

1200 V SiC Schottky Rectifiers optimized for ≥ 250 °C operation with low junction capacitance

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Abstract— Electrical Characteristics of Industry's first commercially available 1200 V rated SiC Schottky rectifiers, specially designed for operation at ≥ 250 °C are presented. These high-temperature SiC rectifiers fabricated in 1, 5, and 20 A current ratings feature reverse leakage currents of < 3 mA/cm² at 1200 V up to temperatures as high as 300 °C. GeneSiC's 1200 V/20A High Temperature Schottky (designated SHT) rectifier offers a 10x reduction in leakage current and a 23% reduction in junction capacitance when compared to its nearest SiC Schottky rectifier competitor. In addition, these SHT rectifiers demonstrate superior surge-current ratings, and temperature-independent switching capability up to their rated junction temperatures.

I. INTRODUCTION

To address the emerging need for high-temperature (>200 °C) capable high-voltage rectifiers in down-hole oil drilling, geothermal instrumentation, aerospace and other military applications, GeneSiC has successfully commercialized the industry's first 1200 V SiC Schottky rectifiers designed and fabricated for low-leakage performance at > 200 °C junction temperatures. These high-temperature Schottky (SHT) rectifiers are uniquely designed and fabricated to fully exploit the superior high-temperature capability of the 4H-SiC material and associated metallizations, fabrication techniques and designs. A detailed investigation of the on-state, blocking voltage, switching, capacitance-voltage (C-V), and long-term reliability characteristics of these novel SiC SHT rectifiers are presented in this paper. The SHT Rectifiers presented in this paper are excellent diodes for use in conjunction with GeneSiC's SiC "Super" Junction Transistors (SJTs) [1], which offer superior electrical performance over competing SiC transistor technologies (MOSFETs, JFETs) at > 200 °C operating temperatures.

II. DESIGN AND FABRICATION

Device designs and fabrication processes were developed at GeneSiC to enable the SiC SHT rectifiers to block their rated voltage, even at temperatures as high as 300 °C with low leakage currents. The topside metallization for these SHT rectifiers was formed by either thick Al or Au to be compatible with wire-bonded or fully soldered packaging, respectively. The 1200 V SHT rectifiers were fabricated with three different chip sizes, corresponding to 1 A, 5 A and 20 A chip current ratings. When these chips are packaged in different packages with different thermal characteristics, they offer correspondingly different current ratings. These devices are packaged in industry standard 3-leaded TO-257 and Surface Mount (SMB05/TO-276) packages, as shown in *Figure 1*.

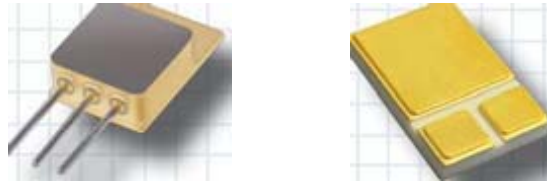


Figure 1: Isolated TO-257 (Left) and Surface Mount SMB05 (TO-276) packages were used for packaging of high temperature SiC Rectifiers.

III. DEVICE CHARACTERISTICS

Although these packages and associated solders and encapsulations were rated for <250 °C junction temperatures, these devices were electrically characterized up to 300 °C. It is assumed that the pulsed measurements do not affect device characteristics appreciably.

A. Voltage Blocking Characteristics

Very low leakage currents are measured on a 1200 V/1 A SiC SHT rectifier up to 300 °C (Figure 1). A clear signature of

avalanche limited breakdown can be inferred from the positive temperature co-efficient of the breakdown voltage as observed in Figure 2.

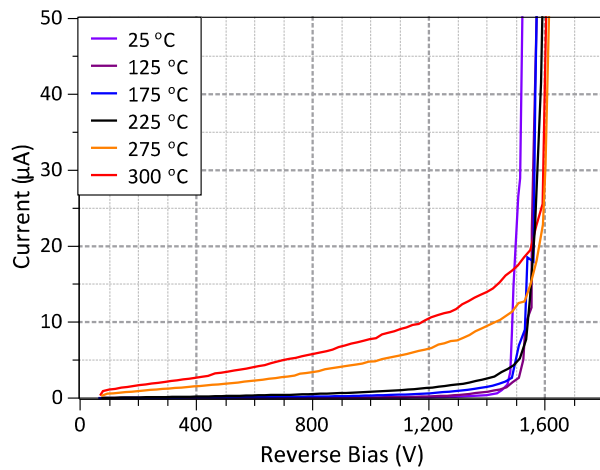


Figure 2: Reverse Blocking I-V Characteristics of (Left, a) 1200 V/1 A SiC Schottky rectifier up to 300 °C.

Leakage currents at rated voltages of the SHT Schottky rectifiers were compared with Schottky rectifiers from other manufacturers. The leakage current comparison is shown in Figure 3.

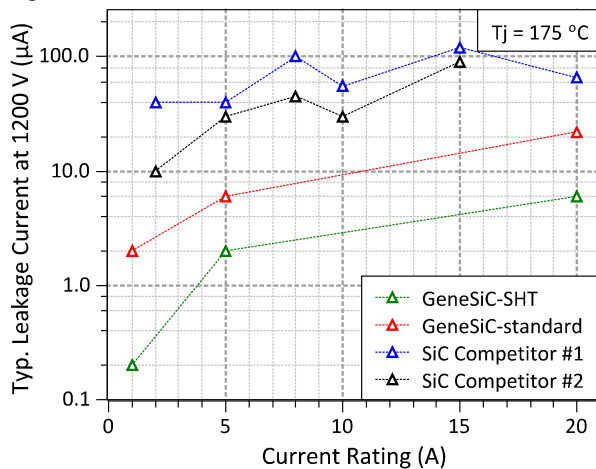


Figure 3: Comparison of blocking characteristics of standard and high-temperature 1200 V/1-20 A SiC Schottky rectifiers fabricated by GeneSiC. Datasheet data from 1200 V SiC Schottky diodes fabricated by other SiC device manufacturers are also shown for comparison.

It can be seen from Figure 3 that the GeneSiC SHT rectifiers offer the lowest reverse leakage currents among commercially available 1200 V SiC Schottky rectifiers at all current ratings. A 20 A SHT rectifier shows a 10x reduction in reverse leakage current at 1200 V and 175 °C, when compared to its nearest SiC Competitor. The special low-leakage process used for GeneSiC's SHT rectifier fabrication results in a further 27% reduction in leakage current at 175 °C, as compared to GeneSiC's standard Schottky rectifier, named SLT rectifier. This enables the operation of the SiC

SHT rectifier at temperatures as high as 250-300 °C, without excessive leakage currents.

B. On-State Performance

The forward I-V characteristics of a 1200 V/5 A SiC SHT rectifier are shown in Figure 4. The on-state voltage drop shows a modest increase at the rated 5 A from 2.18 V at 25 °C to 3.6 V at 250 °C.

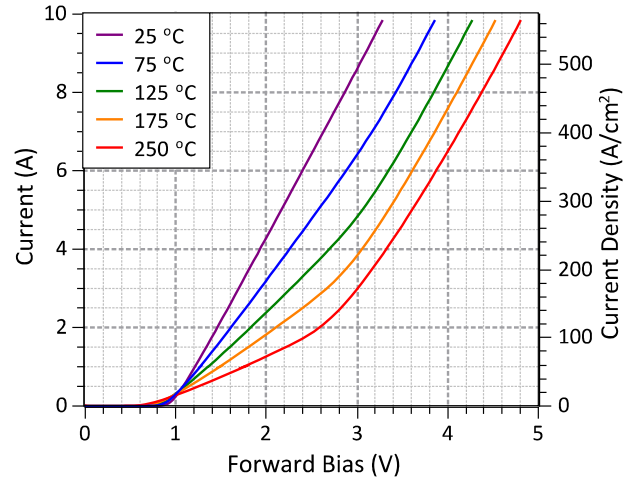


Figure 4: Temperature dependent on-state characteristics measured on a 1200 V/5 A SiC SHT Rectifier.

Almost temperature independent Schottky barrier heights of 1.2 eV and ideality factors < 1.05 (Figure 5) are extracted from low-current (10^{-9} A to 10^{-5} A) forward I-V characteristics measured at different temperatures on the 1200 V/5 A SHT rectifiers, which are evidence of an homogenous Schottky barrier interface, even at temperatures in excess of 200 °C.

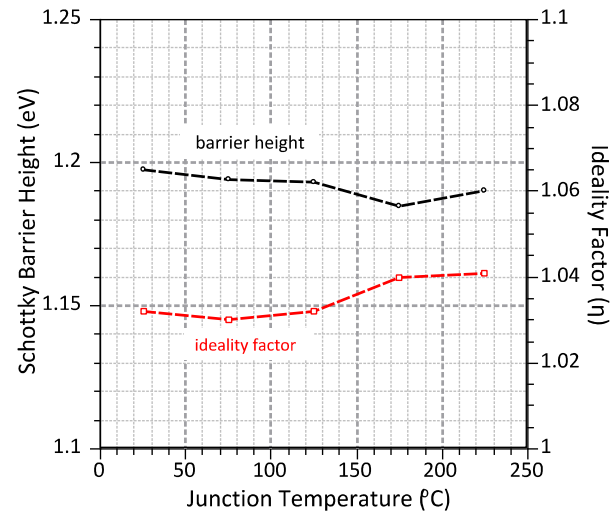


Figure 5: Ideality factor and Schottky barrier height extracted from the I-V-T measurements.

C. Capacitance-Voltage (CV) Characteristics

The reverse recovery loss in a majority carrier SiC Schottky diode originates entirely from charging and discharging of its junction capacitance (C_j). Therefore a measure of

Capacitance, especially at near-zero bias, is considered to be an important parameter used to compare the performance of these type of devices. From the C-V characteristics shown in Figure 6, a 1200 V/5 A SHT rectifier shows 9% reduction of C_j at 1 V reverse bias and a 15% reduction in capacitive charge (Q_c) at 800 V, when compared with a 1200 V/5 A SLT (standard-design) rectifier.

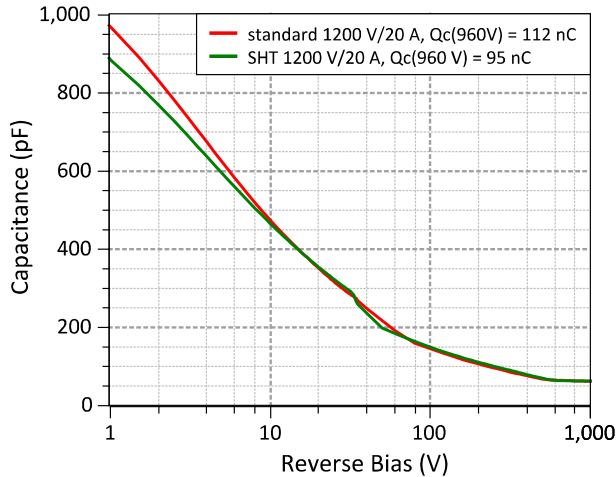


Figure 6: Comparison of C-V characteristics measured on GeneSiC's 1200 V/5 A standard (SLT) Schottky and SHT rectifiers.

As shown in Figure 7, GeneSiC's 1200 V SHT rectifiers offer the lowest near-zero bias (at Anode-Cathode bias, $V_{AK}=-1$ V) junction capacitance (C_j) among all commercially available 1200 V SiC Schottky rectifiers at all current ratings. A 20 A GeneSiC SHT rectifier shows a 23% lower C_j when compared to a 20 A SiC Schottky rectifier from Competitor #1. Thus, these SHT rectifiers offer the fastest switching capability and lowest-in-class switching losses in the 1200 V Schottky rectifier class.

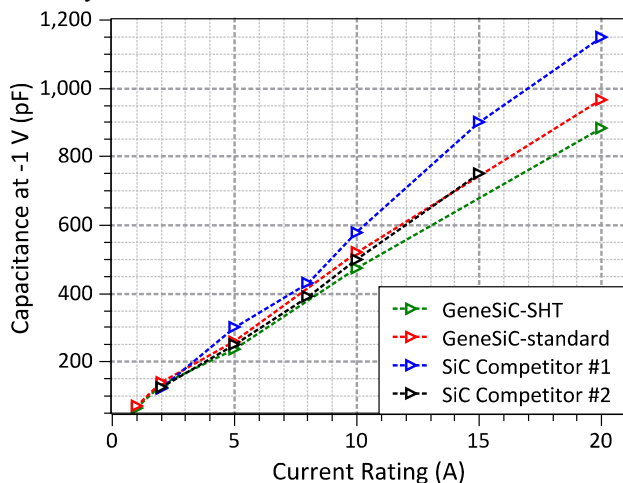


Figure 7: Comparison of junction capacitance of GeneSiC's 1200 V SiC Schottky rectifier product line with SiC Schottky diodes from other manufacturers (data from respective device datasheets).

D. Switching Characteristics

The 1200 V SHT rectifiers were inserted as free-wheeling diodes with a 1200 V/25 A Si IGBT, and a standard double pulse scheme was used for obtaining the switching waveforms. The cathode current waveforms obtained for switching a 1200 V/20 A SHT rectifier under a high reverse di/dt condition (50 A/ μ sec) and reverse bias 960 V, at 25 °C and 205 °C are shown in Figure 8.

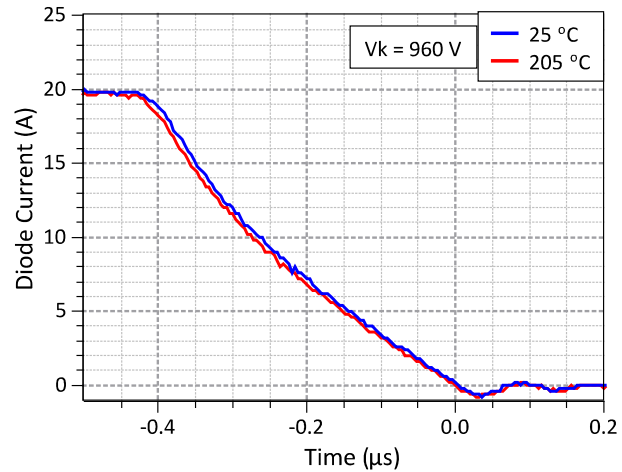


Figure 8: Diode turn-off current waveforms measured on a 1200 V/20 A SiC SHT rectifier at 25 °C and 205 °C. The turn-off measurement was performed to a reverse bias of 960 V.

A very low peak reverse recovery current of <0.5 A is observed from the cathode current waveforms, even for switching at such high (960 V) voltages. Moreover, there is no difference in the switching transients measured at 25 °C and 205 °C, which confirms the majority carrier characteristics of the SiC SHT rectifiers.

IV. CONCLUSIONS

Experimental Results were presented in this paper on the Industry's first 1200 V high-temperature SiC Schottky rectifiers specially designed for 250-300 °C operation. Desirable features of these SiC SHT rectifiers include ultra-low (< 1mA/cm²) reverse leakage currents at 250 °C, lowest-in-class junction capacitance leading to reduced switching losses, and temperature-independent switching performance. Detailed comparisons with several commercial SiC Schottky rectifiers were performed and the performance benefits of the SHT rectifiers were quantified.

REFERENCES

- [1] R. Singh, S. Jeliakov, E. Lieser, "1200 V-class 4H-SiC "Super" Junction Transistors with Current Gains of 88 and Ultra-fast Switching Capability", Materials Science Forum, 717-720, pp.1127-1130 (2012).