SiC “Super” Junction Transistors with Ultra-Fast (< 15 ns) Switching Capability

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Abstract

1200 V-Class Super-High Current Gain Transistors or SJTs developed by GeneSiC are distinguished by low leakage currents of < 100 µA at 325 °C operating temperature, turn-on and turn-off switching transients of < 15 ns at 250 °C, maximum Common Source current gains of 88 and low on-resistance of 5.8 mΩ-cm2. Two-stage cascaded SJTs display a record high current gain of 3475. Results from detailed on-state, blocking, switching and reliability characterization of 1200 V-class 4 mm2 and 16 mm2 SiC SJTs are presented in this paper.

1. Introduction

Silicon Carbide “Super” Junction Transistors (SJTs) are “Super-High” current gain SiC BJTs currently developed by GeneSiC in 1200 V – 10 kV ratings. The SiC SJTs are Gate-oxide free, normally-off, quasi-majority carrier devices with a square reverse biased safe operating area (RBSOA) and a slightly positive temperature co-efficient of on-resistance. The current driven SJTs are capable of 250 °C operation, offer < 20 ns turn-on and turn-off capability, current gains as high as 88, low on-state voltage drop and high-current operation, due to the absence of a channel region and near zero Drain-Source offset voltage. Incorporating high voltage, high frequency and high-temperature capable SiC SJTs will increase the power conversion efficiency and reduce the size/weight/volume of commercial power electronics. This paper will report on an in-depth study of the static, switching and long-term reliability characteristics of the 1200 V-class SiC SJTs recently designed and fabricated at GeneSiC.

2. Static Characteristics of SiC Super Junction Transistors

Optimized edge termination and surface passivation schemes were used for SJT fabrication to achieve near-theoretical breakdown voltages and temperature independent, low reverse leakage currents up to 325 °C (Figure 1(a)). The output I-V characteristics of a 16 mm^2 SiC SJT shown in Figure 1(b) feature a near-zero Drain-Source offset voltage, distinct lack of a quasi-saturation region and the merging of the different Gate current I-V curves in the saturation region. The last two features imply lack of charge storage in the drift region of the SiC SJT and clearly distinguish it from a “bipolar” Si BJT. This inherent property of the SiC SJT enables temperature independent, fast switching transients. Appropriate metallization schemes along with an optimized epilayer design resulted in $V_{DS,SAT}$ values as low as 1.35 V at 25 °C and 2.7 V at 175 °C at 30 A of Drain current. A low on-resistance of 5.8 mΩ-cm^2 is extracted from the 25 °C output I-V characteristics at 30 A. The positive temperature co-efficient of on-resistance observed in Figure is desirable for paralleling multiple devices for high-current configurations.

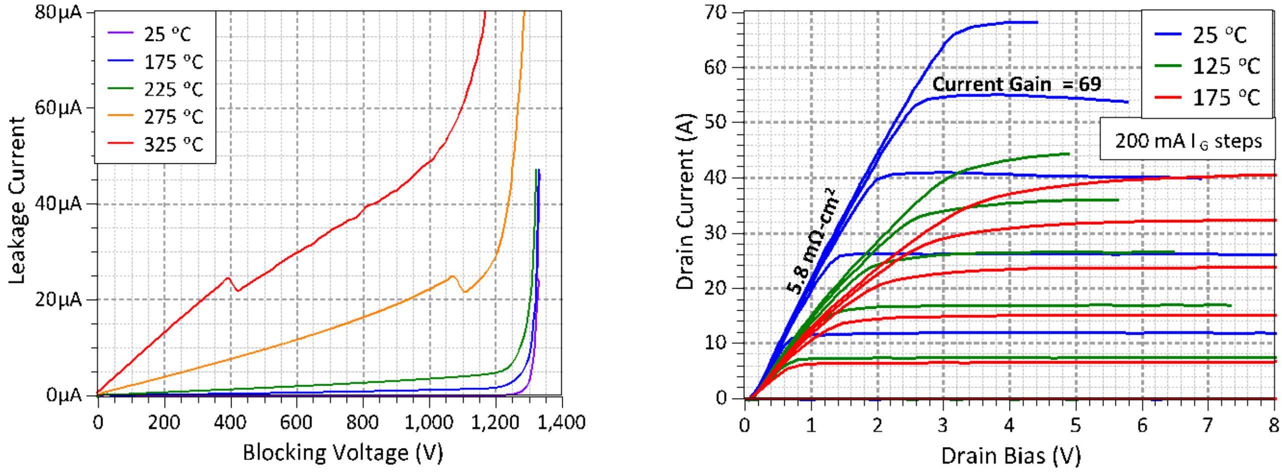

Figure 1: (Left, a) Open-Base Blocking I-V characteristics measured on 4 mm^2 SJTs up to 325 °C and (Right, b) Output characteristics of a 16 mm^2 SJT measured up to 175 °C.

Single, 5 µs wide pulsed current measurements were used to investigate the variation of the common-Source current gain (β) with increasing Drain current with minimal self-heating. For a 4 mm^2 SJT, a β as high as 88 is measured at Drain current levels ranging from 4 A to 10 A at 25 °C, as shown in Figure 2(a). High-level injection effects in the base layer decrease the β at Drain currents > 300 A/cm^2, which is notably greater than the thermal dissipation capability of most commercial packaging. It can be noted from Figure 2(b), that the β shows a negative temperature co-efficient, decreasing from a maximum value of 81 at 25 °C to 44 at 200 °C, due to the increase in ionization of the p-type Al acceptors in the base layer of the SJT.

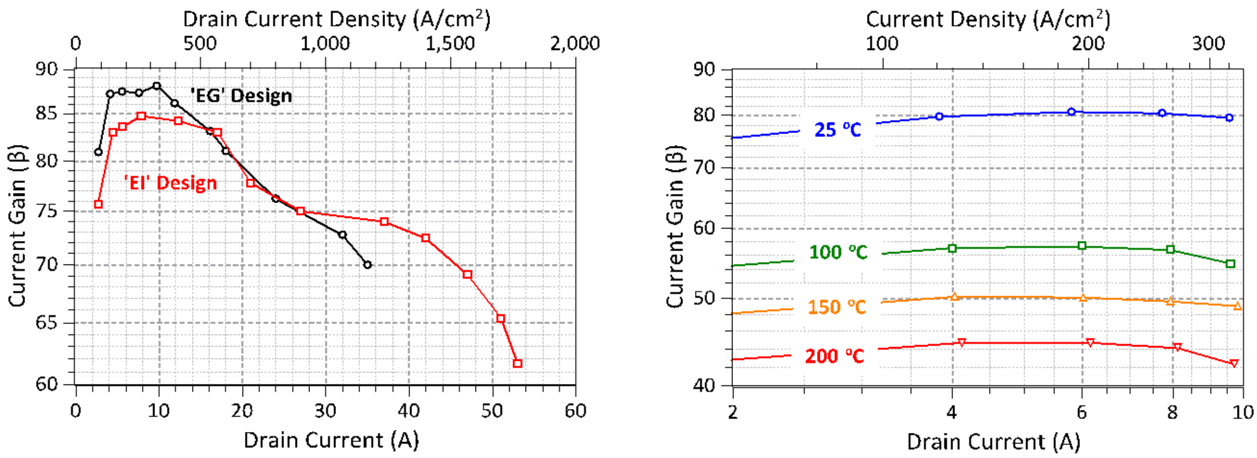

Figure 2 (Left, a) Single-pulse (5 µs) measurements to extract the common-Source current gain, β of a 4 mm^2 SJT as a function of Drain current and (Right, b) negative temperature co-efficient exhibited by the β of a 4 mm^2 SJT, decreasing from a maximum of 81 at 25 °C to 44 at 200 °C.

3. Dynamic Characteristics of Super Junction Transistors

Switching measurements on the 4 mm^2 and 16 mm^2 SiC SJTs were performed with an inductive load and free-wheeling 1200 V/ 7 A or 1200 V/30 A GeneSiC SiC Schottky rectifiers. A commercially available IGBT gate driver with an output voltage swing from -8 V to 15 V was used for driving the SJTs. For the 4 mm^2 SJTs, a 100 nF dynamic capacitor connected in parallel with the Gate resistor generated high initial dynamic Gate currents of 4.5 A and -1 A during turn-on and turn-off switching respectively, while maintaining a constant Gate current of 0.52 A during its turn-on pulse. These large initial dynamic Gate currents charge/discharge the device input capacitance rapidly, yielding a faster switching performance. Temperature-independent, ultra-low Drain current rise and fall times of 12 ns and 13 ns, respectively, were recorded (Figure 3) for switching 8 A and 800 V by the 4 mm^2 SJT. Switching measurements on 4 mm^2 Cascaded SJT devices using a similar test setup yielded relatively higher current rise and fall times of 27 ns and 37 ns, respectively (**Error! Reference source not found.**). The higher switching times observed for the Cascaded SJTs as compared to the discrete device are due to the lack of Gate control over the switching of the output transistor.

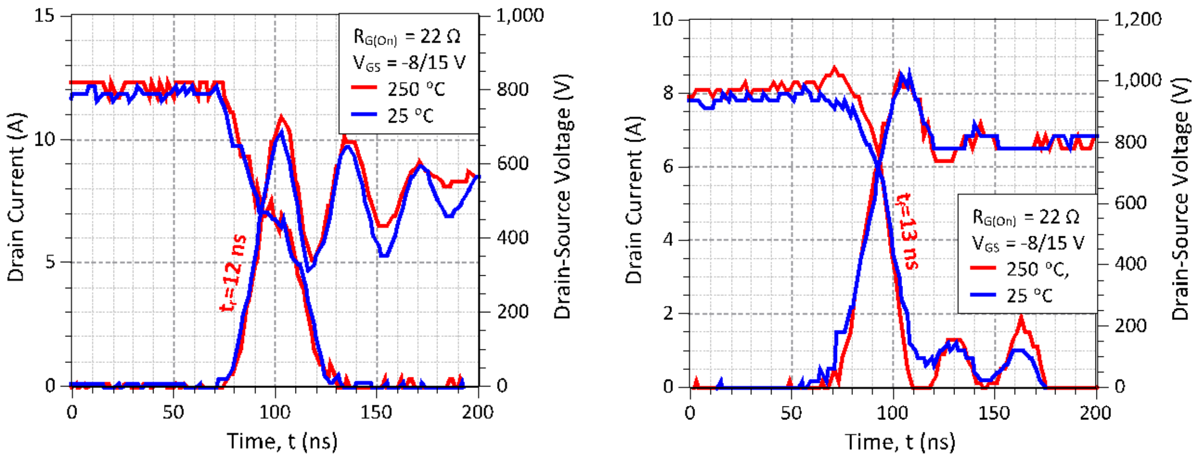

Figure 3: (Left, a) Turn-On and (Right, b) Turn-Off Drain Current and Voltage transients recorded for switching 800 V and 8 A through a 4 mm^2 SiC SJT. There is no difference in switching speed between 25 °C and 250 °C, due to the unipolar nature of the SJT device design.

4. Device Robustness Measurements

Preliminary results from the short-circuit capability and avalanche ruggedness of the 4 mm^2 SJTs fabricated in this work are shown in Figure 4(a) and (b). When the SJT is turned on to a short circuit at a Drain voltage of 800 V with 0.2 A of Gate current, a short circuit current of 13 A and a short circuit withstand time of 22 µs are observed in Figure , which is considerably higher than the 10 µs reported on SiC MOSFETs. Under these short circuit conditions, device destruction occurred at 25 µs. A single-pulse avalanche energy (E_{AS}) of 20.4mJ was extracted from Unclamped Inductive Switching (UIS) performed on the 4 mm^2 SJT at the rated current of 7 A with a 1 mH inductor.

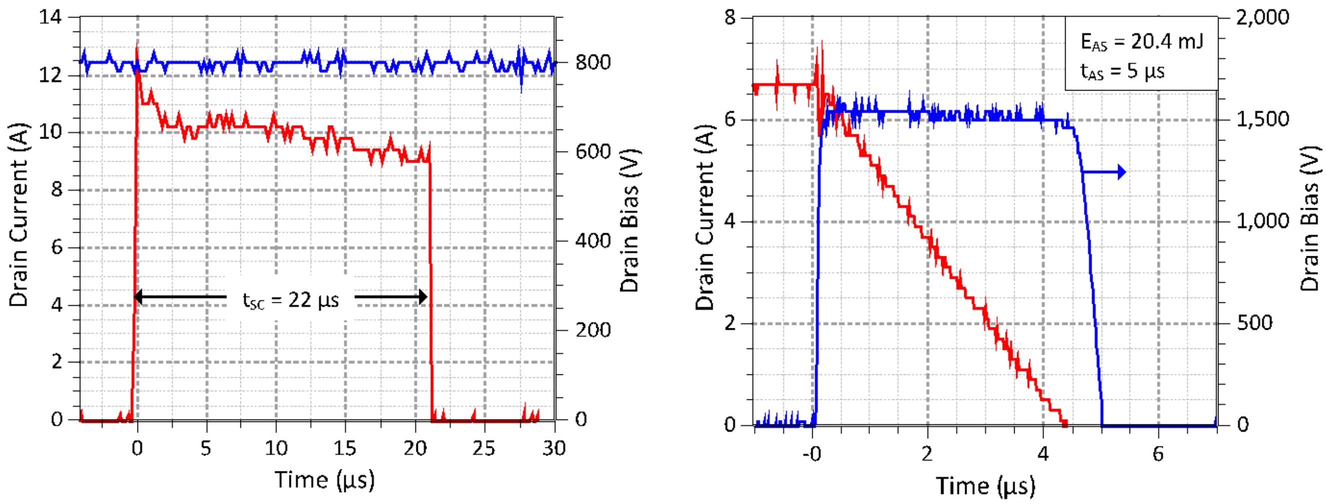

Figure 4: (Left) A short circuit withstand time of 22 µs is obtained, when a 4 mm^2 SJT is switched on to a short-circuited load at a Drain bias of 800 V and a Gate current of 0.2 A. (Right) A single-pulse avalanche energy of 20.4 mJ is obtained for unclamped Inductive switching (UIS) of a 4 mm^2 SJT at the rated Drain current of 7 A.

Literature

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