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A High-efficiency Compact SiC-based Power Converter System

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STTR (DE-FG02-05ER86234), Energy Storage Program, Department of Energy

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Part 1. Aegis Technology

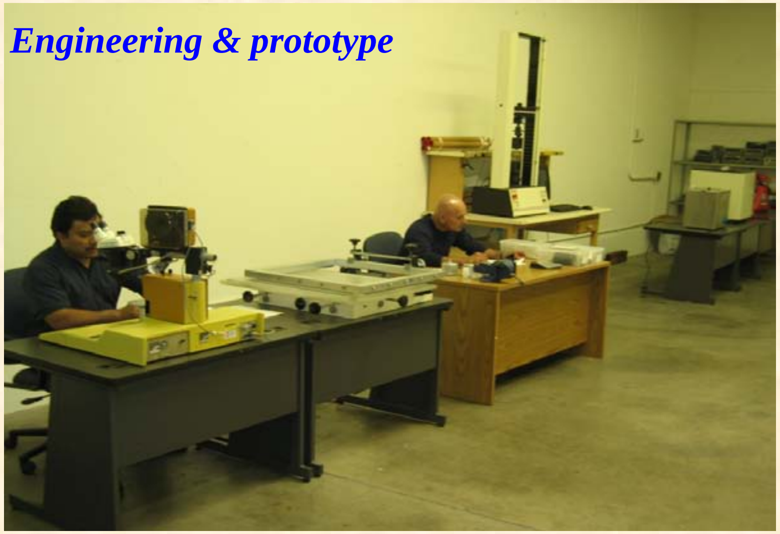
- **A high-technology company with design, development and manufacturing capabilities**
- **Operation since 2002 currently with 4 Ph.D/M.S Scientists/engineers and 10 employee**

Company located at a modern industry park in Santa Ana, CA, 10 miles away from University of California, Irvine

Development and fabrication in: a) thermal management & high-temperature power electronics; b) composites (e.g. nanocomposite)

Capabilities


Assembly

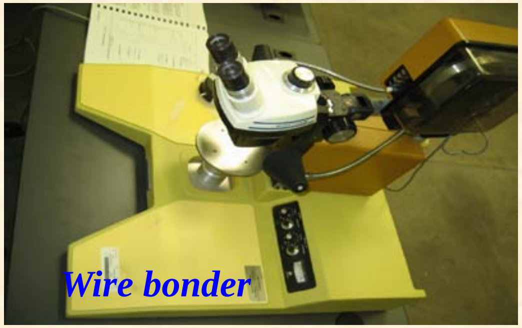

Engineering & prototype

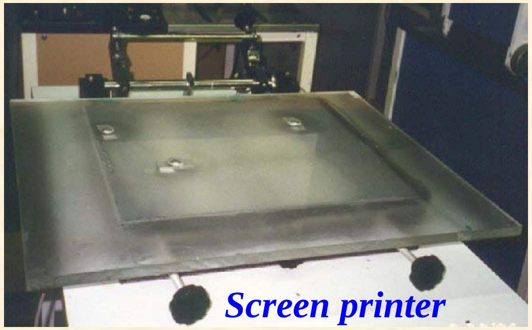

Manufacturing


Testing & inspection

Facilities

- 1. Vacuum and controlled-atmosphere furnace
- 2. Screen printer
- 3. Wire bonder
- 4. Isotemp oven
- 5. Air furnace
- 6. Glovebox system
- 7. Degassing system
- 8. Attritor system
- 9. Hot isostatic press
- 10. Universal mechanical test
- 11. Ultrasonic cleaner, air compressor and a variety of meters and tools
- 12. Computer systems with FEA and AutoCAD software


Wire bonder


Screen printer


Vacuum system

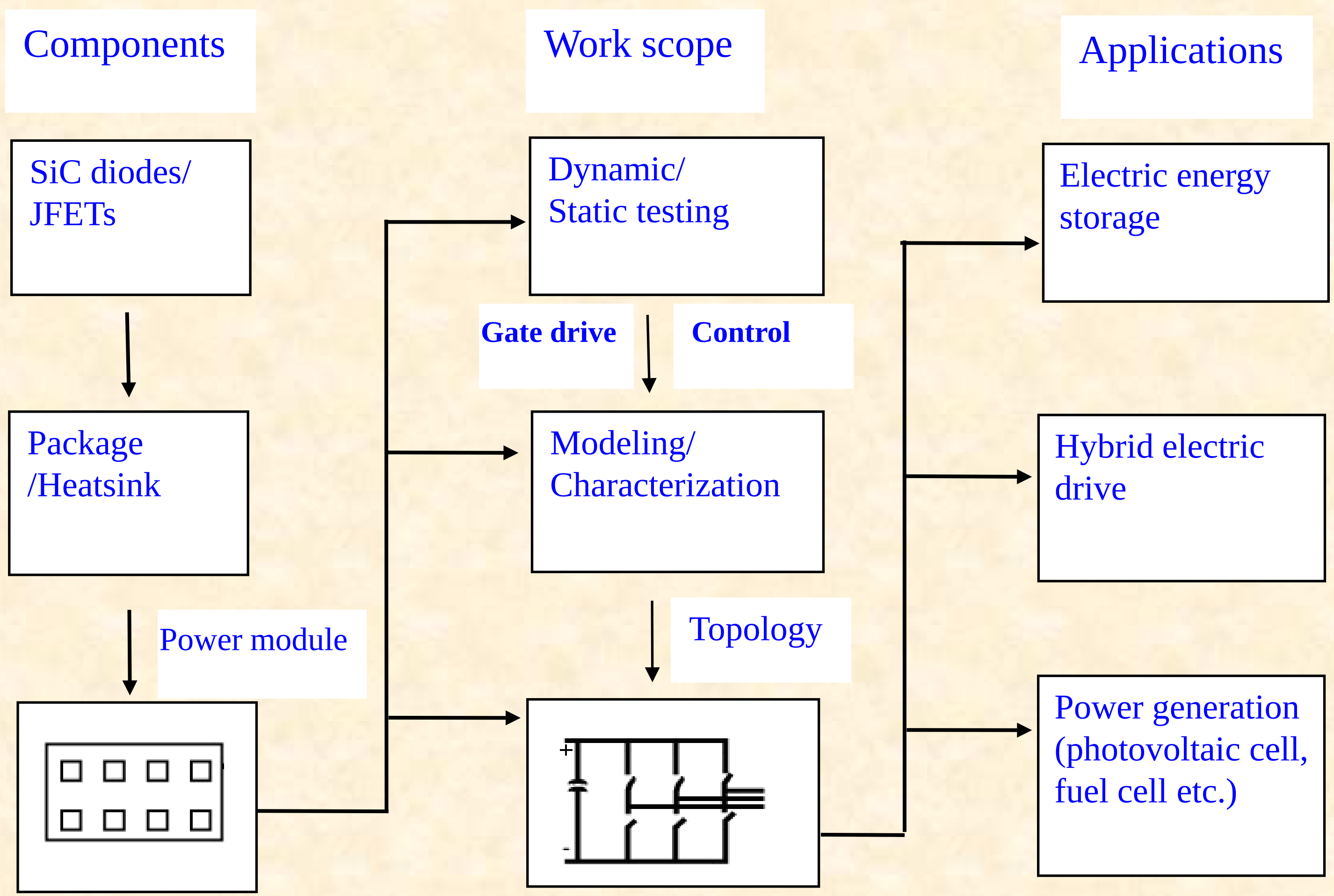
Hot pressing

Part II. DoE STTR —
A High-efficiency Compact SiC-based Power Converter System

Objective & Approach

- Develop a high-efficiency compact power inverter based on SiC-based semiconductor technology
  - High efficiency, small size, and light weight
  - High power density, high temperature, and high frequency
  - Scalable current ratings and power levels
- Address associated technical issues and supporting technologies
  - Design, modeling and simulation
  - Power modules by paralleling multiple SiC devices
  - High-temperature package and thermal management
  - High-frequency gate driver suitable for SiC power devices
- Integrate the technologies for demonstration/test of a SiC inverter that can operate at high junction/environment temperatures
  - Analyze the benefits of using SiC power devices in a systematic level
  - Explore potential applications (e.g. electric energy storage)

Outline of Approach and Applications

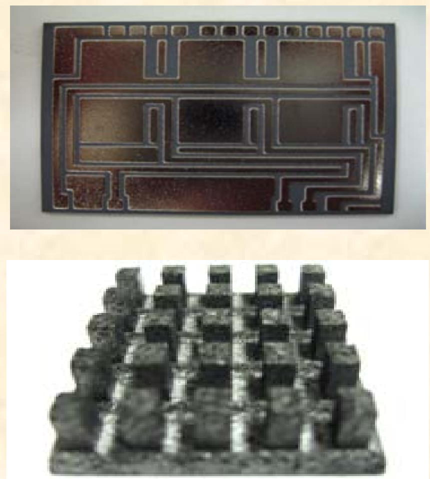


Phase I Accomplishment -Feasibility Study

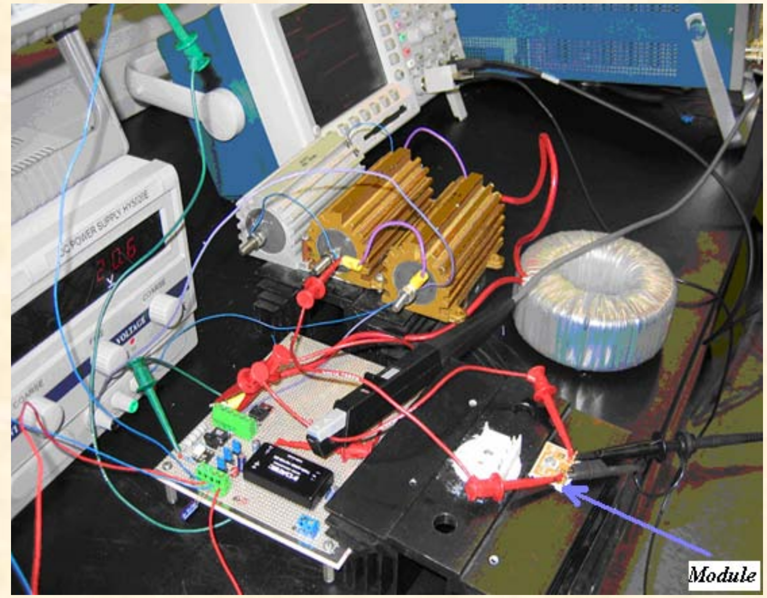
- **Phase I project investigated the feasibility of a SiC-based semiconductor technology with a focus on supporting technologies:**
  - SiC Power module (parallel SiC devices),
  - modeling and simulation,
  - thermal packaging,
  - gate drive
- **Power module design, prototype and test**
  - Design and built two kinds of SiC power modules using SiC diode (1200 V, 15 A) and JFET in parallel (2x 1200 V, 7A), half-bridge and six-packed
  - Characterize power modules
- **Modeling and simulation of inverter**
  - Inverter performance to investigate the device-level and system-level impart
  - Energy efficiency and heatsink size
- **Thermal management**
  - High temperature AlN package
  - High efficiency heatsink (graphite foam for air cooling, microchannel for liquid cooling)
- **Gate drive**
  - Select commercially available design and modify for SiC devices

Phase I Accomplishment - Hardware & Design

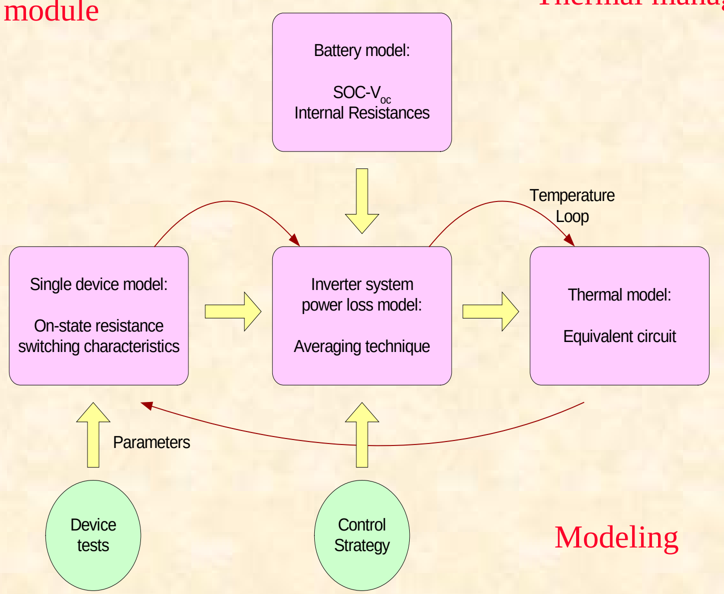
Power module



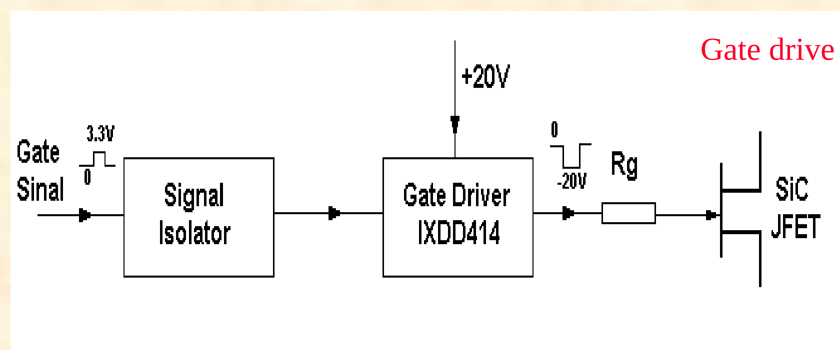
Thermal management



Testing setup

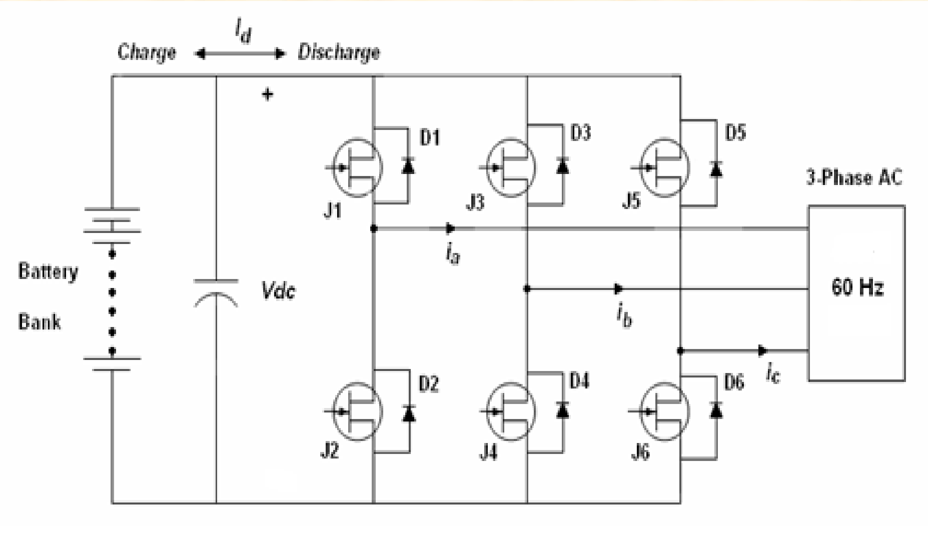


Modeling



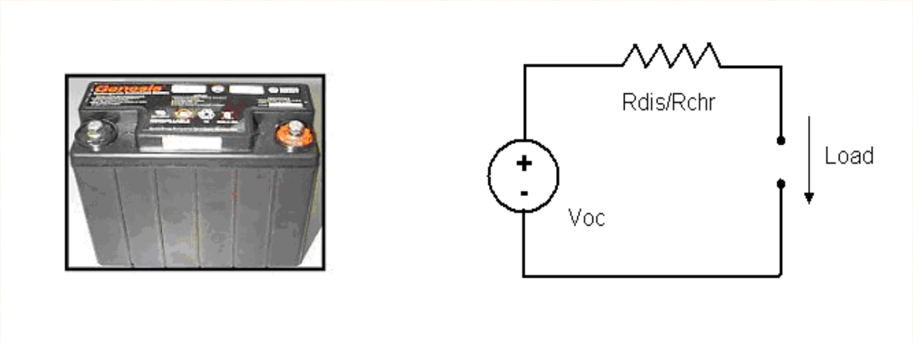
Gate drive

Phase I Accomplishment -Modeling



An inverter is interfaced with:

- A large battery bank for energy storage.
- An AC system.



A Hawker Genesis battery (13Ah, 12V) and its equivalent circuit for the simulation.

Phase I Accomplishment (cont.)-Modeling

Inverter **(1200 V, 20 A)**	JEFT/IGBT temperature rise (C)	Diode temperature rise (C)	Total power losses (W)	Efficiency (%)	Power loss percentage (%)	Heatsink (in^3): Natural convection
	Peak (Ave.)	Peak (Ave.)	Peak (Ave.)	Lowest (Ave.)	Largest (Ave.)	Thermaflo E1353
Si	109 (101)	125 (116)	311 (288)	95.6 (95.9)	*4.6 (4.1)*	*140.1*
SiC	123 (110)	121 (108)	175 (153)	97.6 (97.8)	*2.4 (2.2)*	*25.4*
SiC	171 (146)	169 (143)	271 (223)	96.1 (96.8)	*3.9 (3.2)*	*17.9*

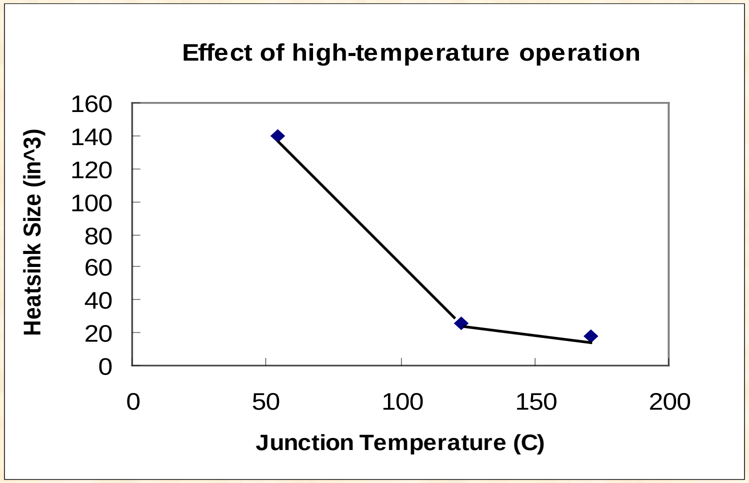
Inverter (1200 V , 120 A)	JEFT/IGBT temperature rise (C)	Diode temperature rise (C)	Total Power losses (W)	Efficiency (%)	Power loss percentage (%)	Heatsink (in^3): Forced convection (6.1 m/s)
	Peak (Ave.)	Peak (Ave.)	Peak (Ave.)	Lowest (Ave.)	Largest (Ave.)	Thermaflo E1357
Si	109 (100)	124 (113)	*3658 (3309)*	*96.2 (96.5)*	*3.8 (3.5)*	*423.3*
SiC	124 (115)	121 (108)	*545 (490)*	*99.4 (99.5)*	*0.6 (0.5)*	*5.75*
SiC	175 (154)	169 (143)	*690 (594)*	*99.3 (98.4)*	*0.7 (1.6)*	*3.75*

Primary simulation results in the discharging state of battery system

Phase I Accomplishment (cont.)-Modeling

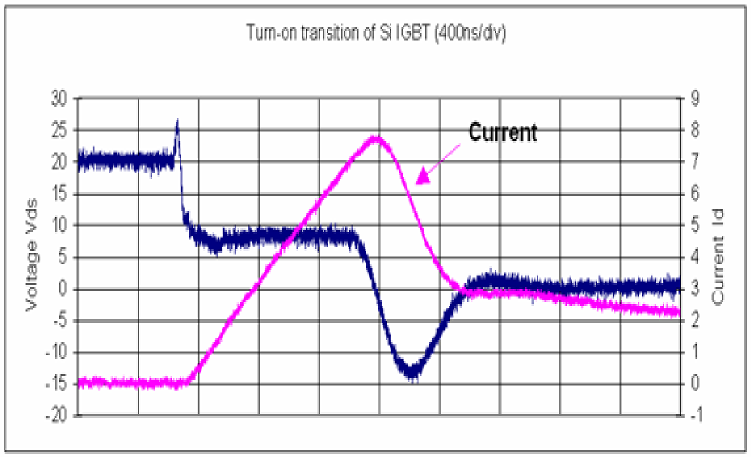
Simulation in one discharge/charge cycle

Inverter (1200 V, 20A)		JEFT/IGBT temperature rise (C)	Diode temperature rise (C)	Total power losses (W)	Efficiency (%)	Power loss percentage (%)
	Peak (Ave.)	Peak (Ave.)	Peak (Ave.)	Peak (Ave.)	Lowest (Ave.)	Largest (Ave.)
Discharge	Si	109 (101)	125 (116)	*311 (288)*	95.7 (95.9)	*4.6 (4.1)*
	SiC	54 (51)	52 (49)	*112 (105)*	98.4 (98.5)	*1.6 (1.5)*
Charge	Si	99 (62)	117 (72)	*311 (288)*	95.6 (95.9)	*4.6 (4.1)*
	SiC	49 (35)	48 (34)	*99 (32)*	98.6(99.3)	*1.4 (0.7)*

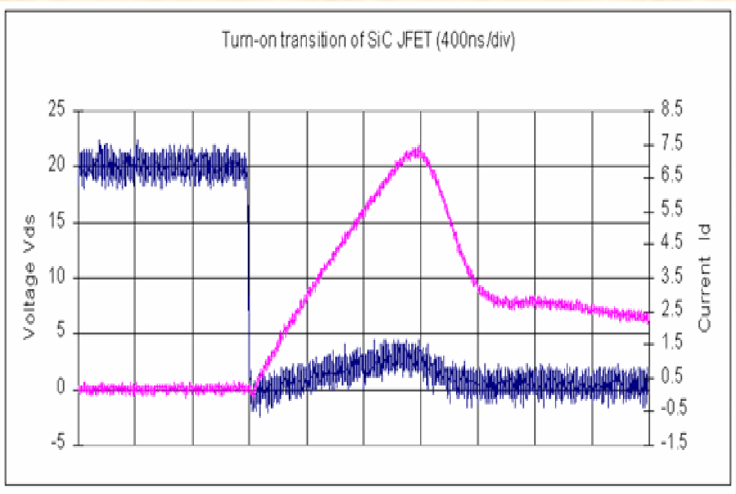


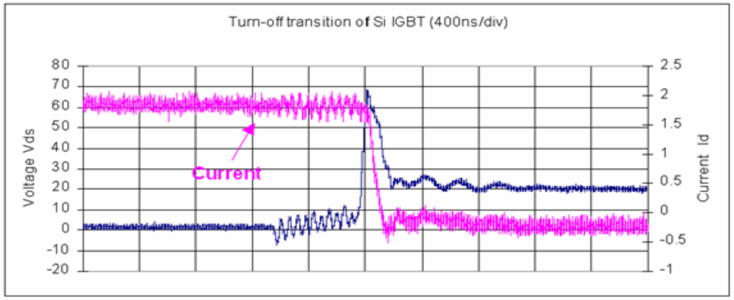
Item in simulation	Voltage rating	Current rating	Part number
SiC JFETs	1200 V	(7A×2) ×2	SiCED
SiC Schottky diodes	1200 V	15A ×2	SiCED
Si IGBTs Module	600 V	21A×2	SK 25GB 065 (Semikron)

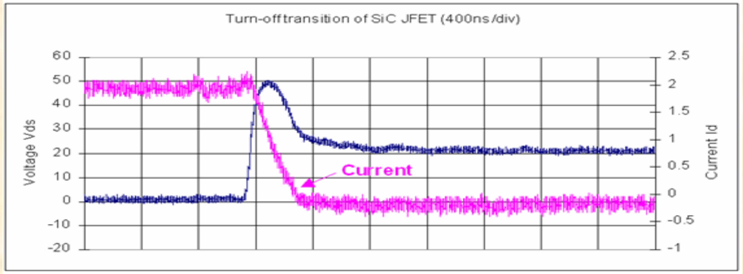
Phase I Accomplishment -Testing Result



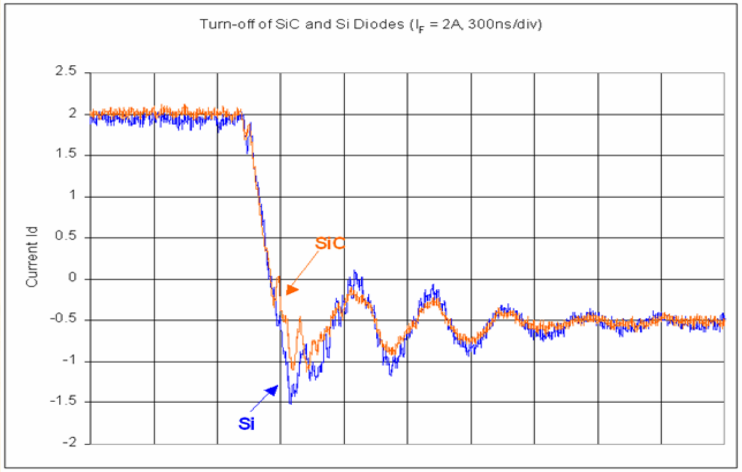
Turn-on transition







Turn-off transition



Recovery

Phase II Work Scope- System integration, scaling up and demonstration

- ***Converter fabrication and characterization***
  - **Utilize technology/components currently available or demonstrated in Phase I**
    - **A power module array (1200V, 120 A) by paralleling module units of 1200 V, 20 A**
    - **Gate drive (Honeywell SOI-based high temperature drive)**
    - **High- temperature thermal packaging**
  - **Fabricate, test and characterize inverter**
- ***Modeling and system analysis***
  - **Analyze the device/system-level impacts of the SiC inverter with similar Si inverter**
  - **Advantages of operations at high temperatures (smaller heatsink), power densities and frequencies (smaller passive component)**
  - **Technical/economical benefits in terms of efficiency, size and cost**
- ***Application and commercialization***
  - **Electric storage system (battery, capacitors)**
  - **Transportation (traction drive, hybrid electric vehicles)**
  - **Power systems (Fuel cells, micro turbine, nuclear energy, and renewable sources)**
  - **Document the benefits in terms of performance and costs for potential customers**
- ***Teaming with Powerex for production/commercialization***
  - **SiC power modules and converters**

Through this project, a high-efficiency compact affordable SiC inverter can be anticipated

Phase II Work Being Accomplished

- **Contract initiated at October 2006**
- **Design of power module**
  - **Paralleling of multiple devices for a unit of power**
  - **Paralleling of multiple modules for a power module array**
- **Design of gate drive based on SOI technology**
- **Procurement of SiC power devices**
- **Fabrication of SiC/Al composite and Metallization of AlN for thermal packaging**
- **Establishment of a commercial partner, Powerex Inc. (Youngwood, PA) for SiC-based power electronics**

Phase II Work Ongoing

- ***Device***
  - Procure and characterize commercially available SiC devices
- ***Circuit***
  - Design suitable SiC circuits of power modules
  - Power modules through Device paralleling
  - Modeling and simulation
  - Thermal testing of modules
- ***Package (thermal management) and gate drive***
  - Develop high temperature package, high-efficiency heatsink
  - Develop high temperature gate drive
- ***System integration/demonstration/testing/applications***
  - Select high temperature auxiliary devices/components (capacitor etc.)
  - Document the system impacts of using SiC devices
  - Approaching potential customers

Acknowledgement

- **This project is sponsored by Energy Storage Program, U.S. Department of Energy**
- **DoE STTR project Phase I and ongoing Phase II (DE-FG02-05ER86234)**
- **Special thanks extend to**
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  - ***Mr. Stanley Atcitty, Senior Member of Technical Staff, Sandia National Laboratories***