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

# Overview

## Timeline

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

## Budget

- Total project funding
  - DOE 100%
- FY08 - $432K
- FY09 - $367K
- FY10 - $282K

## Barriers

- Barriers
  - Acquiring new prototype devices.
  - Building new gate drivers and test set-ups for power switches with fast switching times .
- Vehicle Technology Program Targets
  - DOE 2020 inverter target: 13.4 kW/l
  - DOE 2020 inverter target: 3.3 $/kW

## Partners

- Industrial suppliers of SiC and GaN devices
- University of Tennessee

# 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

- **FY09**
  - Completed device characterization.
  - Go No/Go Decision Point: Availability of new devices of interest.
- **FY10**
  - Complete the traction drive simulation with new device loss models.
  - Go No/Go Decision Point: Availability of new devices of interest.

# Technical Approach

- Device Characterizations 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 behavioral SPICE models for 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.

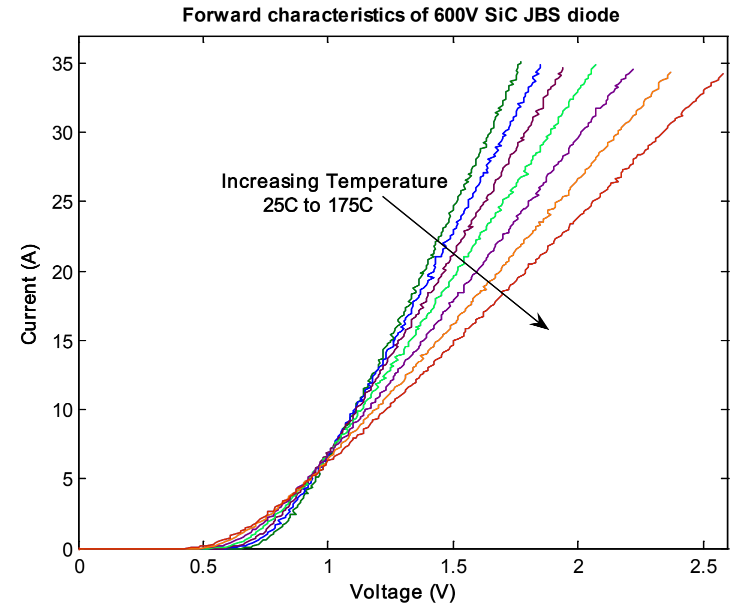
# Technical Accomplishments - FY09

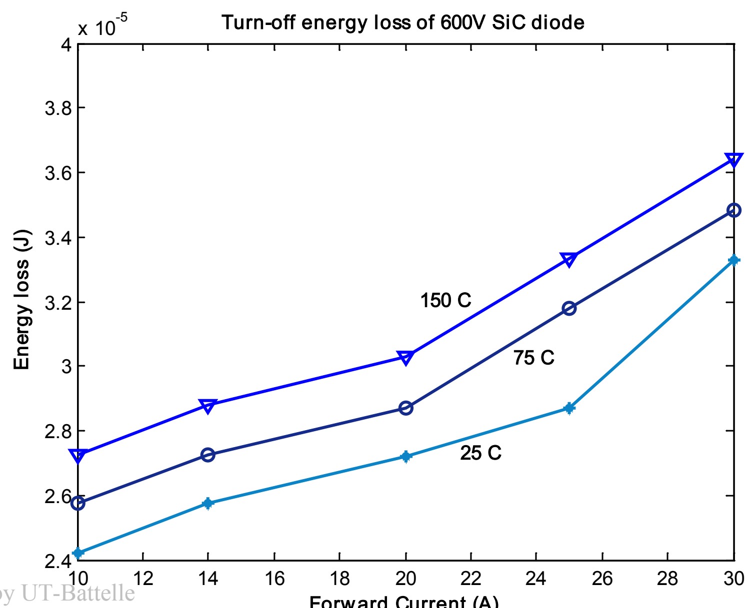
| Device type | Ratings | On-resistance (Ω) | Forward voltage drop (Volts) | Year tested |
|---|---|---|---|---|
| SiC MOSFET | 1200V, 100A | 0.0134 Ω at 20 °C to 0.0162 Ω at 175°C. | 1.34 V @ Vgs= 20V * | 2009 |
| SiC JBS diode | 1200V, 100 A | 0.0077 Ω at 25° C to 0.0176 Ω at 200° C | 1.71 V at 25°C to 2.53 V at 200°C. | 2009 |
| SiC JFET ( normally-off) | 1200V, 10 A | 0.093 Ω at 25°C to 0.2 Ω at 150°C | 0.93 V @ Vgs= 3V * | 2009 |
| SiC JFET ( normally-off) | 1200V, 50 A | 0.0369 Ω at 25 °C to 0.1478 Ω at 175°C | 1.84 V @ Vgs= 3V * | 2009 |
| SiC Schottky Diode | 1200V, 40 A | 0.0364 Ω at 25°C to 0.066 Ω at 175°C | 2.38 V at 25°C to 3.4 V at 175°C. | 2009 |

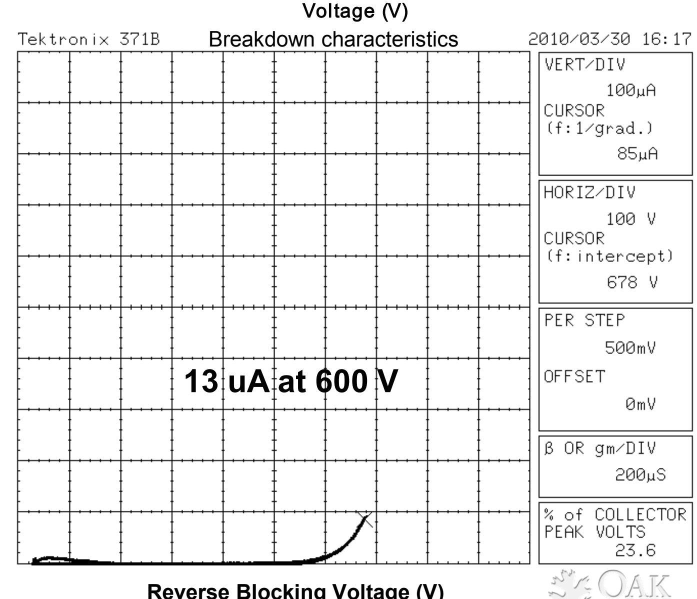
*** Voltage drop at rated current @ room temperature**

# Technical Accomplishments - FY10

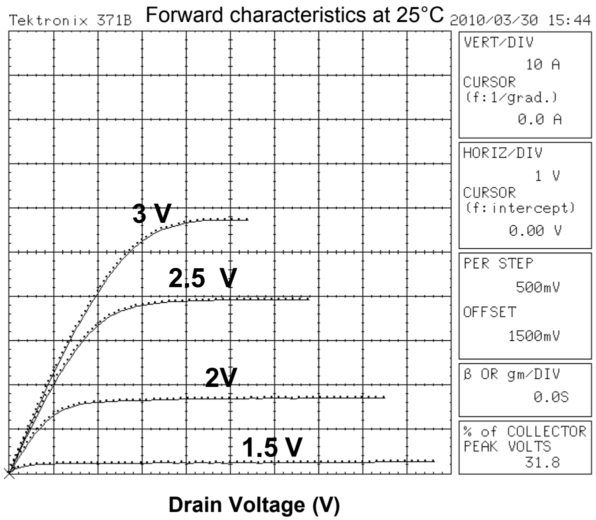
- The static characteristics of a 600 V, 20 A SiC JBS diode (TO-247) were obtained in a wide temperature range of (25°C-175°C). The forward voltage drop at 20 A current increased from 2.4 V at 25°C to 4.66 V at 175°C. The on-state voltage drop decreased from 0.7 V at 25°C to 0.5 V at 175°C.
- The static characteristics of a 600 V, 50 A SiC JBS diode (TO-247) were obtained in a wide temperature range of (25°C-175°C). The forward voltage drop at 35 A current increased from 1.77 V at 25°C to 2.6 V at 175°C. The on-state voltage drop decreased from 0.74 V at 25°C to 0.58 V at 175°C.
- The turn-off energy losses did not change much with temperature.

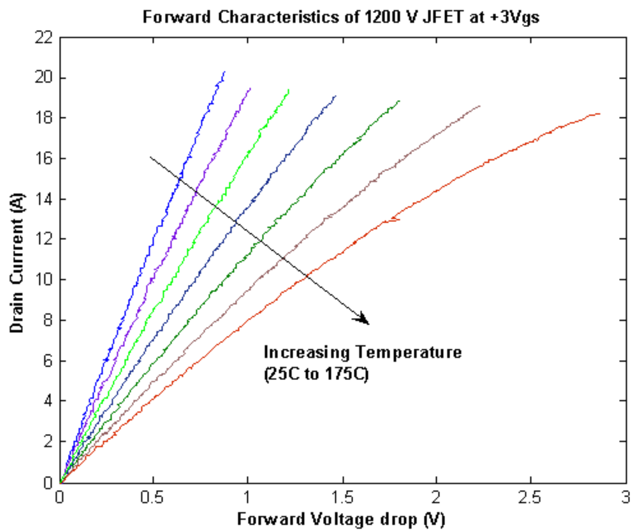


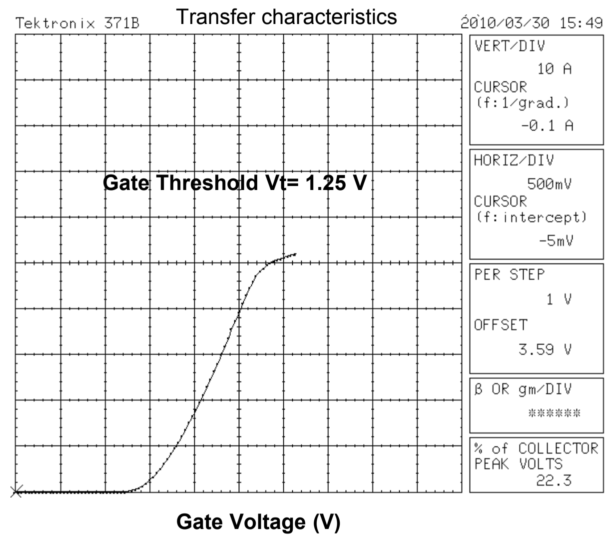



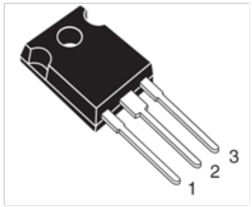
# Technical Accomplishments - FY10



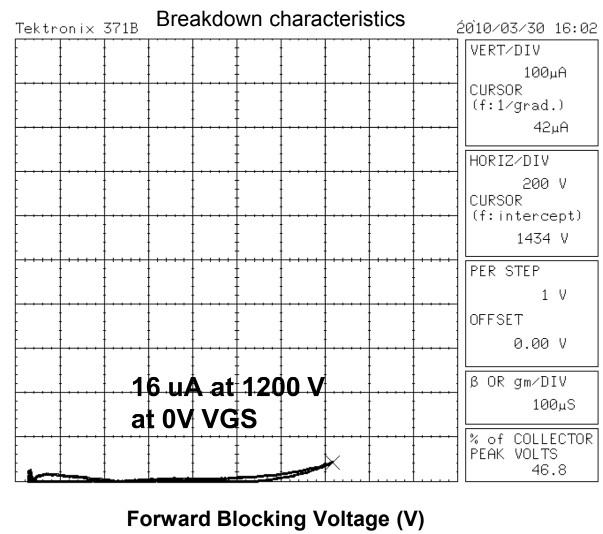




- At 3V Vgs the device is de-rated from 50A to 20A.
- The static characteristics of a 1200 V A SiC normally-off JFET were obtained in a wide temperature range of (25°C-175°C).
- The on-resistance increased from 0.0424 Ohm at 25°C to 0.1552 Ohm at 175°C.
- At 25°C the leakage current is approximately 16 uA at 1200 V and the gate threshold voltage is 1.25 V.

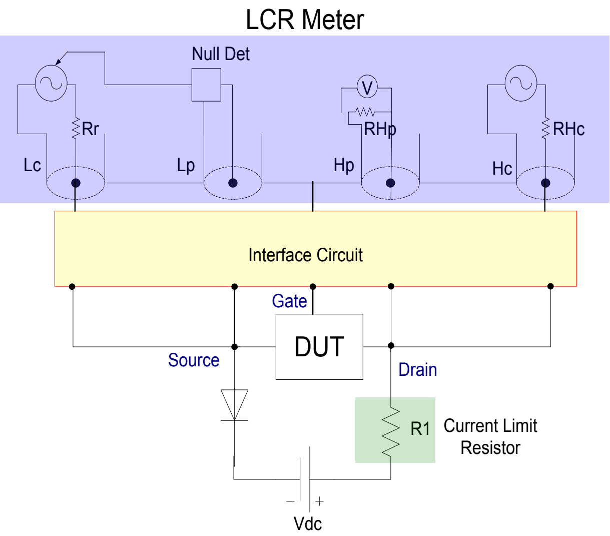



**1200V, 50 A JFET TO-247**

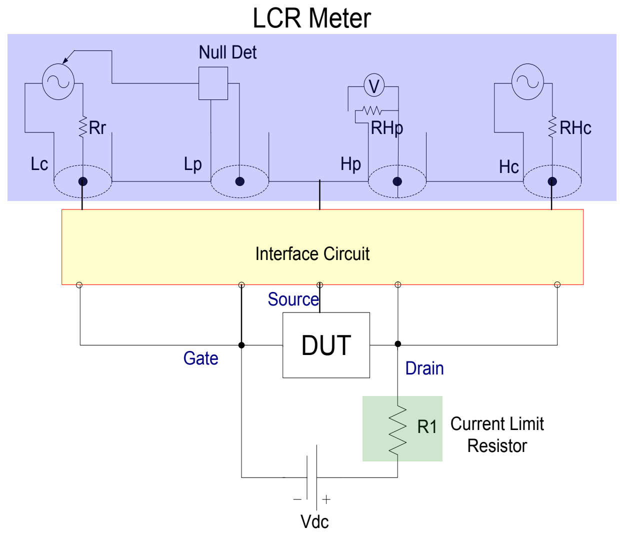


# Technical Accomplishments - FY10

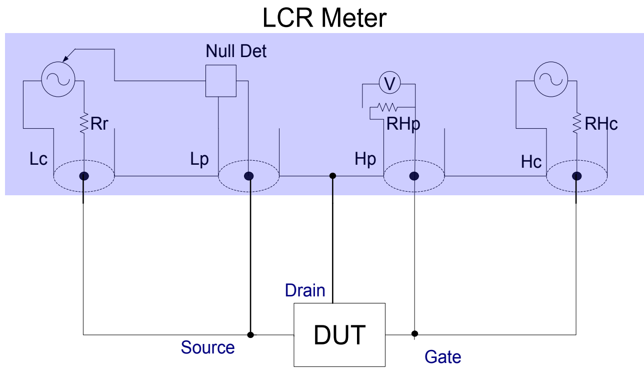
## Device Capacitance Measurements




Schematic of test fixture for Cds measurement




Schematic of test fixture for Cgd measurement



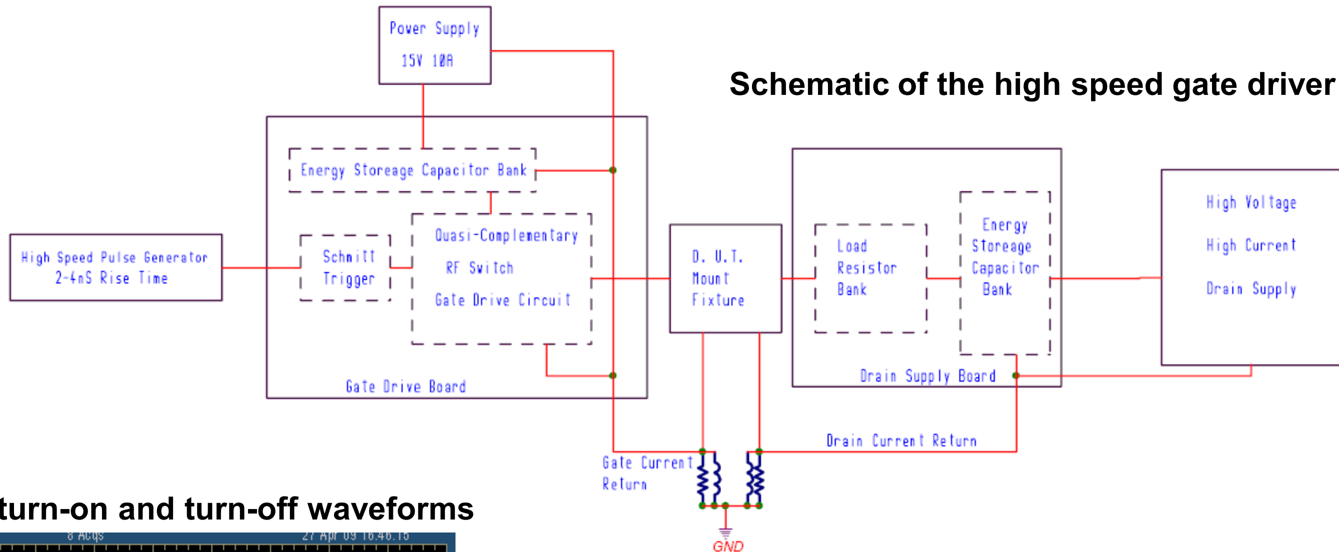

Schematic of test fixture for Cgs measurement



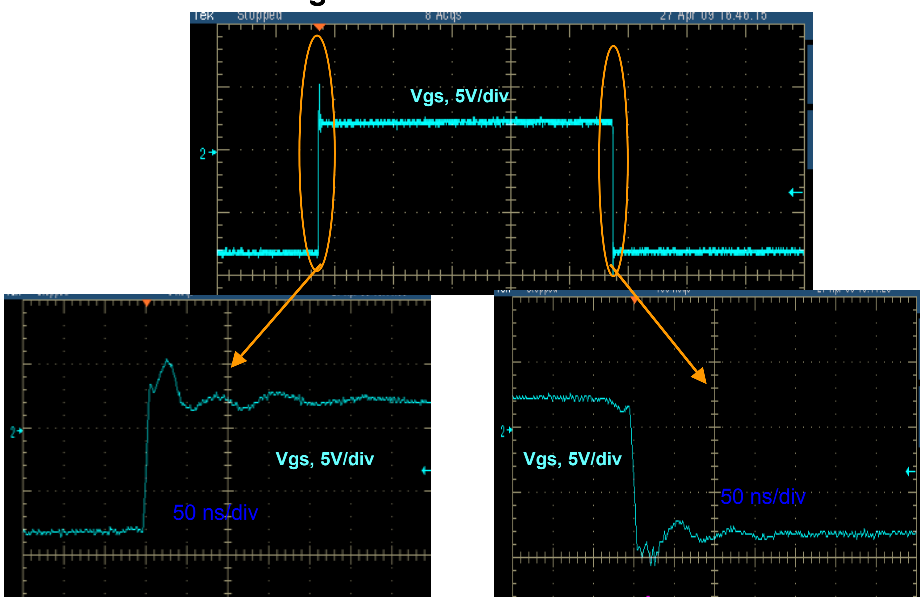

- Designed, built and tested capacitance extraction fixtures to be used with LCR meter.
- The devices can be tested up to 1000 V.
- The capacitance measurements were validated by testing a commercial coolMOS device. The values matched the datasheet measurement.

# Technical Accomplishments - FY10

**Schematic of the high speed gate driver board**




**Gate voltage turn-on and turn-off waveforms**




- **A new gate driver board to characterize the power devices with fast switching times has been added to the automated test facility.**
- **The board has the capability of driving up to +/- 15 V gate drive voltage with 10 ns switching times.**
- **The board was tested with a 600V GaN FET with a Vgs of (+3V to - 8V).**



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# Technical Accomplishments - FY10

**Automated Device/Component Test Facility**

**Capabilities:**

- Device/component characterization at temperatures up to 600°C.
- Static and dynamic measurements of diodes and switches up to 1,200 V, 200 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.

# 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

# Future Work

- **FY10**
  - Continue to test and characterize new devices.
  - Build capacitance extraction fixtures for devices with negative gate bias.
  - Complete the behavioral SPICE models for packaging.
  - Complete the traction drive simulation for assessment for selected devices tested FY10.

- **FY11 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 (FY10):
  - 1,200 V, 20A SiC JFET
  - 600 V, 20 A, 50 A SiC JBS diodes
  - 600 V, 1A GaN FET
- New SiC JFET modules with normally-off devices have been acquired for future testing.
- Automated Device Test Facility:
  - The automated test facility is currently functional and being used for characterizing devices.
  - A new gate driver board for testing devices with fast switching times has been completed and added.
- Capacitance extraction test fixtures have been developed and tested.