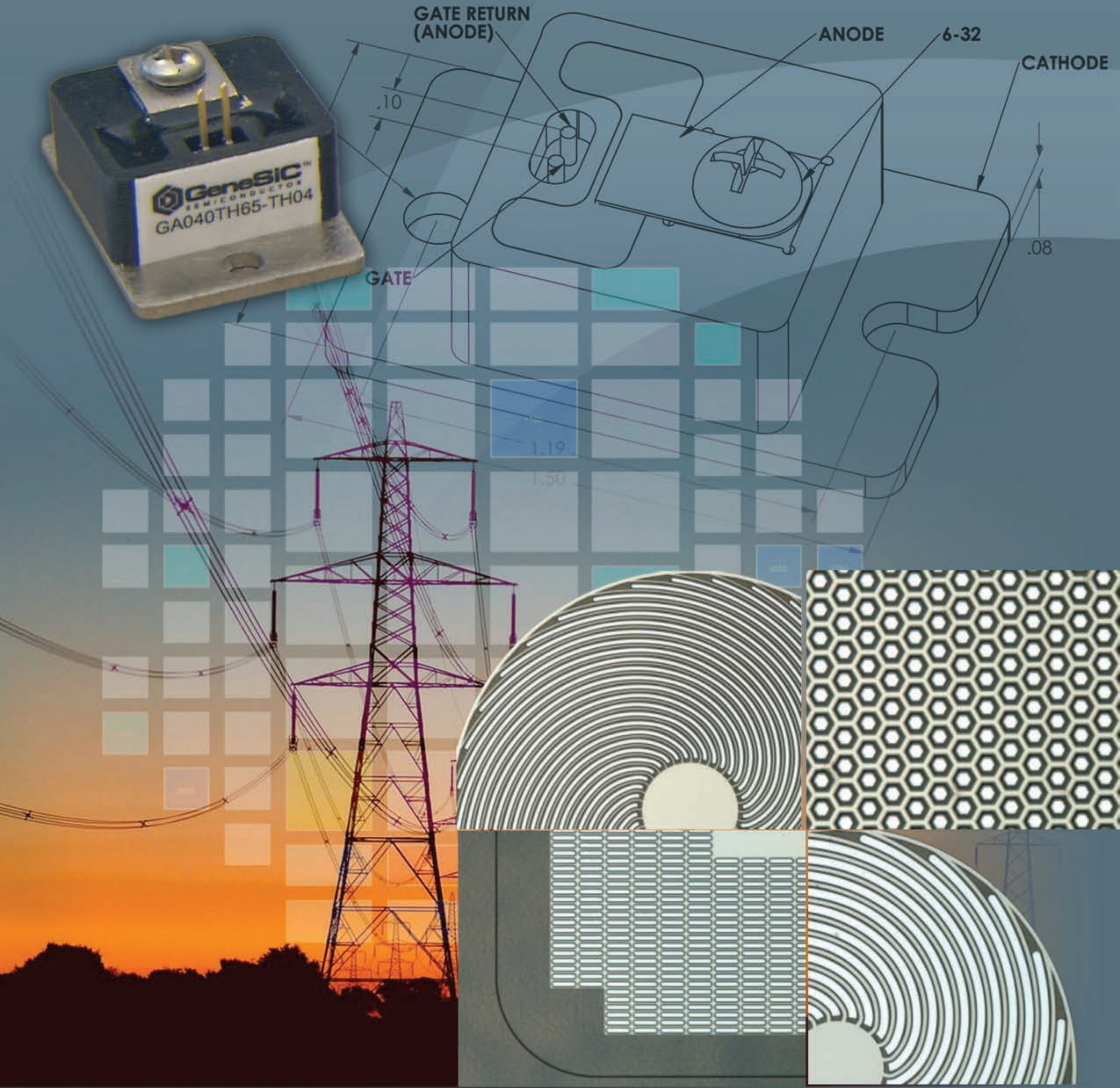
Ultra-high-voltage Silicon-Carbide (SiC) Thyristor

R&D 100 2011



Sandia National Laboratories

ULTRA-HIGH-VOLTAGE SILICON CARBIDE THYRISTOR

1. DEVELOPER INFORMATION

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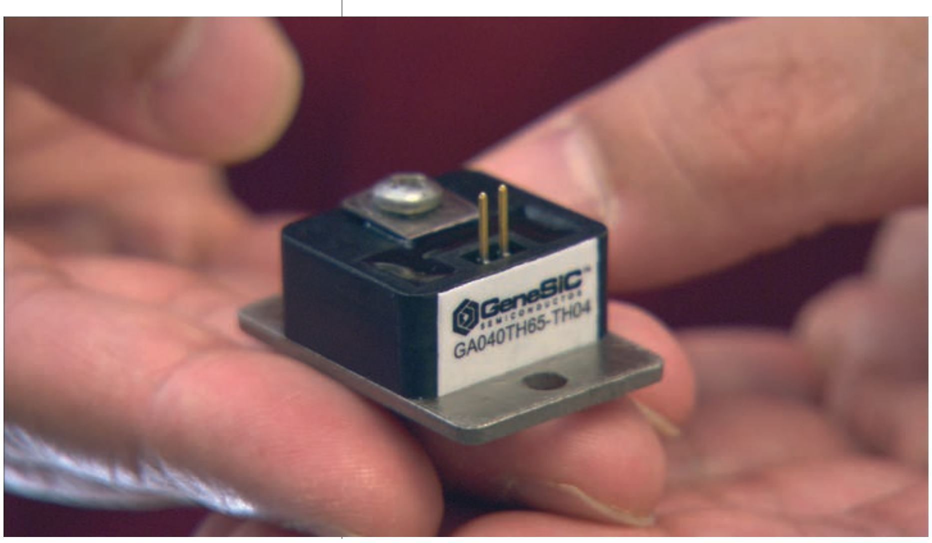

2. PRODUCT INFORMATION

Ultra-high-voltage Silicon Carbide Thyristor

In a first of its kind offering, GeneSiC Semiconductor announces the availability of a family of 6.5kV SCR-mode Silicon Carbide Thyristors for use in power electronics for Smart Grid applications.

3. DESCRIPTION

These SiC Thyristors are the world's first commercially available, high-voltage, high-frequency, high-current, high-temperature, single-chip devices with ratings exceeding 6.5 kV, 200 kHz (pulsed), 80 A, and 200º C.

4. PRODUCT FIRST MARKETED OR AVAILABLE FOR ORDER

The product was available for sampling on November 1, 2010. An order to produce these devices was made in advance. The sample announcement was made on November 1, 2010 through the following Press Release:

GeneSiC™ SEMICONDUCTOR

Multi-kHz, Ultra-High Voltage Silicon Carbide Thyristors sampled to US Researchers

DULLES, VA, Nov. 1, 2010 --In a first of its kind offering, GeneSiC Semiconductor announces the availability of a family of 6.5kV SCR-mode Silicon Carbide Thyristors for use in power electronics for Smart Grid applications. Revolutionary performance advantages of these power devices are expected to spur key innovations in utility-scale power electronics hardware to increase the accessibility and exploitation of Distributed Energy Resources (DER). "Until now, multi-kV Silicon Carbide (SiC) power devices were not openly available to US researchers to fully exploit the well-known advantages– namely 2-10kHz operating frequencies at 5-15kV ratings – of SiC-based power devices." commented Dr. Ranbir Singh, President of GeneSiC. "GeneSiC has recently completed delivery of many 6.5kV/40A, 6.5kV/60A and 6.5kV/80A Thyristors to multiple customers conducting research in renewable energy, Army and Naval power system applications. SiC devices with these ratings are now being offered more widely."

Silicon Carbide-based Thyristors offer 10X higher voltage, 100X faster switching frequencies and higher temperature operation as compared to conventional Silicon-based Thyristors. Targeted applications research opportunities for these devices include general purpose medium voltage power conversion (MVDC), Grid-tied solar inverters, wind power inverters, pulsed power, weapon systems, ignition control, and trigger control. It is now well established that ultra-high voltage (>10kV) Silicon Carbide (SiC) device technology will play a revolutionary role in the next-generation utility grid. Thyristor-based SiC devices offer the highest on-state performance for >5 kV devices, and are widely applicable towards medium voltage power conversion circuits like Fault-Current Limiters, AC-DC converters, Static VAR compensators and Series Compensators. SiC-based Thyristors also offer the best chance of early adoption due to their similarities to conventional power grid elements. Deploying these advanced power semiconductor technologies could provide as much as a 25-30 percent reduction in electricity consumption through increased efficiencies in delivery of electrical power.

Dr. Singh continues "It is anticipated that large-scale markets in solid-state electrical substations and wind turbine generators will open up after researchers in the power conversion arena will fully realize the benefits of SiC Thyristors. These first generation SiC Thyristors utilize the lowest demonstrated on-state voltage drop and differential on-resistances ever achieved in SiC Thyristors. We intend to release future generations of SiC Thyristors optimized for Gate-controlled Turn Off capability and >10kV ratings. As we continue to develop high temperature ultra-high voltage packaging solutions, the present 6.5kV Thyristors are packaged in modules with fully soldered contacts, limited to 150ºC junction temperatures." GeneSiC is a fast emerging innovator in the area of SiC power devices and has a strong commitment to the development of Silicon Carbide (SiC)-based devices for: (a) HV-HF SiC devices for Power Grid, Pulsed power and Directed Energy Weapons; and (b) High temperature SiC power devices for aircraft actuators and oil exploration.

Located near Washington, DC in Dulles, Virginia, GeneSiC Semiconductor Inc. is a leading innovator in high-temperature, high-power and ultra high-voltage silicon carbide (SiC) devices. Current development projects include high-temperature rectifiers, SuperJunction Transistors (SJT) and a wide variety of Thyristor based devices. GeneSiC has or has had prime/sub-contracts from major US Government agencies, including the Department of Energy, Navy, Army, DARPA, and the Department of Homeland Security. The company is currently experiencing substantial growth, and hiring qualified personnel in power-device and detector design, fabrication, and testing. To find out more, please visit www.genesicsemi.com.

5. Has this product or an earlier version been entered in the R&D 100 awards competition previously?

This product or any earlier version has not been entered into an R&D 100 award competition.

6. Principal Investigator(s)

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7. PRODUCT PRICE

SiC Thyristors with three ratings were released with the following pricing:

6.5kV/40 A	$1200 (for quantities of >200)
6.5kV/60 A	$1800 (for quantities of >200)
6.5kV/80 A	$2200 (for quantities of >200)

8. PATENTS OR PATENTS PENDING

The design and fabrication techniques used to realize these devices are held using strong trade secrets, but no patents are held. GeneSiC adopts this IP strategy in order to keep the important aspects of the realization within the company.

9. PRODUCT'S PRIMARY FUNCTION

The goal of an electric power grid is to supply reliable power from the generators to industrial and residential customers via a transmission and distribution (T&D) network. Advanced power electronics systems will play a key role in increasing the reliability, security, and flexibility of future power grids by mitigating potential problems (e.g., uneven power flow through the system or "loop flows"), improving transient and dynamic stability, improving frequency regulation, and reducing subsychronous oscillations and dynamic overvoltages and undervoltages across T&D networks.

Power electronics devices currently used in the electric utility system include fault-current limiters, high-voltage direct current (HVDC) converters for DC transmission, flexible AC transmission systems (FACTS) for reactive power (volt-ampere reactive or VAR) control, active filters, solid-state circuit breakers and solid-state transfer switches. Power conversion systems (PCS) are used in energy storage and distributed generation systems to produce high-quality AC output at desired voltages.

Future electric utility systems are envisioned to be highly automated, interactive "smart" grids that can self-adjust to meet the demand for electricity reliably, securely, and economically. *Such systems will be highly dependent on power electronics devices and systems, and improvements in both power electronics systems and the devices on which the systems are based will be key components in the development of "smart" grids.*

All power electronics systems in use today rely on silicon-based semiconductor switches to perform their functions. Indeed, for over five decades, silicon-based semiconductors have been the power device of choice for most, if not all, high-power applications. In particular, silicon-based insulated-gate bipolar transistors (IGBTs) and gate turn-off Thyristors (GTOs) have been the dominant semiconductor switches for high-power applications, and technology improvements over the last several decades have resulted in consistently higher power levels for these devices. Nevertheless, silicon-based semiconductors have inherent limitations that reduce their suitability for use in utility-scale applications. These limitations include a low-voltage blocking capability, low switching speeds, and a limited junction operating temperature.

Although switch-mode power supplies (e.g., pulse-width-modulation-based converters), which feature greater control capability and provide better conversion efficiency, have been developed in the last two decades and have changed they way power is converted in many high-power applications, utility-scale applications would directly benefit from the development of semiconductor switches with higher voltage blocking capability and a higher junction temperature.

Recently, new, wide-band-gap materials such as silicon carbide (SiC) have become attractive alternatives to silicon for semiconductor switches. These materials offer the potential for higher switching speeds, a higher breakdown voltage, lower switching losses, and a higher junction temperature than traditional silicon-based switches. SiC-based diodes are coming on the market now and switching devices with increased capabilities are currently being developed. Higher voltages and higher operating temperatures pose numerous development challenges which must be resolved before commercial systems can be built. These devices offer all of the advantages of SiC-based devices as well as improved voltage standoff capability, increased operational flexibility, and higher current carrying capability than traditional silicon-based devices.

Figure 1. Single-chip SiC-based Thyristors

They can reduce next-generation Smart Grid power electronics system size and weight by up to an order of magnitude over the existing state-of-the-art Si-technologies.

Our team developed the world's first commercially available high-voltage, high-frequency, high-current, high-temperature, single-chip SiC-based Thyristors; their ratings are up to 6.5 kV, 200 kHz (pulsed), 80 A, and 200º C. They can reduce next-generation Smart Grid power electronics system size and weight by up to an order of magnitude over the existing state-of-the-art silicon technologies. Samples of these revolutionary devices have generated worldwide interest and have allowed GeneSiC to book orders worth more than $400K within six months.

10. HOW DOES IT OPERATE?

SiC Thyristors control large amounts of electrical power (voltage, current) through high-frequency switching of high voltages and currents at high temperatures. SiC is a novel, wide-bandgap material that offers the realization of semiconductor devices that can offer an order-of-magnitude higher rating as compared to silicon. However, the design and fabrication techniques required to fully exploit this important material system are extremely challenging. Until now, all commercial devices were limited to less than 1700 V.

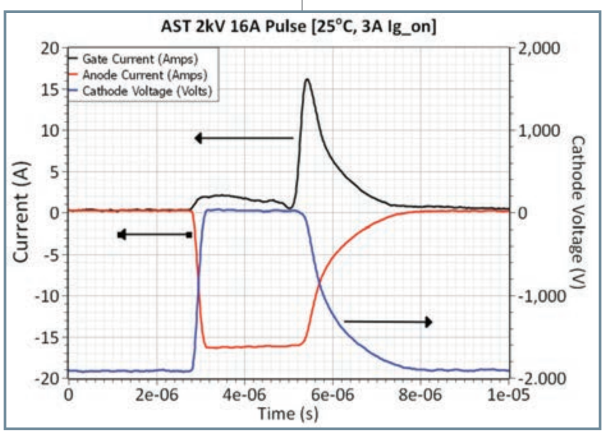


Figure 2. A Silicon Carbide Thyristor being switched under a unity-gain turn-off condition. In this plot, the SiC Thyristor undergoes a switching between 2000 V and 16 Amperes of current.

SiC Thyristors are used to switch very high voltages and very high currents. Figure 2 shows the anode-cathode voltage, anode-current and gate-current pulse waveforms of a SiC Thyristor turning off 16 A of anode current in a unity-gain turn-off condition. Here, the entire anode current is extracted from the gate terminal to turn off the Thyristor. Initially, the Thyristor is blocking a V_{AK} of 2000 V, following which it is triggered to its on-state by applying a gate-current pulse of 2.4 A. For turning off the device, the anode current is switched off using an external Metal Oxide Semiconductor Field Effect Transistor (MOSFET) and the entire anode current is commutated to the gate electrode and the Thyristor turns off like an open-base npn transistor. It can be seen that a unity gain turn-off condition is established here ($I_G = I_{AK}$). The total turn-off time was measured to be 1.5 µs.

The entire turn-on and turn-off transient takes less than 4 µsec, indicating that the device is capable of a pulsed switching frequency of >250 kHz. One advantage of the developed Silicon Carbide Thyristors is their ability to turn off in less than 4 micro-seconds even at 200º C, allowing a theoretical switching speed exceeding 200 kHz. Measurements shown in Figure 3 demonstrate the variation of switching times with temperatures up to 200° C. It can be seen from this figure that the minority carrier lifetime in the p- base increases from 1.52 µs at 25° C to 3.8 µs at 200° C.

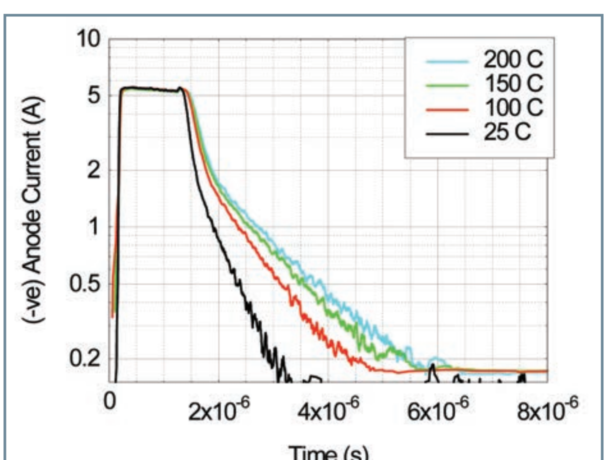


Figure 3. Hard turn-off measurements performed on a packaged 6.5 kV SiC Thyristor.

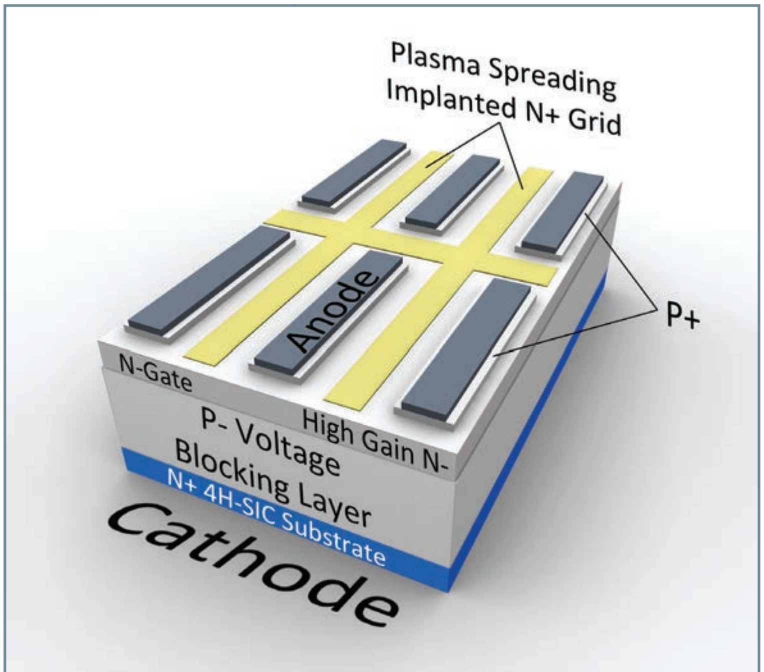


Figure 4. These npnp Thyristors have their three electrical terminals–anode and gate regions on top, and cathode contact at the bottom. Various SiC layers and their doping types from the top are P+ anode layer, N-type gate layer, P- blocking layer, and the N+ cathode layer. The rated voltage is supported between with n-gate/p-blocking layers, so that the p-blocking layer doping and thickness primarily determines the breakdown voltage of the device.

These SiC Thyristors are three-terminal, bipolar-mode devices (as compared to uncontrolled two-terminal, unipolar devices such as diodes) that use a different physics of operation relying on minority carrier transportation. Minority carrier transportation allows much lower on-state voltage for >3 kV power devices as compared to unipolar power devices. In contrast, three-terminal devices like SiC Thyristors are critical towards actively controlling electrical power. Although bipolar devices in Silicon Thyristors have been known previously, bipolar devices operate in somewhat unexpected performance levels (e.g., 1000X lower minority carrier charge; lower temperature-dependence). These new modes of operation were verified and optimized in the present efforts. These commercial devices offer near-theoretical, on-state blocking voltage and switching performance as compared to anything that has ever been demonstrated before, even in a laboratory.

Figure 5. Various anode-gate inter-digitations patterns of the Thyristor structure were explored during the development of these Thyristors. An involute pattern shown here was found to provide the best switching performance. In this chip structure, a central gate terminal provides trigger currents to turn on this Thyristor by flowing the impressed gate current through equidistant anode-gate fingers.

When no current flows through the gate-anode junction, the device blocks a high voltage in both the forward and the reverse bias. To turn the device on, a trigger current flows through the anode-gate junction, thereby activating the inherent anode-gate-P-based transistor. This gate current is amplified to supply the gate current to the other inherent N-gate/P-blocking and N-cathode transistor. This leads to a turn on of both inherent transistors by a regenerative action. A Thyristor conducts a large current between the anode and cathode terminals with little forward voltage drop in this condition. To turn the device off, the gate-anode junction is reverse biased for a short period of time by the application of an external current pulse. When a sufficient loss of minority base current occurs through the gate terminal of the pnp transistor, it turns off and stops supplying

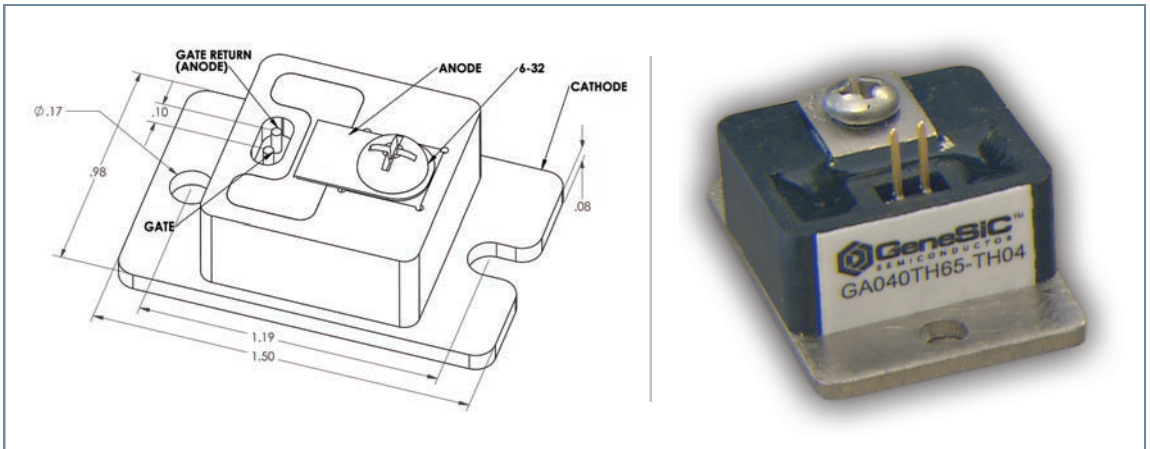


Figure 6. Packaged SiC Thyristors produced. The CAD design of the package housing the SiC Thyristor is shown on the left, and the final packaged SiC Thyristor is shown on the right.

gate current to the npn transistor as well. Hence, the npn transistor also turns off. The device is capable of supporting a large anode-cathode voltage under this condition.

A high-performance Thyristor developed here offers withdrawal of the gate charge more effectively through stringent design of the gate-anode layout design. The gate contact must surround the anode region everywhere and must be closely spaced. The developed Thyristor provides highly inter-digitated gate-anode patterns, like the involute pattern. Additionally, it has an implanted n+ type region below the gate contact of the device. This makes the extraction of gate charge from the pnp transistor more effective during the turn-off of the device, thereby requiring a smaller gate current requirement for both turn-on and turn-off.

11. BUILDING BLOCKS OF OUR TECHNOLOGY

The GeneSiC-developed Thyristors required developing, implementing, and integrating many new technologies:

1. Design and fabrication techniques that support >6 kV ratings;
2. Novel gate-anode designs for large-area (high-current) devices;
3. Novel SiC fabrication processes (e.g., highly uniform, sloped sidewall dry etching; multi-level metallizations; low resistance contacts; and passivation techniques);
4. Advanced measurement techniques, circuits, and components for accurately characterizing devices with ultra-high operating ratings; and
5. Advanced fully soldered contact, wire-bondless packaging technology.

This newly designed package offers an effective electrical connection of gate, anode, and cathode terminals from the chip to the external user. It also provides easy mounting of the Thyristor on to an external heat-sink to extract the heat generated during the operation of the device.

12. PRODUCT COMPARISON

Highest-voltage, commercially available Silicon Carbide devices include:

- 1700 V/25 A SiC Schottky Rectifier by Cree, Inc. Part No. CPW3-1700S025 (Released May 17, 2010)
- 1200 V/33 A SiC Power MOSFET by Cree, Inc. Part No. CMF20120D (Released January 17, 2011)
- 1200 V/20 A SiC Schottky Rectifier by Infineon AG. Part No. IDH05S120 (Released 2007)
- 6500 V/350 A Silicon Thyristor by ABB. Part No. 5STP 03X6500

TABLE 1. COMPARISON MATRIX

	GeneSiC Semiconductor	Cree, Inc.	Cree, Inc.	Infineon	ABB
Type of commercial Semiconductor Device	Silicon Carbide Thyristor	Silicon Carbide Schottky Rectifier	Silicon Carbide MOSFET	Silicon Carbide Schottky Rectifier	Silicon Thyristor
Max. Junction Temperature	200° C	175° C	125° C	175° C	125° C
Max. Blocking Voltage	6500 V	1700 V	1200 V	1200 V	6500 V
Max. Current Rating	80 A	25 A	33 A	20 A	>100 A
Switching Speed (pulsed)	200 kHz	>300 kHz	>200 kHz	>300kHz	1 kHz

As compared to Silicon Thyristors, SiC Thyristors offer much higher switching speeds (100–1000X) and higher temperature operation (up to 300° C, versus 125° C).

IMPROVEMENTS OVER COMPETITIVE PRODUCTS

This product not only improves on the competition, but it is a *revolutionary step towards power electronic system integration*. GeneSiC's Thyristors offer unique and pioneering performance advantages. As compared to other commercial SiC devices—which comprise of only two terminal rectifiers—these devices offer much higher (3–4X) blocking voltages and current/voltage control capability. As compared to Silicon Thyristors, SiC Thyristors offer much higher switching speeds (100–1000X) and higher temperature operation (up to 300° C, versus 125° C). These advantages result in exceptionally high usability and efficiencies in next-generation power circuits.

In the near future, power semiconductor switches for power conversion tied to the power grid are likely to be SiC-based Thyristors due to their high-voltage capability, high-temperature capability, and fast switching speeds. Presently, three thrusts being explored by power conversion elements are:

1. management of heat generated during the operation of semiconductors during system operation to increase reliability;
2. decreasing the number of high-voltage devices stacked to be usable in standard >4.16 kV utility line voltages to reduce system complexity; and

3. increasing switching speeds beyond 1 kHz to allow widespread use of pulse width modulators (PWM) circuits to enhance power quality.

LIMITATIONS OF OUR PRODUCT

The main limitation of this product is its cost. As compared to its competitors, its cost is as much as 10X higher. However, as volumes rise, economies of scale will reduce the cost of production, resulting in lower prices, as in most semiconductor and manufacturing technologies.

13. PRODUCT USE

PRINCIPAL APPLICATIONS AND BENEFITS

Global demand for high-efficiency, green energy technologies and products has placed new challenges on the electrical grid, on efficient exploitation of renewable energy resources, and on electric-based solutions for military applications. All of these applications require ultra-high-voltage power devices (to reduce energy loss) with high-frequency ratings (to reduce system size, weight, and volume). Annually, over $2 trillion of electricity is processed through the U.S. electric grid. Thus, even relatively small improvements in system efficiency represent tremendous economic and environmental benefits.

SiC-based Thyristors offer 10X higher voltage, 100X faster switching frequencies, and higher-temperature operation compared with conventional Silicon-based Thyristors. Targeted research applications include general-purpose medium-voltage power conversion (MVDC), grid-tied solar inverters, wind-power inverters, and ignition and trigger control for pulsed-power weapon systems.

Ultra-high-voltage SiC-device technology will play a revolutionary role in the next-generation utility grid. SiC-based Thyristors also offer the best chance of early adoption due to their similarities to conventional power grid elements. Deploying these power semiconductor technologies could provide as much as a 25–30% reduction in electricity consumption through increased efficiencies in the delivery of electrical power.

The utilization of a single-package ultra-fast, high-temperature 6.5 kV SiC GTO Thyristor module will revolutionize electricity delivery, renewable energy integration, and energy storage technology. By increasing power electronics efficiency, advanced interconnection technologies widen the practical end-use of fuel cells, photovoltaics, wind power, batteries, superconducting magnetic storage, adjustable speed drives, and efficient power supplies. It is well recognized that silicon-based semiconductors have inherent limitations that reduce their suitability for use in utility-scale applications. Power electronics applications including static transfer switches, dynamic voltage restorers, static VAR compensators (SVCs), high-voltage direct current (HVDC) transmission, and flexible alternate current transmission systems (FACTS) will become economically feasible. Some of these applications require voltage-blocking capabilities in the tens and hundreds of kV, and thousands of amperes, which are logical extensions from this project.

The utilization of a single-package ultra-fast, high-temperature 6.5 kV SiC GTO Thyristor module will revolutionize electricity delivery, renewable energy integration, and energy storage technology.

By increasing power electronics efficiency, advanced interconnection technologies widen the practical end-use of fuel cells, photovoltaics, wind power, batteries, superconducting magnetic storage, adjustable speed drives, and efficient power supplies.

OTHER APPLICATIONS

Power semiconductor switches are the core components of all power electronics systems. They can convert energy from renewable sources (i.e., photovoltaic, wind), direct power flow in electric utility systems (e.g., FACTS controllers, HVDC), and enable pulse-power circuits for military applications.

Utility-grade power electronics elements can play a pivotal role in integration of renewable energy elements such as grid-tied solar and wind power systems by increasing their reliability, efficiency, and usability. Although it is very difficult to quantify reliability benefits, studies show the estimated present value of aggregated attributes of a reliable, modernized grid to be $638–$802 billion over a 20-year horizon, with annualized values of between $51 and $64 billion/year.

The utilization of a single-package ultra-fast, high-temperature SiC Thyristor module will revolutionize electricity delivery, renewable energy integration and energy storage technology not only through the proposed fault-current limiter demonstration, but further through higher efficiencies in power electronics circuits. By increasing power electronics efficiency, advanced interconnection technologies widen the practical end-use of fuel cells, photovoltaics, wind power, batteries, superconducting magnetic storage, adjustable speed drives, and efficient power supplies. It is well recognized that silicon-based semiconductors have inherent limitations that reduce their suitability for use in utility-scale applications.

Figure 7 shows the future vision by Electric Power Research Institute (EPRI) for applications of Thyristors in Smart Grids. According to this vision, the growth in the generation of electrical energy, increased penetration of distributed resources and increased interconnection of the networks leads to higher incidence of fault currents. The growth in capacity requires replacing existing circuit breakers with higher fault-current ratings resulting in significant impact on cost and down time. Further, higher fault causes more stress on the system reducing the life of critical components such as transformers. It is estimated that financial losses from power quality problems could amount to nearly $23 Billion over the next 10 years, while benefits of time-of-use energy cost management through energy storage could exceed $32 Billion.

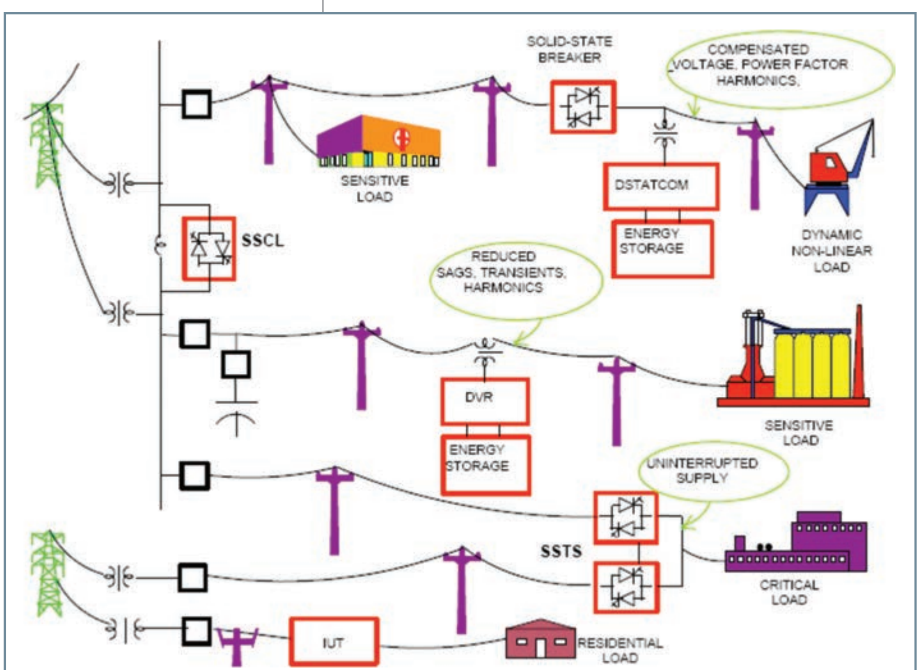


Figure 7. Solid-state current limiters and solid-state breakers play a critical role in EPRI's vision of Smart Grid power electronics based technologies.

Other compelling applications include pulsed-power circuits used in fuzing of ammunition, and power modulators used in high-energy physics experiments. Pulsed-power is a term used to describe the accumulation of energy over

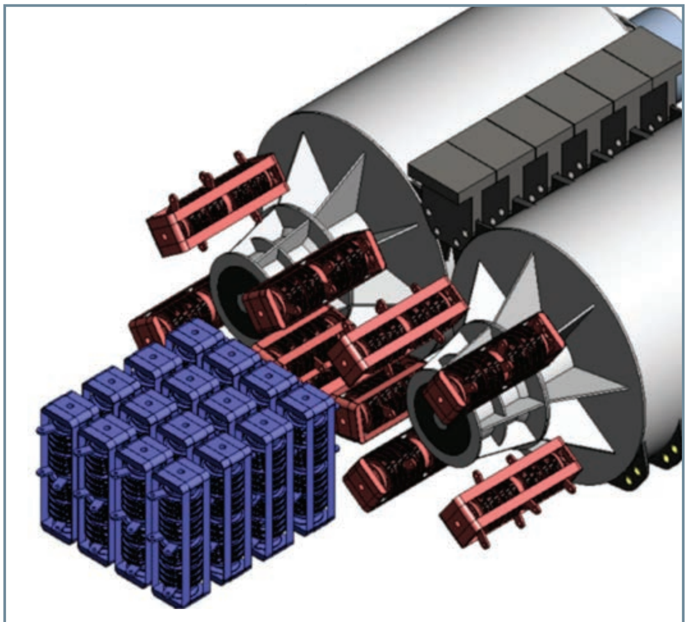


Figure 8. Power semiconductors like pulsed-power Thyristors play a critical role in railgun applications, as shown in this Army electric gun program. The blue devices are stacks of Thyristors required to meet the voltage and current requirements for such a gun. SiC Thyristors have the potential to reduce the size/weight/volume of these device stacks by 10–100X.

time and releasing of that energy in a very short timeframe. Examples of pulsed-power technologies include high-power lasers, electromagnetic pulse for railgun applications, and radar. Pulsed alternators and capacitor banks are the two primary energy storage mechanisms used to power very high-current loads with pulse lengths on the order of several milliseconds. Both of these sources require switches capable of conducting megamperes of current and operating at voltages on the order of several kilovolts. Most commonly used switches are high-pressure spark gaps, vacuum switches of varying architectures, and now solid-state Thyristors. Spark gaps and vacuum switches are lifetime dependent on accumulated total coulomb transfer as a dominant rating factor. For the solid-state Thyristors, the action (current squared times pulse width) is the most significant parameter. Thyristors hold potential for applications in rugged duty, long-life, high-energy pulsers, and Thyristor switch modules can be constructed using solid-state silicon switches in large series/parallel arrangements; however, these modules make up a considerable portion of the mass and volume of the pulsed-power system. In an effort to reduce the size of the pulsed-power systems, it has been proposed that the superior electrical and mechanical properties of SiC will result in mass and volume savings in the range of up to 60 percent for systems with the high-current Si devices replaced with SiC devices. The capabilities offered by SiC Thyristors will benefit these types of systems by making them highly efficient, sustainable, lethal, and controllable.

One prominent application that has attracted significant interest from the U.S. military is the use of pulse-power circuits in railguns. A railgun is an electric gun that accelerates a projectile along a pair of metal rails, called a linear machine. The rails produce strong magnetic fields that interact with and accelerate the projectile. Figure 8 shows a schematic of an electric railgun for military applications. High-voltage capacitors are charged to store the energy, and then released through high-power switches to linear machines that accelerate projectiles through electromagnetic induction. Depending on the weight and range specifications of the projectiles, the switches must be able to switch thousands of volts of potential and thousands of amperes of currents over micro-second timeframes. This requires ultra-high speed Thyristors with ultra-high voltage, high pulsed-power currents like those made using Silicon Carbide. Figure 8 also illustrates stacks of silicon Thyristors (in blue) required to discharge ultra-high-voltage capacitor banks (in coral) through barrel-shaped linear machines.

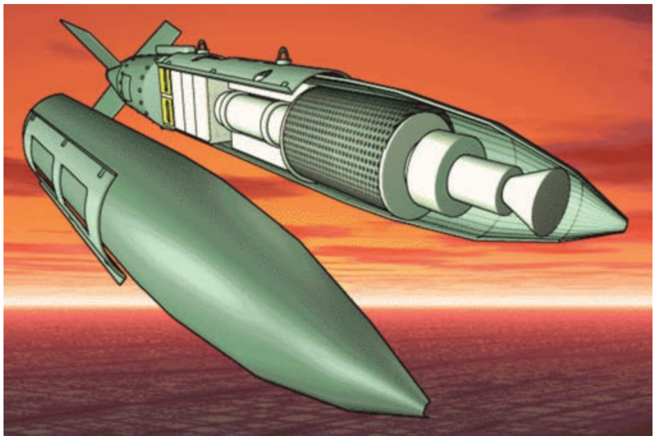


Figure 9. High-power microwave weapons require compact pulsed-power Thyristor devices.

Directed-energy weapons is another application that can benefit from SiC Thyristors. Directed-energy weapons use electromagnetic radiation to deliver electrical, mechanical, and heat energy to a military or critical electronic equipment target. The U.S. Army is interested in high-power microwaves to introduce a high level of electromagnetic noise in the battlespace to incapacitate an enemy's electronic command, control, and communications infrastructure. This is done using high-power microwave (HPM) rounds as shown in Figure 9. In this example, high-power microwave energy is produced using a traveling wave tube device that requires >100kV to energize. Such high voltages are produced using complex pulse-forming networks (PFNs) necessitating ultra-fast power semiconductor devices. SiC Thyristors are expected to play an enabling role in the realization of compact HPM rounds, as shown in Figure 9.

14. SUMMARY

Technology Description

What is it? These packaged power devices are the world's first commercially available, high-voltage, high-frequency, high-current, high-temperature, single-chip SiC-based Thyristors; their ratings are up to 6.5 kV, 200 kHz (pulsed), 80 A, and 200^{o}C. They can reduce next-generation Smart Grid power electronics system size and weight by up to an order-of-magnitude over the existing state-of-the-art silicon technologies.

What does it do? Power devices are the core component of all power electronics systems. These ultra-high-voltage SiC devices could be used in a variety of medium-voltage power conversion circuits (e.g., fault-current limiters, AC-DC converters, static VAR compensators, and series compensators). The revolutionary performance advantages of SiC Thyristors are expected to spur key innovations in utility-scale power electronics hardware and to increase the accessibility and use of distributed energy resources.

What technical, economic, or social problem does it address? Global demand for high-efficiency, green energy technologies and products has placed new challenges on the electrical grid, efficient exploitation of renewable energy resources, and on electric-based solutions for military applications. All of these applications require ultra-high-voltage power devices (to reduce energy loss) with high-frequency ratings (to reduce system size, weight, and volume). Annually, over $2 trillion of electricity is processed through the U.S. electric grid. Thus, even relatively small improvements in system efficiency represent tremendous economic and environmental benefits.

Technology Significance

What is the technological advance? These leading-edge devices required developing, implementing, and integrating many new technologies: (1) design and fabrication techniques that support >6.5 kV ratings; (2) novel gate-anode designs for large-area (high-current) devices; (3) novel SiC fabrication processes (e.g., highly uniform, sloped sidewall dry etching; multi-level metallizations; low-resistance contacts; and passivation techniques); (4) advanced measurement techniques, circuits, and components for accurately characterizing devices with ultra-high operating ratings, and (5) advanced fully soldered contact, wire-bondless packaging technology.

What is the social/economic significance? GeneSiC is a pioneer in ultra-high-voltage (>5 kV) SiC power device development and intends to become a market leader in high-voltage (>1200 V) SiC device manufacturing. GeneSiC's ultra-high-voltage devices will allow higher efficiency FACTS and HVDC components to be produced for the next-generation Smart Grid. Widespread use could result in $100s of millions in energy savings.

Competitiveness

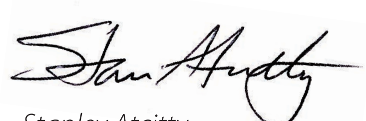
How does this technology compare with the competition? What factors are crucial to the technology? These Thyristors have operating voltages almost 4× higher than other currently available SiC devices. They also offer >100× higher operating frequencies than comparably rated state-of-the-art silicon Thyristors. Ultra-high operating voltages are critical for realizing grid-scale power electronics. High-frequency, high-temperature operation will increase power system efficiency and reliability while dramatically reducing size, weight, and volume.

Wow! Factor

Ultra-high-voltage SiC-based power electronics systems will revolutionize the Smart Grid. It is anticipated that large-scale markets in solid-state electrical substations and wind turbine generators will open when researchers in the power conversion arena fully realize the benefits of SiC Thyristors. This leading-edge device will be the world's first commercially available >2-kV SiC-based power device, and it is ready for manufacturing now.

15. AFFIRMATION

I affirm that all the information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this product.



Stanley Atcitty

APPENDICES

APPENDICES

APPENDIX A: SUBMITTER INFORMATION

1. Contact person to handle all arrangements on exhibits, banquet, and publicity.

Name: Glenn Kubiak

Position: Director

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2. Contact person for media and editorial inquiries.

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APPENDIX B: LETTERS OF SUPPORT/TESTIMONIALS

Department of Energy
Washington, DC 20585

February 9, 2011

RE: R&D Magazine's R&D 100 Awards

To Whom It May Concern:

This letter is in support of the Ultra-high-voltage Silicon-Carbide (SiC) Thyristor developed by GeneSiC Semiconductor and Sandia National Laboratories.

Genesic developed this technology, through two phases of a DOE Small Business Innovative Research grant, from the initial concept all the way to commercialization. Many innovative design and manufacturing techniques were incorporated. The device represents a very important advance in power electronics as the world's first commercially available, high-voltage, high-current, high-temperature, single-chip SiC-based thyristor semiconductor switch. SiC thyristors will reduce SmartGrid power electronics size and weight by an order of magnitude and find wide application on the electric grid for converters, VAR compensators, fault-current limiters and other power control functions.

SiC based thyristors can be expected to find a large market in applications such as renewable energy generators, energy storage devices, and other forms of distributed generation. We anticipate that this device will generate a wave of innovation in power electronics to keep pace with and enable the rapid modernization of the grid

We believe that the Genesic Thristor is an excellent candidate for an R&D100 Award.

Sincerely,

Dr. Imre Gyuk
Program Manager
Energy Storage Research

Printed with soy ink on recycled paper

APPENDIX C: PRESS RELEASES AND ARTICLES

GeneSiC samples multi-kHz, ultra-high-voltage SiC Thyristors to US researchers

Medical Design Technology | Tuesday, November 9, 2010

Performance advantages of the power devices are expected to spur key innovations in utility-scale power electronics hardware to increase the accessibility and exploitation of distributed energy resources (DER). *"Until now, multi-kV silicon carbide power devices were not openly available to US researchers to fully exploit the well-known advantages — namely 2–10kHz operating frequencies at 5–15kV ratings — of SiC-based power devices,"* says president **Dr Ranbir Singh**. *"GeneSiC has recently completed delivery of many 6.5kV/40A, 6.5kV/60A and 6.5kV/80A thyristors to multiple customers conducting research in renewable energy, army and naval power system applications. SiC devices with these ratings are now being offered more widely."*

SiC-based thyristors offer 10X higher voltage, 100X faster switching frequencies and higher-temperature operation compared with conventional silicon-based thyristors. Targeted research applications include general-purpose medium-voltage power conversion (MVDC), grid-tied solar inverters, wind-power inverters, pulsed power, weapon systems, ignition control, and trigger control.

Ultra-high-voltage (>10kV) SiC device technology will play a revolutionary role in the next-generation utility grid, believes GeneSiC. Thyristor-based SiC devices offer the highest on-state performance for >5kV devices, and are widely applicable to medium-voltage power conversion circuits like fault-current limiters, AC–DC converters, static VAR compensators (SVCs) and series compensators. SiC-based thyristors also offer the best chance of early adoption due to their similarities to conventional power grid elements, adds the firm. Deploying these power semiconductor technologies could provide as much as a 25–30% reduction in electricity consumption through increased efficiencies in the delivery of electrical power.

"It is anticipated that large-scale markets in solid-state electrical sub-stations and wind turbine generators will open up after researchers in the power conversion arena will fully realize the benefits of SiC thyristors," says **Singh**. *"These first-generation SiC thyristors utilize the lowest demonstrated on-state voltage drop and differential on-resistances ever achieved in SiC thyristors,"* he claims.

"We intend to release future generations of SiC thyristors optimized for gate-controlled turn-off capability and >10kV ratings," **Singh** says. *"As we continue to develop high-temperature ultra-high-voltage packaging solutions, the present 6.5kV thyristors are packaged in modules with fully soldered contacts, limited to 150ºC junction temperatures,"* he adds.

GeneSiC says it is committed to developing SiC-based devices for: (a) HV–HF SiC devices for power grid, pulsed power and directed-energy weapons; and (b) high-temperature SiC power devices for aircraft actuators and oil exploration.

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Multi-kHz, Ultra-High Voltage Silicon Carbide Thyristors sampled to US Researchers

Energy & Environment
Press release from: GeneSiC Semiconductor

(openPR) - In a first of its kind offering, GeneSiC Semiconductor announces the availability of a family of 6.5kV SCR-mode Silicon Carbide Thyristors for use in power electronics for Smart Grid applications. Revolutionary performance advantages of these power devices are expected to spur key innovations in utility-scale power electronics hardware to increase the accessibility and exploitation of Distributed Energy Resources (DER).

"Until now, multi-kV Silicon Carbide (SiC) power devices were not openly available to US researchers to fully exploit the well-known advantages– namely 2-10kHz operating frequencies at 5-15kV ratings – of SiC-based power devices." commented Dr. Ranbir Singh, President of GeneSiC. "GeneSiC has recently completed delivery of many 6.5kV/40A, 6.5kV/60A and 6.5kV/80A Thyristors to multiple customers conducting research in renewable energy, Army and Naval power system applications. SiC devices with these ratings are now being offered more widely."

Silicon Carbide based Thyristors offer 10X higher voltage, 100X faster switching frequencies and higher temperature operation as compared to conventional Silicon-based Thyristors. Targeted applications research opportunities for these devices include general purpose medium voltage power conversion (MVDC), Grid-tied solar inverters, wind power inverters, pulsed power, weapon systems, ignition control, and trigger control. It is now well established that ultra-high voltage (>10kV) Silicon Carbide (SiC) device technology will play a revolutionary role in the next-generation utility grid. Thyristor-based SiC devices offer the highest on-state performance for >5 kV devices, and are widely applicable towards medium voltage power conversion circuits like Fault-Current Limiters, AC-DC converters, Static VAR compensators and Series Compensators. SiC based Thyristors also offer the best chance of early adoption due to their similarities to conventional power grid elements. Deploying these advanced power semiconductor technologies could provide as much as a 25-30 percent reduction in electricity consumption through increased efficiencies in delivery of electrical power.

Dr. Singh continues "It is anticipated that large-scale markets in solid-state electrical substations and wind turbine generators will open up after researchers in the power conversion arena will fully realize the benefits of SiC Thyristors. These first generation SiC Thyristors utilize the lowest demonstrated on-state voltage drop and differential on-resistances ever achieved in SiC Thyristors. We intend to release future generations of SiC Thyristors optimized for gate-controlled Turn Off capability and >10kV ratings. As we continue to develop high temperature ultra-high voltage packaging solutions, the present 6.5kV Thyristors are packaged in modules with fully soldered contacts, limited to 150ºC junction temperatures."

GeneSiC is a fast emerging innovator in the area of SiC power devices and has a strong commitment to the development of Silicon Carbide (SiC) based devices for: (a) HV-HF SiC devices for Power Grid, Pulsed power and Directed Energy Weapons; and (b) High temperature SiC power devices for aircraft actuators and oil exploration.

Located near Washington, DC in Dulles, Virginia, GeneSiC Semiconductor Inc. is a leading innovator in high-temperature, high-power and ultra high-voltage silicon carbide (SiC) devices. Current development projects include high-temperature rectifiers, SuperJunction Transistors (SJT) and a wide variety of Thyristor based devices. GeneSiC has or has had prime/sub-contracts from major US Government agencies, including the Department of Energy, Navy, Army, DARPA, and the Department of Homeland Security. The company is currently experiencing substantial growth, and hiring qualified personnel in power-device and detector design, fabrication, and testing. To find out more, please visit www.genesicsemi.com.

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