

SiC “Super” Junction Transistors Offer Breakthrough High Temp Performance

GeneSiC’s SiC-based 1200 V/220 mΩ Super Junction Transistors (SJTs) feature high temperature (> 300 °C) operation capability, ultra-fast switching transitions (< 15 ns), extremely low losses, and a large short-circuit withstand time of 22 μs. Integrating SiC SJTs with GeneSiC’s freewheeling SiC Schottky rectifiers provides a 64% power loss reduction over best-in-class silicon counterparts.

Power electronics fabricated on the Silicon Carbide (SiC) platform can operate at higher temperatures, higher frequencies, and can deliver higher circuit efficiencies as compared to traditional Si-based technologies [1]. The SiC transistors are especially attractive at 1.2 kV-10 kV ratings, particularly for medium and high-frequency applications [2]. Though SiC-based Schottky diodes were readily available since 2001[3], the commercialization of SiC power transistors has lagged behind. [4-5].

GeneSiC is developing an innovative SiC power switch, a “Super” Junction Transistor (SJT) in 1.2 kV to 10 kV voltage ratings for high efficiency power conversion in Switched-Mode Power Supply (SMPS), Uninterruptible Power Supply (UPS), aerospace, defense, down-hole oil drilling, geothermal, Hybrid Electric Vehicle (HEV) and inverter applications.

The Gate-oxide free, normally-off, current driven, quasi-majority device, SJT is a “Super-High” current gain SiC-based BJT that features a square reverse biased safe operating area (RBSOA), high temperature (> 300 °C) operation capability, low $V_{DS(on)}$ and faster switching capability (10’s of MHz) than any other competitor SiC switch. The MOS interface reliability-related issues and high channel resistance of SiC MOSFETs have limited their temperature capability to 150 °C where as the Gate-oxide and channel free SiC SJTs deliver high temperature performance (> 300 °C). Unlike SiC SJT, SiC MOSFET requires a customized gate driver with +20 V V_{GS} capability due to their transconductance resulting from poor MOS channel mobility characteristics. On the other hand, the commercially available normally-off SiC JFET displays a very high positive temperature coefficient of $V_{DS(on)}$ and lower temperature capability as compared to the SiC SJT.

GeneSiC’s 1200 V/220 mΩ SiC SJTs are packaged in standard TO-220 and high temperature TO-257 packages (Fig. 1.) The following three best-in-class Si IGBT co-packs with internally integrated anti-parallel Si FREDs were chosen for comparing their electrical performance with that of 1200 V/220 mΩ SiC SJT:

- NPT1: 125 °C/1200 V rated Si Non-Punch-

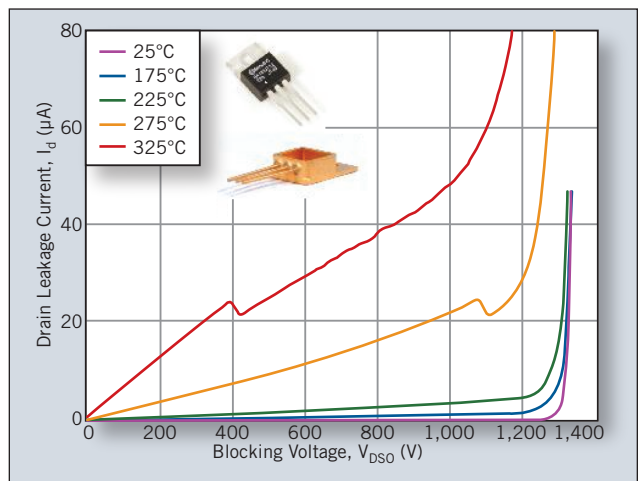


Fig. 1: Temperature variant blocking performance of a 1200 V/220 mΩ SJT

Through IGBT

- NPT2: 150 °C/1200 V rated Si Non-Punch-Through IGBT
- TFS: 175 °C/1200 V rated Si Trench Field Stop IGBT

ON-STATE AND BLOCKING PERFORMANCE

Open-gate, blocking voltage performance of a 1200 V/220 mΩ SJT at temperatures as high as 325 °C is shown in Fig. 1. The leakage current in the SJT at $V_{DS} = 1200$ V is below 5 μ A up to temperatures as high as 225 °C. Leakage currents of < 100 μ A were measured even at 325 °C, validating the high-temperature operation of the SJT. Fig. 2. compares the temperature-dependent leakage currents of the three Si IGBT co-packs with the 1200 V/220 mΩ SiC SJT. The leakage current in the SJT shows a smaller positive temperature coefficient as compared to the Si IGBTs. It must be noted that the 325 °C temperature capability

of the SJT is only limited by the current packaging.

The on-state characteristics of a 1200 V/220 mΩ SJT were generated using a curve tracer for operating temperatures up to 250 °C (Fig. 3.). The distinct lack of quasi-saturation region and merging of the on state curves for various Gate currents in the saturation region of a SJT indicate the absence of the minority carrier injection and clearly distinguishes it from a Si “BJT”. Appropriate metallization schemes and an optimized device design yield low Drain Source saturation voltages. The on-state voltage values of SJT are relatively smaller than the existing same current/voltage rated Si IGBTs with $V_{DS(on)}$ values of 1.5 V at 25 °C and 2.6 V at 125 °C at 7 A of drain current. The SJTs display a positive temperature coefficient of $V_{DS(on)}$ that facilitates paralleling of multiple devices for high current configurations. Common source current gains as high as 88 was measured on this batch of SJTs.

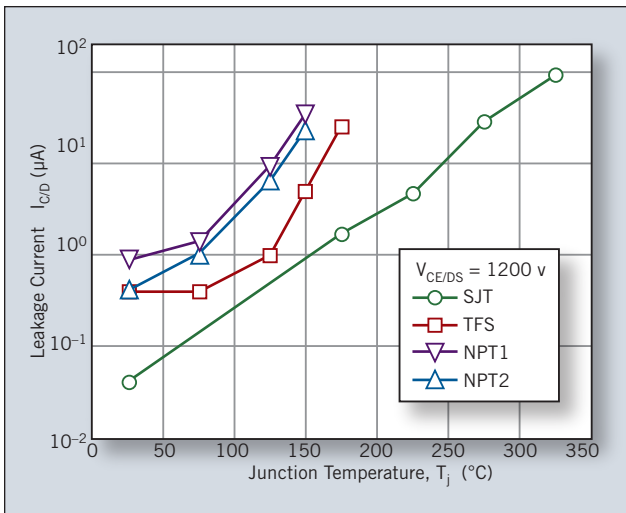


Fig. 2: Leakage current comparison of Si IGBTs and 1200 V/220 mΩ SJT as a function of temperature.

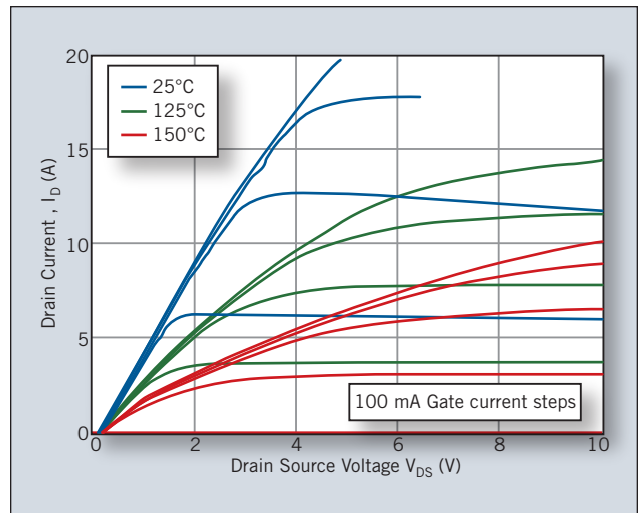


Fig. 3: Temperature variant output characteristics of a 1200 V/220 mΩ SJT.

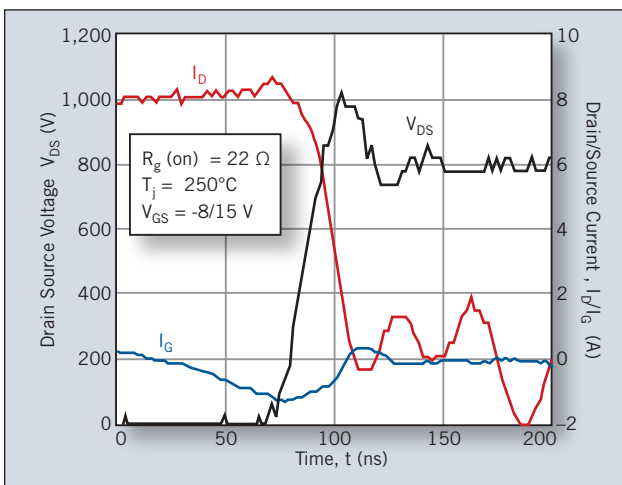


Fig. 4: Turn-Off switching transients of a 1200 V/220 mΩ SJT

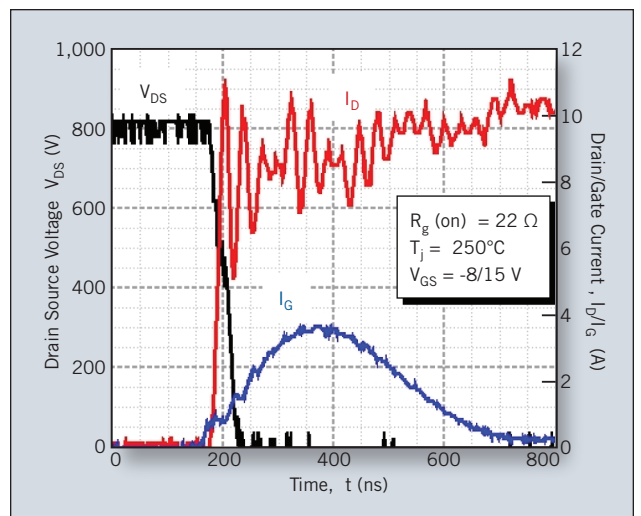


Fig. 5: Turn-On switching transients of a 1200 V/220 mΩ SJT

Modeling the z-transform difference equations in the z-domain requires the insertion of zero order holds at the A/D and D/A interface.

SWITCHING PERFORMANCE

An inductively loaded chopper circuit configuration and a standard double-pulse scheme were used for comparing the switching performance of SiC SJT and Si IGBTs comprises of an inductively loaded chopper circuit configuration. A GeneSiC 1200 V/ 7A SiC Schottky diode [6] and Si IGBT co-packs were used as Free Wheeling Diodes (FWDs) in the switching test circuit. The Gate and Source terminals of Si IGBTs were tied together ($V_{GS} = 0$ V) to avoid spurious IGBT conduction during the dynamic testing. A 1 μ F charging capacitor, a 150 μ H inductor, 22 Ω Gate resistor and a supply voltage of 800 V were used in the testing process.

A commercial standard IGBT Gate driver with an output voltage swing from -8 V to 15 V is used for driving the Si IGBTs as well as the Si SJT. A 100 nF dynamic capacitor connected in parallel with the Gate resistor generated an initial large dynamic Gate currents of 4 A and -1 A (Figs. 4 and 5) during turn-on and turn-off switching respectively, while maintaining a constant Gate current of 0.52 A during its turn-on pulse. The initial dynamic gate currents charge/discharge the device capacitance rapidly, yielding a superior switching performance.

A drain current rise time of about 12 ns and a fall time of 14 ns were obtained for 7 A, 800 V SJT switching at a

temperature of 250 °C, resulting in extremely low switching energies when compared to the Si IGBT co-packs, even though the Si devices could be measured only up to 150 °C. A comparison of the overall power losses measured on the SJT and Si IGBT co-packs is shown in Fig. 6. Si TFS + SiC FWD represents Si TFS IGBT as the DUT and SiC Schottky diode as FWD respectively where as Si TFS + Si TFS represents Si TFS IGBT as DUT and Si TFS IGBT co-pack as FWD respectively. The calculated gate drive, conduction and switching losses of SJT are 5.25 W, 26.65 W and 20 W respectively at 250 °C operating temperature. Though the gate driver losses of SJT are higher than Si IGBTs, their contribution to the overall losses is insignificant. The higher conduction losses of SJT when compared to the Si IGBT co-packs in Fig. 6 is due to the fact that the SJT was evaluated at a higher temperature (250 °C), as compared to the IGBT's 125 to 175°C. In spite of its higher temperature operation, an all-SiC solution reduces the overall losses by about 64% when compared to the best Si IGBT solution investigated in this report.

SHORT-CIRCUIT PERFORMANCE

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 (I_{SC}) of 22 μ s are obtained (Fig. 7), which is considerably higher than the 10 μ s reported [5] on 1200 V/20 A SiC MOSFETs. The factor of 2 improvement in t_{sc} for the SiC SJT is due to its low I_{SC} of 13 A in comparison with a rated current of 7 A. Short-channel effects inherent to the SiC MOSFET reported in [5] result in an undesirably high I_{SC} of 180 A, as compared to its rated 20 A, which limits the t_{sc} to 10 μ s.

CONCLUSIONS

The SiC SJTs developed by GeneSiC offer significant benefits over the Si IGBTs, SiC MOSFETs and JFETs by reducing the power losses tremendously and delivering high temperature performance respectively. These benefits result in improving the system efficiencies, and reducing its cost and size. As SiC SJTs are a direct replacement to the Si IGBTs, they can be driven using the standard IGBT/MOSFET gate drivers, unlike SiC MOSFETs and JFETs which require specialized gate driver architectures.

GeneSiC's silicon carbide products have the largest range of SiC Schottky Diodes to date – 10 Products in 1200 V and above voltage ratings. GeneSiC also has the largest range of packages

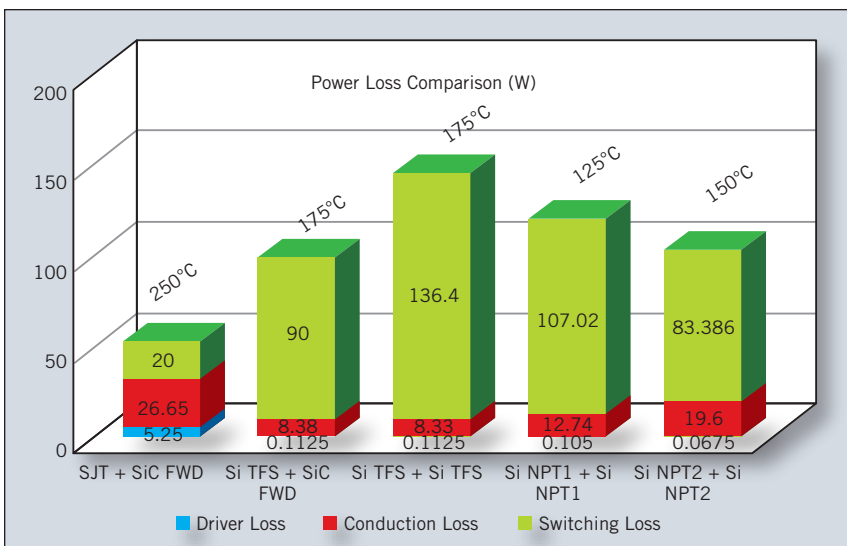


Fig. 6: Power loss comparison of SiC SJT and Si IGBT co-packs at their maximum operating temperature.

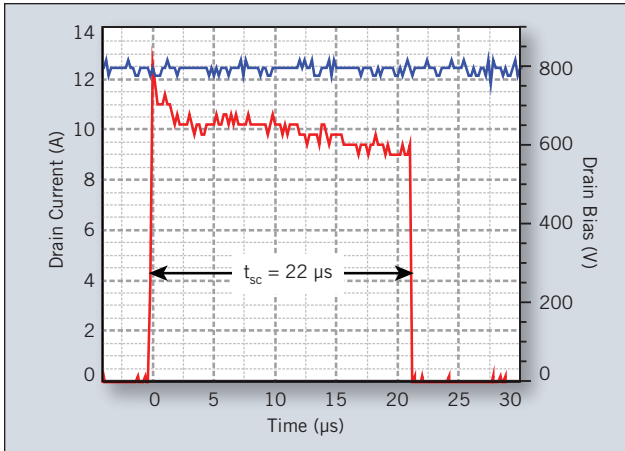


Fig. 7: Current and Voltage waveforms of a 1200 V/220 mΩ SJT under a short-circuit load condition..

in 1200 V and above voltage ratings – TO-220, TO-247, TO-263 and SOT-89. The company’s co-packaged IGBT with SiC Diodes is currently in 100-A and 35 A/ 1200 V, ISO-Top and TO-247 packages which are best-in-class Hybrid Si-SiC IGBT Co packs. The company has also

introduced the industry’s first 1200 V/ 3 A SiC Schottky product for cost-conscious customers who want save money utilizing this product instead of an off-the-shelf 5 Amp 1,200 Volt that is a standard in SiC industry.

The company’s Silicon Product Portfolio is easily cross-referenced to major manufacturers, with short leadtimes of 6 to 8 weeks. All of GeneSiC’s silicon products are RoHS and UL approved, and boost the largest range of Schottky Diode modules. GeneSiC’s products can be purchased through its global distribution channel, or through manufacturer representatives listed on the company’s site at www.genesicsemi.com.

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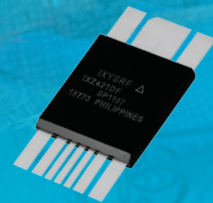
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