# ULTRA-HIGH VOLTAGE SILICON CARBIDE THYRISTORS – NEXT-GENERATION POWER ELECTRONICS BUILDING BLOCKS

**R. Singh and S.G. Sundaresan**

GeneSiC Semiconductor, 43670 Trade Center Place, Suite 155, Dulles, Virginia, USA

## ABSTRACT

Advanced power electronics hardware requiring ultra-high-voltage (>6.5 kilovolts [kV]), high-current (>50 amperes) switches have limited alternatives. Present silicon-based bipolar devices like insulated gate bipolar transistors (IGBTs), gate turn-off (GTO) thyristors, integrated gate-commutated thyristors (IGCTs), and emitter turn-off (ETO) thyristors suffer from low switching speeds, low junction temperature, poor paralleling behavior, lack of effective gate control, long repetitive recovery times ($t_q$), and a low theoretical upper limit (~10 kV) of device voltage rating. Silicon carbide (SiC)-based double-junction injecting devices like thyristors have the potential to alleviate many of these limitations by offering lower $V_F$, multi-kHz switching, and ease of paralleling since they require thinner/higher-doped epitaxial layers with smaller carrier lifetimes, and low intrinsic carrier densities to achieve a given device blocking voltage. These capabilities are expected to usher in a revolution in power electronics hardware for the utility grid, as well as pulsed power applications within the next decade.

**Keywords:** SiC thyristor, high-voltage, high-current, power conversion, utility grid

This paper outlines the progress on high-voltage (≥ 6500 volts [V]) power silicon carbide (SiC) thyristor developments that is targeted at applications ranging from utility grid power conversion to pulsed power and high-temperature applications. Several flavors of SiC thyristor-based devices are presented to address the widely different performance metrics demanded by various application areas. Fast plasma spreading (FPS) thyristors are pursued for pulsed power applications requiring ultra-fast turn-on capability, while anode switched thyristors (ASTs) are developed for applications requiring ease of gate control and 5 to 10 kHz frequency operation. Detailed on-state, blocking voltage, turn-on, turn-off, and reliability metrics of the SiC thyristor-based devices are presented. A special focus of this paper will be the insertion of SiC thyristors in two diverse applications: a pulsed power circuit and a power converter test bench.

A number of key process steps including controlled slope SiC etching (Figure 1), precise edge terminations, surface passivation, and optimized metallization schemes were developed at GeneSiC in support of high-voltage SiC thyristor fabrication. As a result of numerous design and process innovations, near-ideal blocking voltages with low leakage currents at high temperatures (Figure 2) are recorded on packaged 6.5-kV SiC thyristors. A photograph of a packaged 6.5-kV/40-ampere (A) SiC thyristor is shown as an inset in Figure 2. Nearly temperature-independent differential on-resistances as low as 2.5 mΩ-cm$^2$ are extracted from high-current measurements (Figure 3) on large-area 28 mm$^2$ and 77 mm$^2$ SiC thyristors. A comparison with a commercial 4-kV Si thyristor (Figure 4) shows a smaller $V_F$ for the GeneSiC SiC thyristor at current densities > 430 A/cm$^2$ on account of its lower on-resistance. The thyristor turn-on or turn-off is accomplished by switching the appropriate Si metal-oxide-semiconductor field-effect transistors (MOSFETs) on or off. In Figure 5, a cathode current of 28 A is turned off in ≈ 1 µs at 25 °C by the AST circuit. In Figure 5, a cathode current of 62 A flowing through a 77-mm$^2$ SiC thyristor is turned off by the forced commutation technique by applying a reverse bias of +30 V to the cathode and maintaining a turn-off dI/dt of 405 A/µs. For a re-applied dV/dt of 520 V/µs, a minimum turn-off time ($t_q$) of 6.3 µs needs to elapse before the thyristor is capable of supporting a forward blocking voltage without exhibiting a spurious turn-on by the dV/dt effect.

These demonstrations bode well towards adopting SiC-based thyristors as fundamental building blocks for advanced power electronics hardware for energy storage and smart grid applications

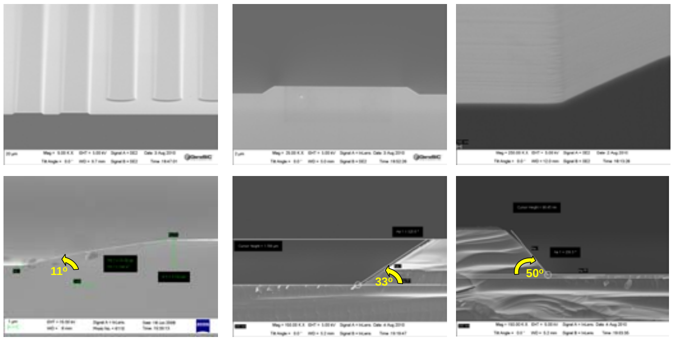

**Fig. 1. Cross-sectional SEMs of SiC Mesas etched with arbitrarily chosen sidewall slopes.**

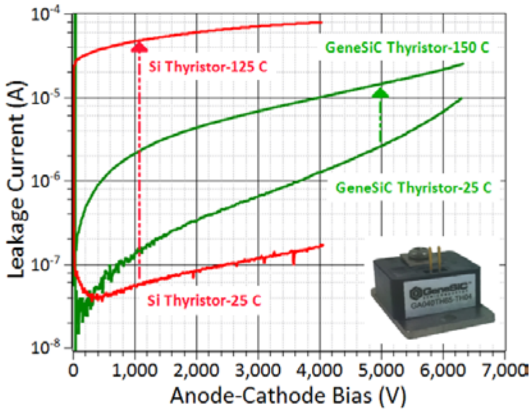

**Fig. 2. Comparison of blocking voltages of GeneSiC's SiC thyristor with a 4-kV Si thyristor.**

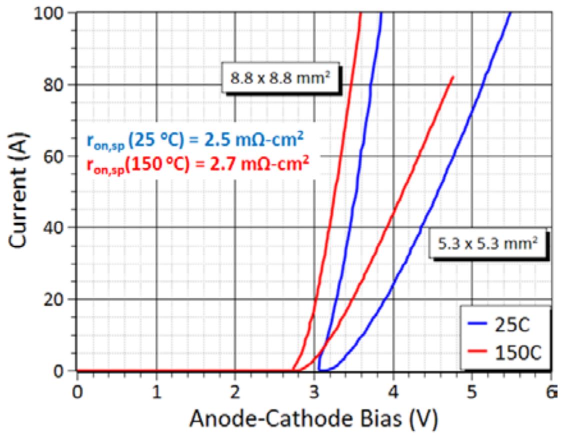

**Fig. 3. On-state I-V characteristics of large-area 77-mm$^2$ and 28-mm$^2$ 6.5-kV SiC thyristors.**

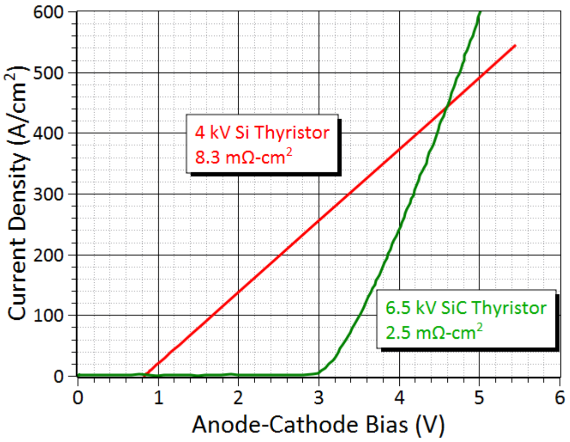

**Fig. 4. Comparison of 25 °C on-state characteristics of GeneSiC's SiC thyristor with a 4-kV Si thyristor.**

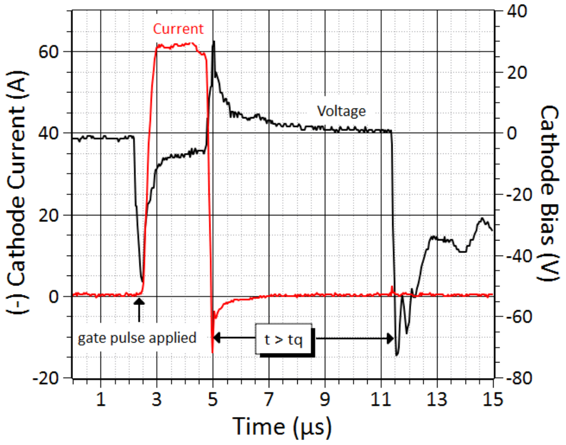

**Fig. 5. Reverse recovery characteristics of 77-mm$^2$ Thyristor commutating 62 A at 405 A/μs by applying +30 V cathode bias. Minimum turn-off time = 6.3 μs.**

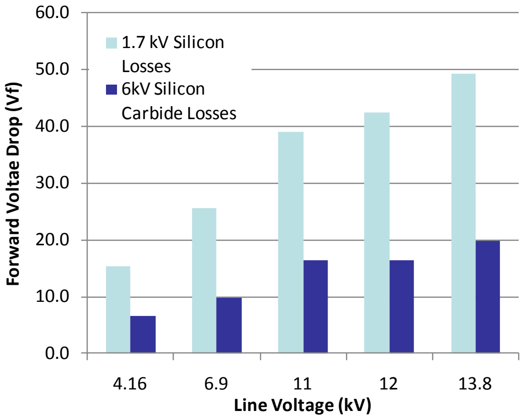

**Fig. 6. On-state voltage drop comparison between silicon and SiC bipolar devices for various utility voltages.**

## BIOGRAPHICAL NOTE

**Conference presenter:** Dr. Ranbir Singh founded GeneSiC Semiconductor Inc. in 2004. He has developed critical understanding and published on a wide range of silicon carbide (SiC) power devices including PiN, JBS and Schottky diodes, metal-oxide-semiconductor field-effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs), thyristors, and field controlled thyristors. He has co-authored over 110 publications in various refereed journals and conference proceedings and is an inventor on 26 issued U.S. patents. He conducted research on SiC power devices first at Cree Inc., and then at the National Institute of Standards and Technology (NIST), Gaithersburg, MD. He received the B. Tech (Electrical Engineering) degree from the Indian Institute of Technology (IIT), Delhi, India. He received his M.S. and Ph.D. degrees from North Carolina State University (NCSU) under the tutelage of power device pioneer Prof. B. Jayant Baliga.