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%
- FY10 - $282K
- FY11 - $335K
- FY12 - $288K

Barriers

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

  WBG devices maybe the enabling technology to meet the VTP 2020 inverter targets:
  - 13.4 kW/l, 3.3 $/kW and 14.1 kW/kg

Partners

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

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

- **FY11**
  - Completed characterization of various devices.
  - Completed behavioral Pspice model of SiC MOSFET.
  - Go No/Go Decision Point: Determine if the technology has matured to a level commercializable for the automotive industry.

- **FY12**
  - Perform an assessment of WBG technology to understand the performance trends, cost time line, and system level benefits.
  - Go No/Go Decision Point: Determine if the technology matured to a level commercializable for the automotive industry.

Technical Approach

- Device Characterizations Includes:
  - ✓ Static Characteristics
    - - Forward characteristics over a range of temperatures.
    - - Transfer characteristics over a 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.

- System level evaluation of devices: Performance of selected devices are evaluated in a traction drive simulation model to demonstrate the benefits.

- Perform an assessment of WBG technology to determine when the viable market introduction for automotive use will occur.

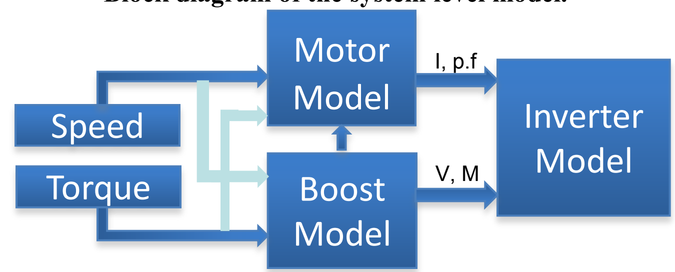
Technical Accomplishments – FY11

- **Devices tested and characterized (FY11):**
  - SiC JBS Diodes 1200 V, 100 A, 35 A
  - SiC MOSFET 1,200 V, 33 A
  - SiC SJT 1200 V, 10 A
- **Developed SPICE model for a 1200 V, 33 A SiC MOSFET.**
- **A traction drive model was developed to simulate the performance of the WBG devices over different drive cycles using Si IGBT and SiC JBS diodes in an hybrid configuration.**

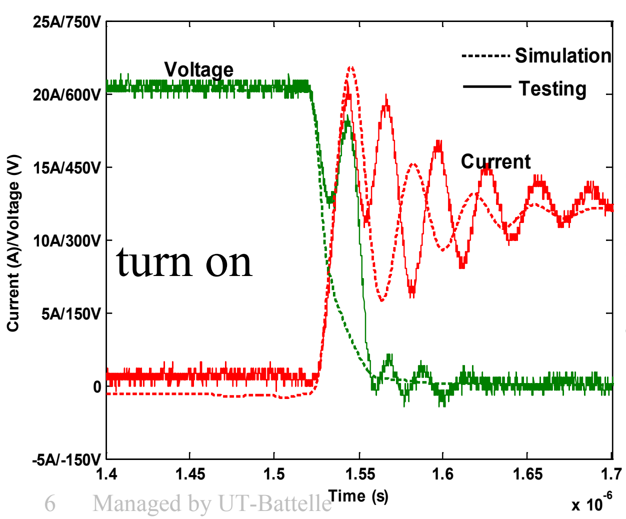
Simulation results of traction drive for US06 drive cycle

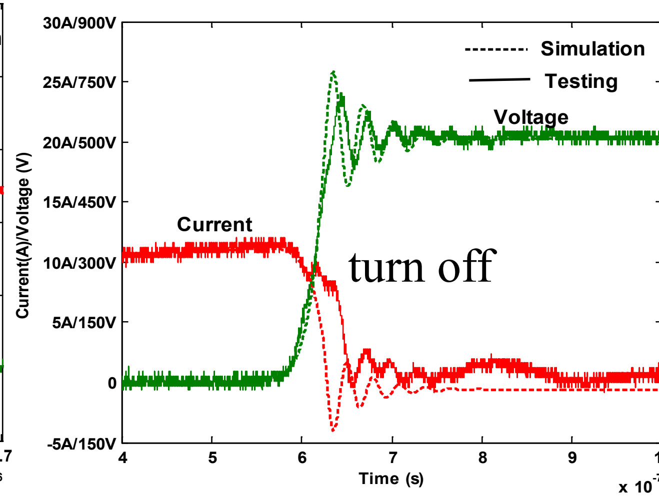
10 kHz		20 kHz	
Inverter Efficiency [%]			
70°C	105°C	70°C	105°C
95.97	95.76	92.67	92.28
Inverter Energy Loss [kJ]			
70°C	105°C	70°C	105°C
536.4	565.2	1004.5	1061.5

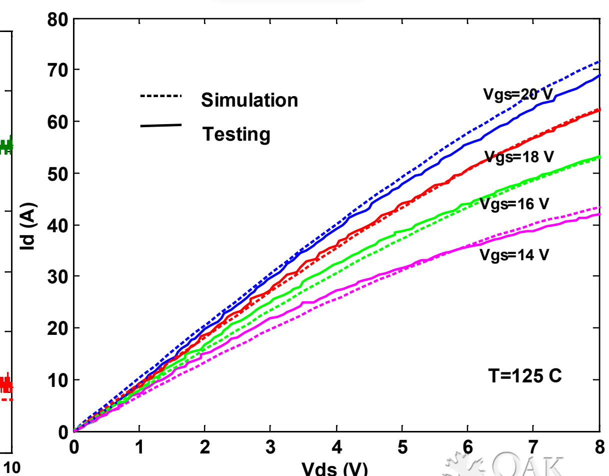
Block diagram of the system level model.



Comparison of switching characteristics between testing and simulation.



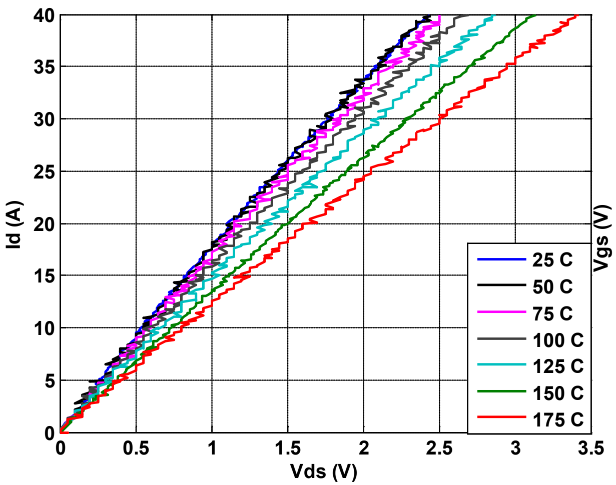




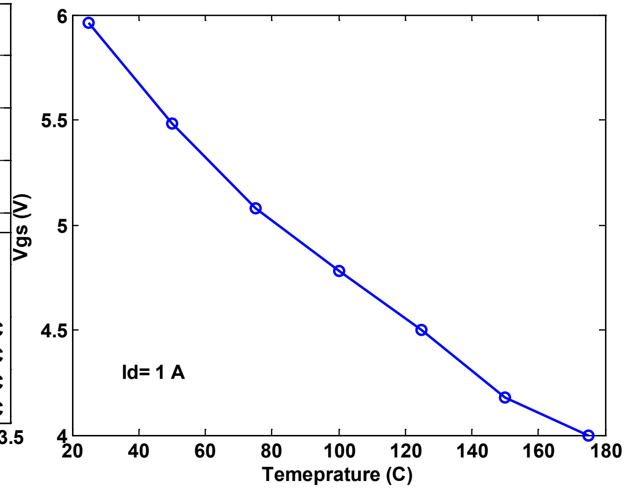
Comparison of simulated and test data

Technical Accomplishments – FY12

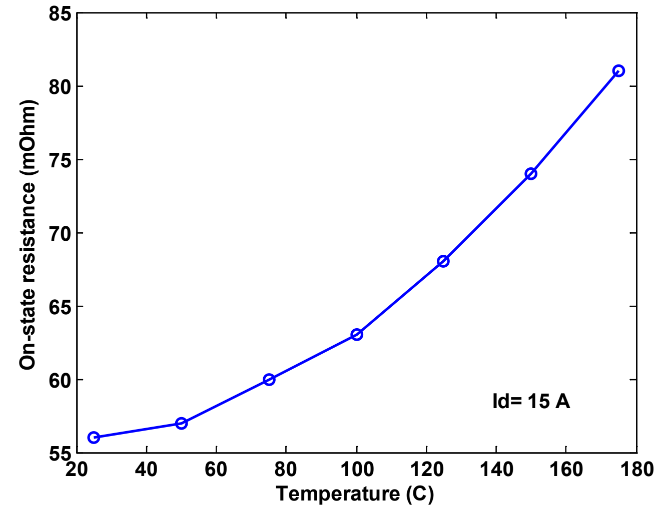
Forward characteristics



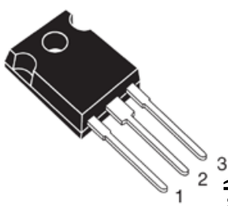
Transfer characteristics



On-resistance

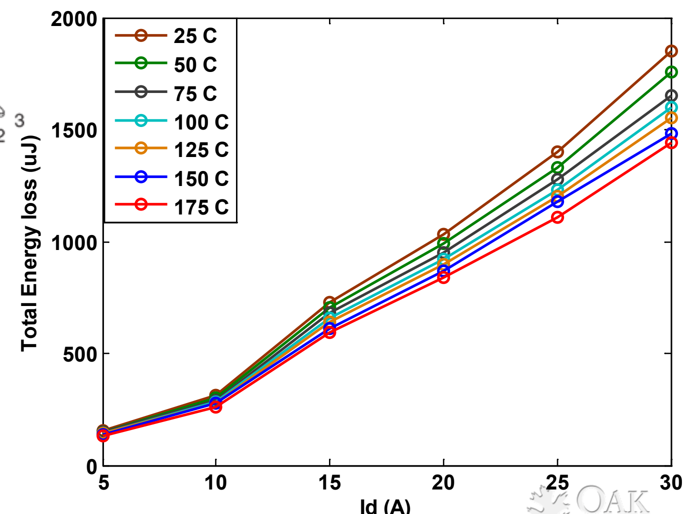


- Obtained 1200 V , 33 A SiC MOSFET, 1200 V, 100 A MOSFET, 1200 V 20 A SJT device and 1200 V, 50 A Schottky diode (bare die).
- The static characteristics of a 1,200 V, 33 A SiC MOSFET were obtained over a temperature range of 25°C - 175°C.
- The on-resistance increased from 0.055 Ohms at 25°C to 0.082 Ohms at 175°C.
- The threshold voltage at 1 A drain current decreases from 5.9V at 25°C to 4 V at 175°C.



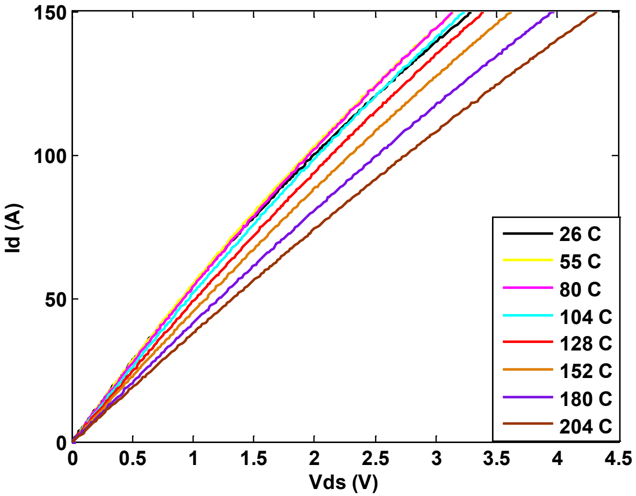
1,200 V, 33 A MOSFET TO-247

Switching losses of SiC MOSFET

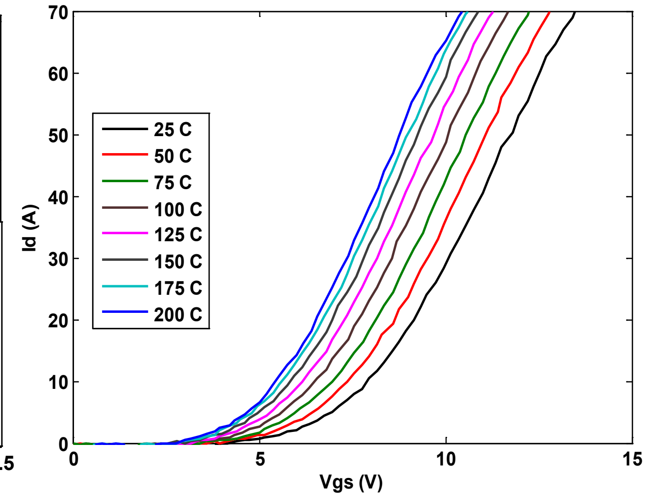


Technical Accomplishments – FY12

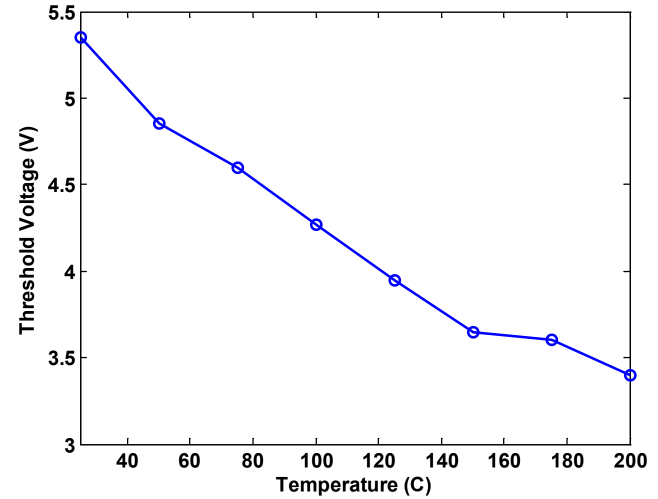
Forward characteristics



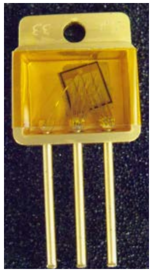
Transfer characteristics



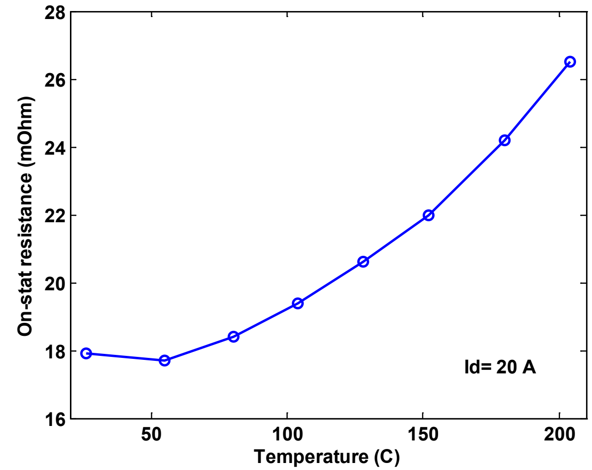
Threshold voltage



- The static characteristics of a 1,200 V, 33 A SiC MOSFET were obtained over a temperature range of 25°C - 175°C.
- The on-resistance increased from 0.018 Ohms at 25°C to 0.027 Ohms at 200°C.
- The threshold voltage at 1 A drain current decreases from 5.4 V at 25°C to 3.4 V at 200°C.



1,200 V, 100 A MOSFET



On-resistance

Device database:

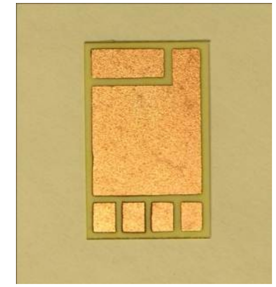
http://www.ornl.gov/sci/ees/etsd/pes/device_testing.shtml

Technical Accomplishments - FY12

High temperature test coupon

- **Test coupon capable of operating up to 250°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.**

1200 V, 50 A SiC Schottky diode

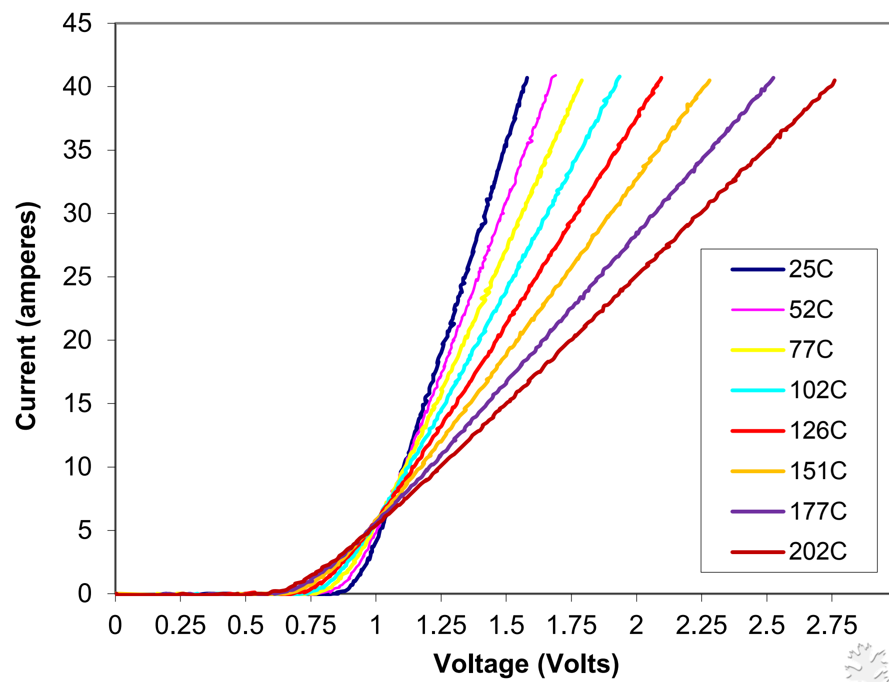


DBC Substrate

Test coupon for co-pack

Packages were developed at ORNL through the VTP packaging project

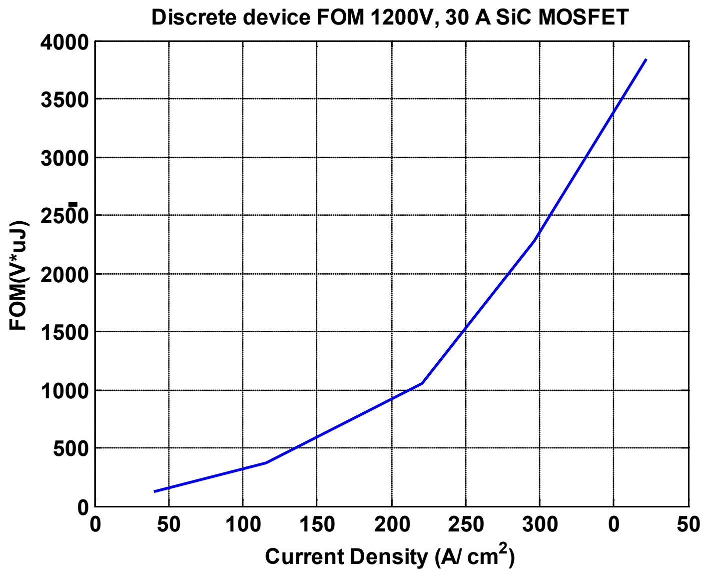
Diode Temp Profile

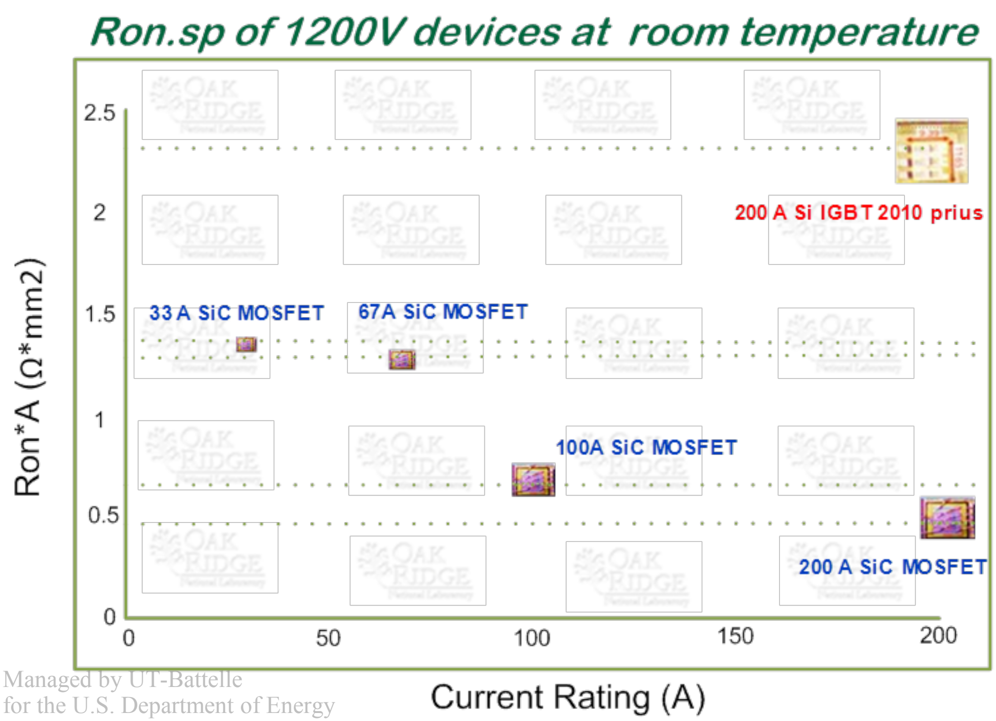


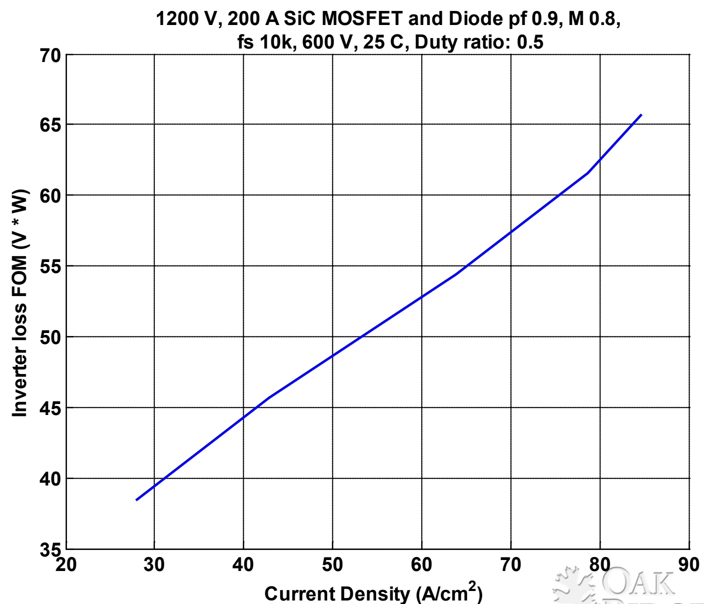
Accomplishments to Date- FY12 -WBG Assessment

- A survey was sent to several WBG device and wafer manufacturers.
- Received responses from four companies.

  The data will be used to evaluate $/cm^2 for WBG.
- Several figure of merits (FOM) were created.
  - Discrete device FOM
  - Inverter loss FOM
  - Capacitance FOM
- Comparison charts of devices parameters.
- Completed initial draft of the assessment report.







Technical Accomplishments – FY12

Survey Questions

1. What is the current density of the device at present and what is the maximum value that you are targeting for future?
2. What is the $/A cost of the devices that are currently available and what is the projected future cost with no packaging cost included?
3. What are the key steps in the manufacturing processes of the device that are the bottlenecks for reliability or for cost?
4. What is the timeline in terms of device availability for commercial automotive use?
5. What is cost of packaging for the discrete components and modules anticipated for the temperature limits that your devices can handle?
6. What is cost of packaging in percentage of the overall product?
7. What are the key applications that your products are anticipated to go into (other than automotive)?
8. What is the approximate cost of the (wafer/epi) for a particular size (3,4,6 inches)? Also please include the yield per wafer.
9. What are the key steps in the manufacturing processes of the wafer that are the bottlenecks for reliability or for cost?
10. What are the ratings of the device that you will be manufacturing (single discrete device)? Assuming that the packaging in not a limitation [voltage ,current, temperature] and what are the die sizes?
11. What is the market goal for your company for the successful commercialization of this technology?
    - Timeline for commercialization
    - Cost reduction as wafer size increases.

Collaboration and Coordination with Other Institutions

Industrial suppliers of WBG devices:

- SiC
  - GeneSiC
  - GE
  - Cree
  - USiC
  - Semisouth
  - Infineon
  - Fairchild
  - DOW

- GaN
  - International Rectifier
  - HRL
  - Transphorm
  - EPC

Future Work

- **FY12**
  - Continue to test and characterize new devices.
  - Integrate the high temperature test coupon into the automated test facility.
  - Complete the WBG assessment.
  - Complete the traction drive simulation for assessment of selected devices tested in FY11.
- **FY13 and Beyond**
  - Acquire, test, and characterize newer technology WBG power devices.
  - Develop behavioral SPICE models to aid ORNL packaging work.
  - Develop vehicle level system model for evaluating device performance.

Summary

- Devices tested and characterized (FY12):
  - 1,200 V, 50 A SiC JBS diode
  - 1,200 V, 33 A SiC MOSFET
  - 1,200 V, 100 A SiC MOSFET
- Testing of 1,200 V, 20 A SiC SJT and 1,200 V, 100 A SiC discrete devices will be completed.
- Automated device test facility upgrade:
  - New capacitance boards for high voltage testing have been built.
- A high temperature test coupon for device evaluation was built and tested with a SiC Schottky diode.
- WBG assessment:
  - The survey has been sent to WBG wafer and device manufacturers
  - Device comparison charts have been developed