Breakthrough High Temperature Electrical Performance of SiC "Super" Junction Transistors

SiC are being explored for power electronic conversion applications

The SiC based 1200 V/220 mÙ Super Junction Transistors (SJTs) feature high temperature (> 300 °C) operation capability, faster switching transitions (< 20 ns), extremely low losses and superior avalanche ruggedness performance (36 mJ). Integration of SiC SJTs with GeneSiC's freewheeling SiC JBS rectifiers will result in a power loss reduction by about 64% than its comparable Si counterpart.

By Deepak Veereddy, Device Engineer, Siddarth Sundaresan, Director-Device Design & Fabrication, Stoyan Jeliazkov, Process Engineer, Michael Digangi, Chief Business Development Officer and Ranbir Singh, President, GeneSiC Semiconductor, Inc.

With Silicon almost reaching its theoretical limit, alternate semiconductor materials like SiC are being explored for power electronic conversion applications [1]. SiC transistors are identified as an attractive alternate solution to the existing Si counterparts in the high voltage regime (1.2 kV-10 kV), particularly for medium and high frequency applications [2]. Though SiC based Schottky diodes were readily available since 2001[3], commercial SiC transistors came into limelight only in the last two to three years [4-5].

GeneSiC is developing the innovative SiC power switch, "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 custom made Gate driver design due to its poor transconductance characteristics. On the other hand, the commercially available SiC normally-off 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 (see Figure 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 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

An almost temperature independent blocking performance of a 1200 V/220 mΩ SJT till 225 °C operating temperature is depicted in Figure 1. The leakage current in a SJT while blocking 1200 V do not change by a large extent up to temperatures as high as 225 °C. Leakage currents of < 100 µA were measured even at 325 °C on a 1200 V/220 mΩ SJT. Figure 2 shows the comparison of the temperature dependent leakage currents of the three Si IGBT co-packs and SiC SJT. Unlike Si IGBTs, the leakage current in SJTs do not show a strong dependence of temperature. Moreover, the operation temperature capability (< 325 °C) of SJTs is solely limited by the power package capability.

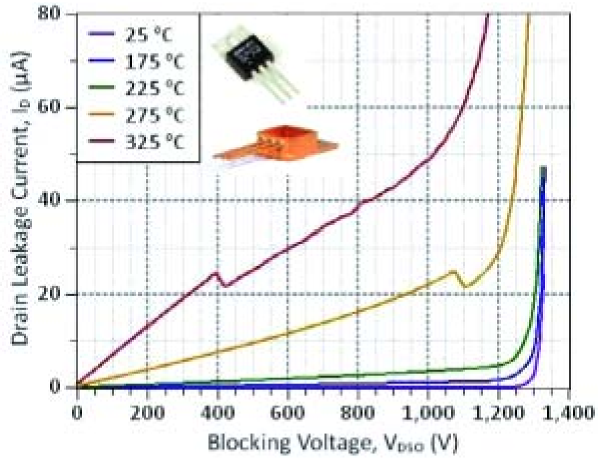

Figure 1:
Temperature variant blocking performance of a 1200 V/220 mΩ SJT

The on state characteristics of a 1200 V/220 mΩ SJT were generated using a curve tracer for operating temperatures up to 250 °C (see Figure 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. SJTs display a positive temperature coefficient of $V_{DS(on)}$ that make their paralleling easy for high current configurations. A highest Common Source current gain value of 88 was measured on this batch of SJTs.

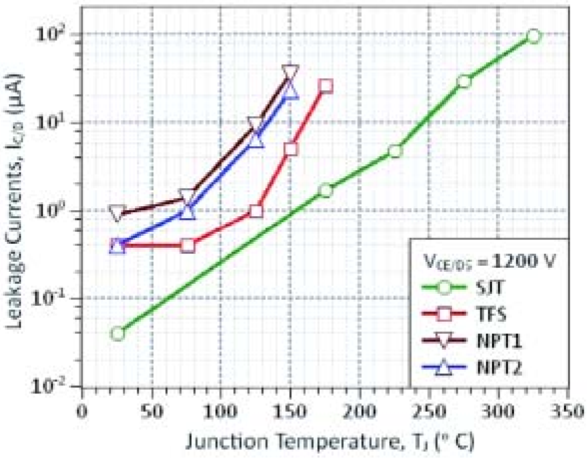

Figure 2: Leakage current comparison of Si IGBTs and 1200 V/220 mΩ SJT as a function of temperature

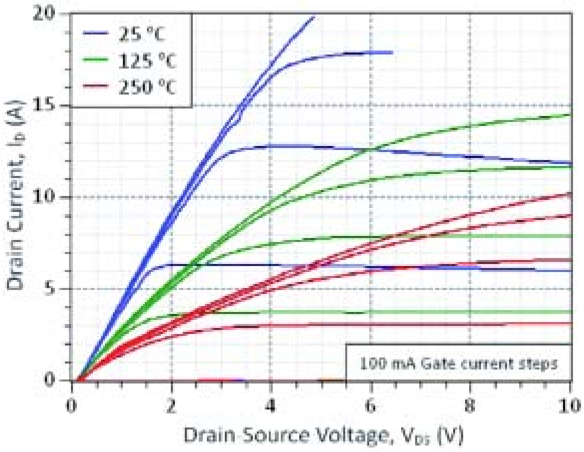

Figure 3 : Temperature variant output characteristics of a 1200 V/220 mΩ SJT

Dynamic Electrical Performance

The dynamic test setup 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 Source terminals of Si IGBT co-pack (FWD) are tied together (V_{GS} = 0 V) to avoid the IGBT conduction during the dynamic testing. A 1 µF charging capacitor, a 150 µH inductor, 22 Ω Gate resistor and a supply voltage of 800 V were used in the testing process. A commercially available IGBT Gate driver with an output voltage swing from -8 V to 15 V is used for driving all the devices. 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 (Figure 4 and Figure 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

AD

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.

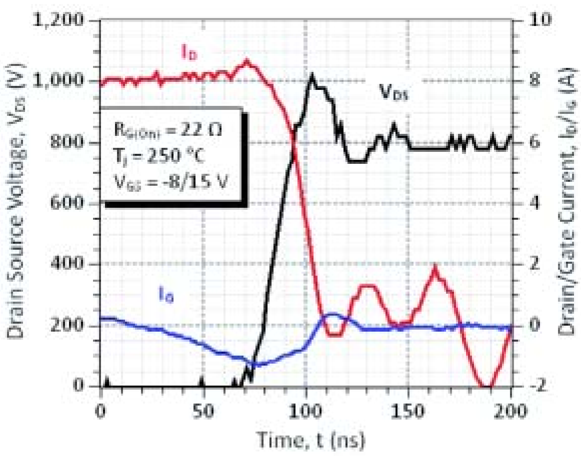

Figure 4:Turn-Off switching transients of a 1200 V/220 mΩ SJT

A comparison of the overall power losses measured on the SJT and Si IGBT co-packs is shown in Figure 6 for a switching frequency of 100 kHz and 0.7 Duty Cycle. 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 relatively high conduction losses of SJT when compared to the Si IGBT co-packs can be attributed to its high temperature operation (250 °C). An all-SiC solution reduces the overall losses by about 64% when compared to an all-Si solution.

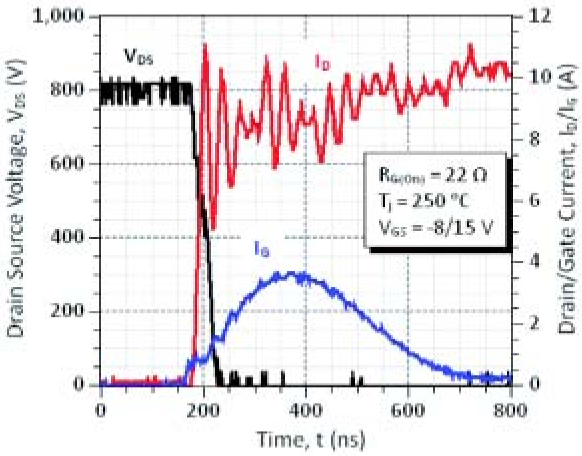

Figure 5: Turn-On switching transients of a 1200 V/220 mΩ SJT

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

Avalanche Ruggedness Performance

A single pulse Unclamped Inductive Switching (UIS) [7] setup was used to obtain the nonrepetitive avalanche energy rating on the SiC 1200 V/220 mΩ SJTs. Using a supply voltage of 60 V and 210 µH inductor for the single pulse UIS test, resulted in non-repetitive avalanche energy and current ratings of 36 mJ and 20 A respectively (see Figure 7). The measured avalanche voltage (1650 V) is about 37% larger than the rated blocking voltage (1200 V).

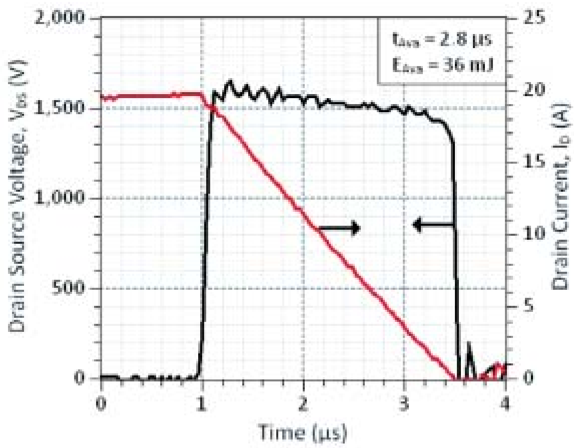

Figure 7 : Unclamped Inductive Switching waveforms of a 1200 V/220 mΩ SJT

Conclusions

GeneSiC highly rugged SJTs offer significant benefits over the Si IGBTs and SiC competitor transistors 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 direct replacement to the Si IGBTs, they can be driven using the standard IGBT/MOSFET gate drivers.

http://genesicsemi.com

References

[1] B.J. Baliga, “Trends in power semiconductor devices”, IEEE Trans. Electron Devices, vol 43, pp. 1717-31, 1996.

[2] A. Hefner et al, “Recent Advances in High-Voltage, High-Frequency Silicon-Carbide Power Devices,” in IEEE 2006 Industry Applications Conference, 2006, pp. 330-337.

[3] I. Zverev, M. Treu, H. Kapels, O. Hellmund, R. Rupp, “SiC Schottky Rectifiers: Performance, Reliability and Key Applications”, Proceedings of EPE 2001 Conference, August 2001.

[4] I. Sankin, D.C. Sheridan, W. Draper, V. Bondarenko, R. Kelley, M.S. Mazzola, J.B. Casady, “Normally-off SiC VJFETs for 800 V and 1200 V Power Switching Applications”, in ISPSD 2008 International Symposium on Power Semiconductor Devices and IC’s, 2008, pp. 260-262.

[5] B.A. Hull, J. Henning, C. Jonas, R. Callanan, A. Olmeda, R. Sousa, J.M. Solovey, “1700V 4H-SiC MOSFETs and Schottky diodes for next generation power conversion applications” in IEEE 2011 Applied Power Electronics Conference and Exposition, 2011, pp. 1042-1048.

[6] GeneSiC Semiconductor, Inc. Available: http://genesicsemi.com/index.php/silicon-carbide-products/schottky-rectifiers/discrete-rectifiers

[7] Microsemi Application note, http://www.microsemi.com/micnotes/APT9402.pdf