U.S. DEPARTMENT OF ENERGY

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

Power Device Packaging

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2011 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

Project ID: APE023

Overview

Timeline

- **Start Date: Oct. 2009**
- **End Date: Sept. 2013**
- **40% Complete**

Budget

- **DOE Share – 100%**
- **FY11 received: $650K**
- **FY10 received: $480K**

Barriers

- **Existing automotive power module is one of the big obstacles to meet the VTP 2020 targets: Cost and Power Density**
- **State-of-the-Art power device/module packaging technologies have limitations in electrical, thermal, and reliability performance, as well as manufacturability**
- **Targets:**
  - **60% power density increase and 40%cost reduction, in line with DOE power electronics 2020 targets**

Partners

- **ORNL Team Members:** Puqi Ning, Andy Wereszczak, Randy Wiles, Laura Marlino
- **The University of Tennessee:** Fred Wang

Objective

The fundamental efforts of this project is to

Identify the limitations and shortcomings with existing device packaging approaches;

Develop new packaging concepts for improved electrical performance, thermal management, reliability, and manufacturability; and

Complement other packaging and thermal management research efforts within the VTP Program.

FY11

- **New power module packaging development: electrical and thermal, thermo-mechanical performance evaluation and characterization, material/structure selection**
- **Sample modules fabrication, testing and analysis**
- **Continue to benchmark State-of-the-art (SOA) technologies and supply data to NREL for thermal/reliability modeling and simulation**
- **Provide packaging support for other APEEM projects**

Milestone

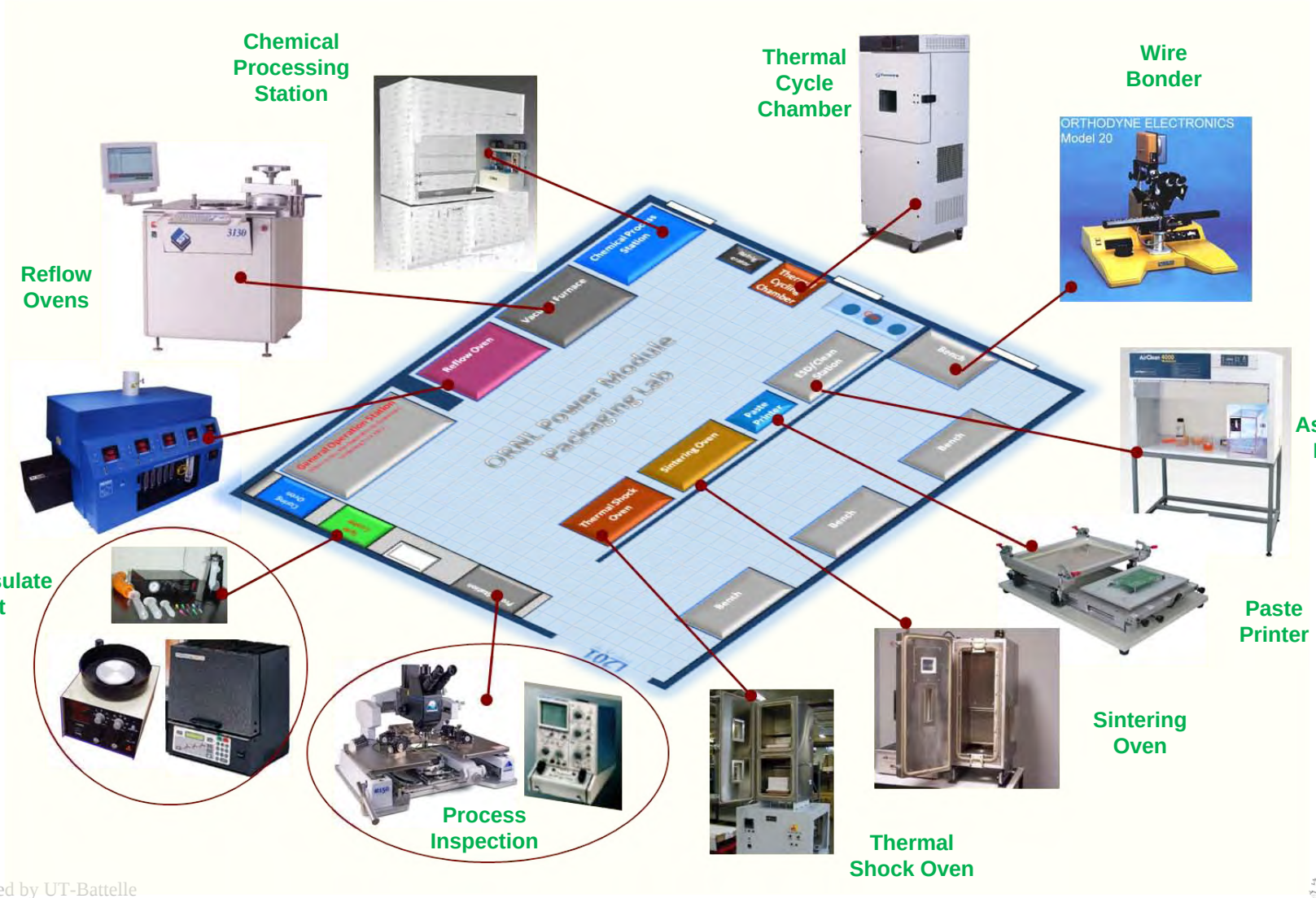
- **Sept. 2010** - Selected/developed candidate technology concepts.
- **Go No/Go Decision Point**: Determined if selected candidate packaging technologies could potentially meet the cost and density targets without compromising performance and reliability.
- **Sept. 2011:** Developed power modules offers improved performance in electrical, thermal and thermo-mechanical aspects; provided packaging support to other projects.
- **Go/No Go** – Whether the developed power modules have been identified that meet the target on cost and power density without compromising performance and reliability.

Approach

- **Develop in-house power electronics packaging capabilities**
  - **Processing facilities for power electronics module packaging**
  - **Equipments and technologies for electrical, thermal and thermo-mechanical characterization and analysis**
  - **Software and tools for power module design and analysis**
- **Benchmarking the state-of-the-art technologies**
  - **Comprehensively analyze the SOA automotive power modules**
  - **Micro-structural, mechanical and material characterization and analysis of SOA module packaging technologies**
  - **Electrical, thermal and thermo-mechanical characterization of SOA power modules**
- **Develop new power electronics packaging technologies**
  - **Electrical, mechanical structure optimization**
  - **High temperature, CTE matched material development**
  - **Processing innovation**
- **Provide prototype packaging and samples for other projects within the program**

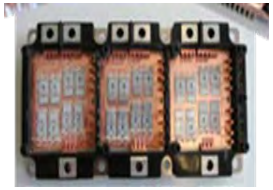
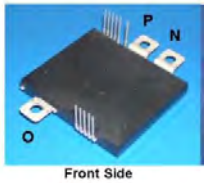
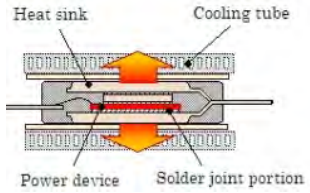
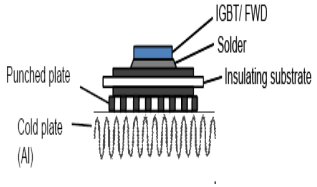
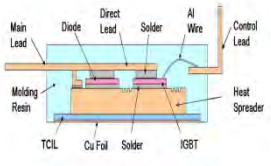
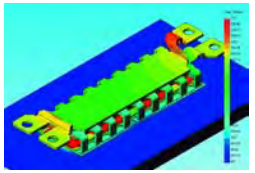
FY11 Technical Accomplishments (1)

Integration of Power Electronics Packaging Capabilities



FY11 Technical Accomplishments (2)

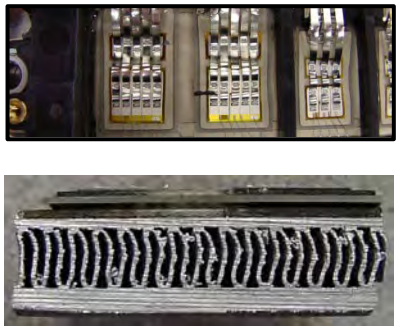
General Evaluation of SOA Automotive Module Packaging

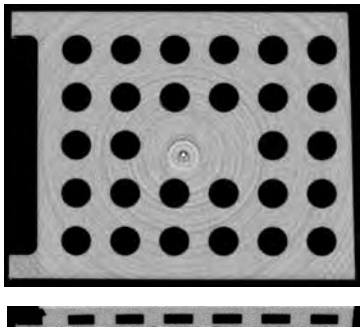
	Toyota LS600	Toyota Prius III	Infineon Hybridpack2	Mitsubishi TPM	Semikron SKiM
Module					
Features					
Advantage	• Double sided planar interconnection; • No baseplate; • Double sided cooling.	• Direct bond cooler; • No base plate; • No TiM layer; • Al Ribbon bond.	• Direct cooled base plate; • No TiM layer; • Integrated cooler.	• No DBC substrate; • Phase leg unit; • Direct planar lead bond;	• No base plate; • Press contact; • Ag sintered die attach.
Disadvantage	• Complex inverter (electrical and thermal) assembly; • Ceramic slice insulation and double TiM layers.	• Stress relax buffer layer worsen thermal conductivity; • Large electrical parasitic parameters.	• Difficulty in pin fin manufacture; • Large electrical parasitic parameters; • Difficult integration of cooler.	• Double TiM layers; • Poor thermal of TCIL; • Module level assembly needed.	• Mechanical integrity concern; • Large electrical parasitic parameters; • Poor TiM layer uniformity.

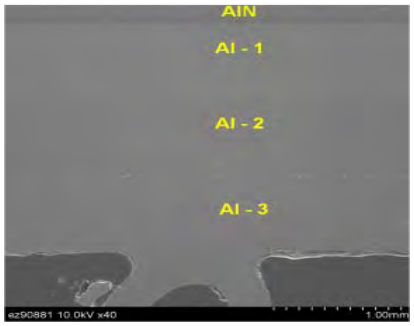
FY11 Technical Accomplishments (3)

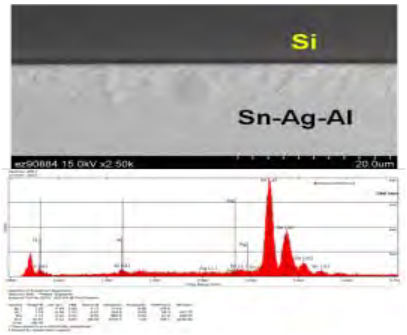
Microstructure & Mechanics Examination of SOA Packaging

Prius 2010

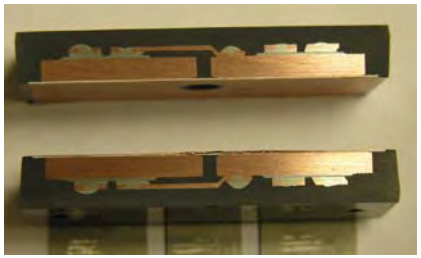


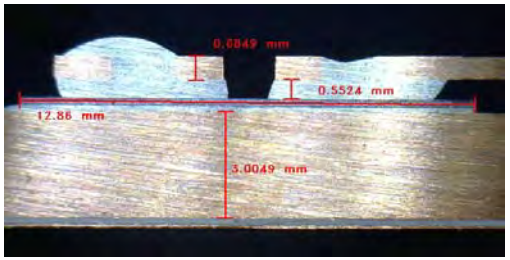


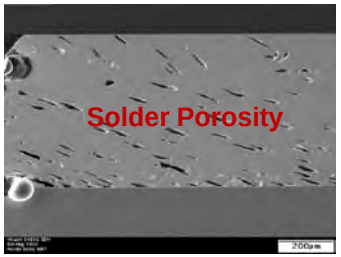


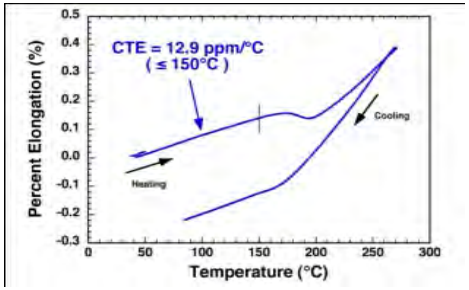


TPM

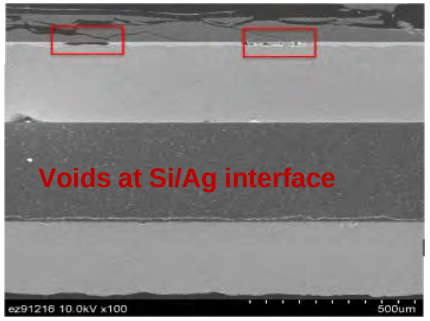


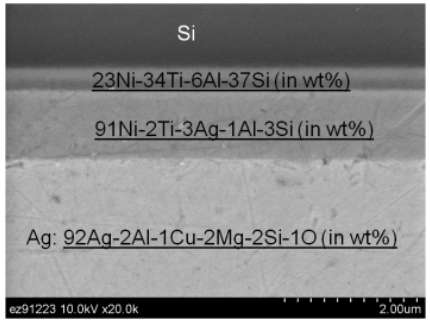




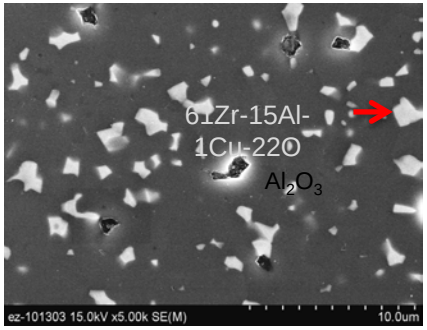


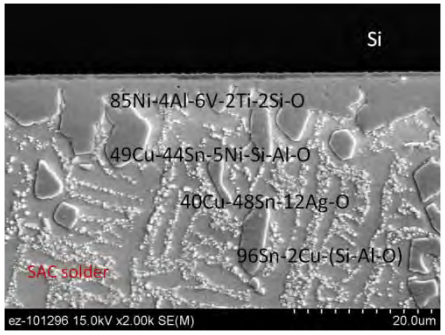
SKiM





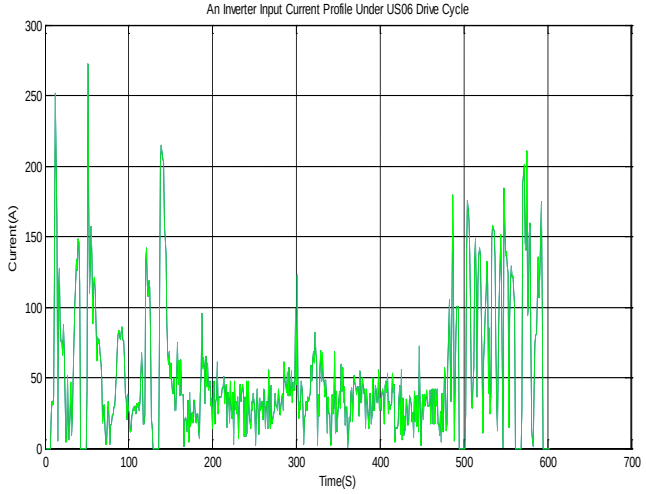
HybridPack

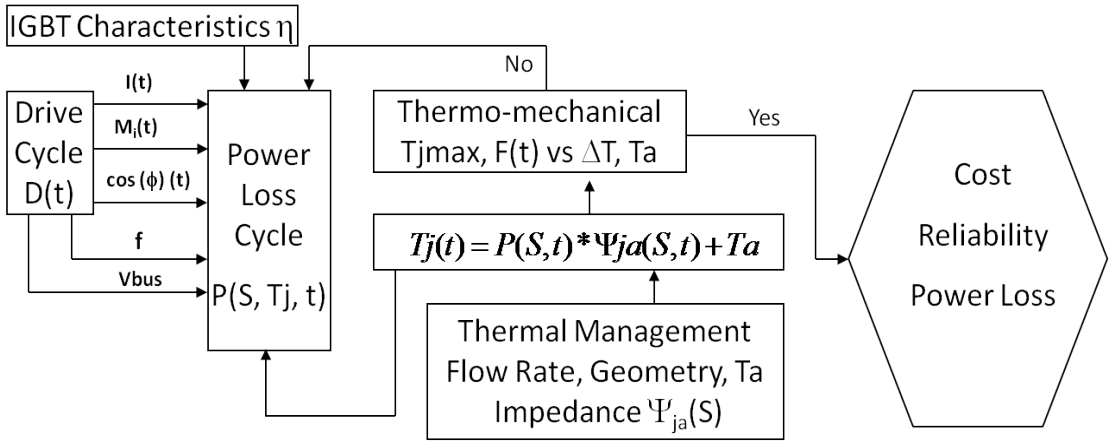


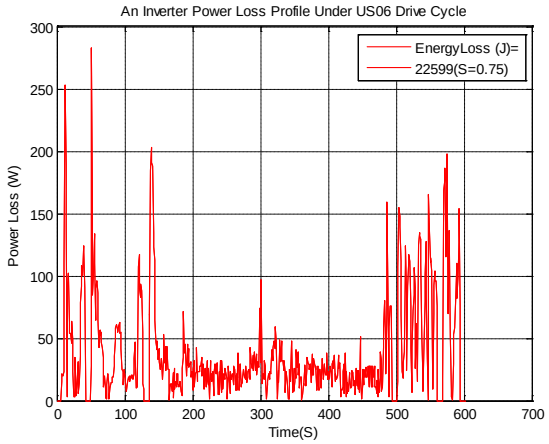


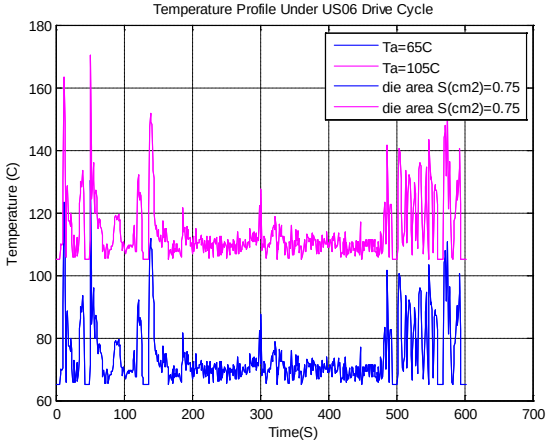
FY11 Technical Accomplishments (4)

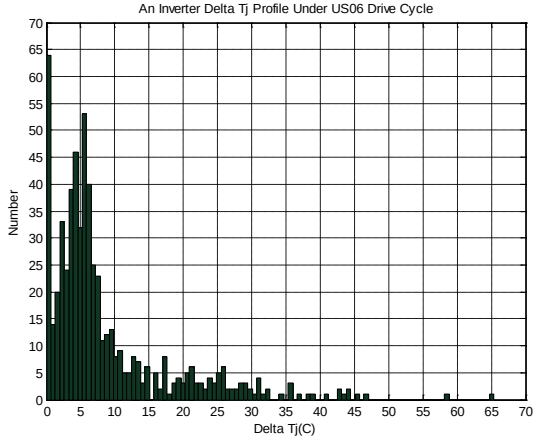
Automotive Power Module Design/Analysis Tool





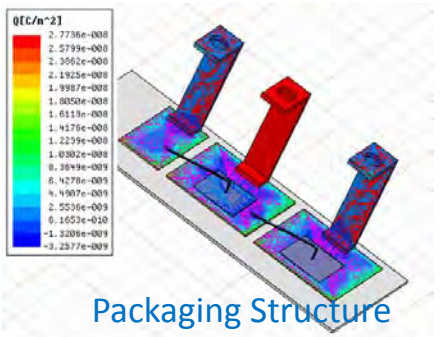


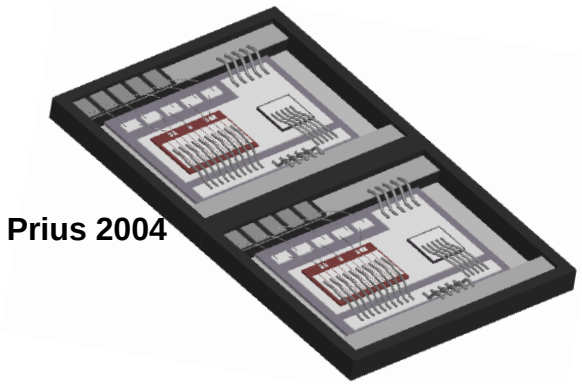


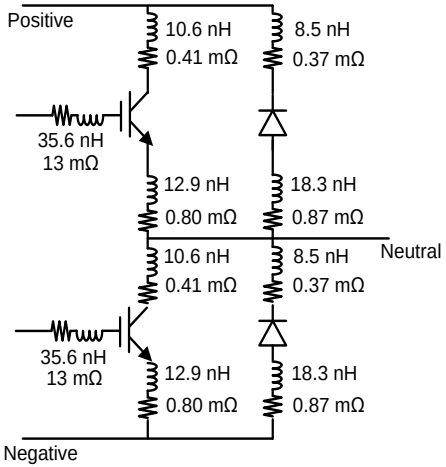


FY11 Technical Accomplishments (5)

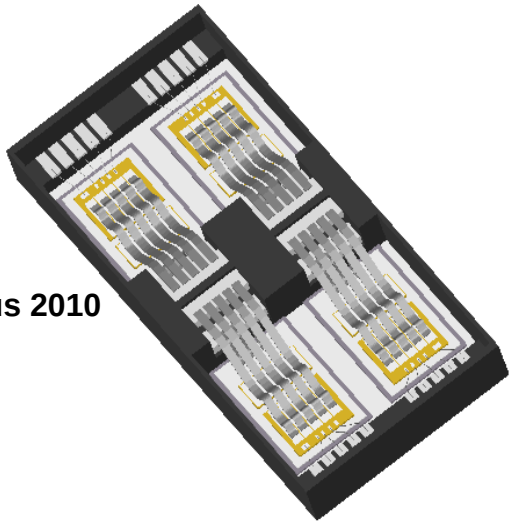
Electrical Examination of SOA Module Packaging

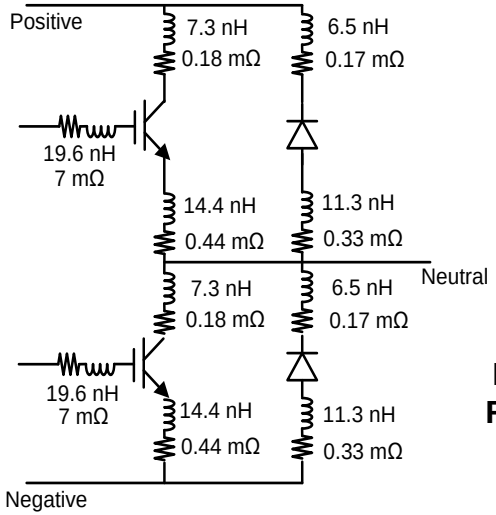






L=50.3nH
R=2.35mΩ

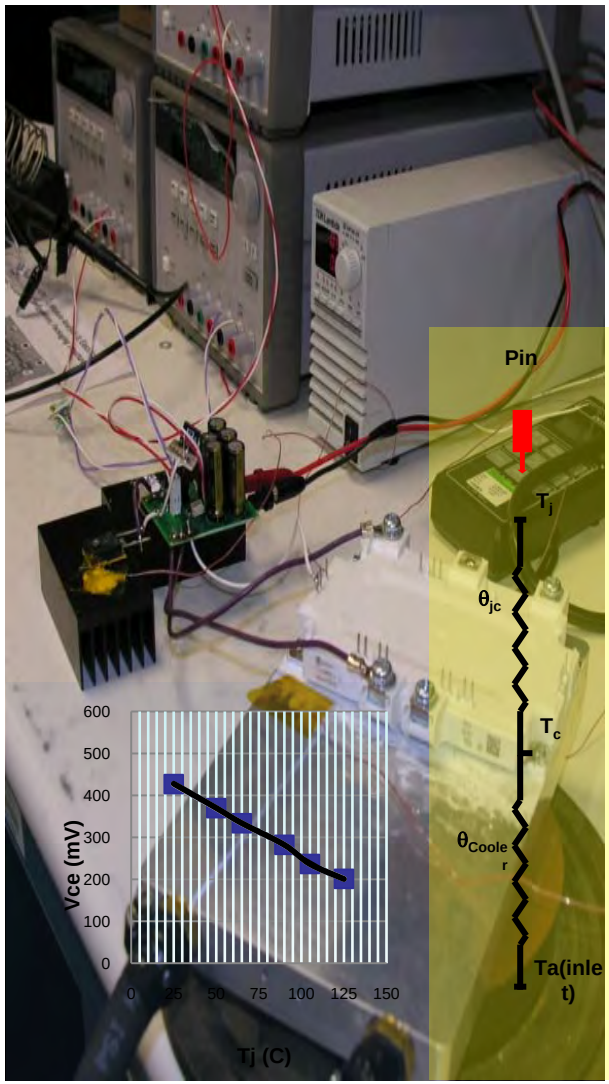


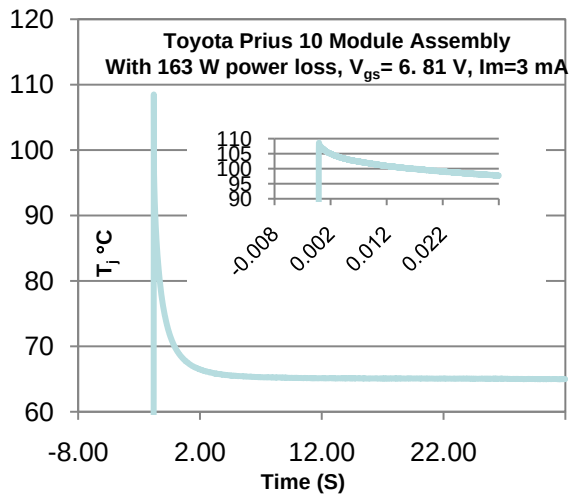


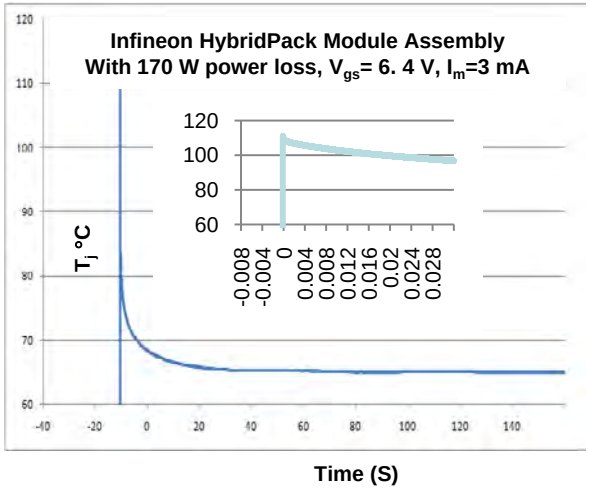
L=39.5nH
R=1.12mΩ

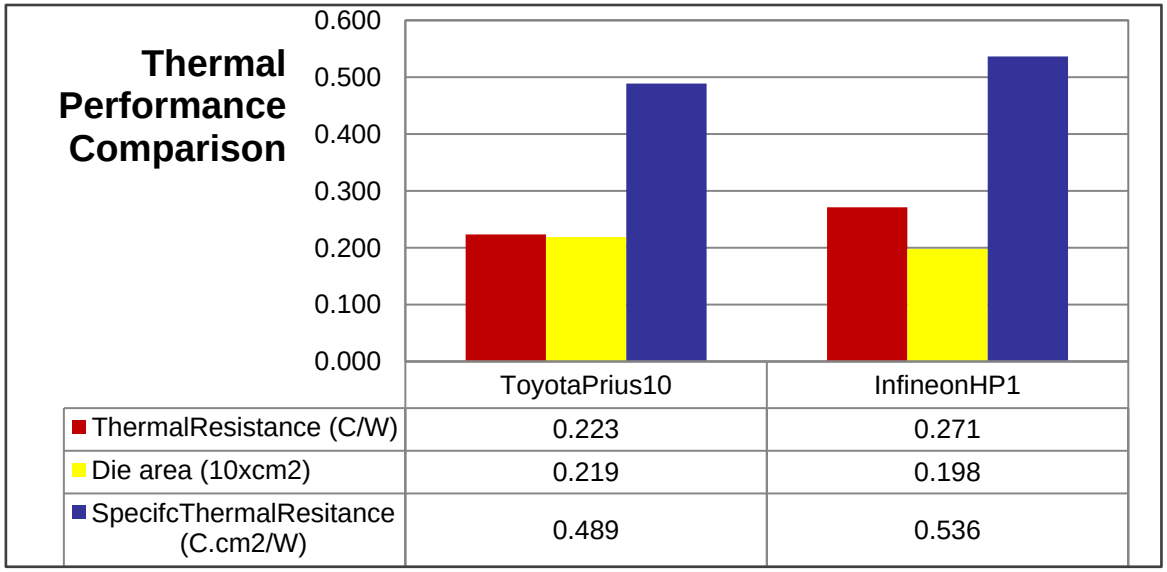
FY11 Technical Accomplishments (6)

Thermal Performance Examination of SOA Module Packaging





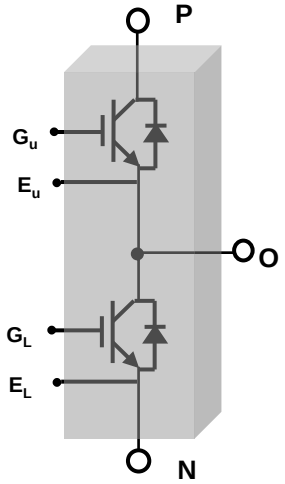




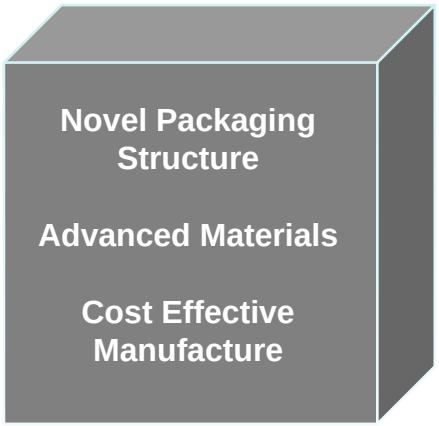
	ToyotaPrius10	InfineonHP1
ThermalResistance (C/W)	0.223	0.271
Die area (10xcm2)	0.219	0.198
SpecifcThermalResitance (C.cm2/W)	0.489	0.536

FY11 Technical Accomplishments (7)

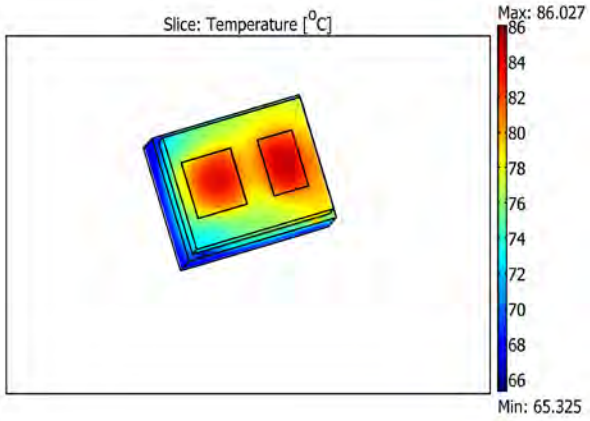
Develop New Packaging Concepts: Performance and Cost



Module Electrical Schematic

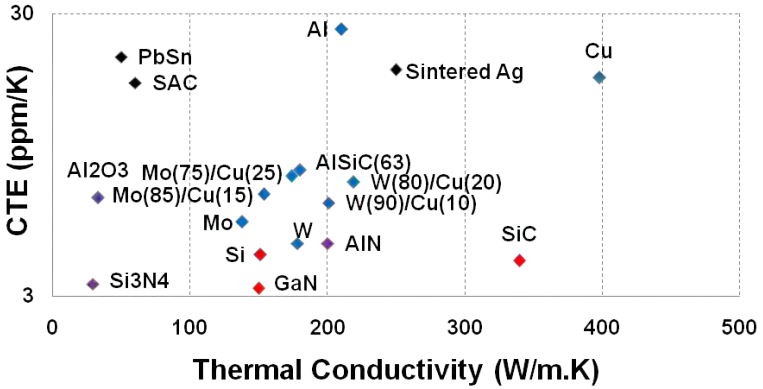


Advanced Power Device Packaging Design

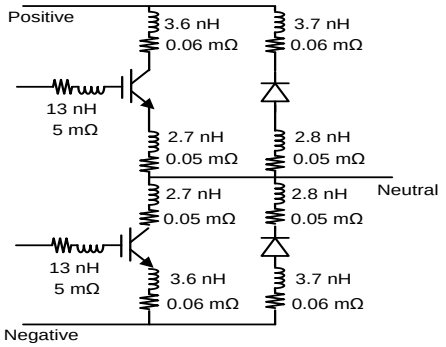


60% Thermal Performance Improvement of Infineon HP1

200°C Reliable Operation Temperature; Material Selection



Electrical Parasitic Parameters (20-30% of Prius)

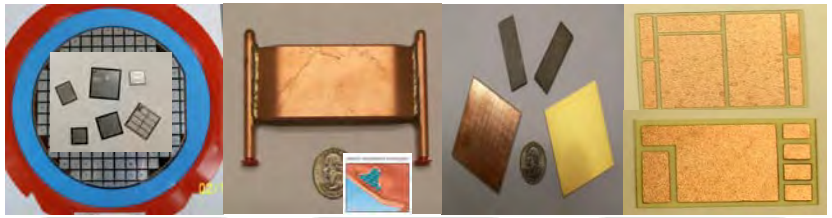


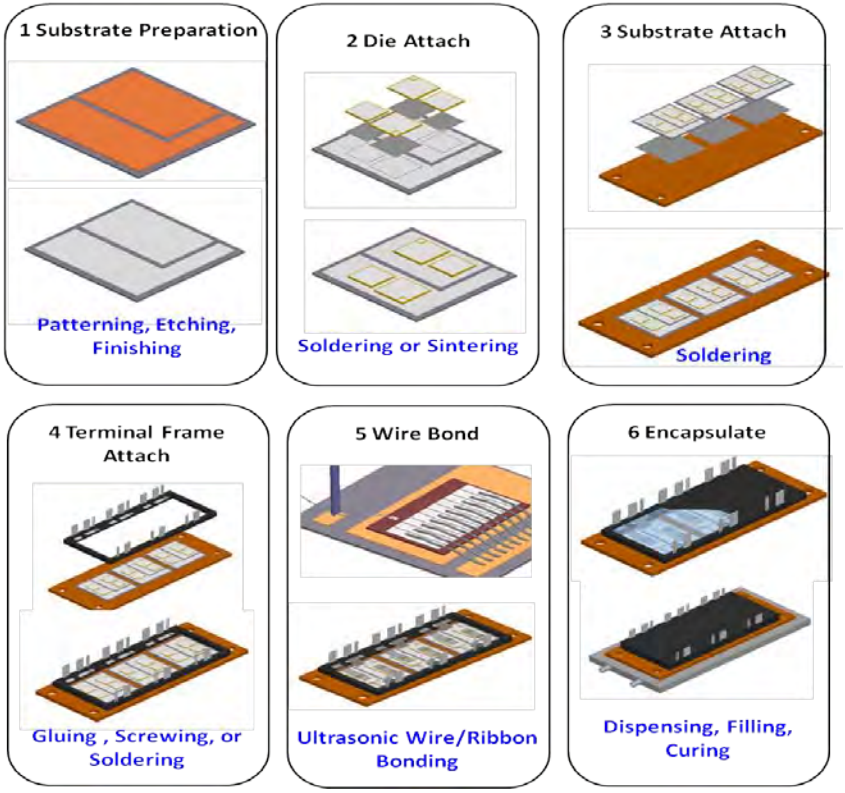
L=12.8nH

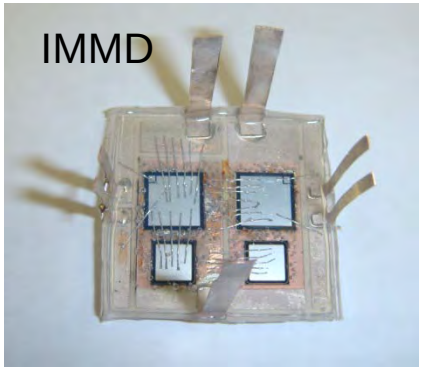
R=0.22mΩ

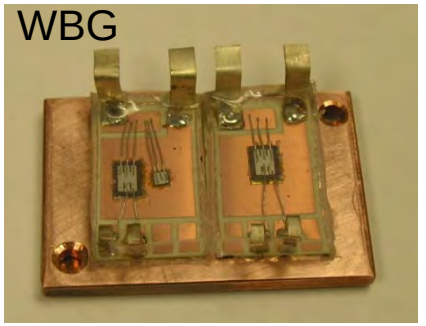
FY11 Technical Accomplishments (8)

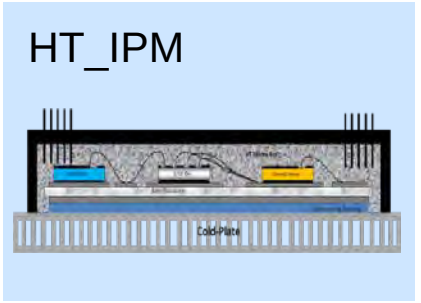
Packaging Materials and Processes Development and Support Other Projects within the Program











Collaboration and Coordination

- **NREL**
  - **Collaborated within the Vehicle Technologies Program on thermal management/reliability**
- **ORNL Materials Science and Technology Division**
  - **Funded by DOE Materials Program**
  - **Coordinated their research activities to serve the materials need of power electronics packaging**
- **University of Tennessee**
  - **Subcontractor, to help benchmark commercial packages**
- **Virginia Tech University**
  - **Collaborated on die attach material and power electronics module packaging**

Future Work – FY11

- **Complete fabrication of the new concept power modules in-house**
  - **Complete the fixtures design and process parameters selection**
  - **Complete the process integration for designed all planar bonding structure**
  - **Conduct preliminary performance tests**
- **Continue to evaluate and down select packaging technologies (materials and processes)**
- **Continue to support new power electronics module development**

Future Work – FY12 and Beyond

- **Power module packaging structure optimization**
  - **Electrical and thermo-mechanical performance evaluation and characterization, based on the experimental data**
- **Inverter-level packaging study and new concept development**
  - **Integration of power modules into high density inverter/converter**
- **Testing and analysis**
  - **Electrical, thermal, and thermal-mechanical properties**
- **Continue to benchmark SOA technologies**
- **Continue materials evaluation and process development for high temperature power module**
- **Provide packaging support for other projects**

Summary

- **The in-house power electronics packaging capability has been enhanced, which enables greatly advanced packaging technology development.**
- **The state-of-the-art automotive power modules and their packaging technologies have been benchmarked by various methods, electrically, thermally and mechanically.**
- **An advanced automotive power module has been designed. The associated packaging materials and processes development have been performed.**
- **The power electronics packaging support has been provided for several projects in the portfolio.**