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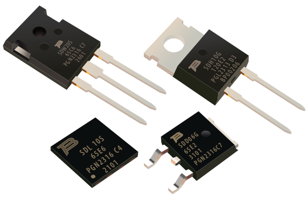

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## SUMMARY

In summary, when SiC Schottky diodes are used, there is reduced heating that results in increased efficiency, lower power dissipation temperature, and reduced stress in switching components. SiC semiconductors have inherently high thermal conductivity, which reduces their junction temperature during operation. These contribute to higher MTBF (Mean Time Between Failure) and can contribute to saving operational costs over the lifetime of the system.



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