

Integration of Cooling Function into 3-D Power Module Packaging

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APEC 2014_ Industrial Session_3-D Power Packaging

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Outline

□ Introduction

- Power Electronics Packaging Functions
- Power Electronics Packaging Assessment
- Advancement of 3-D Power Electronics Packaging Integration

□ Development of Integrated Cooling Packaging

- Power Electronics Packaging Thermal Performance Characterization
- Integrated packaging I: Pin_fin Baseplate
- Integrated packaging II: Cold-Baseplate

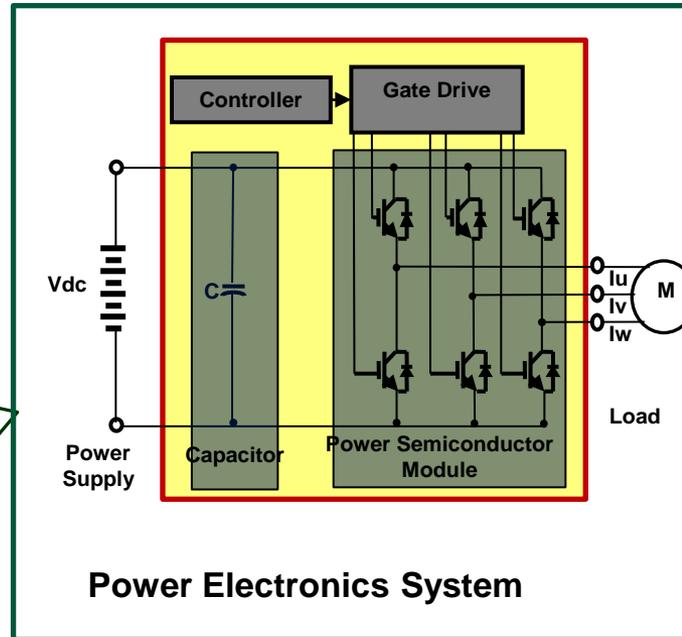
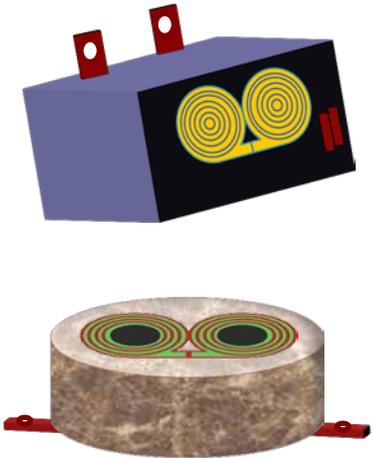
□ Integration of Cooling Function into 3-D Power Module Packaging

- Planar-Bond-All: 3-D Power Module Packaging
- Process Integration
- 3-D Packaging of Cooling and Power Modules

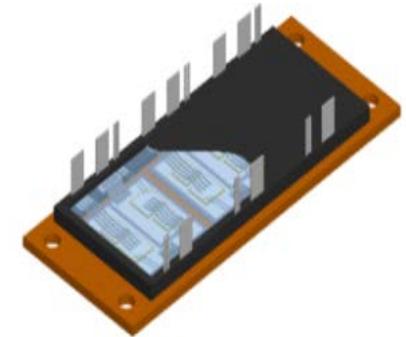
□ Summary

Power Electronics Packaging: Assembly of Multiple Components

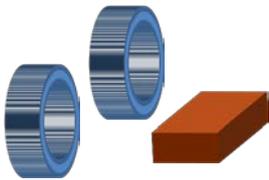
Passive Component



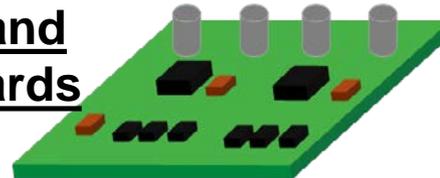
Power Module



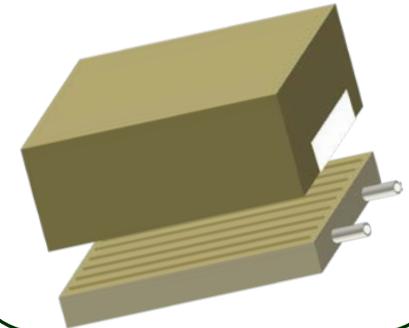
Sensors



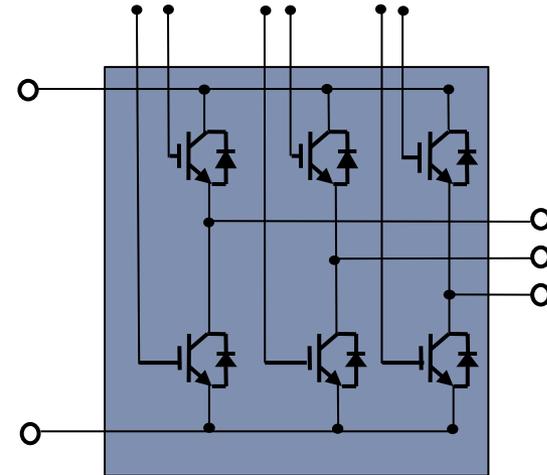
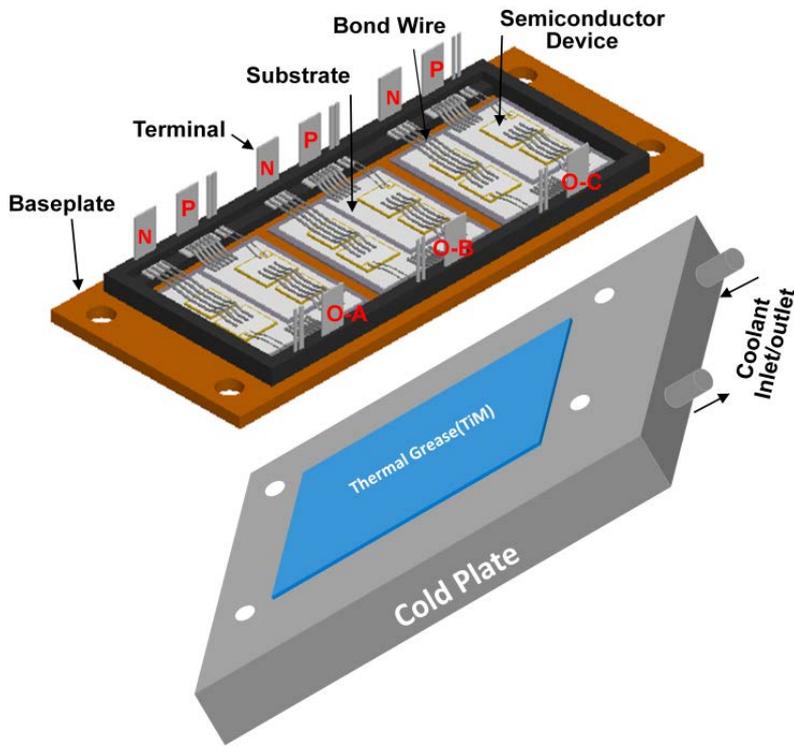
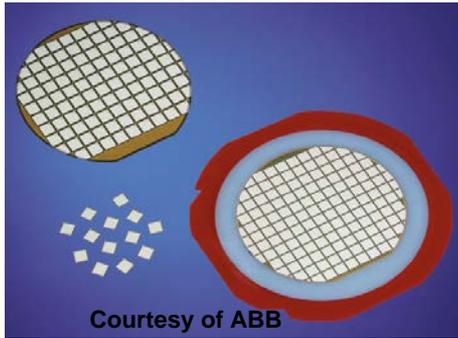
Control and Drive Boards



Cold Plate



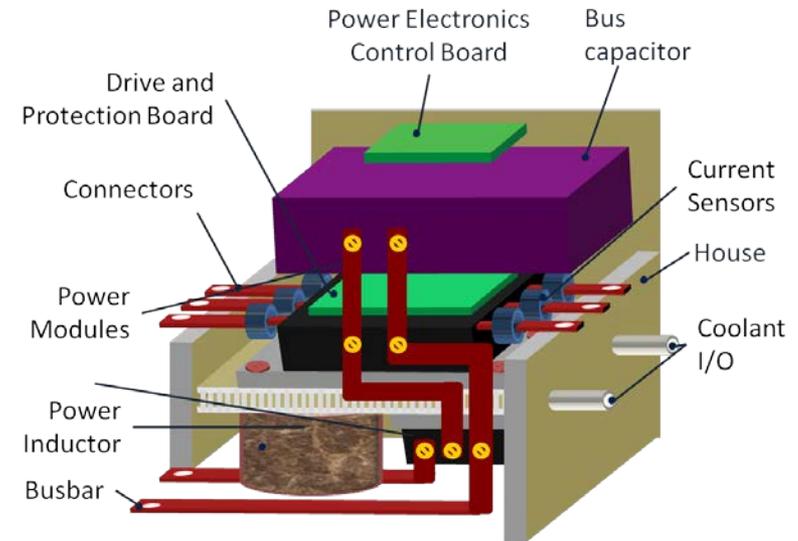
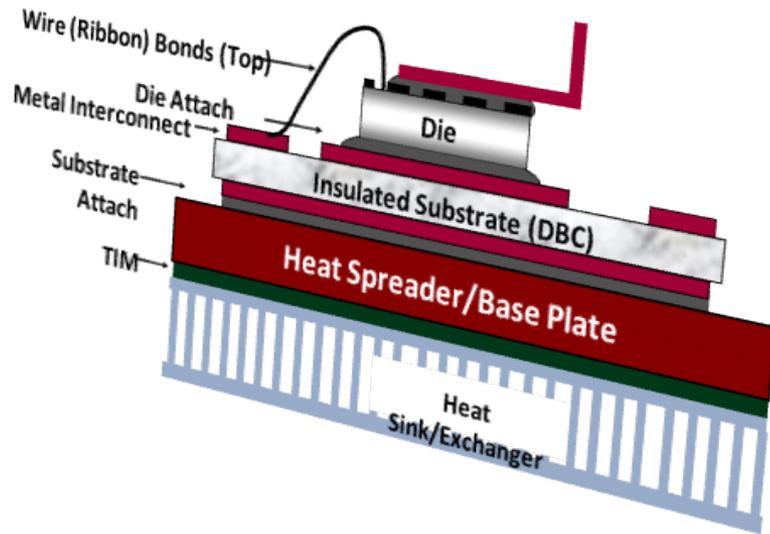
Power Electronics Packaging: Multi-function Integration



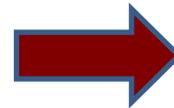
Power Module

- ✓ Multiple Power Semiconductor Devices Integration
- ✓ Monitoring and Protection
- ✓ Electrical Interconnection
 - ✓ Cooling (Thermal Management)
- ✓ Thermo-mechanical and Mechanical Support

Power Electronics Packaging: State-of-the-Art



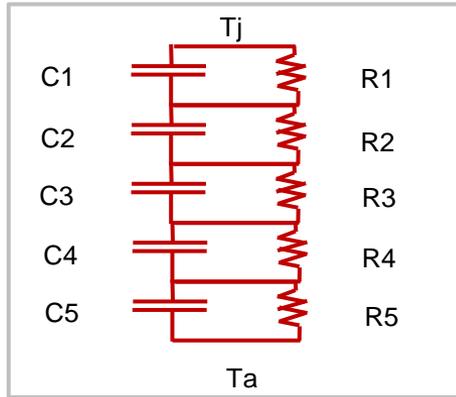
- Discrete Components
- Hierarchical Electrical Interconnection
- Interfacial Thermal Management
- Complicated Manufacture



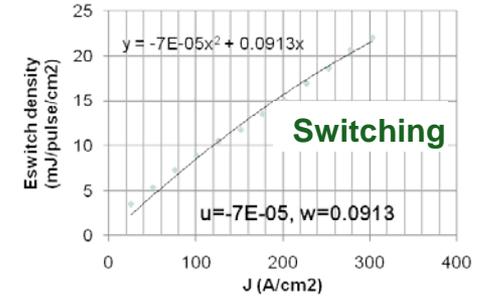
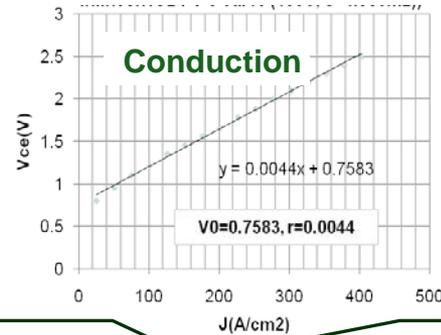
- Cost
- Performance
- Power Density
- Reliability

Power Electronics Packaging: Technical Metrics

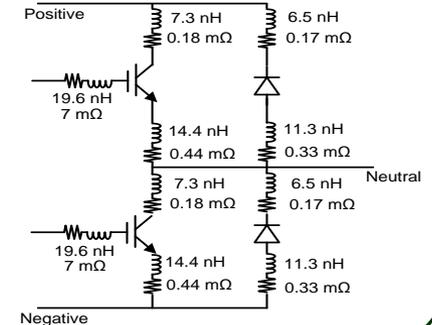
Thermal Impedance



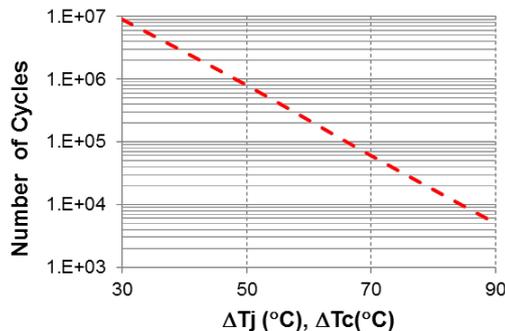
Power Conversion Performance



Electrical Parasitics



Thermal-mechanical Property

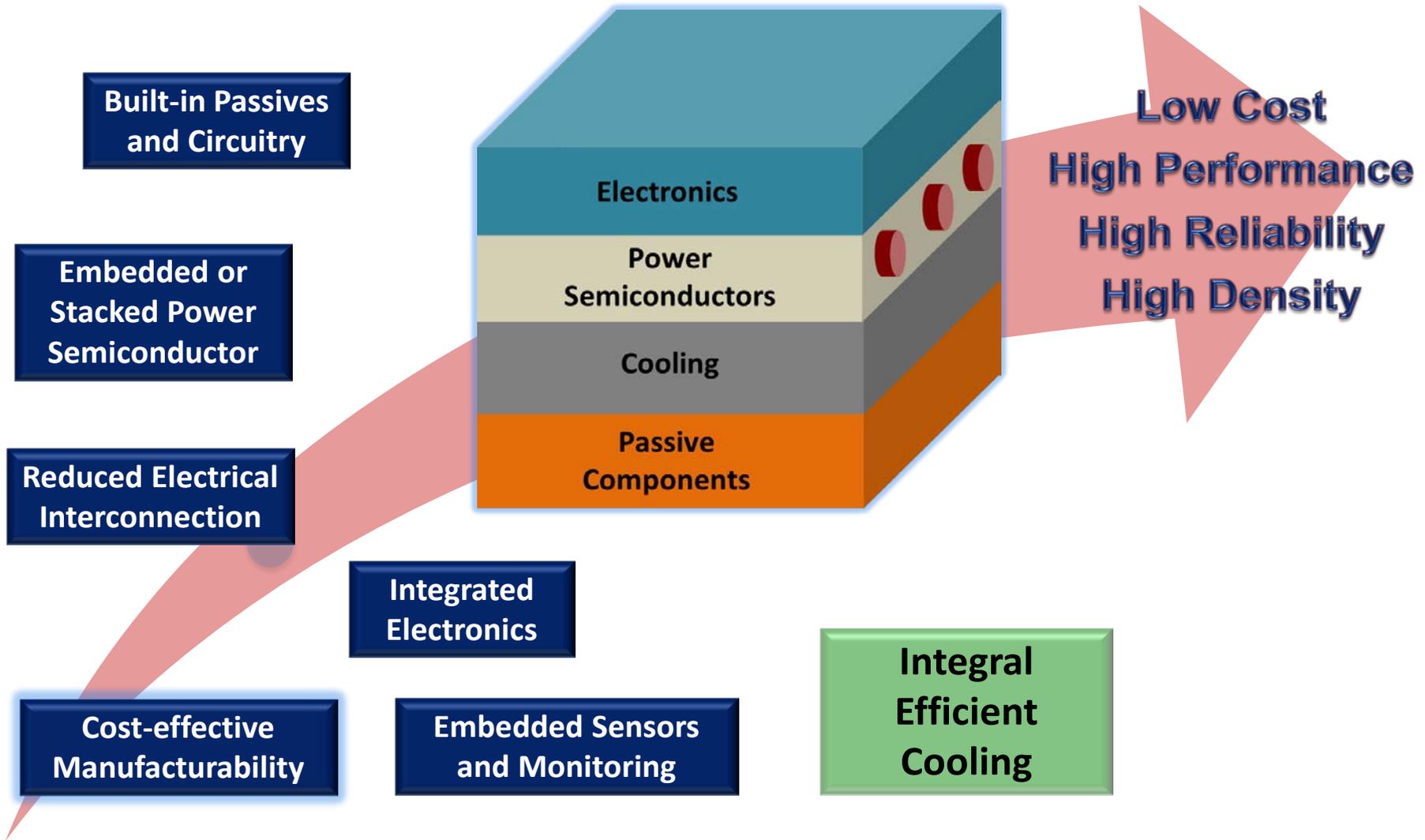


$$\text{Efficiency} \rightarrow \eta = 1 - (P_{con} + P_{sw} + P_{lp} + P_{rp}) / P_{in}$$

$$\text{Cost} \rightarrow \frac{\$}{kW} = A + B \cdot \frac{(1 - \eta) \cdot \theta_{ja,sp}}{(T_j - T_a)}$$

$$\text{Reliability} \rightarrow N_f = \alpha \cdot \left(\frac{1}{T_j - T_a} \right)^\beta \cdot \exp(E_a / kT_m)$$

3-D Power Electronics Packaging: Schemes for Integration



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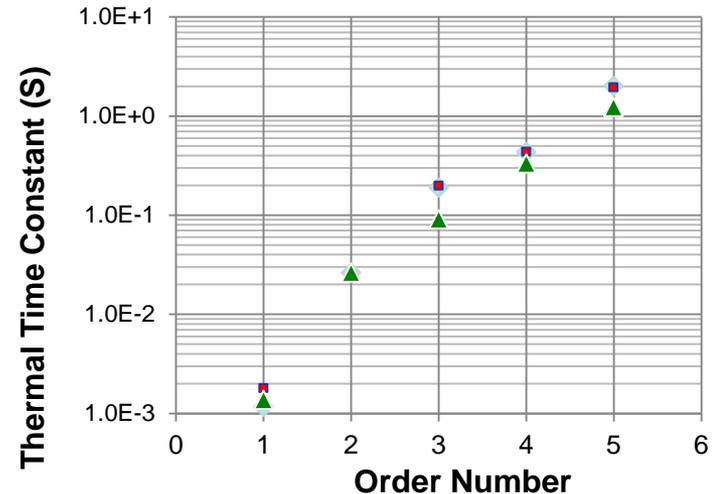
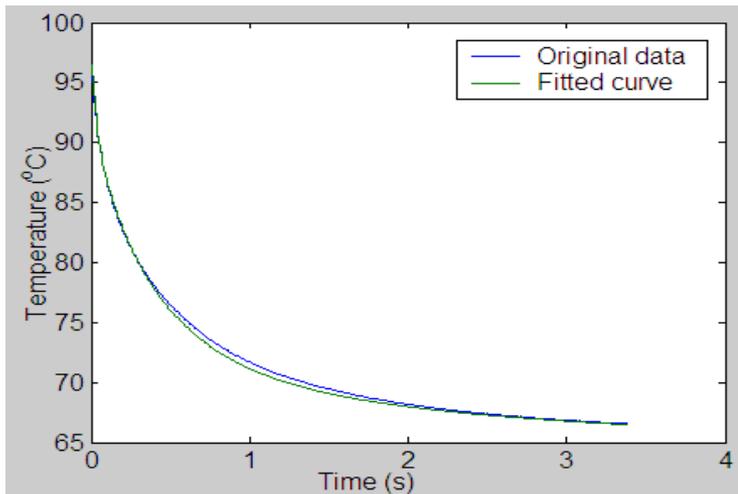
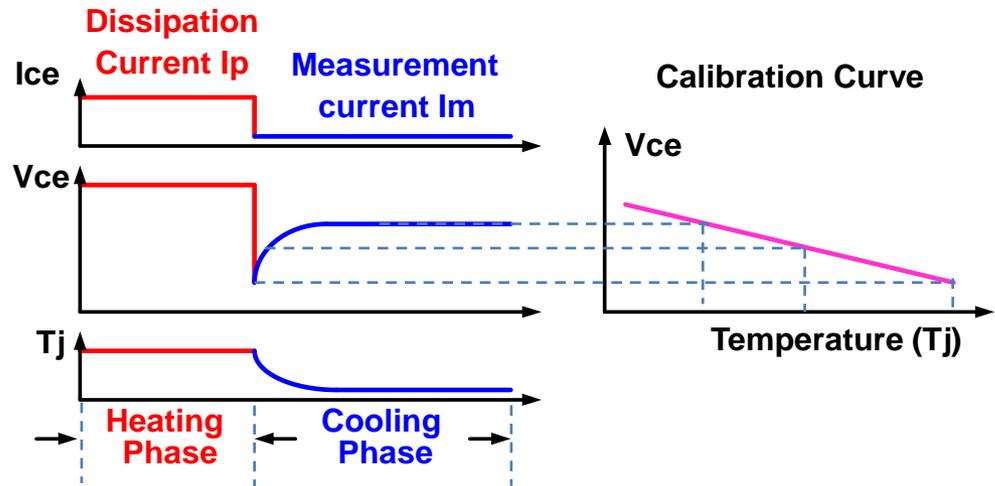
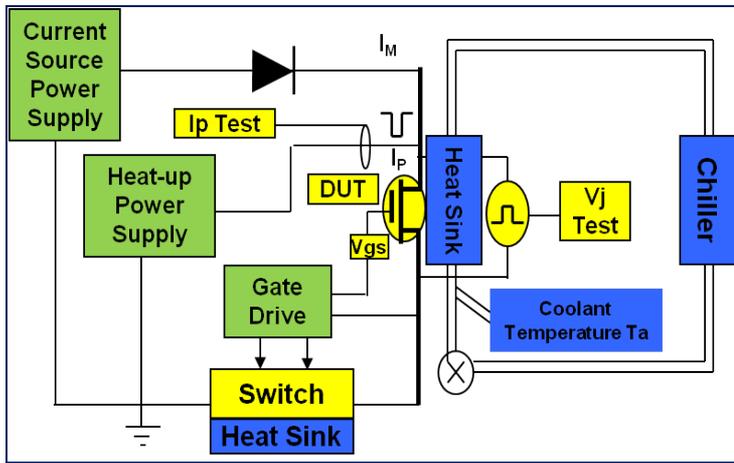
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- Integrated packaging I: Pin_fin Baseplate
- Integrated packaging II: Cold-Baseplate

□ Integration of Cooling Function into 3-D Power Module Packaging

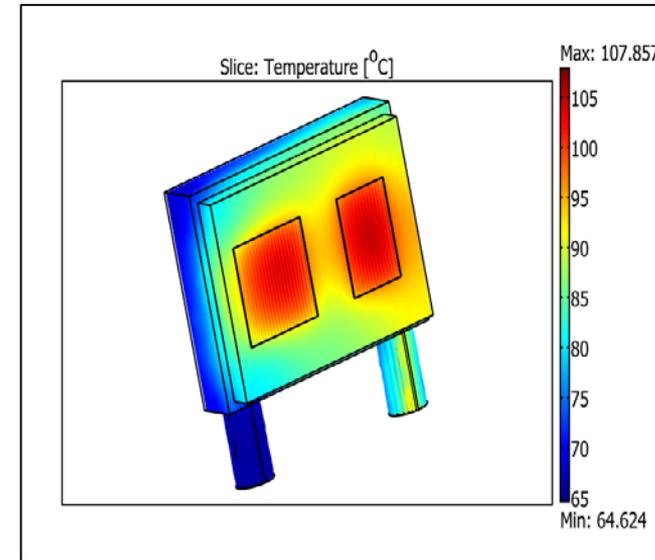
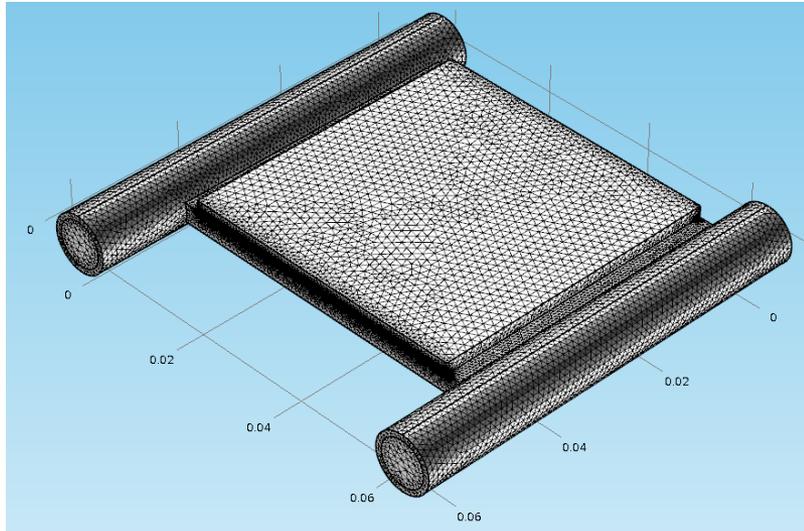
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□ Summary

Power Electronics Packaging: Thermal Performance Characterization_Experimental

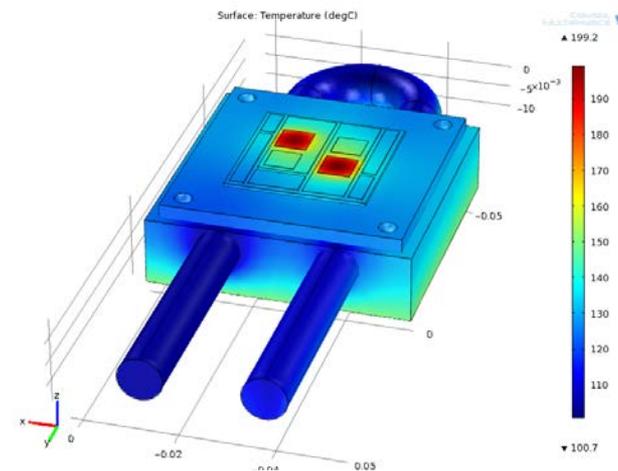


Power Electronics Packaging: Thermal Performance Characterization_Simulation

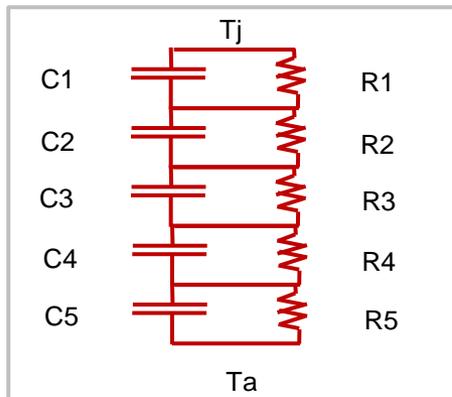
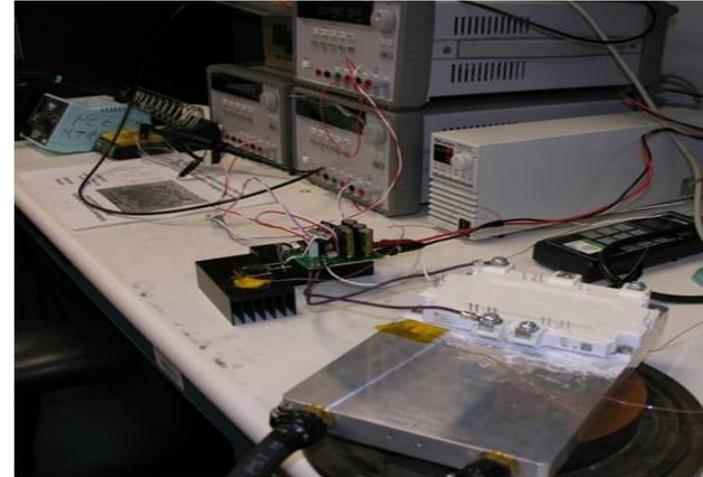
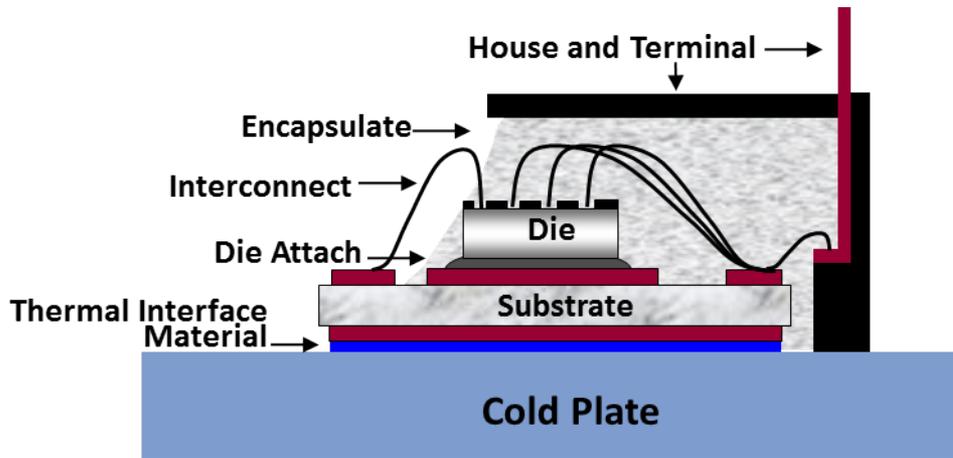


3-D Thermal Model of Power Module with Cooler

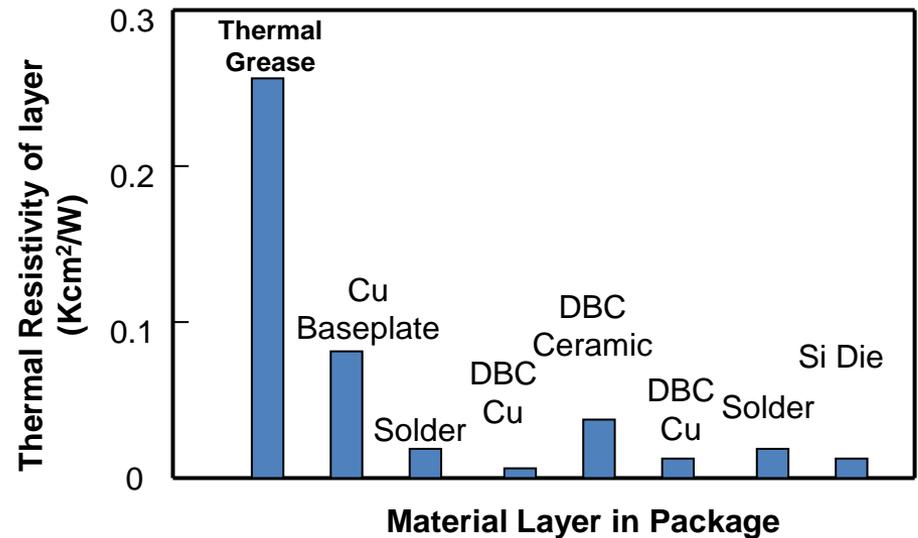
- IGBT, Diode Power loss;
 - Coolant flow rate;
 - Pressure Drop;
- Coolant inlet temperature;
- Single- or Double-sided cooling.



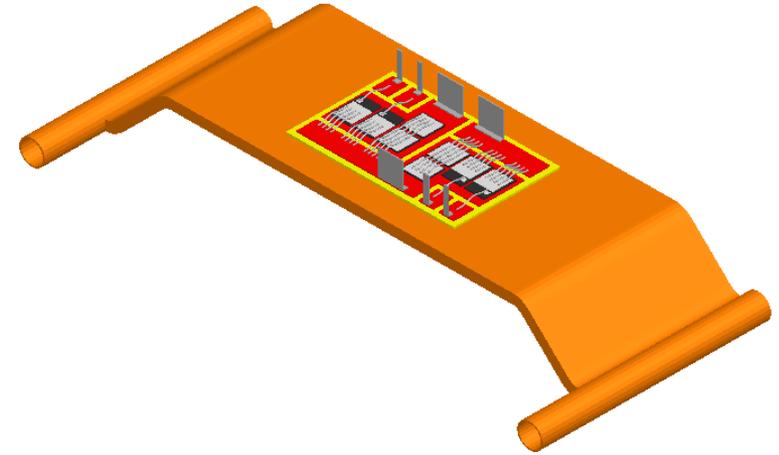
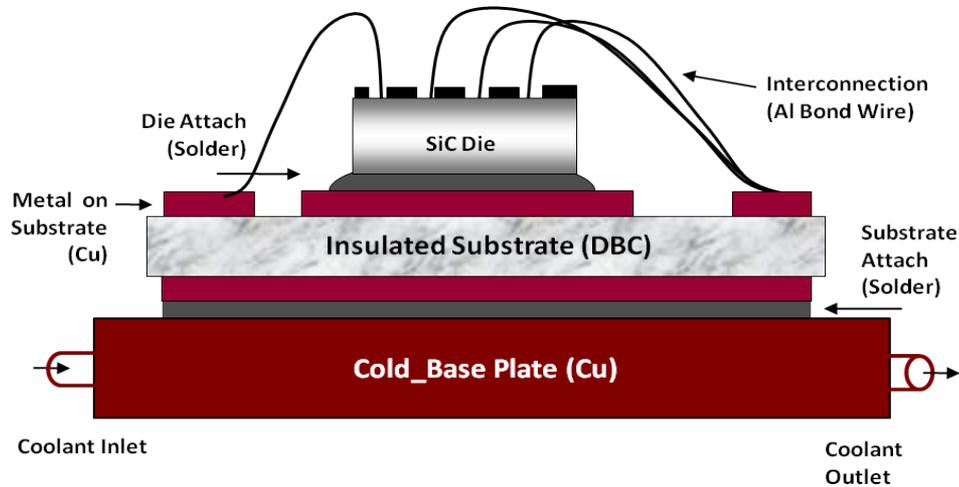
Thermal Resistance In State of the Art Power Module Assembly



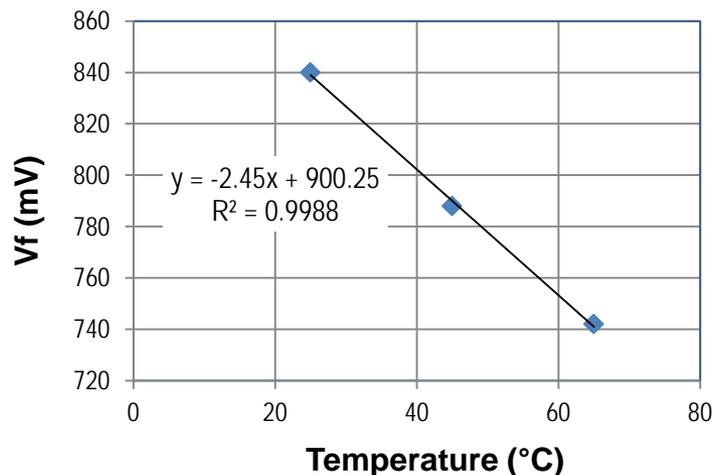
Thermal Network



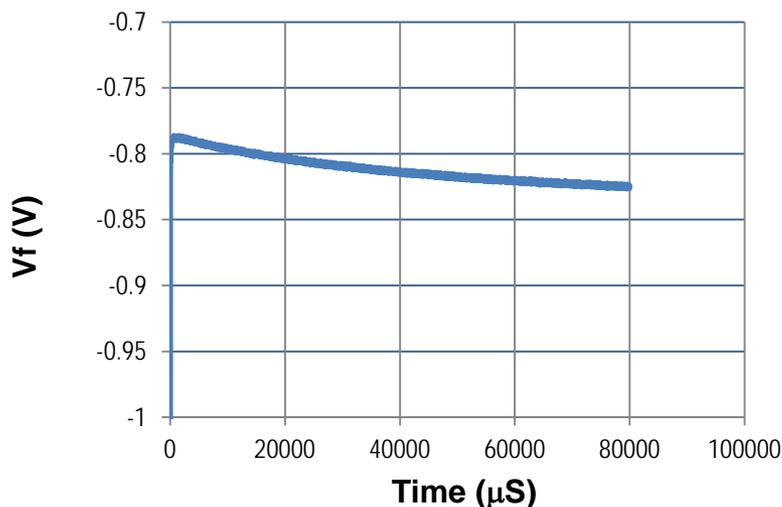
Integrated Cooling Packaging II: Cold-baseplate



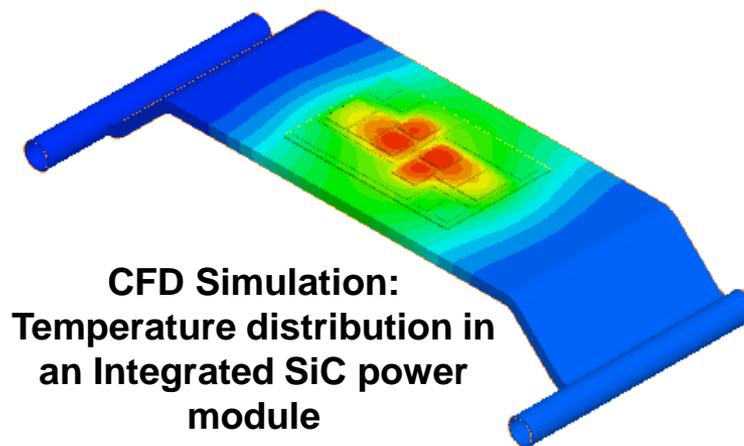
Thermal Performance Characterization



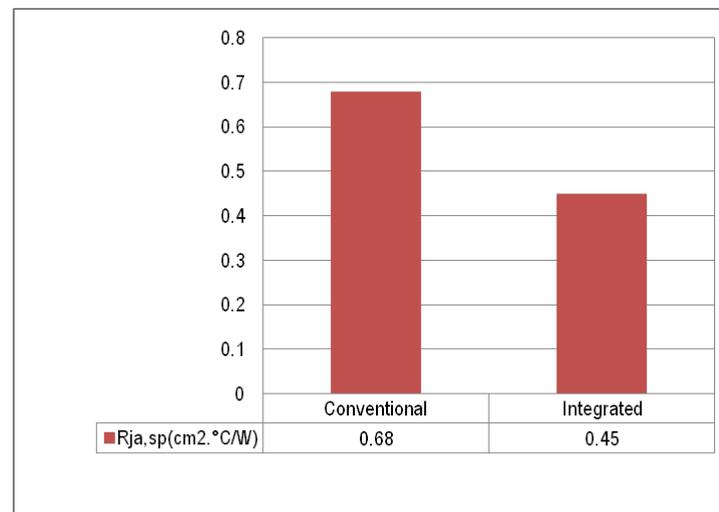
Vf-T calibration curve of body diode in SiC MOSFET



Vf decay of body diode in SiC MOSFET during cooling down

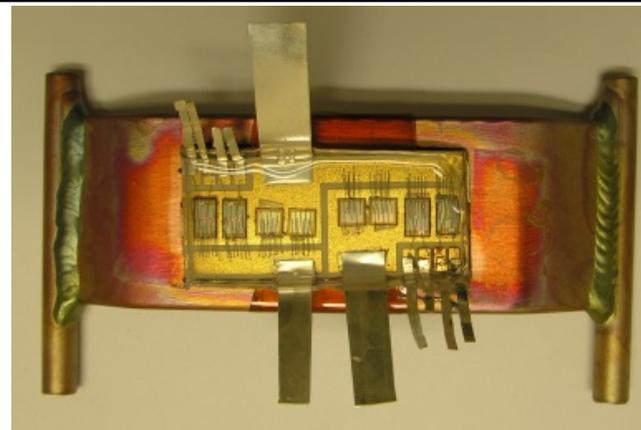
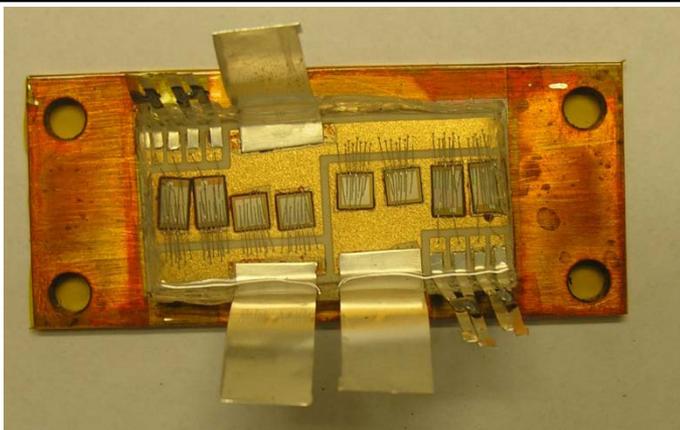


CFD Simulation:
Temperature distribution in
an Integrated SiC power
module

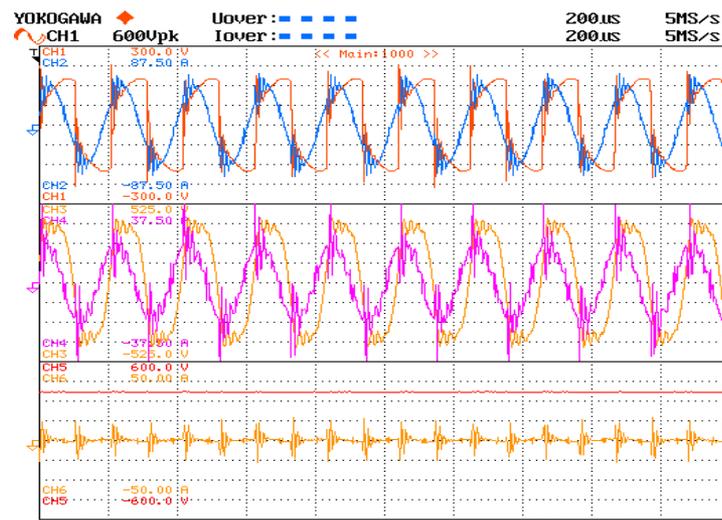
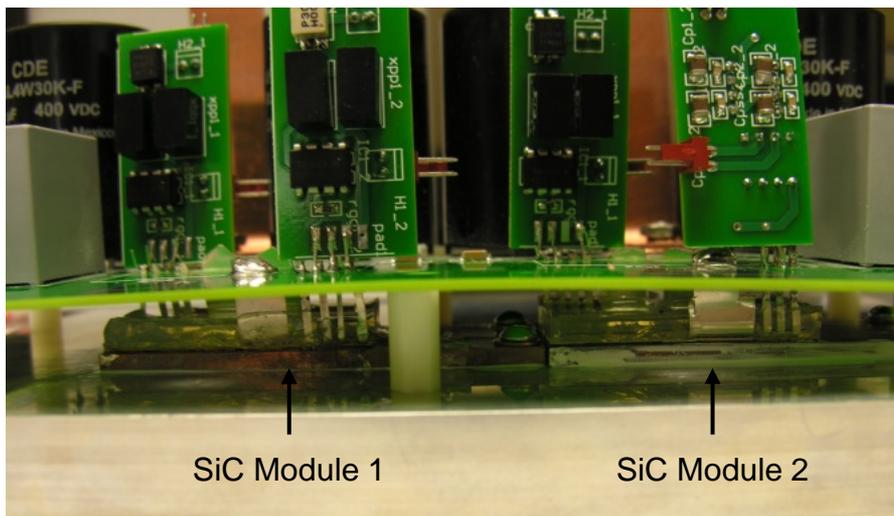


Thermal Resistance Comparison

Performance Evaluation in a High Frequency Converter

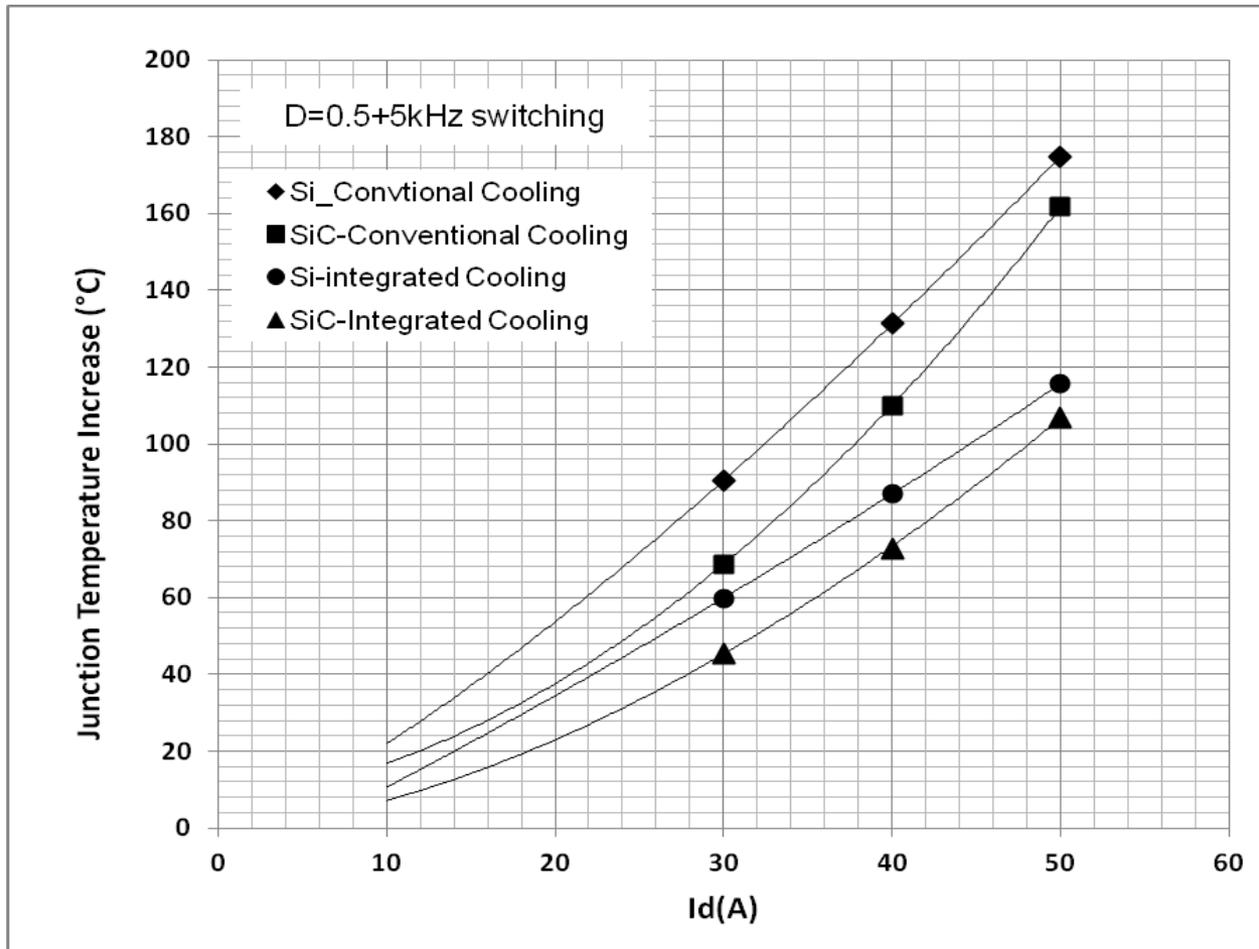


100A/1200V SiC Power Modules: Conventional packaging (left); Integrated cooling packaging (right)



Two 100A/1200V SiC Power Modules in a HF (48kHz) converter: Converter packaging (left); Waveforms (right)

Performance Estimation in a System



Current density allowed for different power semiconductor and cooling combinations at $\Delta T_j=100^\circ\text{C}$ for a typical operation ($D=0.5$, $f=5\text{kHz}$)

Item	Si_Con. Cooling	SiC_Con. Cooling	Si_Integ. Cooling	SiC_Integ. Cooling
Current Density J_d (A/cm^2)	65.35	144.97	97.57	184.98

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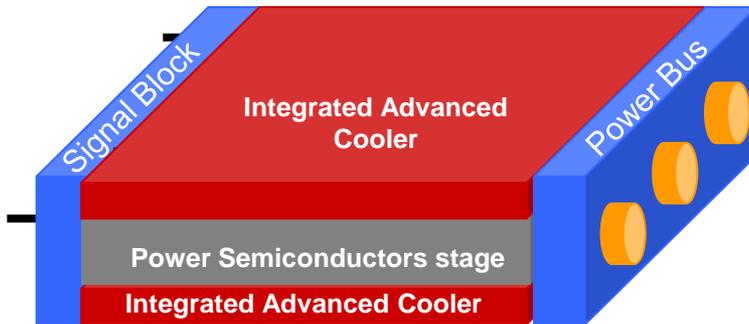
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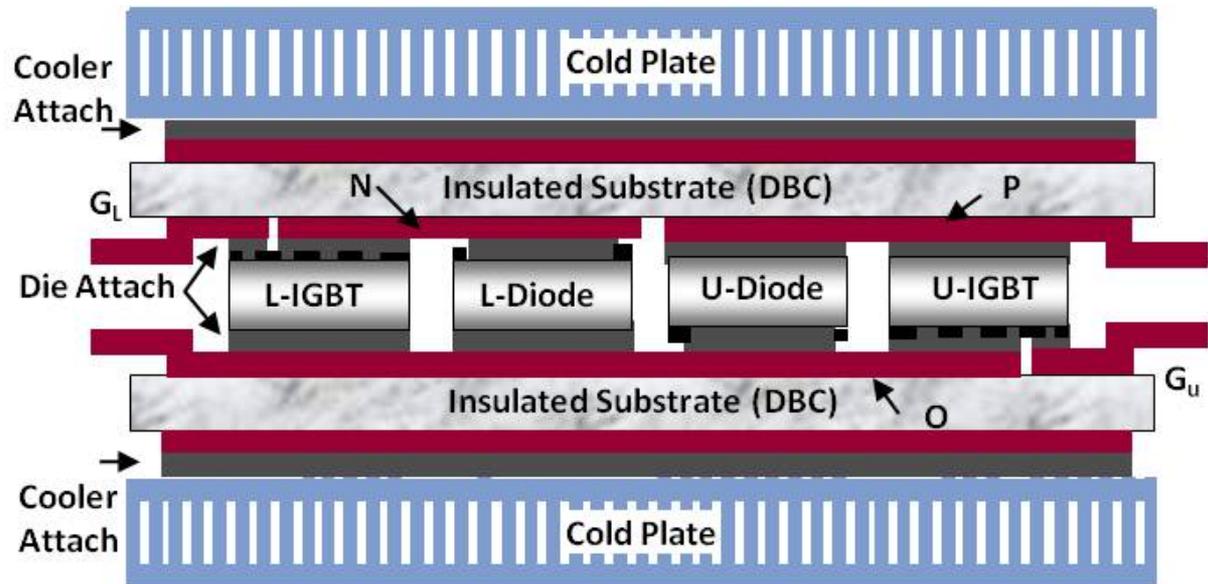
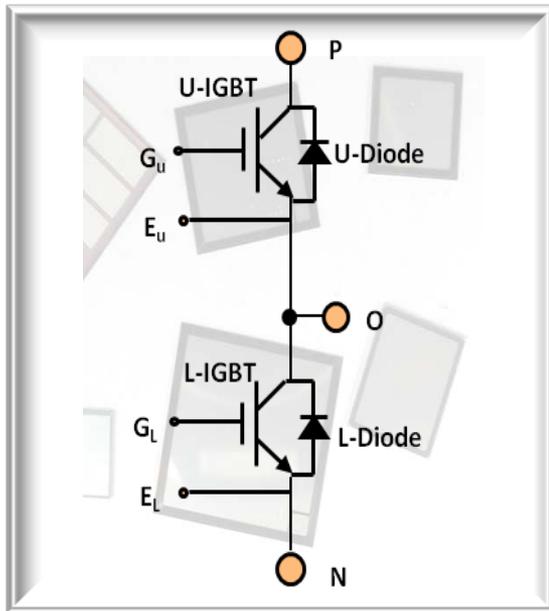
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□ Summary

Planar Bond All Integrated Power Module



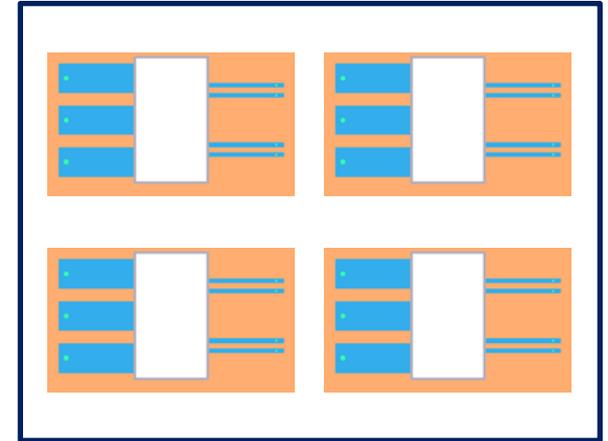
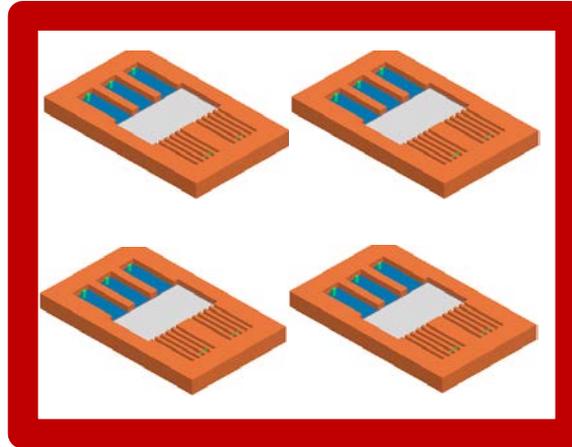
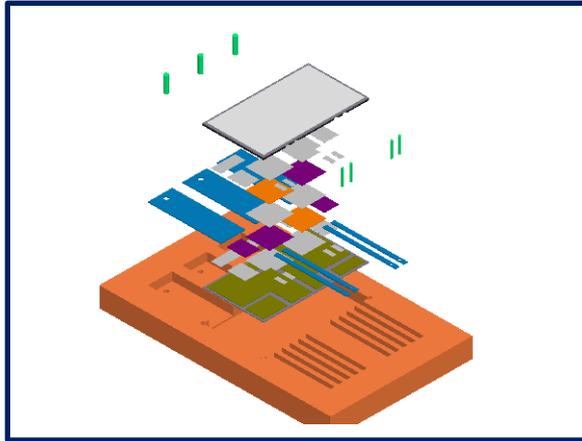
- ❖ *3-D, Planar Power Interconnection*
- ❖ *Integrated, Double Sided Cooling*
- ❖ *Symmetrically Mechanical Structure*
- ❖ *Simplified Manufacture*



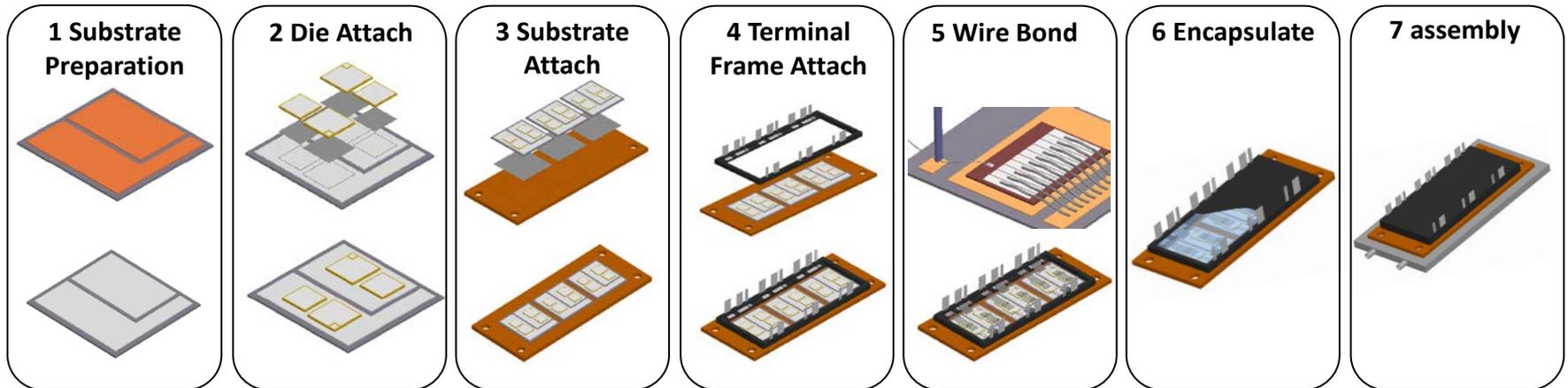
***Patent Pending: Pub No: 2013/0020694 A1**

Develop Integration Packaging Process Technology

Planar_Bond_All*

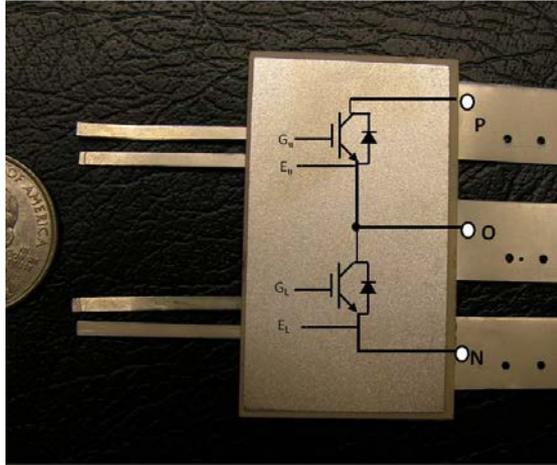


Wire Bond Packaging

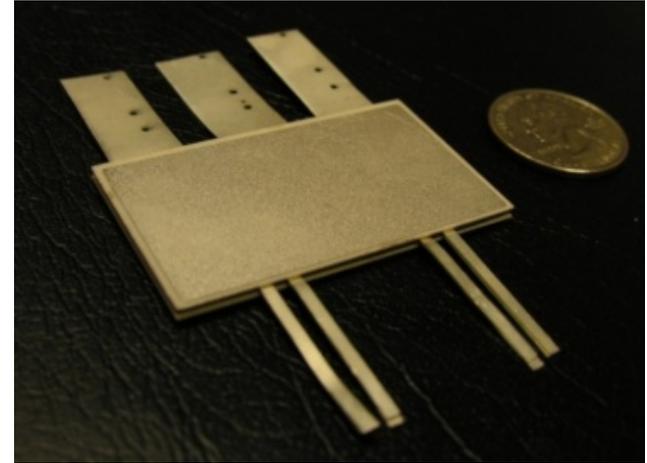


*Patent Pending: Pub No: 2013/0020694 A1

Prototype: Planar_Bond_All Power Modules

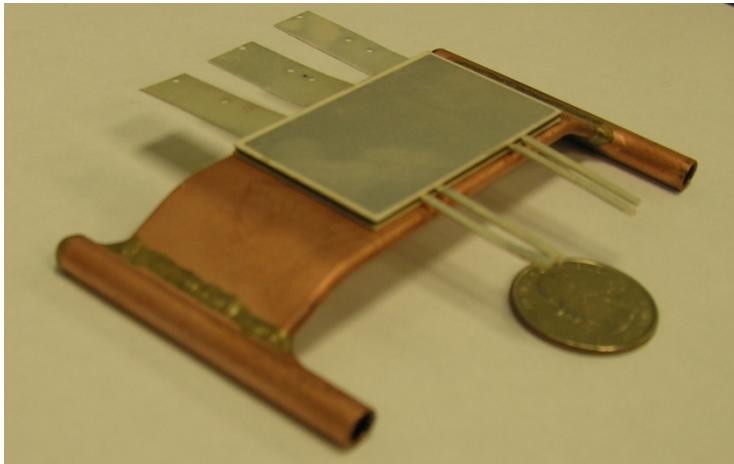


Bare Semiconductor Dies

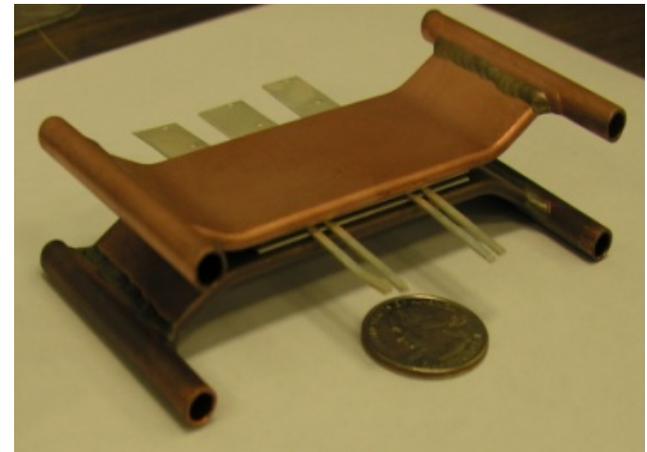


Planar Bond Power Module Stage

Electrical Connection



Double Cooled Power Module

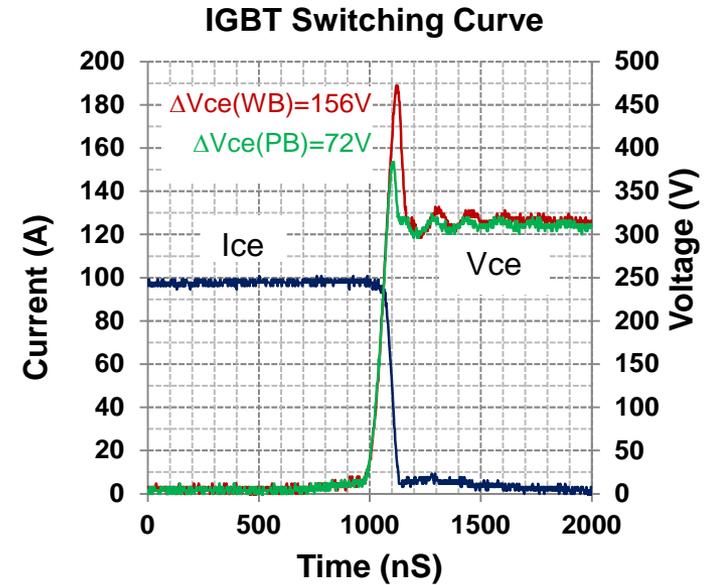
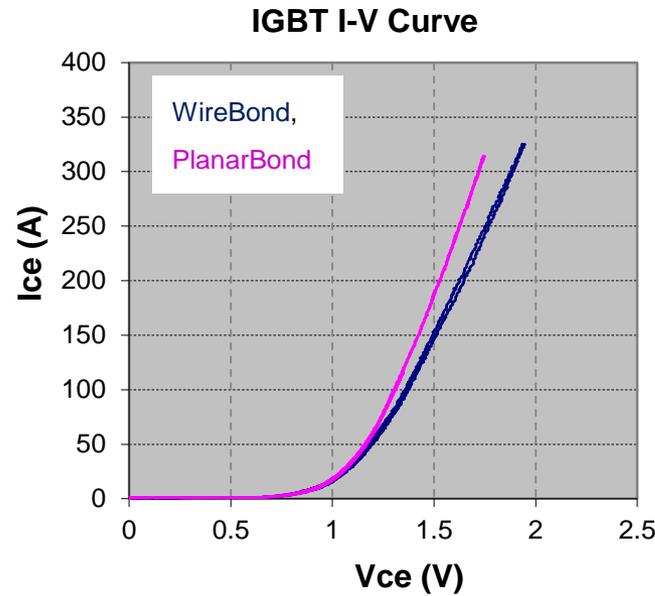


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Electrical Performance Characterization

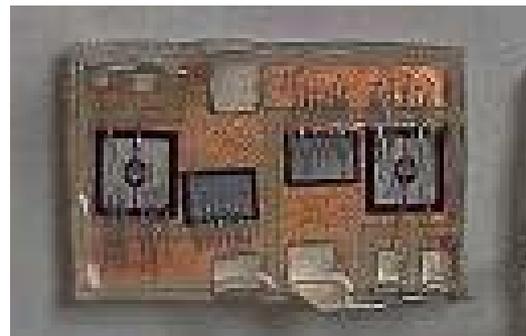


Planar Bond Module



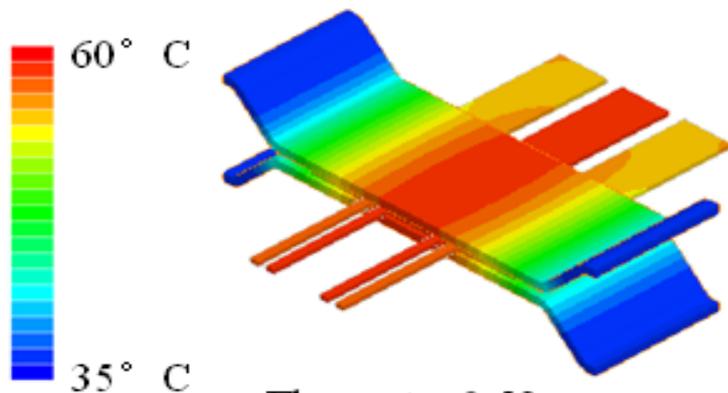
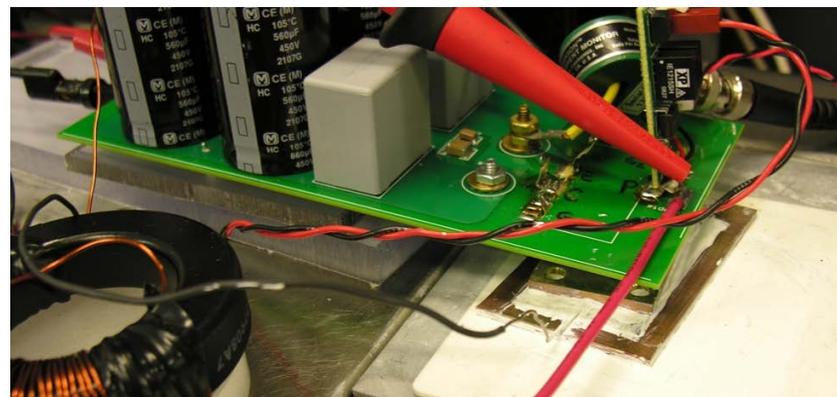
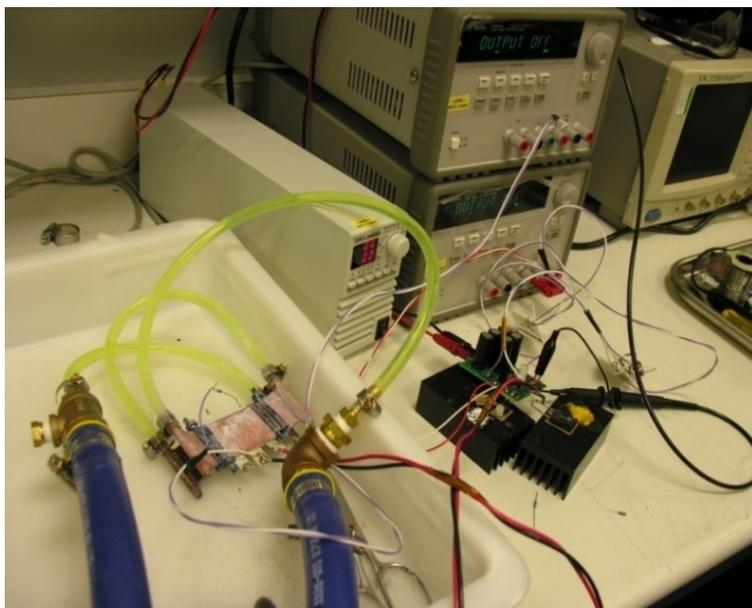
Electrical Parameters Comparison

Inductance (nH)	Experimental Value	Calculated Value
Planar Bond_Lower IGBT	10.5	6.3
Wire Bond-Lower IGBT	31.9	23.5

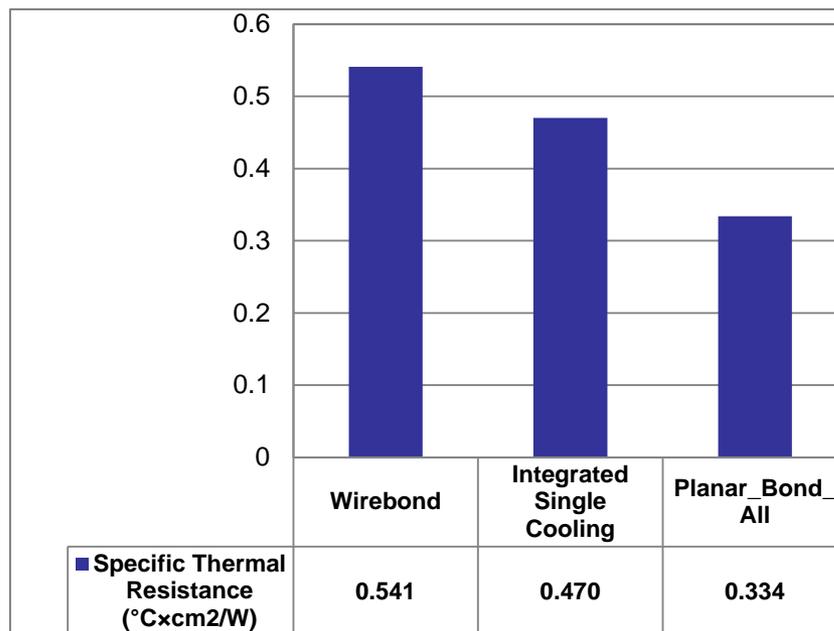


Wire Bond Module

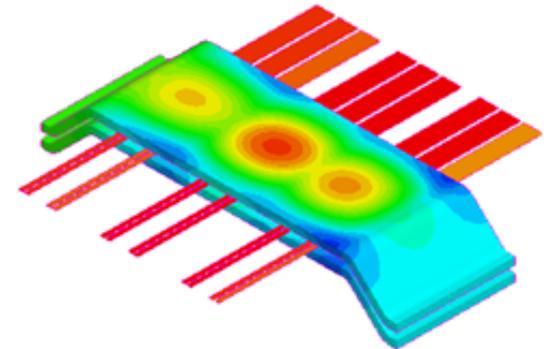
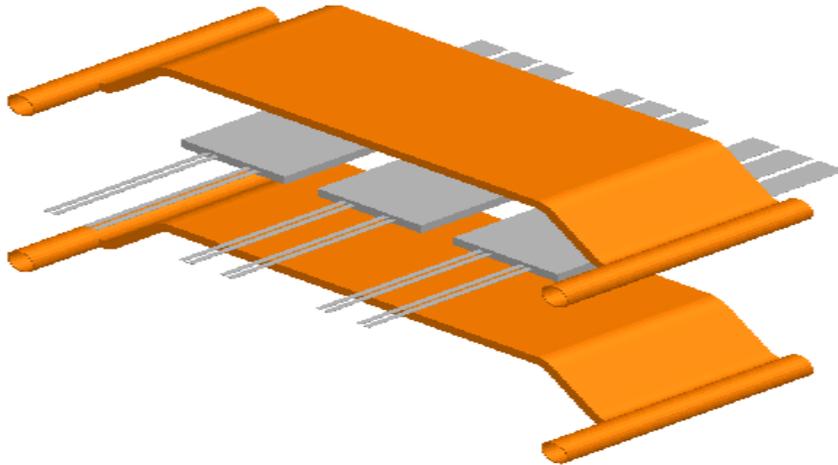
Thermal Performance Characterization



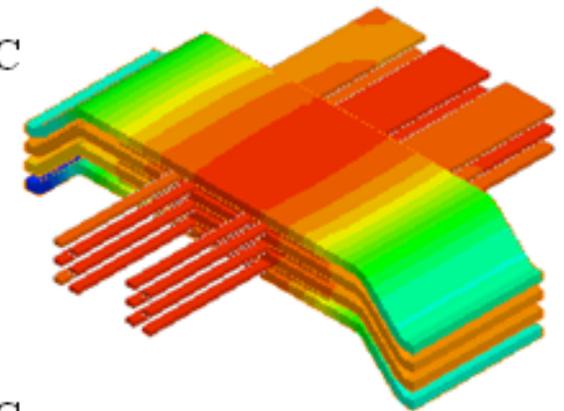
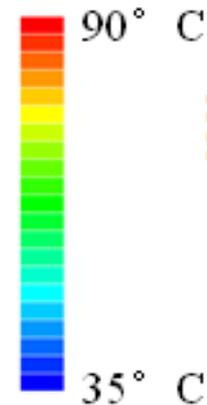
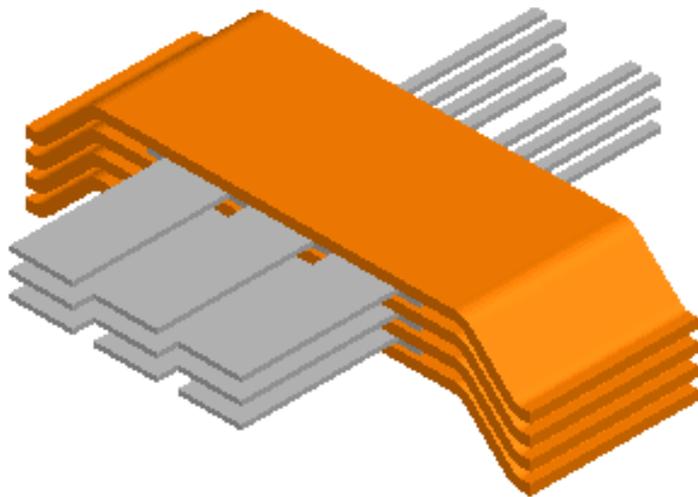
Flow rate: 0.52 gpm
Pressure drop: 22 psi



Design of 3-D Packaging of Cooling and Power Modules



Flow rate: 0.5 gpm, pressure drop: 22 psi
0.291 °C/W for center module



Flow rate: 1.3 gpm
Pressure drop: 38 psi

Summary

- Advance power module packaging technologies, focusing on improvements in cost, reliability, power efficiency and density through structure, material and processing integration.
- A group of power modules with double sided planar interconnections and integrated heat exchangers has been prototyped.
- Their three dimensional power interconnection configuration has been proven to offer low parasitic electric inductance and resistance, leading to high efficiency power conversion
- The double sided cooling reduces dramatically thermal resistance. Additionally, the package allows for ease of fabrication and low manufacturing costs.

ACKNOWLEDGMENT

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Thanks and Questions?