Award-Winning Silicon Carbide Power Electronics

Operating at high temperatures and with reduced energy losses, two power electronics projects awarded prestigious R&D 100 Award

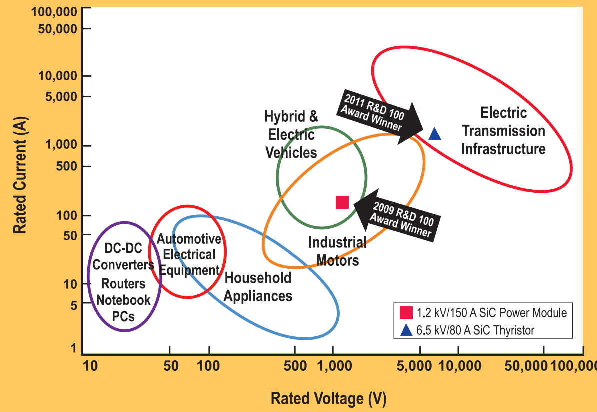
U.S. DEPARTMENT OF ENERGY | Electricity Delivery & Energy Reliability

Energy Storage Program

Sandia National Laboratories

Silicon Carbide Technology Breakthrough

Silicon carbide (SiC) is a semiconductor material under rapid development for use in power electronic (PE) systems due to its unique material and electronic properties. SiC potentially offers several advantages over conventional silicon (Si) for use in PE devices. Comparatively, individual SiC devices (in theory) can endure temperatures up to 600°C (standard Si PE devices are typically limited to 150°C), withstand more voltage, tolerate a larger current density, and operate at a higher frequency. This augmented performance of SiC devices in turn leads to PE devices that are significantly more energy efficient in their operation. Research and development is ongoing to produce SiC PE products with higher currents and voltages, although products are finding applications in a variety of medium- and high-power application areas, as shown in the figure to the right. Also shown in this figure are the two award-winning SiC PE products described in this fact sheet.

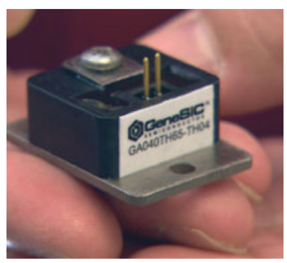


The 1.2 kV/150 A SiC power module is labeled with a red square data point (■). The SiC thyristor, while rated at 6.5 kV/80 A, is shown as a blue triangle point (▲) at a higher voltage and current rating because in practice several thyristors are interconnected to enable their use in higher-power electric transmission infrastructure applications.

First Commercially Available High-Power and High-Temperature Silicon Carbide Thyristor (2011 R&D 100 Award)

Thyristors are a key type of PE device, with a similar electrical conversion function to a power transistor. Thyristors are typically utilized in medium- and high-power conversion applications, while transistors are well known for their use in the computer industry. The development of thyristors will allow for advances in the renewable energy, electric vehicle, and energy storage industries.

This SiC thyristor is the world's first commercially available single-chip SiC-based power device operating at voltages exceeding 2 kV. Its successful commercialization marked the culmination of a multi-year iterative design, fabrication, and characterization process.



A high-frequency 6.5 kV/80 A SiC thyristor

Overview

This technology was funded as a Small Business Innovation Research (SBIR) project as part of the U.S. Department of Energy Office of Electricity Delivery & Energy Reliability Energy Storage Program's effort to develop and commercialize a new generation of PE systems. PE systems are a critical part of all energy storage systems, interfacing the energy storage device and the load (the end user) and often accounting for greater than 25% of the overall storage system cost. This particular SiC thyristor technology can operate at high temperatures (>200°C), high voltage and current levels (6.5 kV, 80 A peak), and high frequencies (>200 kHz pulsed).

Applications

SiC thyristors are critical for a number of applications, including the following:

- Electric infrastructure: Solid-state electrical substations (e.g., fault-current limiters, AC-DC converters, static VAR compensators, and series compensators)
- Renewables: DC-to-AC inverters for converting DC energy produced from solar and wind resources into a more usable AC form
- Military: Naval power distribution systems

Potential Technology Benefits

- Reduces energy losses by more than 50% due to lowest-in-class "on-resistance" and lowest-in-class transistor switching losses
- Reduces overall system size by 10X or more compared to Si due to:
  - SiC's robust high-temperature material stability, which requires significantly less cooling equipment
  - SiC's ability to operate at high frequencies (100X or greater than Si), which reduces the size of auxiliary equipment
- Permits faster turn-on and turn-off performance as compared to traditional Si devices
- Allows high-voltage operation

Project Partners

- Sandia National Laboratories
  www.sandia.gov
- GeneSiC Semiconductor, Inc.
  www.genesicsemi.com/
- U.S. Army Armament Research, Development and Engineering Center
  www.pica.army.mil/PicatinnyPublic/organizations/ardec/index.asp

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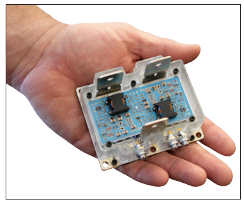
World's First High-Temperature Silicon Carbide Power Module (2009 R&D 100 Award)

PE modules, which consist of PE switching devices such as transistors or thyristors, are the core components of PE systems. These PE systems convert electrical energy from one form to another for running equipment such as electric motors, convert energy from renewable sources to a more usable form, and/or provide power for a wide variety of electronics and electronic systems.

This particular SiC-based power module technology consists of up to 16 power transistors and additional support circuitry. The transistors are the electronic devices that actually perform the electrical energy conversion. The result is a power module that operates at more than twice the maximum-rated temperature of today's state-of-the-art Si technology, with half of the energy losses.



A fully integrated 1.2 kV/ 150 A SiC power module

Overview

This technology was funded as an SBIR project as part of the Office of Electricity Delivery & Energy Reliability's (OE) Energy Storage Program's effort to develop and commercialize a new generation of PE systems. PE systems are a critical part of all energy storage systems, interfacing the energy storage device and the load (the end user) and often accounting for greater than 25% of the overall storage system cost. This particular SiC module can operate at device temperatures up to 250°C and power levels of 50 kW (1.2 kV peak voltage, 150 A peak current).

Applications

In addition to supporting electronics, PE modules are critical for a number of applications, including the following:

- Electric and hybrid vehicles: Electric motor drives for alternative propulsion system drivetrain (initial principal application)
- Renewables: DC-to-AC inverters for converting DC energy produced from solar and wind resources into a more usable AC form
- Aerospace: Lightweight electric and electronic components to replace bulkier traditional hydraulic and electromechanical components

Potential Technology Benefits

- Reduces energy losses by more than 50% due to more efficient transistor operation
- Reduces overall system size by 10X or more compared to Si due to:
  - SiC's robust high-temperature material stability, which requires significantly less cooling equipment
  - SiC's ability to operate at high frequencies, which reduces the size of auxiliary equipment
- Increases device reliability and ability to survive temporary control failures due to the ability to endure short circuit loads for 1 millisecond or more—100X more than Si
- Eliminates the need for external interface electronics due to integrated gate driver

Project Partners

- Sandia National Laboratories
  www.sandia.gov
- Arkansas Power Electronics International, Inc.
  www.apei.net
- University of Arkansas
  www.uark.edu
- Rohm Co., LTD
  www.rohm.com

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Related Reading

Office of Electricity Delivery & Energy Reliability Energy Storage Program, http://energy.gov/oe/technology-development/energy-storage.

Sandia National Laboratories, "Energy Storage Systems Program, Power Electronics," http://www.sandia.gov/ess/tech_power.html.

Sandia National Laboratories, SiC Power Module R&D 100 Entry, 2009, http://www.sandia.gov/mission/ste/r&d100/2009winners/SIC_Power_Module.pdf.

Importance of Energy Storage

Large-scale, low-cost energy storage is needed to improve the reliability, resiliency, and efficiency of next-generation power grids. Energy storage can reduce power fluctuations, enhance system flexibility, and enable the storage and dispatch of electricity generated by variable renewable energy sources such as wind, solar, and water power. The Office of Electricity Delivery and Energy Reliability Energy Storage Program funds applied research, device development, bench and field testing, and analysis to help improve the performance and reduce the cost of energy storage technologies.

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