High Temperature Power Electronics at ORNL

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Oak Ridge National Laboratory

FreedomCAR APEEM Activity Focuses on Electric Drive Systems

- Fuel Cell Vehicle (FCV)
  - **Primary interest**
  - **Sizes: subcompact through SUV**
- Plug-in Hybrid Electric Vehicle (PHEV)
  - **R&D needs being evaluated**
- ICE Hybrid Electric Vehicle (HEV)
  - **Near-term path for introduction**
  - **Focus on mid-size and larger full hybrid**
- Components and Subsystems Developed for FCV Applicable to PHEV & ICE HEV

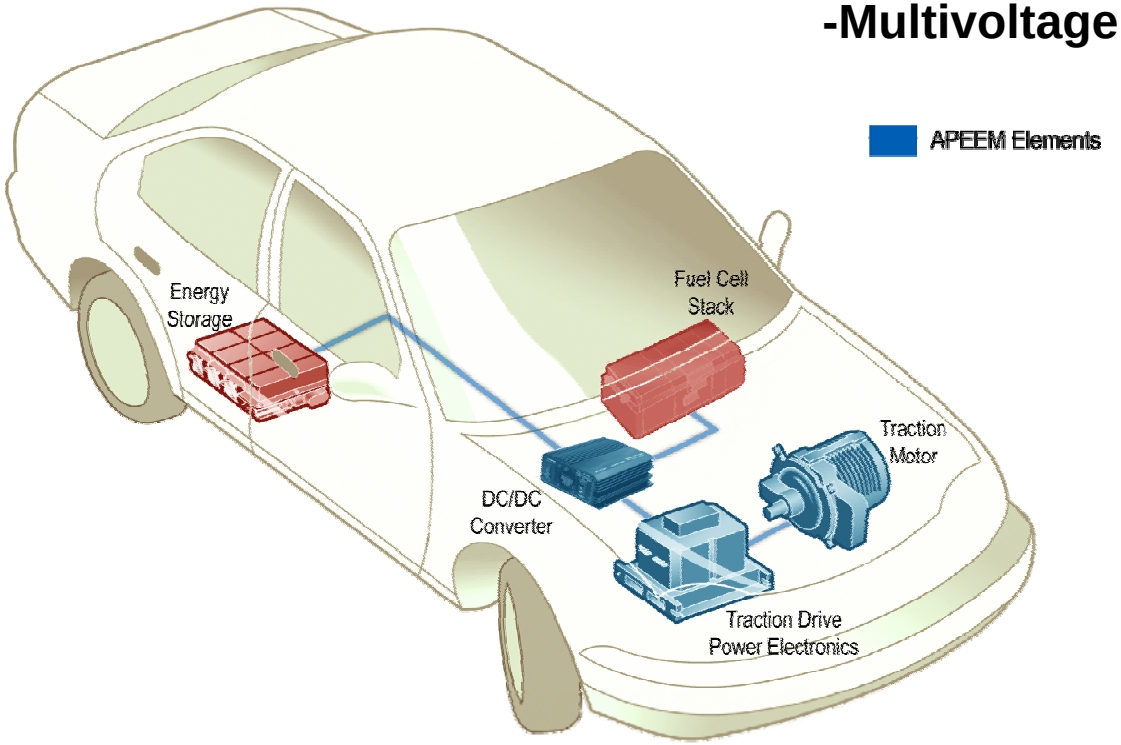
Fuel Cell Powertrain Hybrid Design

Traction Drive

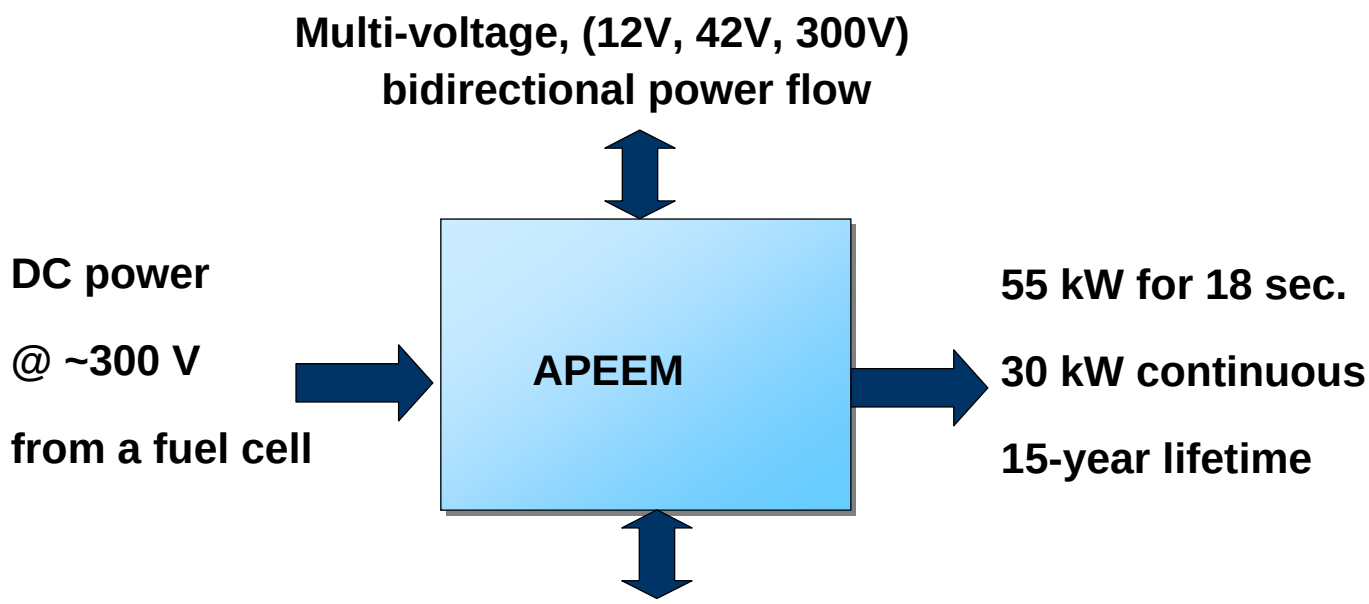
- **Electric Machines**
- **Power Electronics - Inverter & Boost Converter (if needed)**

Vehicle Power Management

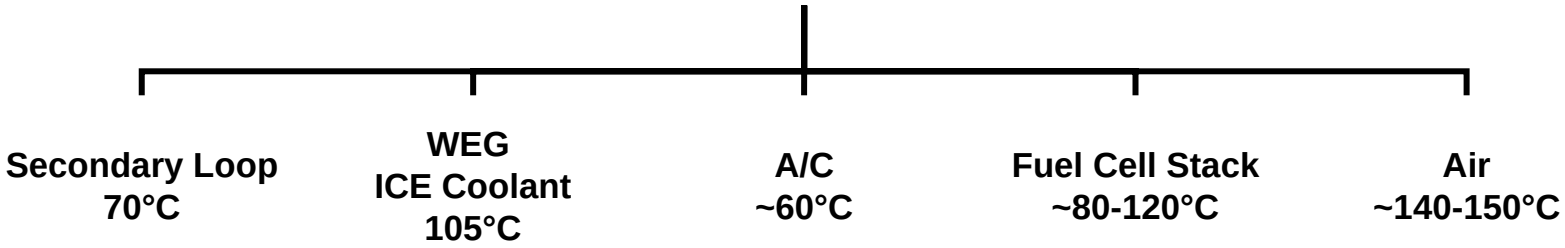
- **DC/DC Bidirectional Converter(s)**
  -Multivoltage 12 V, 42 V, ~300 V buses



Requirements for FCVs Provided by Goal and Function

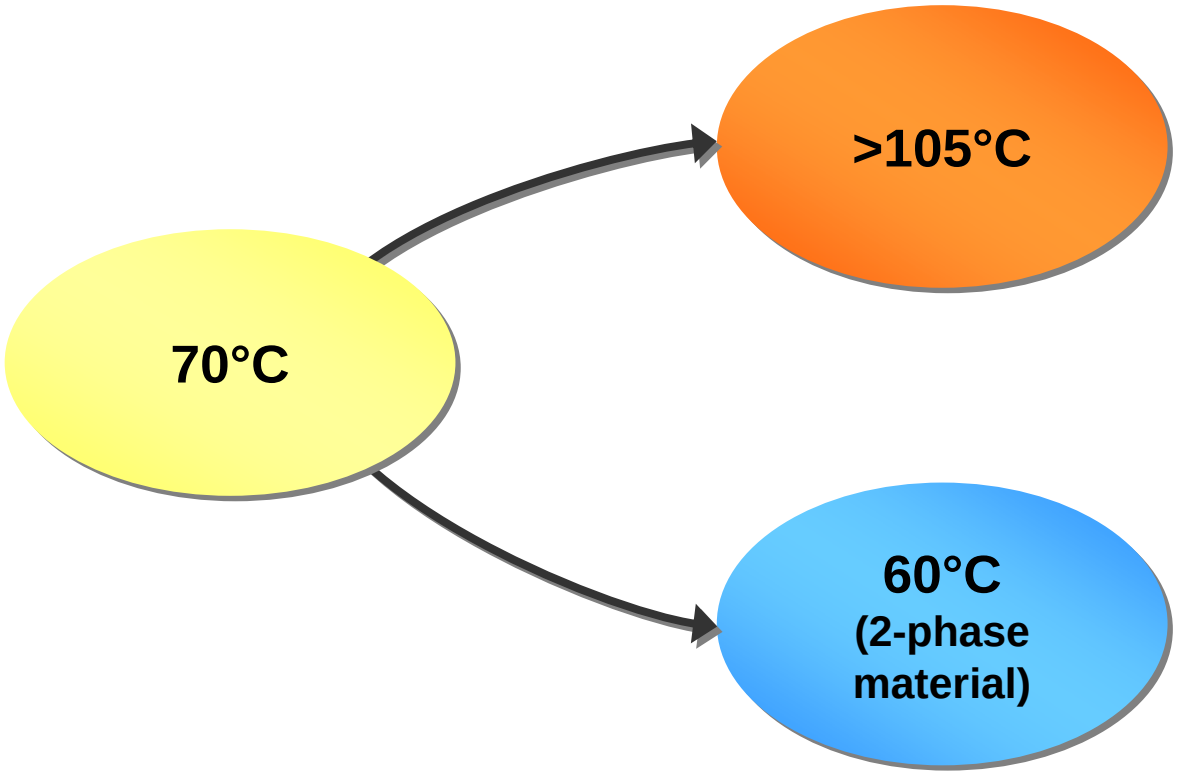


Heat Sink Options

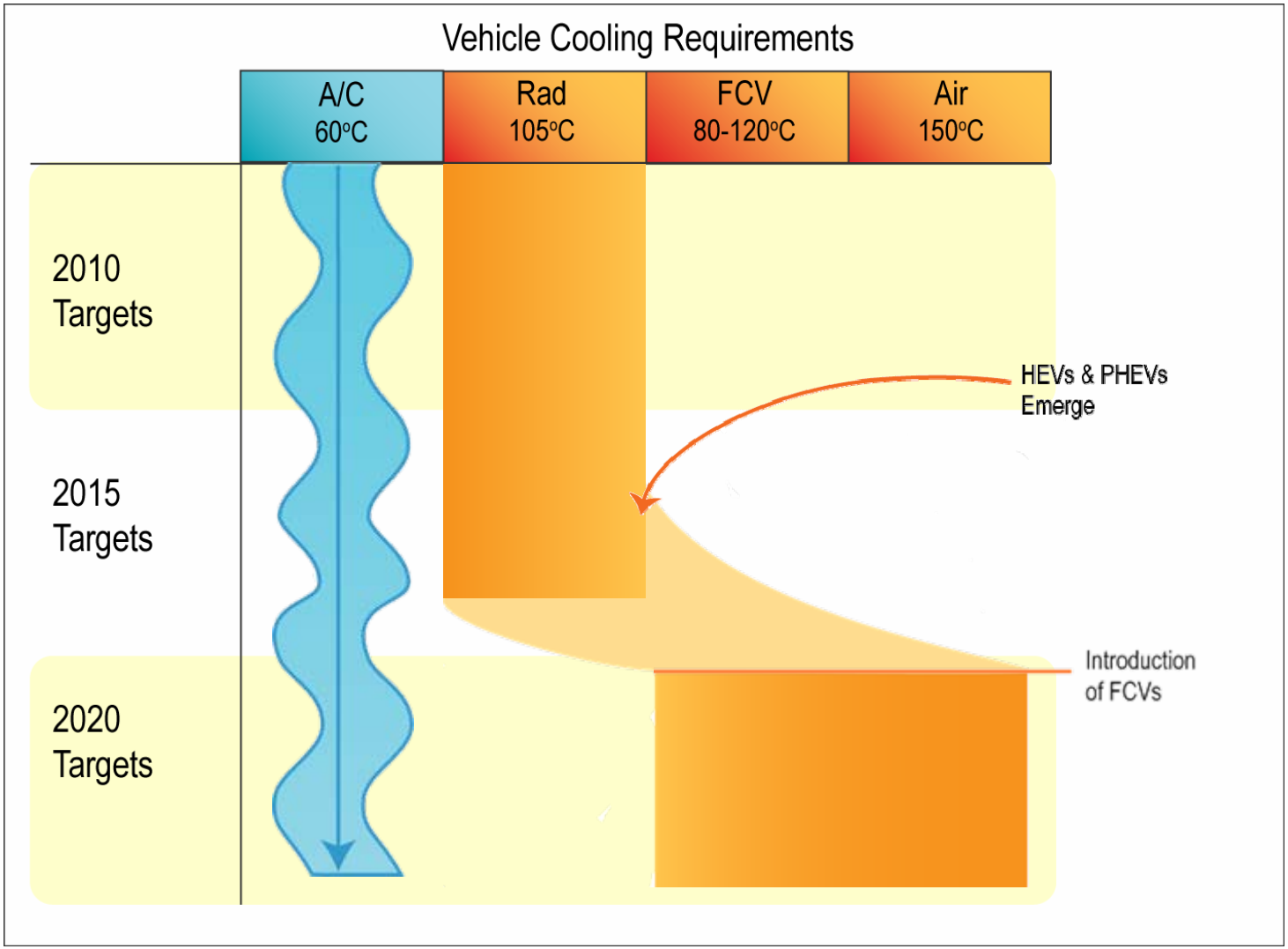


Cooling Requirements Give R&D Activity Structure

- **Two Pathways**



Cooling Requirements Give R&D Activity Structure



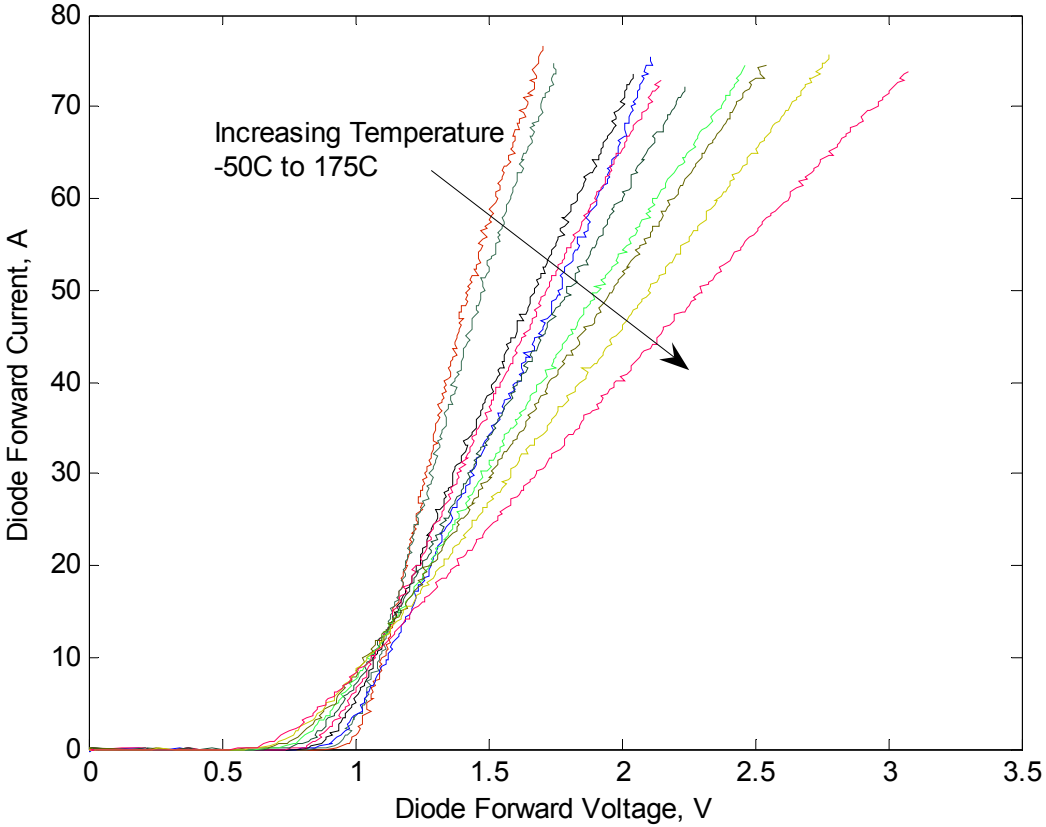
High Temperature Component Requirements

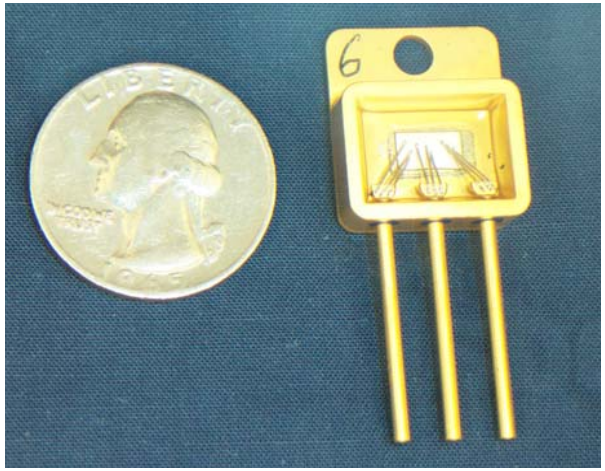
- **Devices - Switches and diodes (>200°C junction temperature)**
- **Device Packaging**
- **Gate drivers and control electronics (>150°C ambient temperature)**
- **Capacitors – Film? Ceramic?**
- **Magnetics**

High-temperature PE work at ORNL

- **Test, characterize, and model SiC and GaN power devices (SiC Schottky diodes, JFETS, MOSFETs, and GaN Schottky diodes)**
- **Build behavioral simulation models to assess the system-level impact of these devices (dc-dc converter and inverter models).**
- **Build power converters utilizing SiC devices (55kW inverter with SiC Schottky diodes, 7.5kW all-SiC inverter, low power dc-dc converters and choppers)**
- **High temperature packaging for power devices.**
- **High temperature gate drives.**

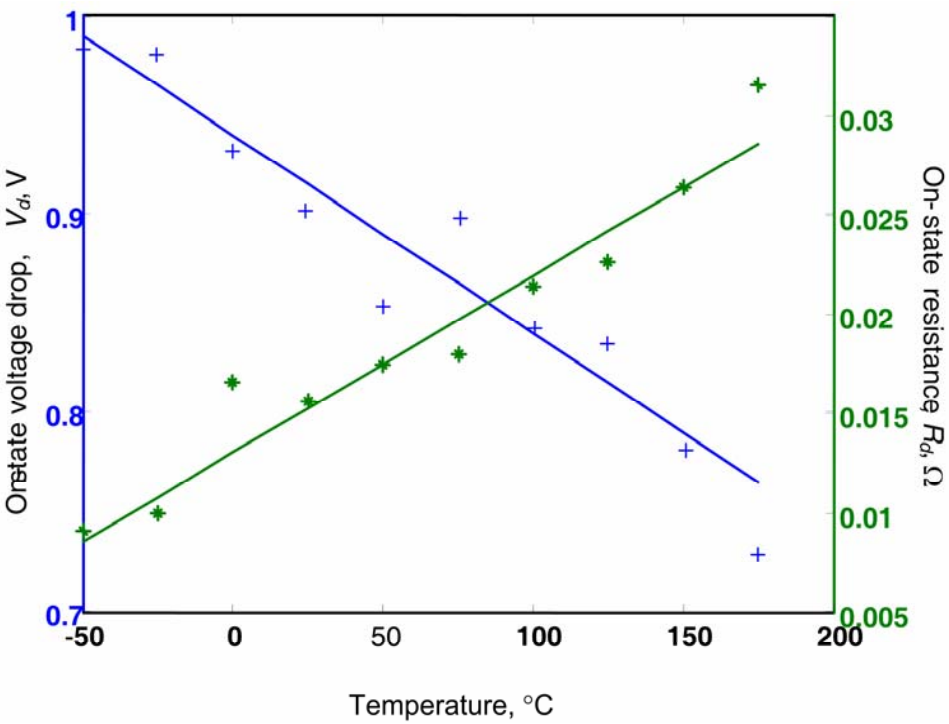
CREE's SiC Schottky Diodes



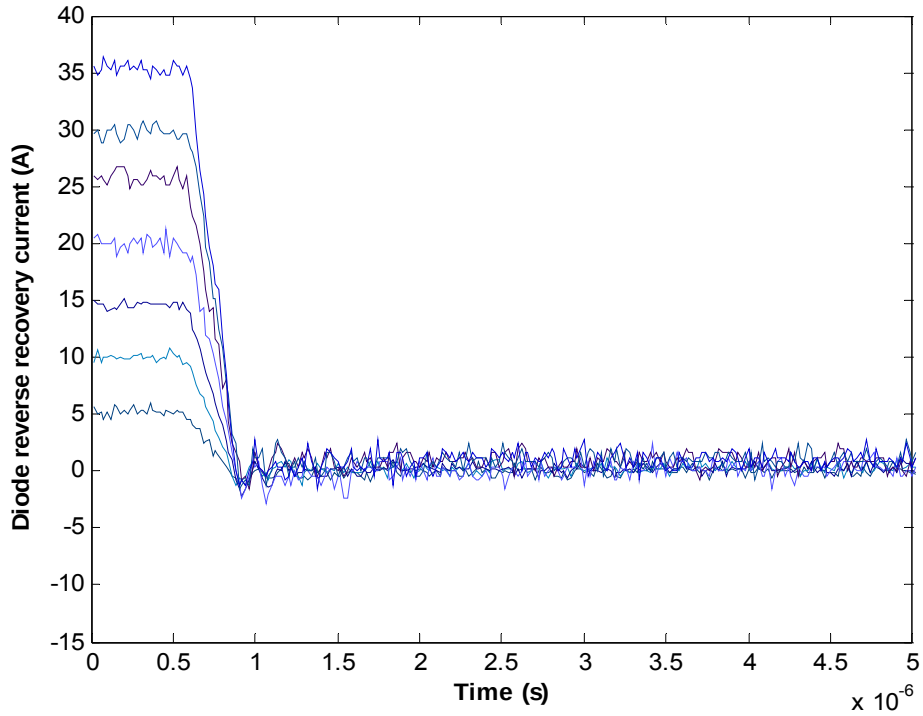


I-V curves of the 75A SiC Schottky diode

CREE's SiC Schottky Diodes (cont'd)

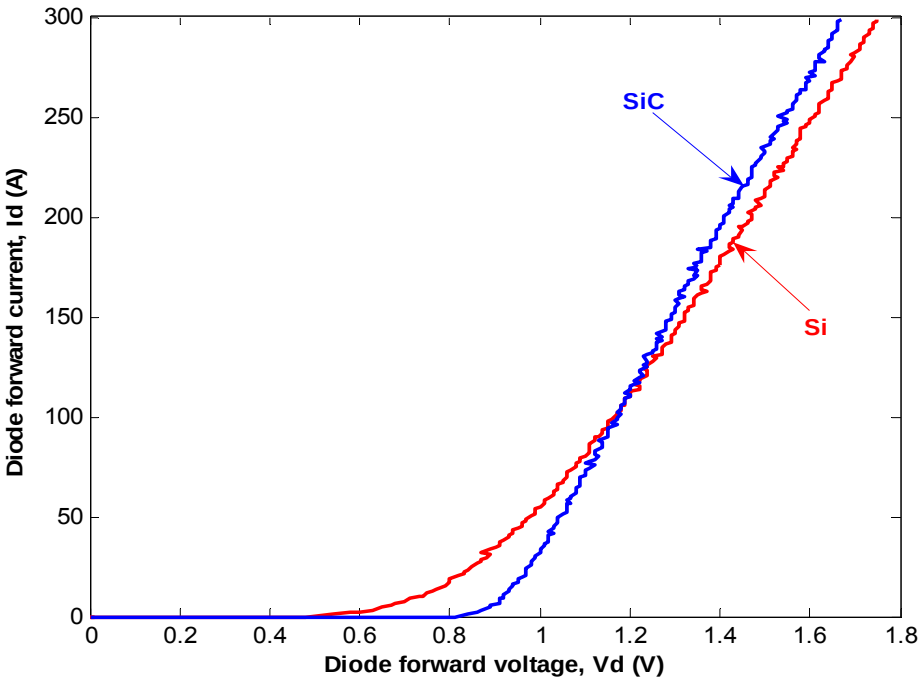


Piecewise linear model parameters

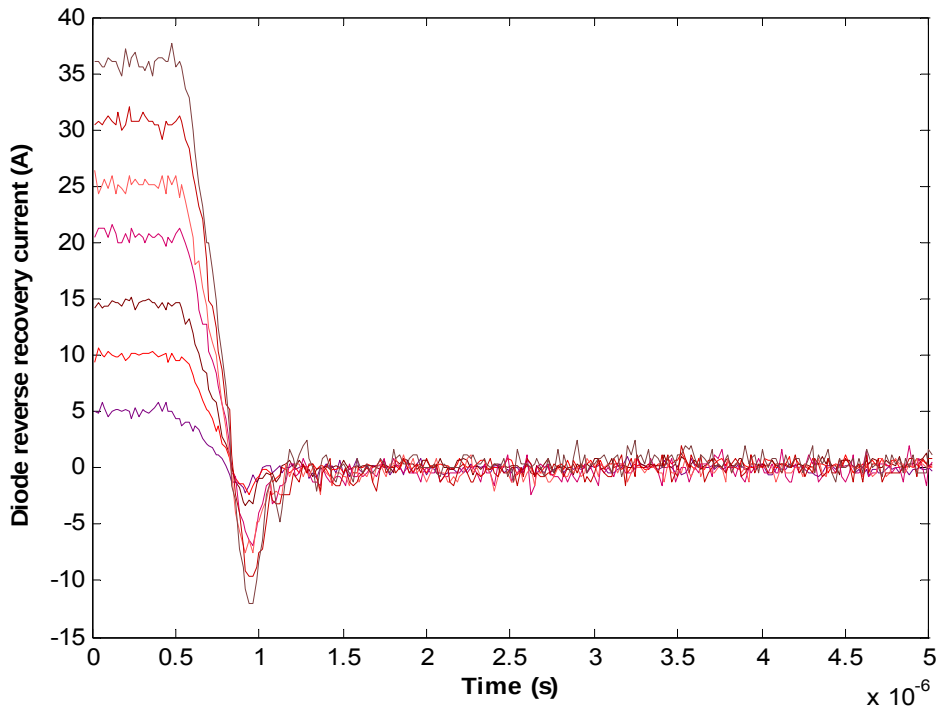


Reverse Recovery waveforms of 75 A SiC diode

Comparison of Si and SiC Diodes

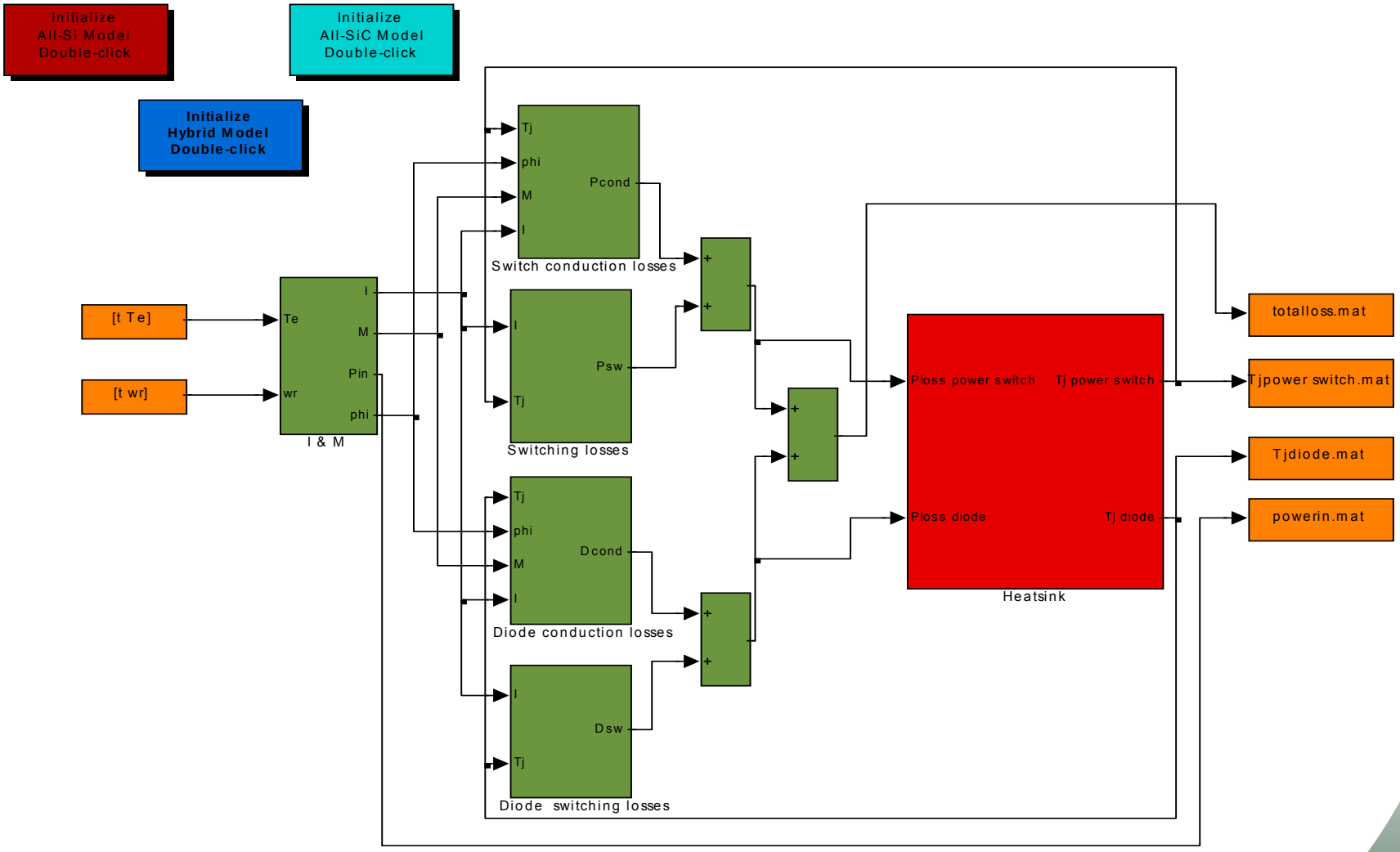


The static characteristics of the packaged 600 v/ 450 a SiC Schottky and Si pn diodes at room temperature.

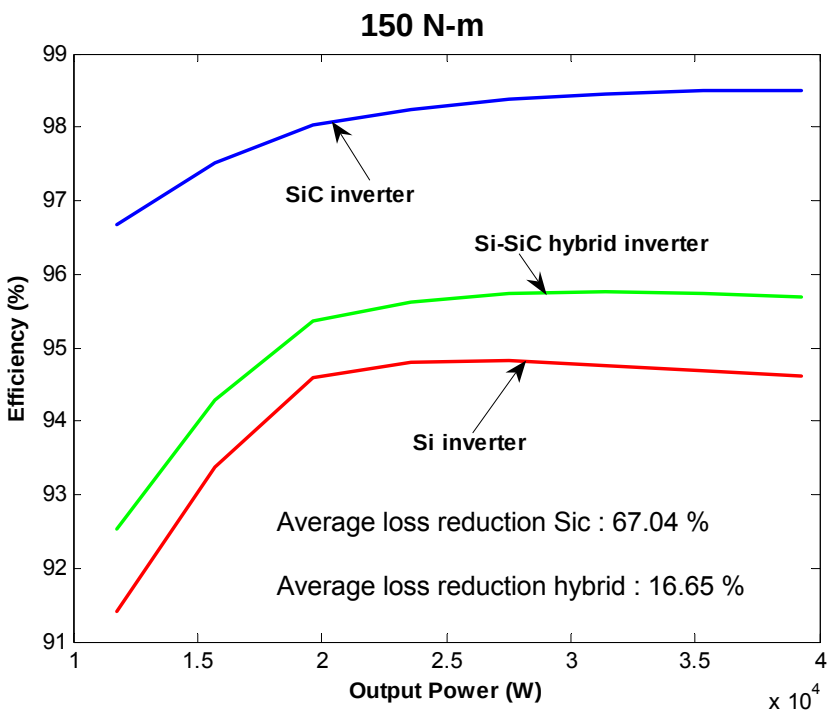


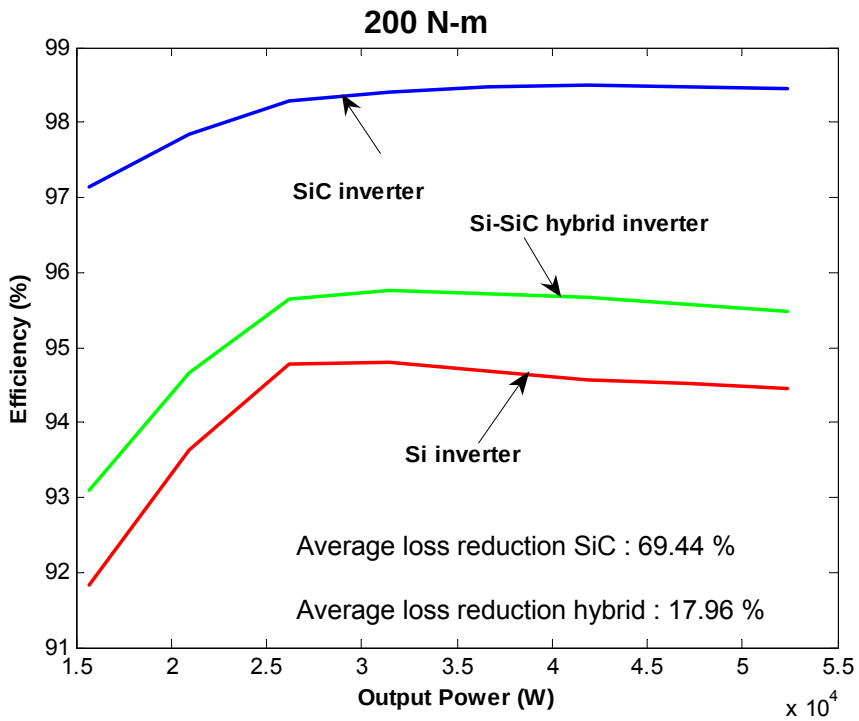
Reverse Recovery waveforms of 150 A Si diode

Simulink model of the 55kW inverter



Inverter efficiencies (25°C ambient)





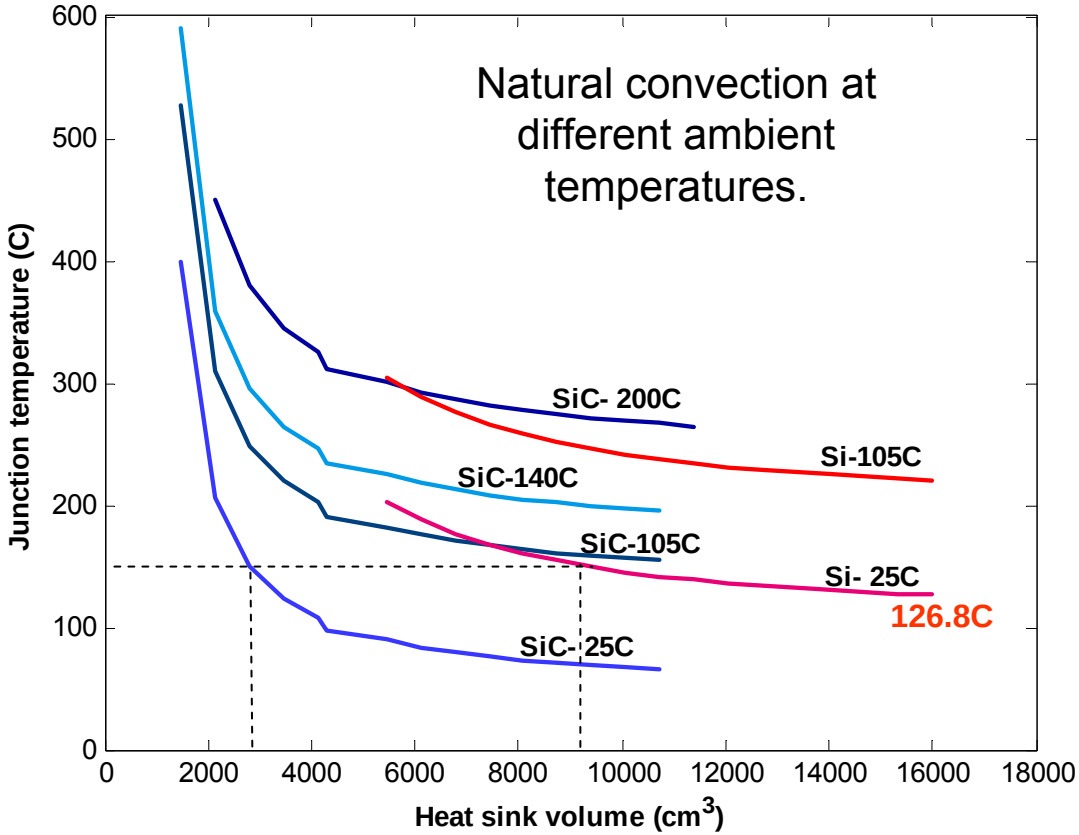
Si inverter: IGBT 600 V, 50 A (175°C)
Diode 600 V, 75 A (175°C)

SiC inverter: JFET 1200 V, 10 A
Diode 600V, 75A

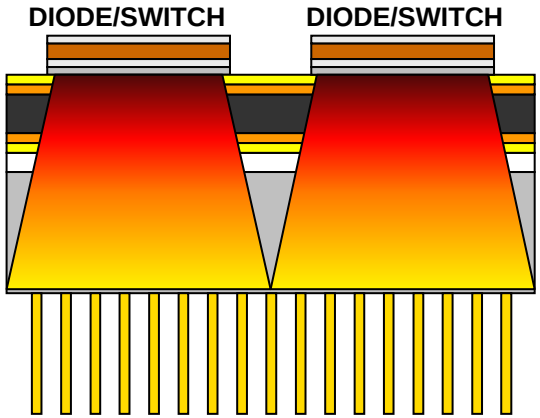
Scale

Power switches – 600 V, 600 A
Diodes – 600 V, 450 A

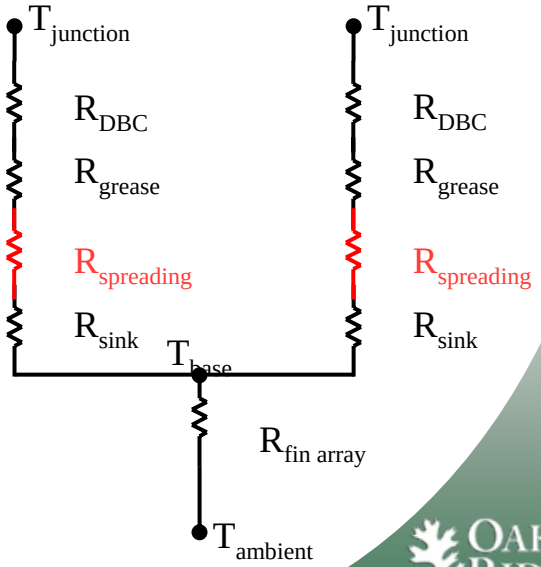
Heat sink volume comparison for Si and SiC inverters



2/3 VOLUME REDUCTION

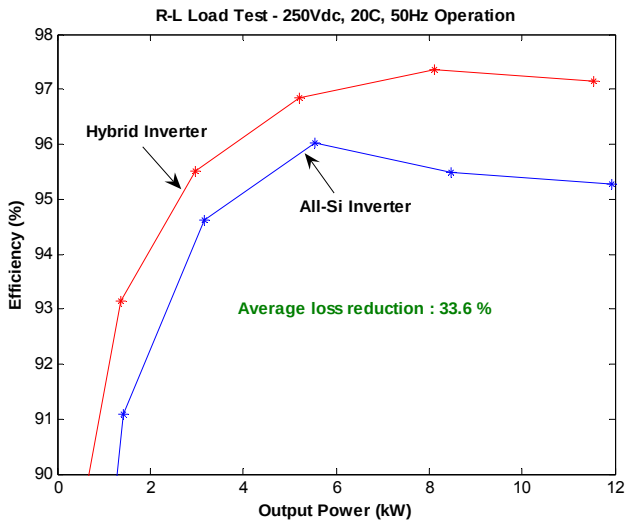


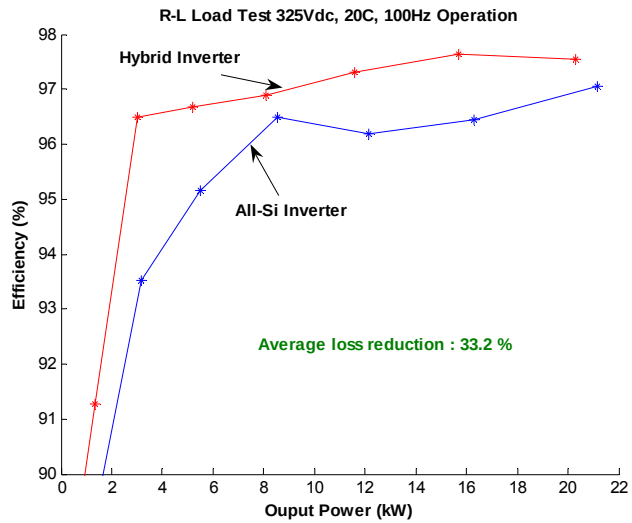
Equivalent Thermal Circuit

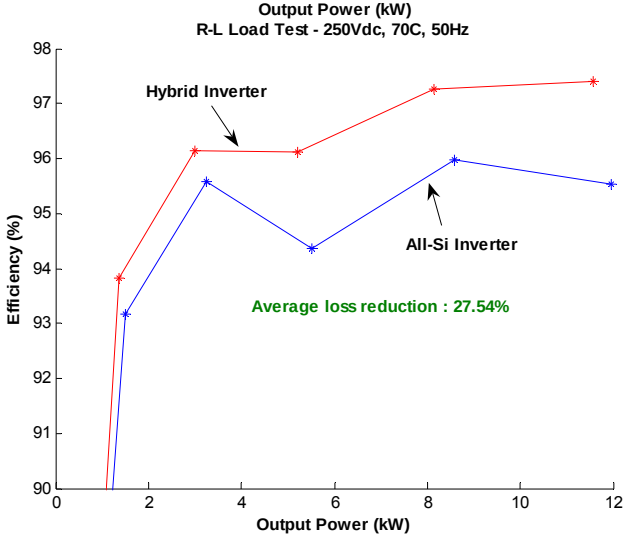


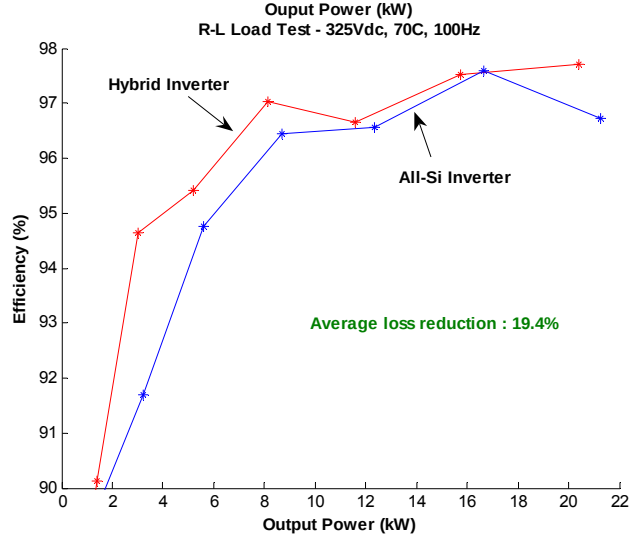
Inverter Test Results (R-L load test)

Efficiency Comparison



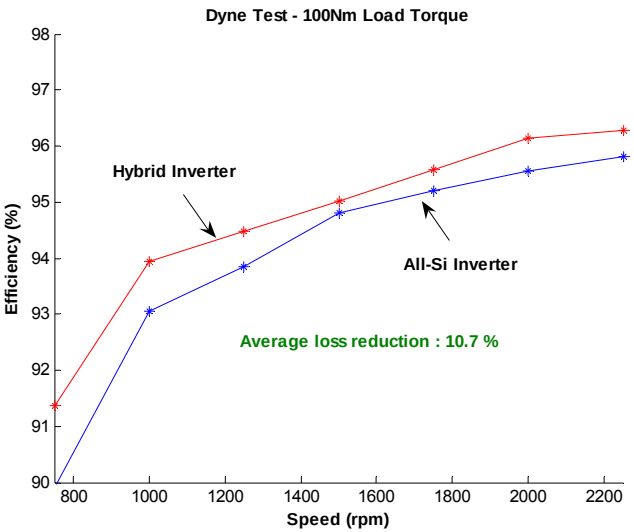


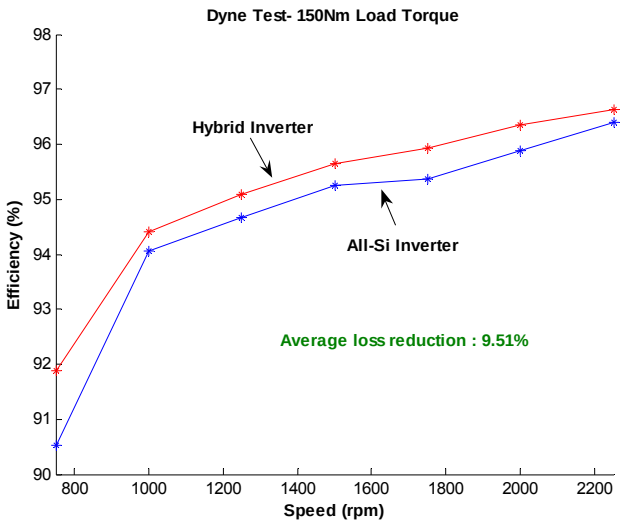


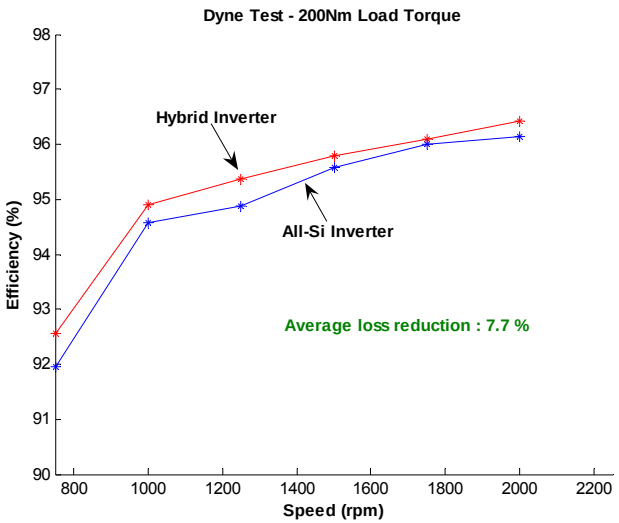


Inverter Test Results (dyne test-motoring)

- **Efficiency comparison 70°C**

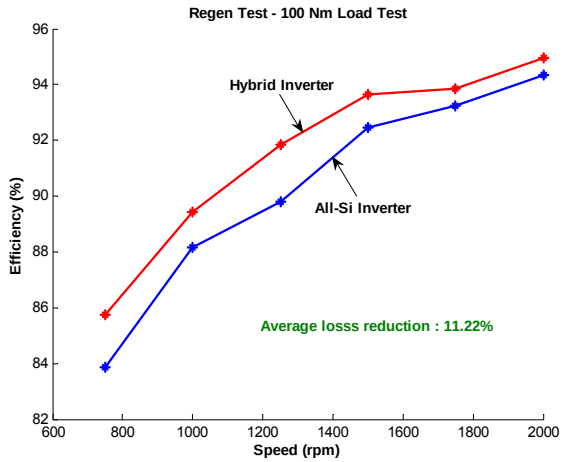


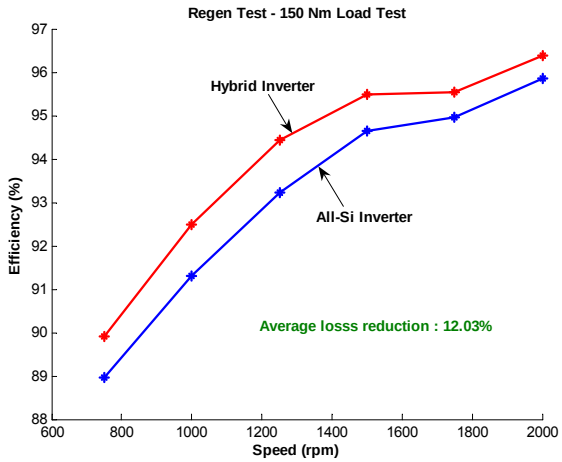


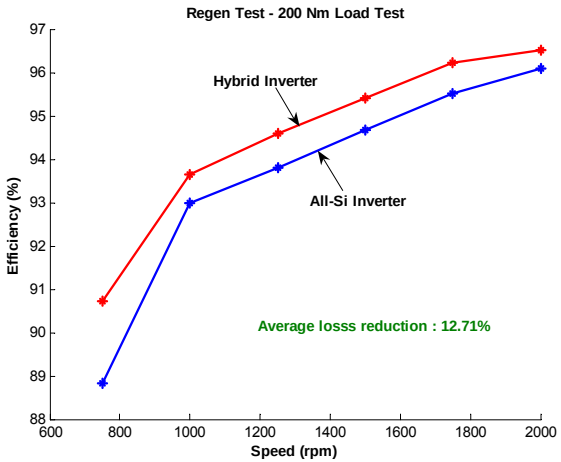


Inverter Test Results (dyne test-regen)

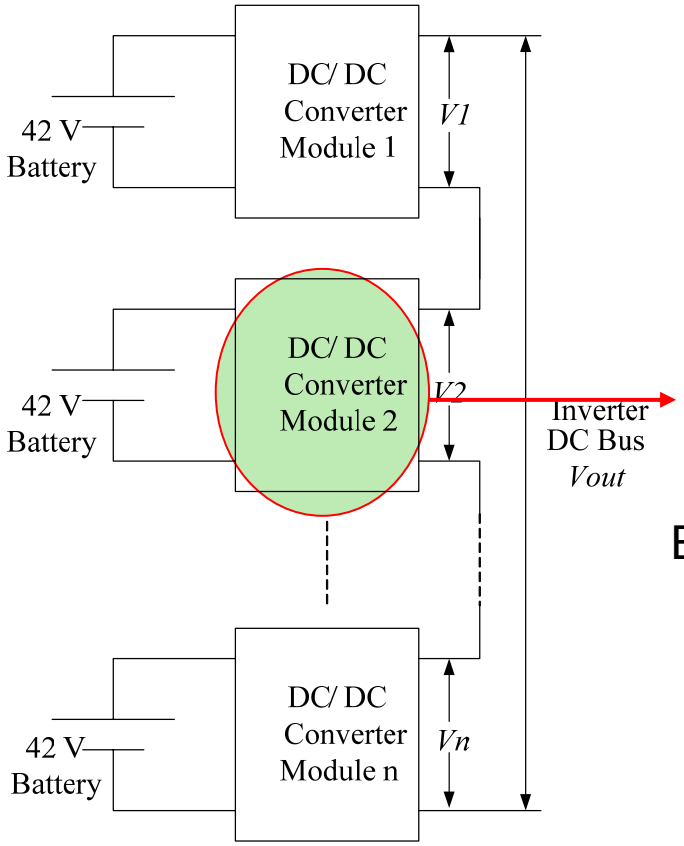
- **Efficiency comparison 70°C**



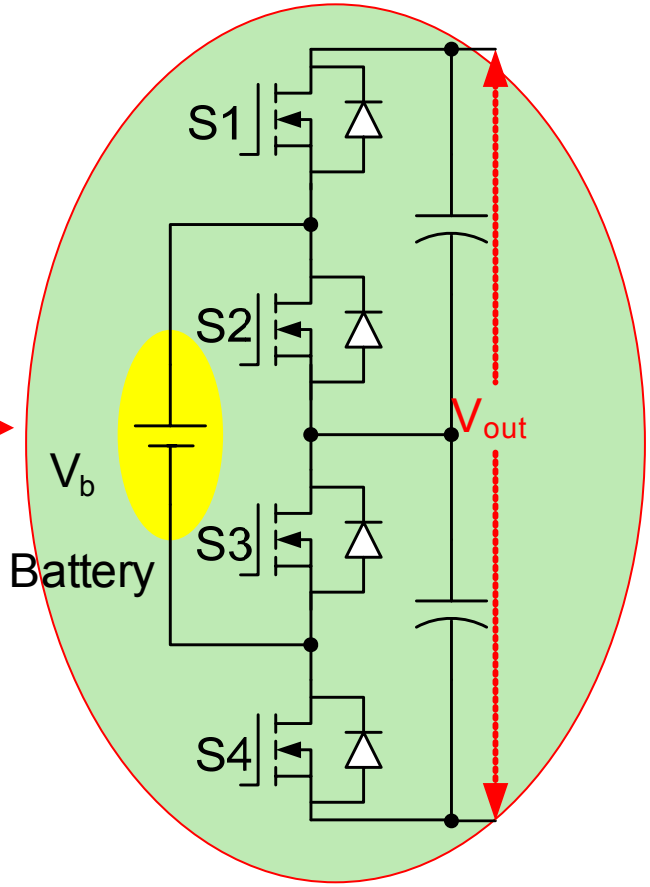




Magnetic-less dc/dc power conversion system



Power conversion system

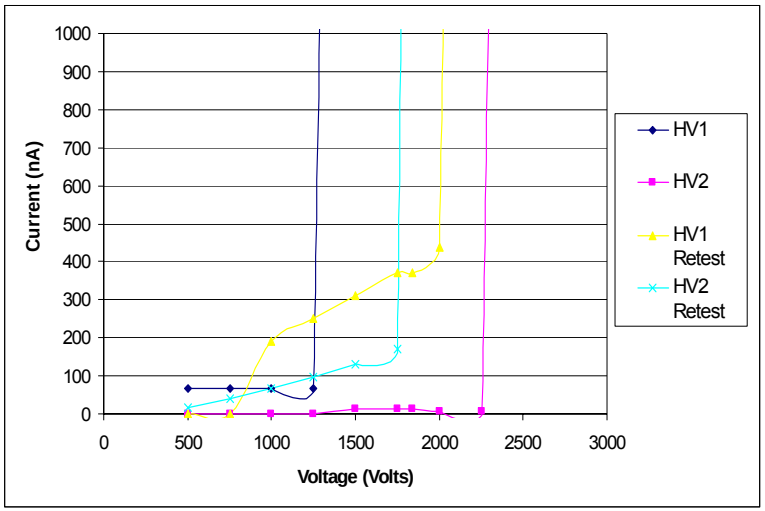


dc/dc converter module

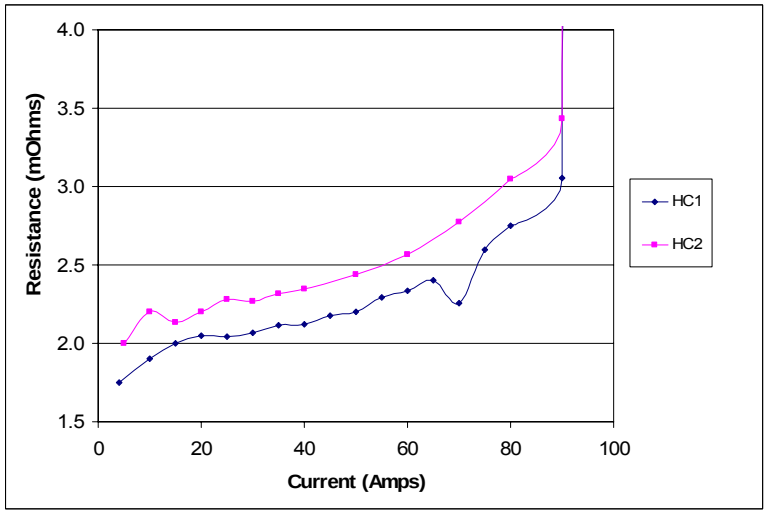
The converter module is able to output either the battery voltage or twice the battery voltage. Thus a power conversion system with *n* modules is able to output 1 to *2n* different voltages with an increment of 42 V.

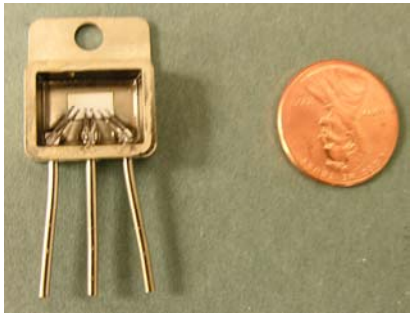
High Temperature Packaging – SiC Schottky Diode

Leakage current versus voltage

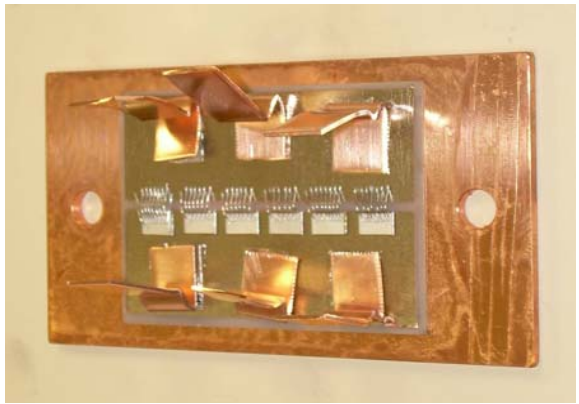


Resistance versus current.



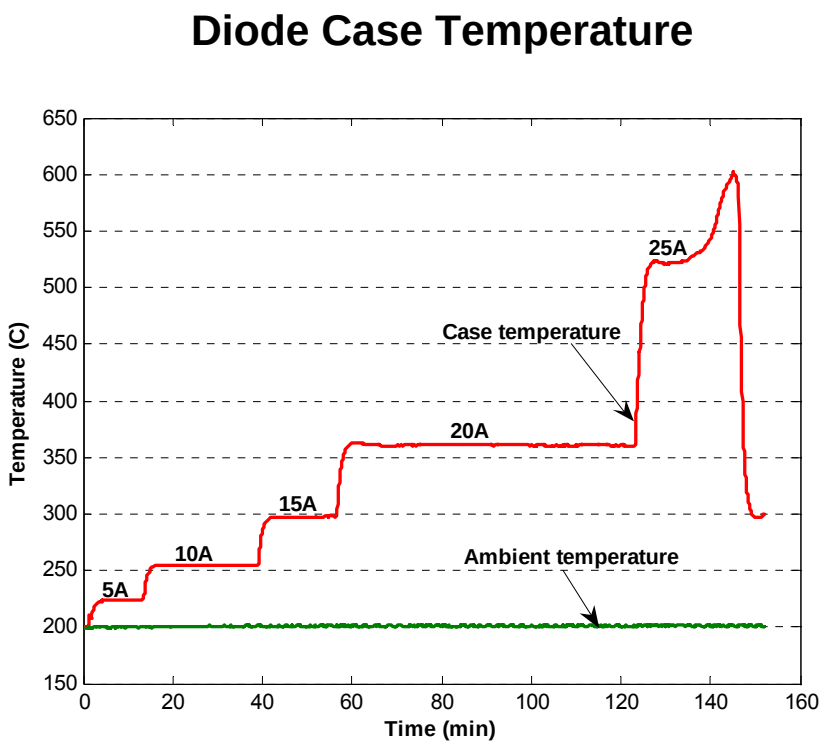


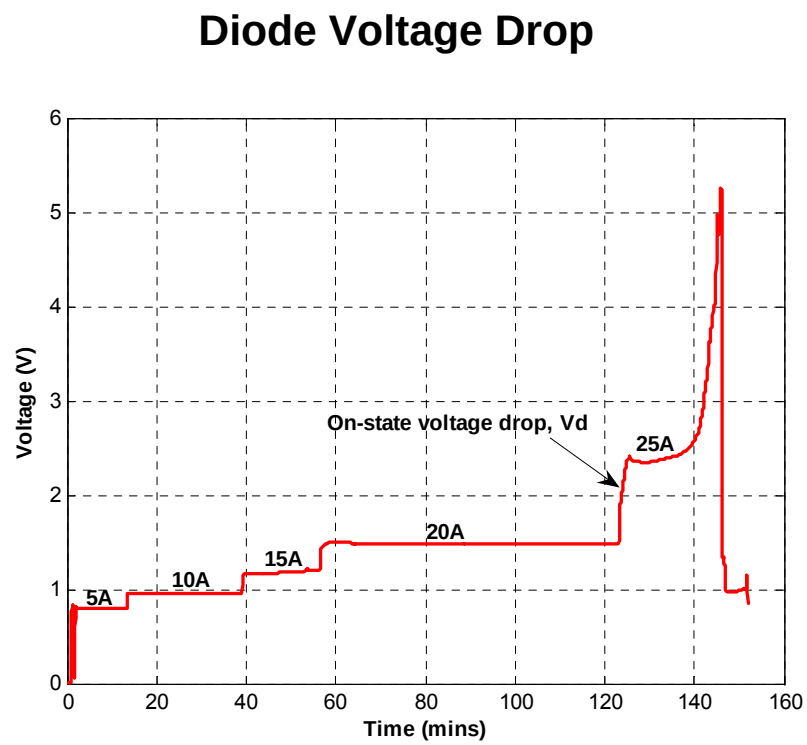
TO-220 through -hole high temperature Package of 75 A SiC Schottky diode



450 A high temperature SiC diode module With six 75 A Schottky diodes in parallel.

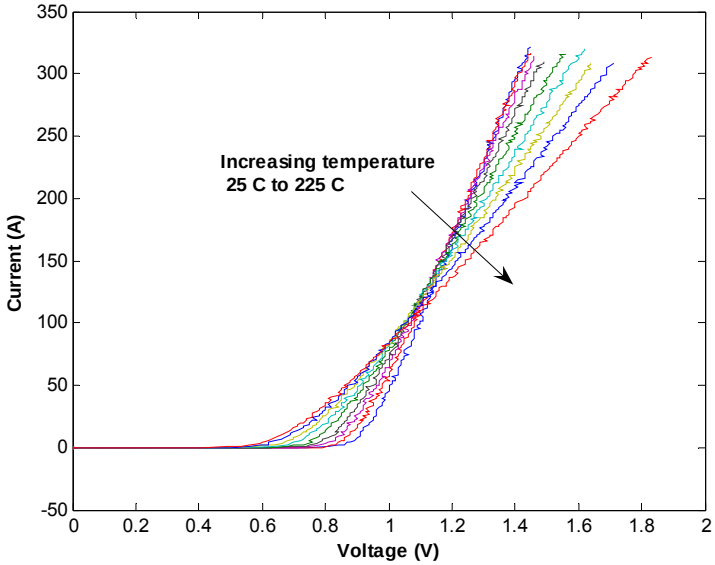
200°C diode package test results



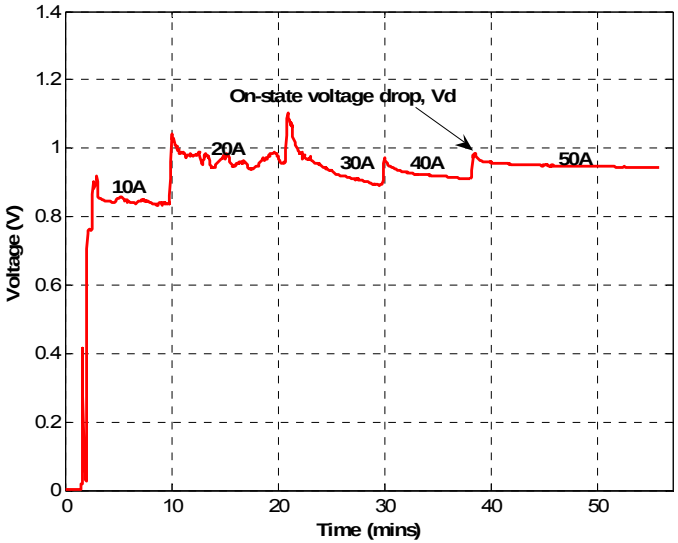


200°C diode package test results

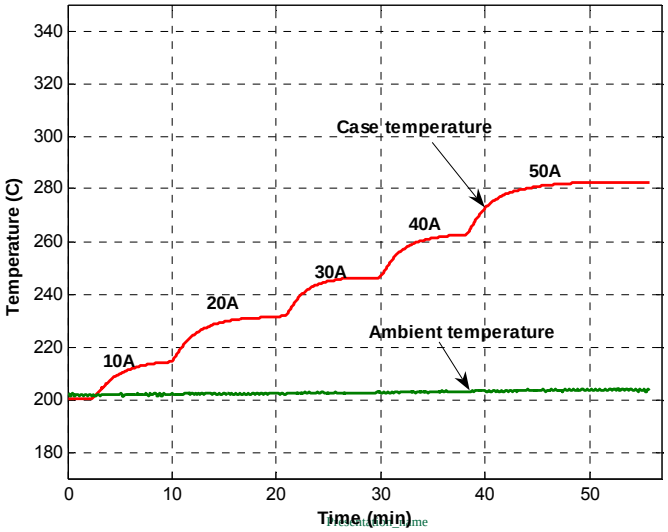
i-v curves of the 450 A diode module



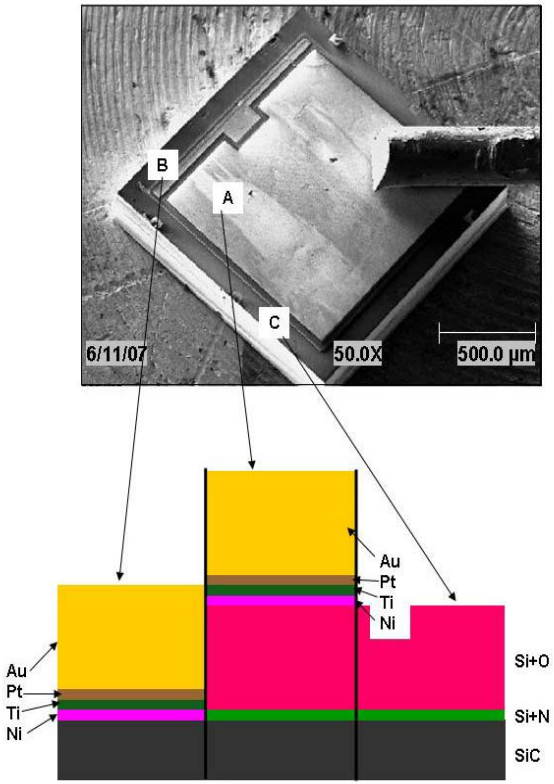
Voltage drop across the diode module at different currents



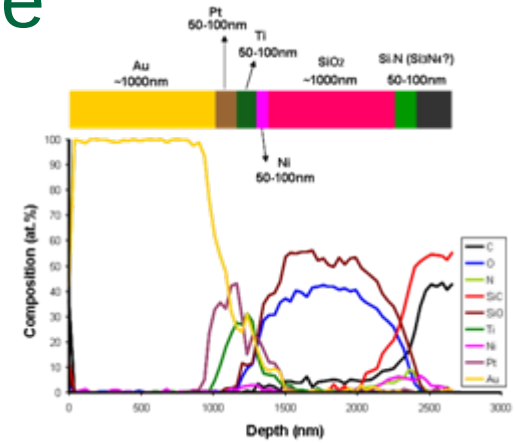
Case temperature of 75 A diode at different current level measured at 200°C ambient



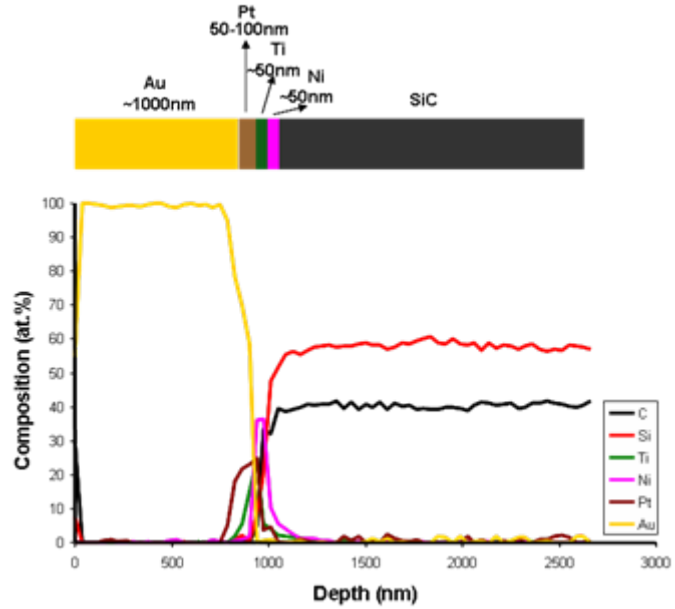
Overall Schematic of Metallization Schemes on Top Side



Topside

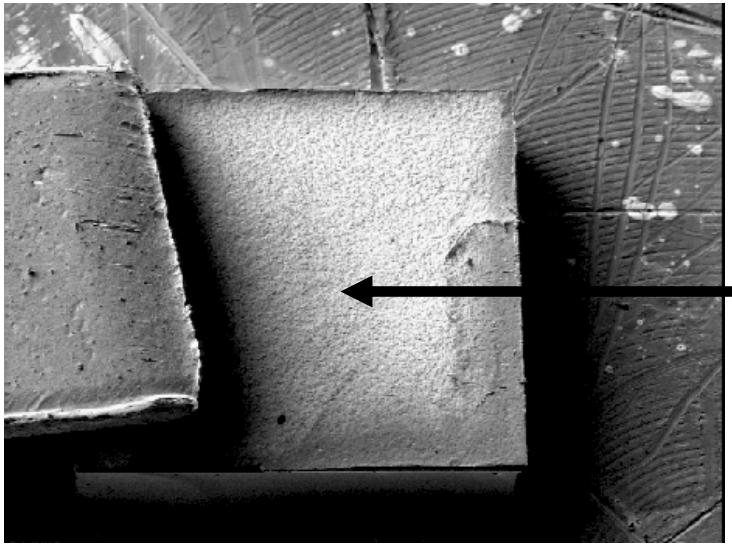


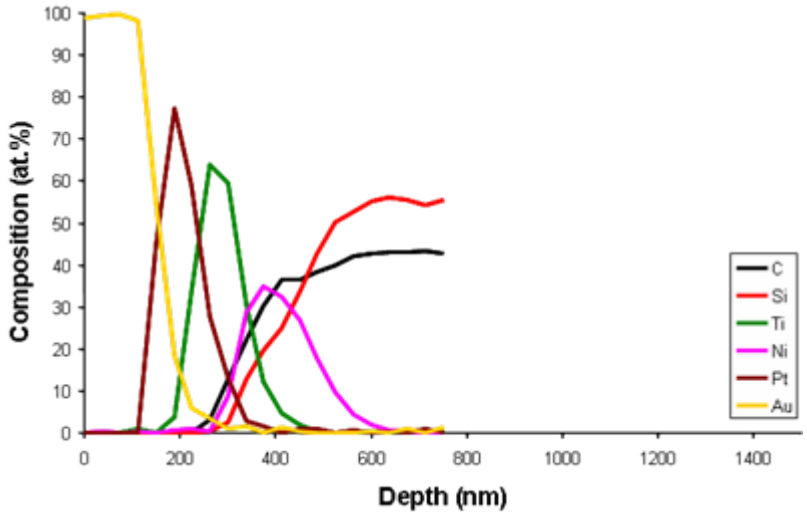
A



Low Magnification SEM image of the Top Side of the Die along with the Materials Constitution in Regions A, B, and C.

Overall Schematic of Metallization Schemes on Back Side



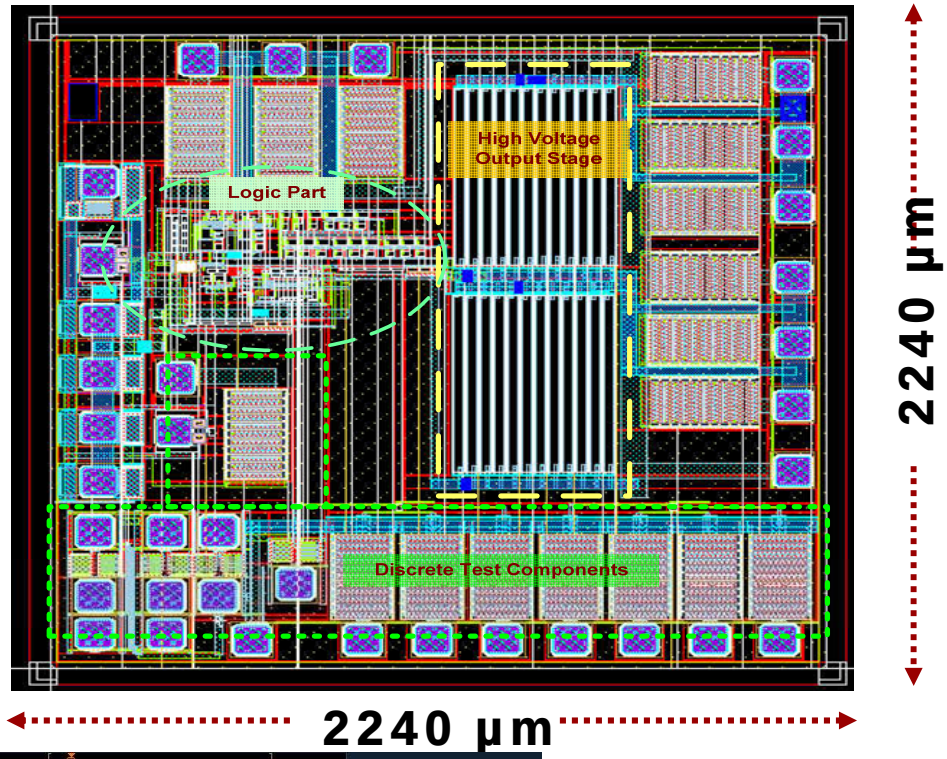


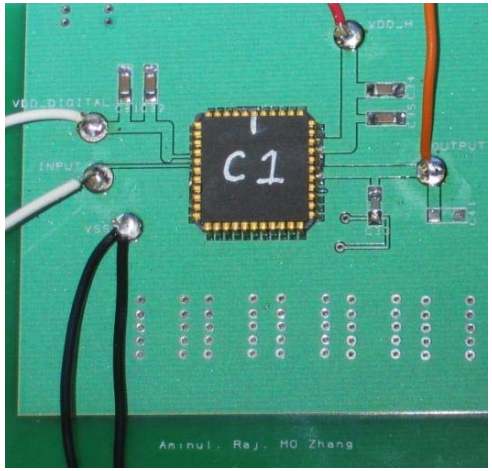
Layers are similar to top side but Au is thinner

High temperature gate drive

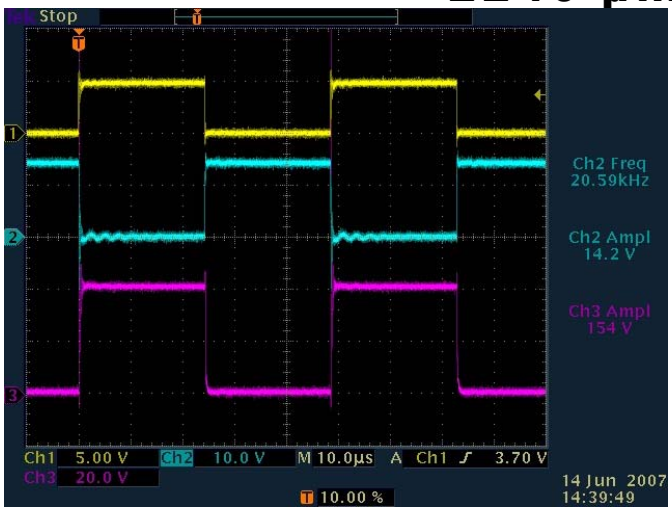
- SOI high temperature gate drive fabricated.
- High temperature PCB test board designed and fabricated
- Chip tested from -40C to 175C with an RC load to simulate gate resistance/capacitance of switch.

SOI gate drive chip layout





Test board with chip



SOI gate drive chip driving a SiC MOSFET at room temp

Future Research

- **In-house**
  - **Testing, characterizing, and modeling state-of-the art SiC power devices**
  - **Developing novel power converter, device packaging, and thermal management concepts to utilize the advantages of SiC power devices.**
  - **High temperature packaging of SiC power devices.**
  - **High temperature magnetic-less dc-dc converter**
  - **High temperature gate driver**
- **Delphi Automotive Systems – High temperature three-phase inverter (105°C coolant)**
- **General Motors – Combined Traction Motor and power electronic inverter (105°C coolant)**