U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Wide Bandgap Materials

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Project ID: APE007

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Overview

Timeline

- Project start – Oct. 2001
- Project end – Ongoing

Budget

- Total project funding
  - DOE 100%
- FY09 - $367K
- FY10 - $282K
- FY11 - $335K

Barriers

- Barriers
  - Acquiring new prototype devices in high temperature packages.
- Vehicle Technologies Program Targets

  WBG devices maybe the enabling technology to meet the VTP inverter targets:
  - 13.4 kW/l, 3.3 $/kW and 14.1 kW/kg

Partners

- Industrial suppliers of SiC and GaN devices
- University of Tennessee
- ORNL team members: Puqi Ning, Steve Campbell

Objectives

- **Test and evaluate new technology devices as they become available to maintain a library of wide bandgap (WBG) device performance characteristics.**

- **Assess the system level impact of wide bandgap semiconductor devices on hybrid electric vehicles.**

Milestones

- **FY10**
  - **Completed characterization of various devices**
  - **Completed a traction drive model.**
  - **Go No/Go Decision Point: Determine if the technology matured to a level commercializable for the automotive industry**
- **FY11**
  - **Complete integration of the new device package into the automated test set up and test functionality.**
  - **Go No/Go Decision Point: Determine if the technology matured to a level commercializable for the automotive industry**

Technical Approach

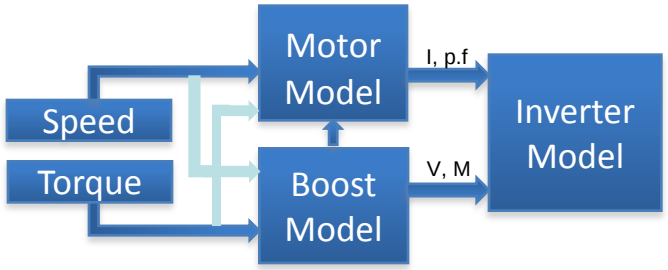
- **Device characterization includes:**
  - ✓ **Static Characteristics**
    - **Forward characteristics over a wide range of temperatures.**
    - **Transfer characteristics over a wide range of temperatures.**
    - **Voltage blocking characteristics.**
  - ✓ **Dynamic Characteristics**
    - **Measuring turn-on and turn-off times with resistive load.**
    - **Turn-on and turn-off energy loss measurements over a wide range of temperatures.**
- **Develop standard high temperature package for die level device evaluation.**
- **Develop behavioral SPICE models for ORNL packaging projects: Specific device tests will be performed to extract the parameters required for behavioral SPICE models.**
- **System level evaluation of devices: Performance of selected devices will be evaluated in a traction drive simulation model to demonstrate the benefits.**

Technical Accomplishments – FY10

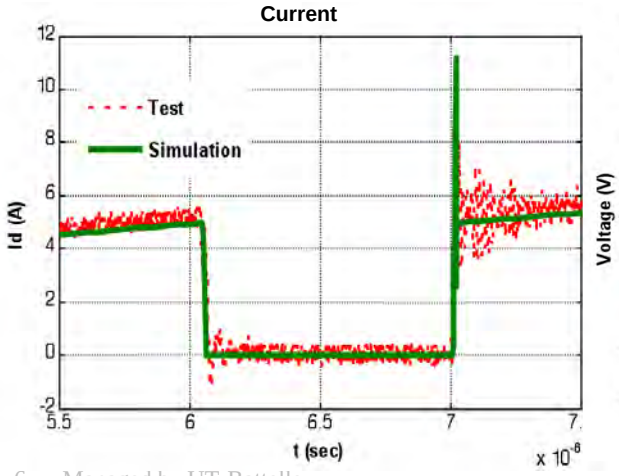
- **Devices tested and characterized (FY10):**
  - **Three SiC JBS Diodes 1,200 V, 8 A, 30 A, 100 A**
  - **SiC BJT 1200 V, 6 A**
  - **SiC MOSFET 1,200 V, 100 A**
  - **Two SiC JFETs (normally-off) 1,200 V, 50 A, 100 A.**
- **Developed SPICE model for a 1,200 V, 10 A SiC JFET.**
- **A traction drive model was developed to simulate the performance of the WBG devices over different drive cycles.**

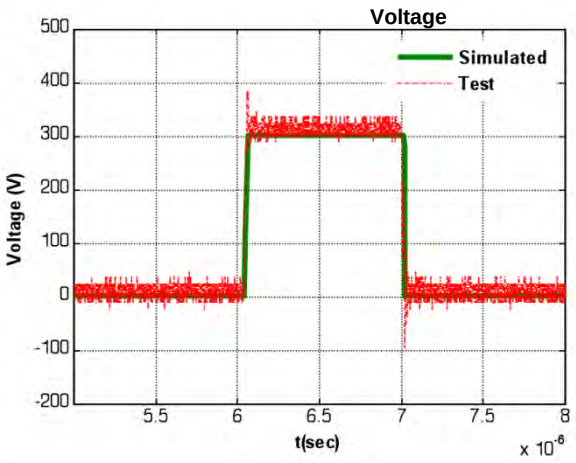
Simulation results of traction drive for US06 drive cycle

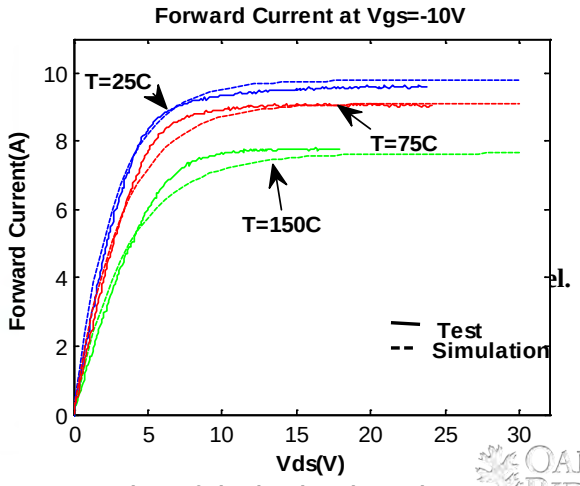
	10 kHz		20 kHz
Inverter Efficiency [%]			
70°C	105°C	70°C	105°C
97.43	97.39	95.41	95.34
Inverter Energy Loss [kJ]			
70°C	105°C	70°C	105°C
338.9	344.3	617.6	626.7



Comparison of simulated and test data : Switching characteristics

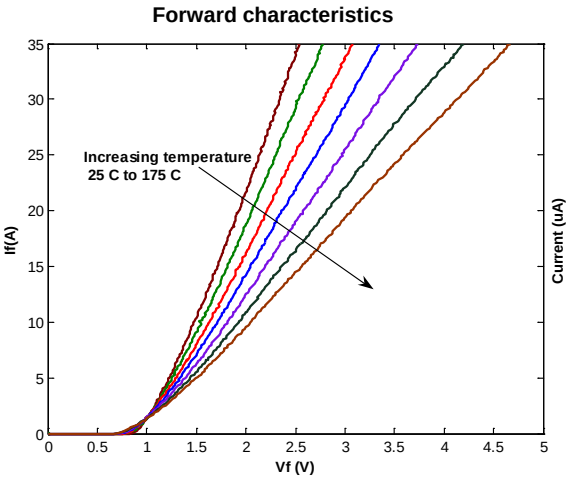


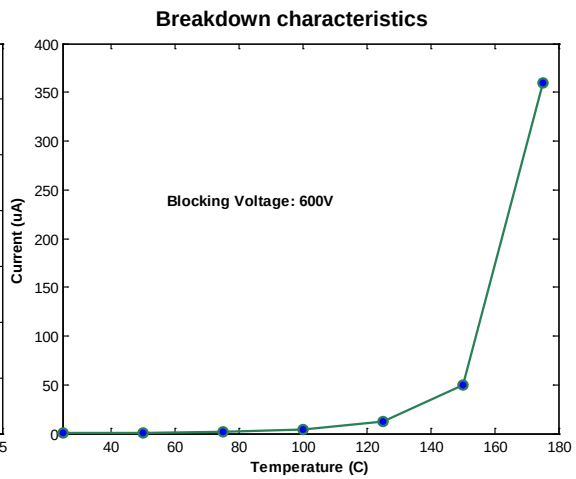




Comparison of simulated and test data

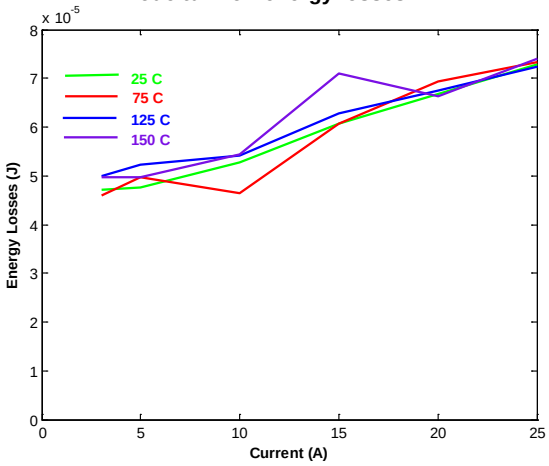
Technical Accomplishments - FY11

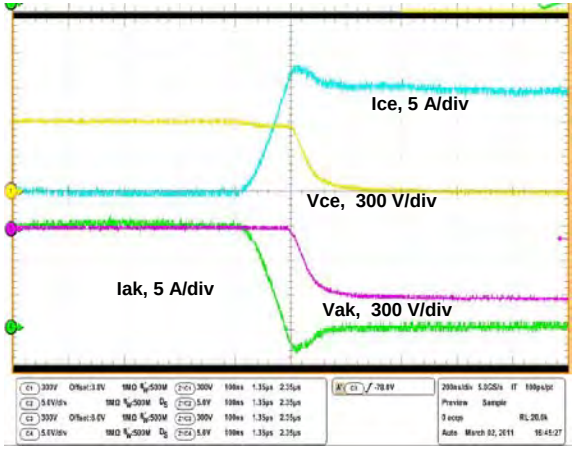


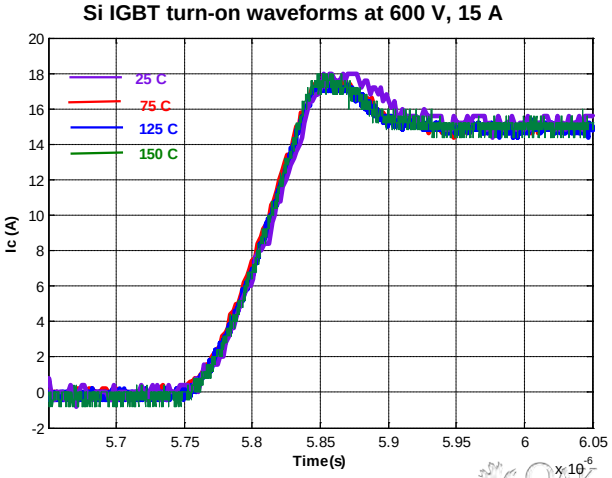


- The static characteristics of a 1,200 V, 35 A SiC JBS diode in an hybrid co-pack with Si IGBT (TO-247) were obtained over a wide temperature range of 25°C - 175°C.
- The forward voltage drop at 35 A current increased from 2.55 V at 25°C to 4.66 V at 175°C. The on-state voltage drop decreased from 0.75 V at 25°C to 0.56 V at 175°C.
- The turn-off energy losses did not change much with temperature.

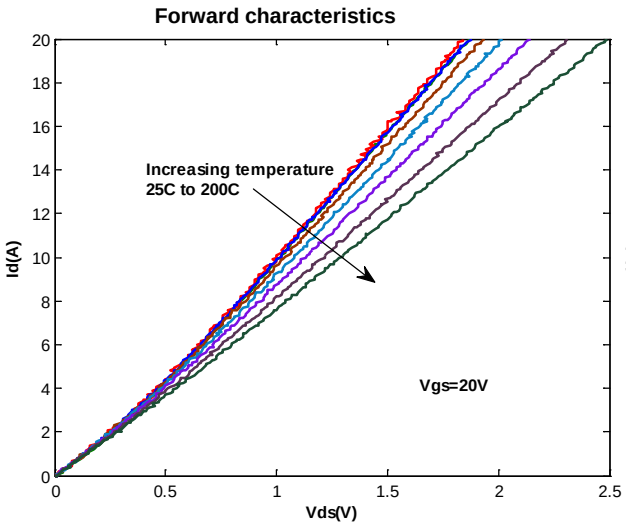
1,200 V, 35 A Si IGBT-SiC diode co-pack TO-247

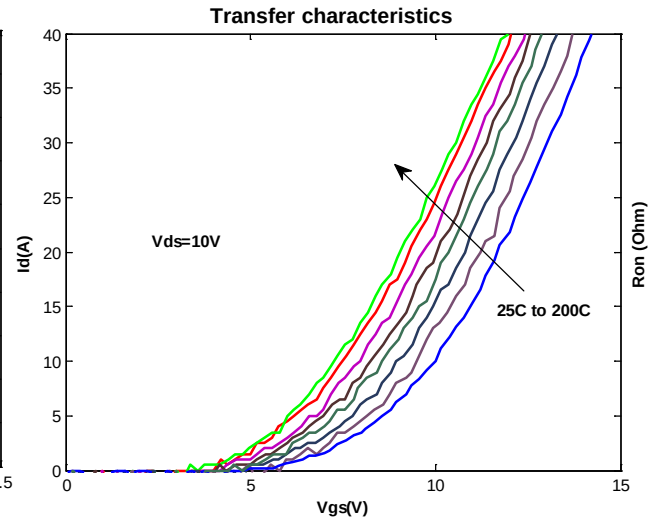


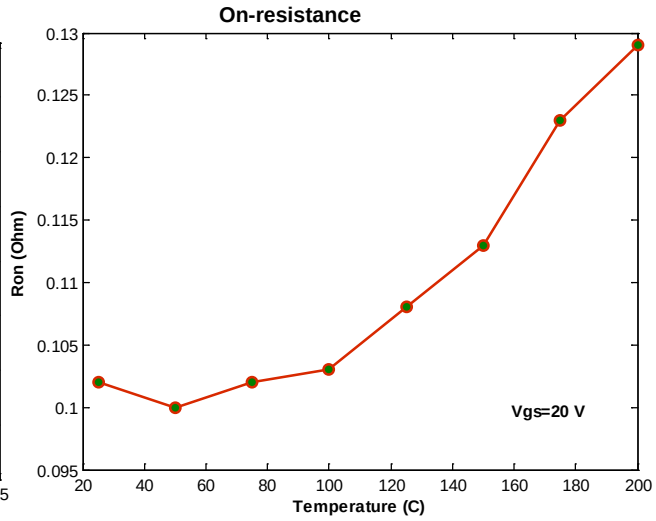




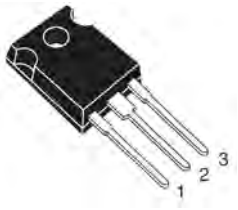
Technical Accomplishments – FY11



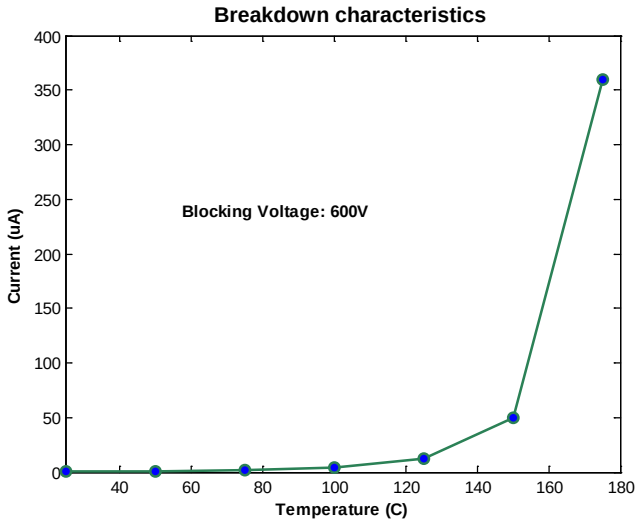




- **The static characteristics of a 1,200 V, 33 A SiC MOSFET were obtained over a wide temperature range of 25°C - 200°C.**
- **The on-resistance increased from 0.102 Ohms at 25°C to 0.128 Ohms at 200°C.**
- **The threshold voltage at 1 A drain current decreases from 6.4 V at 25 C to 4.4 V at 200°C.**



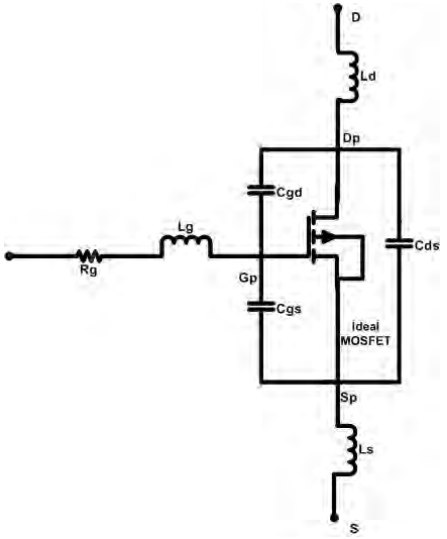
1,200 V, 33 A
MOSFET TO-247



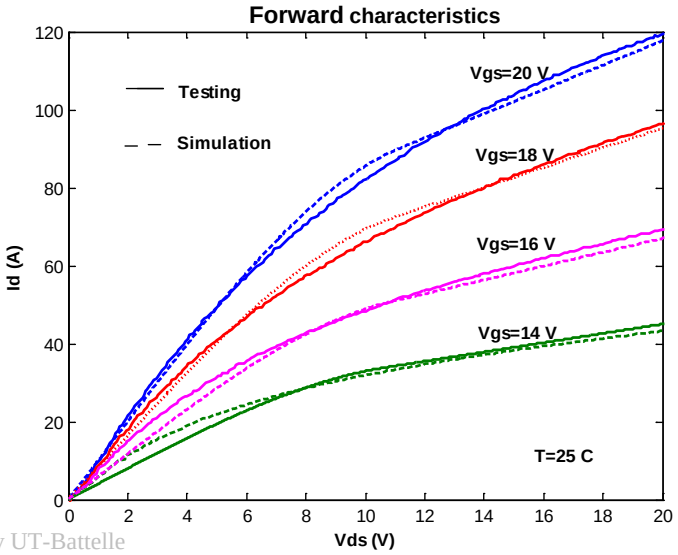
Device database:
http://www.ornl.gov/sci/ees/etsd/pes/device_testing.shtml

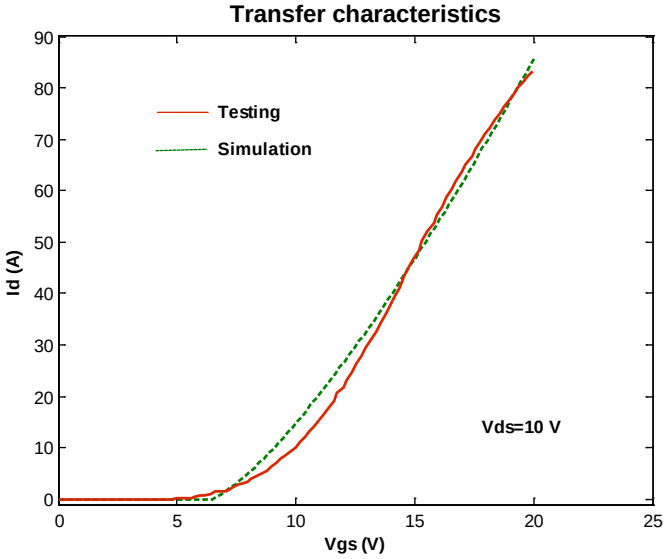
Technical Accomplishments – FY11

- The device chosen this year is a 1,200 V, 33 A SiC MOSFET.
- The circuit elements include:
  - gate resistance and inductance (Rg, Lg).
  - drain series inductance (Ld) and source series inductance (Ls).
  - the junction capacitances between the three terminals gate-to-source (Cgs), gate-to-drain (Cgd) and, drain-to-source (Cds).
- The static characteristics of the device were simulated were obtained by sweeping the current to saturation at different gate voltages.
- The device current in the saturation region and the linear region matches the test results very closely.



Equivalent circuit of 1,200 V, 33 A SiC MOSFET

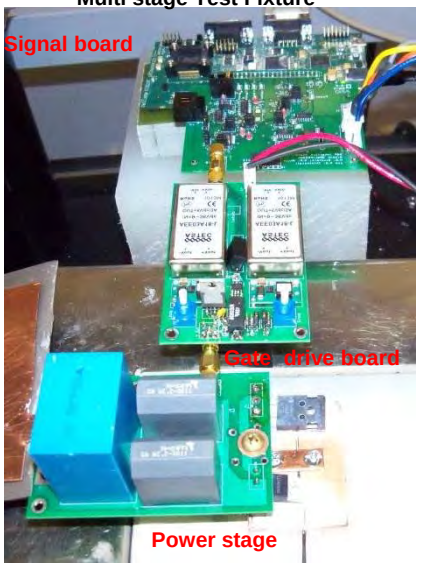




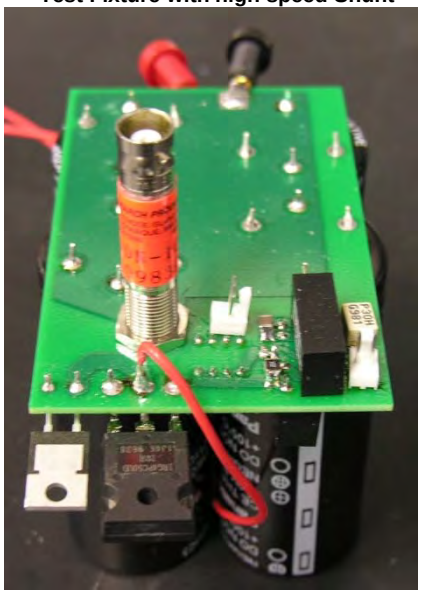
Technical Accomplishments - FY11

Automated Device/Component Test Facility

Multi stage Test Fixture



Test Fixture with high speed Shunt



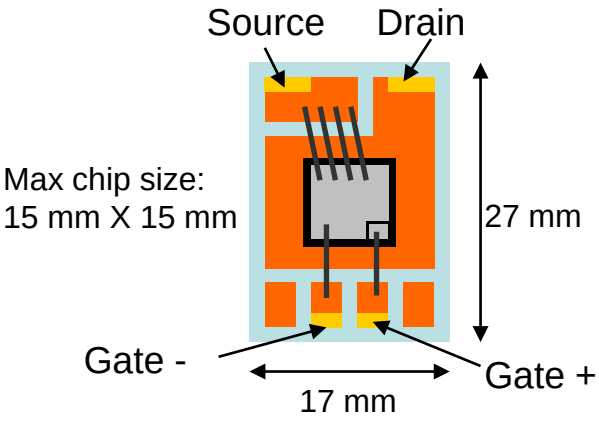
Capabilities:

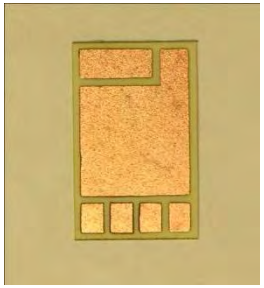
- Device/component characterization at temperatures up to 600°C.
- Static and dynamic measurements of diodes and switches up to 1,200 V, 400 A.
- Test devices up to 30 V gate drive voltage and up to 10 ns switching times.
- Extract device capacitances up to 1,000 V.

Technical Accomplishments - FY11

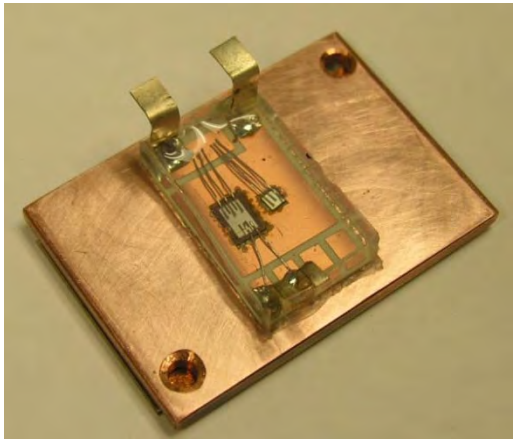
High temperature test coupon

- **Test coupon capable of operating up to 200°C and 1,500 V.**
- **Static and dynamic measurements of diodes and switches in a single co-pack configuration or an half bridge configuration.**
- **Die sizes up to 15 mm^2 can be accommodated.**



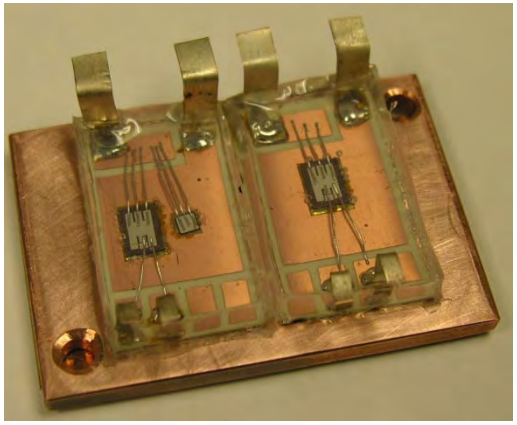


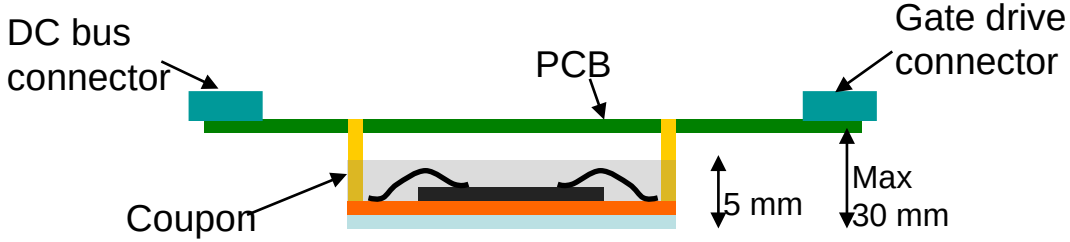
Test coupon for co-pack



Packages were developed at ORNL through the VTP packaging project

Test coupon for half bridge





Collaboration and Coordination with Other Institutions

Industrial suppliers of SiC and GaN devices:

- Cree
- Semisouth
- Velox
- HRL
- Infineon
- SiCED
- TranSiC
- GeneSiC

Behavioral SPICE modeling of devices:

- University of Tennessee

Developing collaboration with other testing facilities:

- Auburn University

Future Work

- **FY11**
  - Continue to test and characterize new devices.
  - Integrate the high temperature test coupon into the automated test facility.
  - Complete the behavioral SPICE models for packaging.
  - Complete the traction drive simulation for assessment of selected devices tested in FY11.
- **FY12 and Beyond**
  - Acquire, test, and characterize newer technology WBG power devices.
  - Develop behavioral SPICE models to aid in ORNL packaging work.
  - Develop vehicle level system model for evaluating device performance.

Summary

- Devices tested and characterized (FY11):
  - 1,200 V, 35 A SiC JBS diode
  - 1,200 V, 33 A SiC MOSFET
- New 1,200 V, 10 A SiC SJT and 1,200 V, 100 A Si IGBT SiC diode co-pack discrete devices have been acquired for future testing.
- Automated device test facility upgrade:
  - A new test board with high speed shunt resistor for testing devices with fast switching times has been completed.
- A high temperature test coupon for device evaluation has been designed and a prototype was built.