Advanced Power Modules & Packaging Technology

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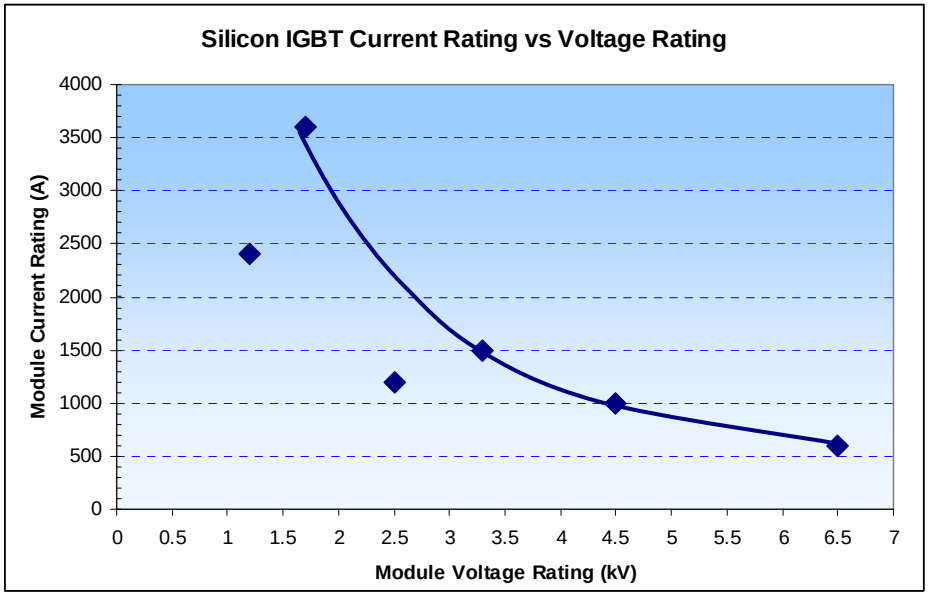
Chief Technologist

Advanced Power Module Technology - Outline

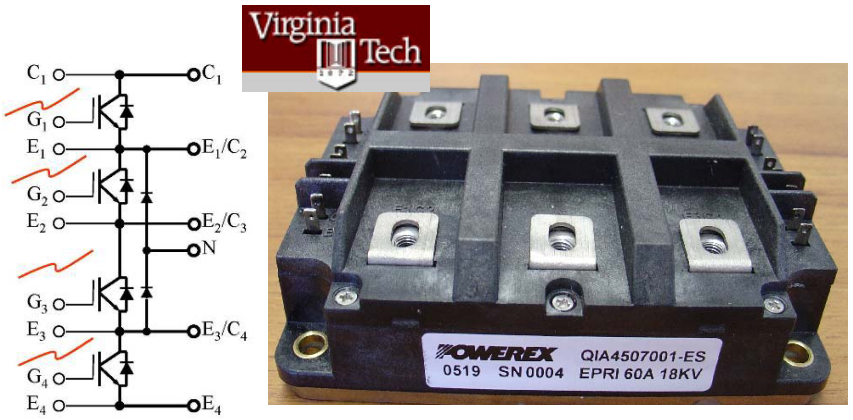
- Voltage & Frequency Limitations of Silicon Based Devices
  - Device Conduction & Switching Losses
- Alternatives to Silicon-Based Power Modules
  - Si IGBT / SiC FW Diode Hybrid Modules
  - All SiC Power Modules
- Technical Challenges for HV / HF Modules
  - Voltage Strike & Creep
  - Dielectrics
  - Inductance
  - Cooling
- Commercial Challenges For SiC Based Power Modules

Present IGBT Module Ratings: 250V to 6.5kV

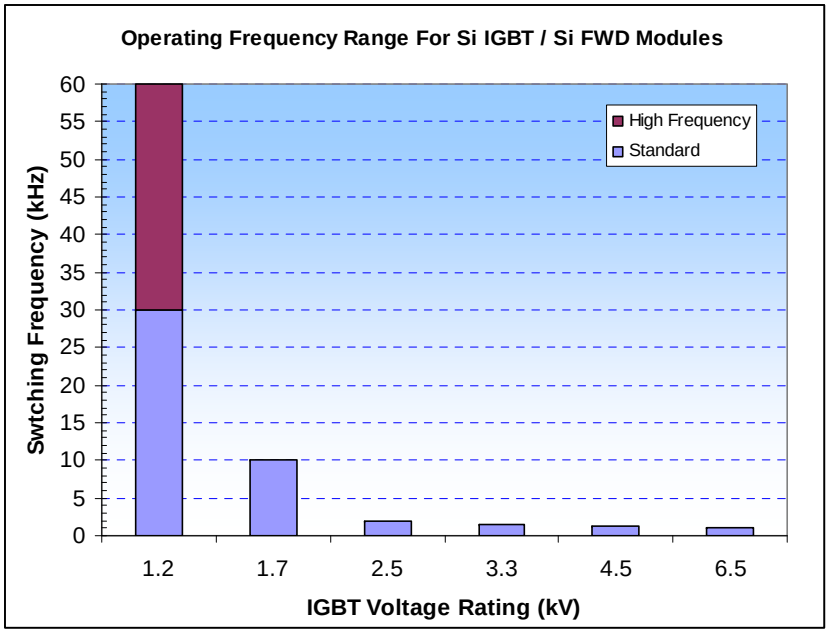


6.5 kV, 600A IGBT

Si IGBT Switching Frequency Capability Decreases Rapidly with Voltage Rating Due to Increased Losses



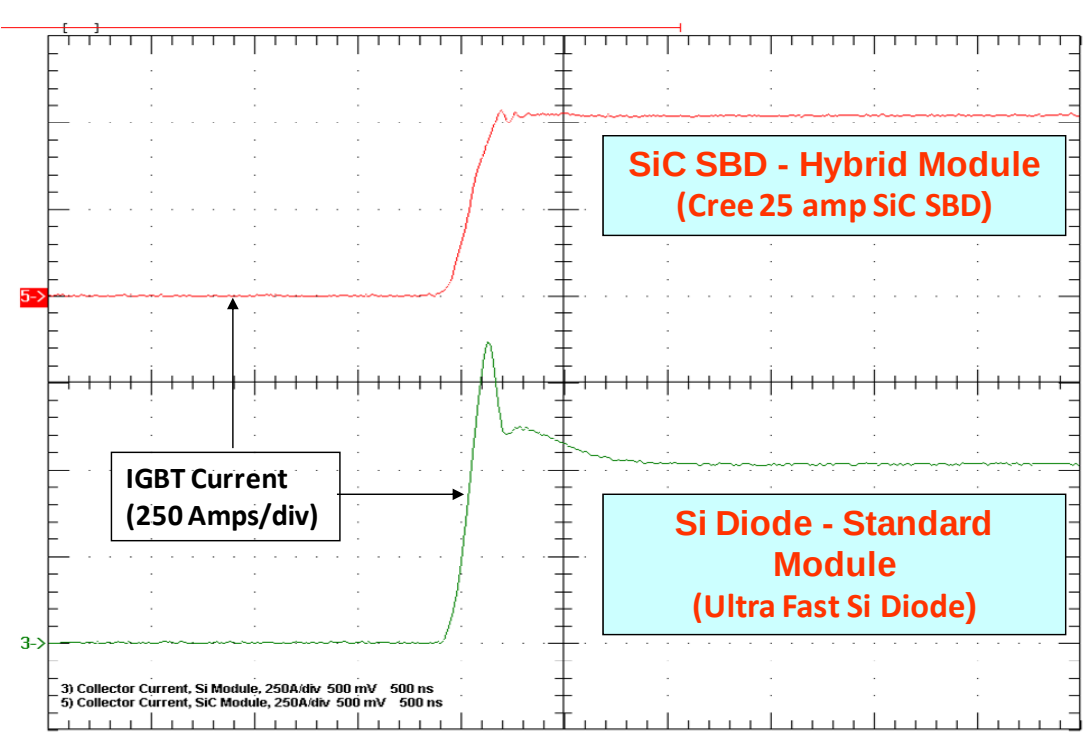
4.5 kV, 60A IGBT (3-Level diode-clamp)

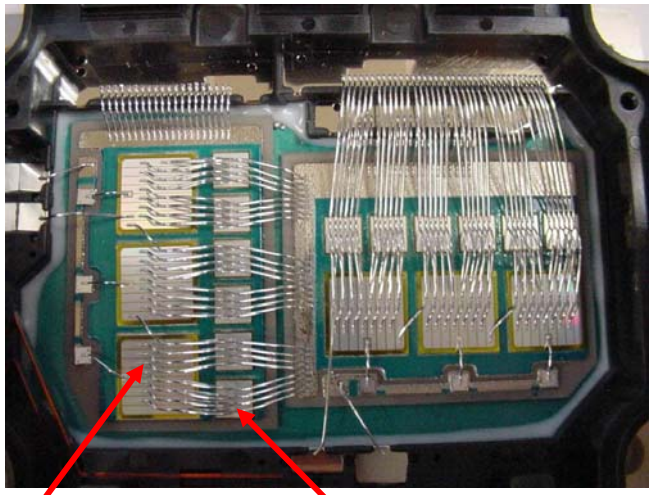


Power Module Technology Trends

- Silicon Power Modules Rated to 6.5kV
  - Switching Frequency Limited for Modules Rated Above 1200V
  - Low Operating Frequency Does Not Permit Reduction of Passive Components
- Hybrid Silicon IGBT/SiC FW Diode Can Extend Switching Frequency
  - "Zero" Recovery Charge of HV SiC Schottky Diodes Reduce IGBT Switching Losses
- Shift to HV, HF SiC-Based Majority Carrier Switches
  - 1.2kV & 10kV SiC MOSFETs Developed
  - Higher Temperature Capability of SiC Can Lead to Higher Converter System Power Densities & Relaxed Cooling Requirements
  - Higher Frequency Reduces Passive Component Sizes

SiC Shottky FW Diodes Reduce Si IGBT Switching Losses





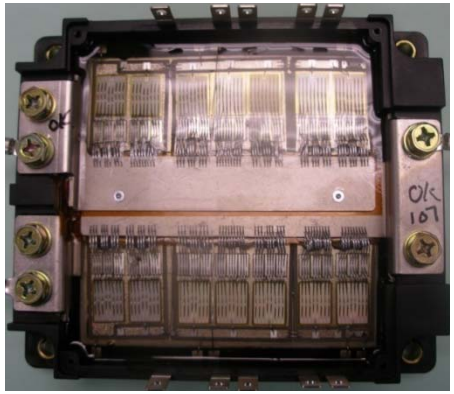
300A -1200V Dual Si/SiC Hybrid Module

1st Annual Ground -Automotive Power & Energy Symposium
July 20-22, 2005, Hilton, Detroit/Troy

CREE
POWEREX

TARDEC
BAE SYSTEMS

Si IGBT / SiC FW Diode Dual & 3 **F** Bridge Modules

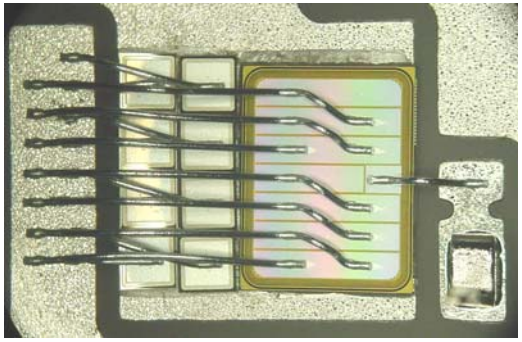


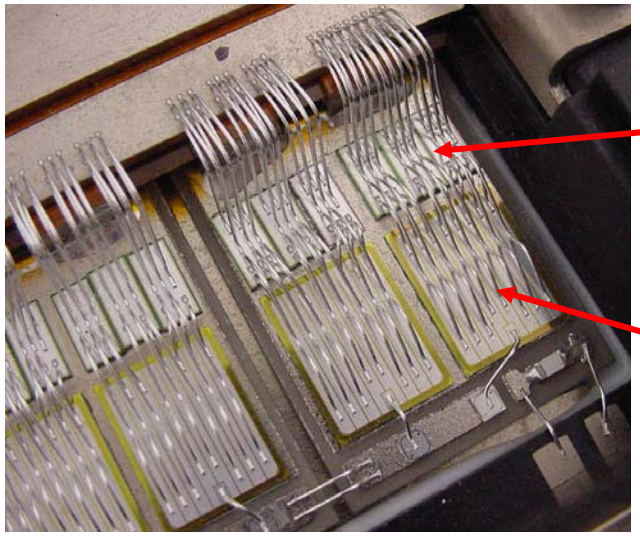
TARDEC

BAE SYSTEMS

POWEREX

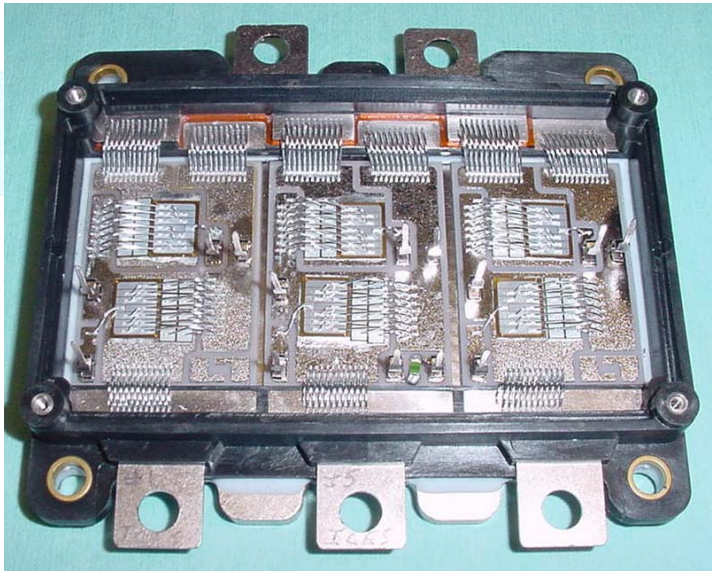
CREE





1200V/50 A SiC Schottky Diodes

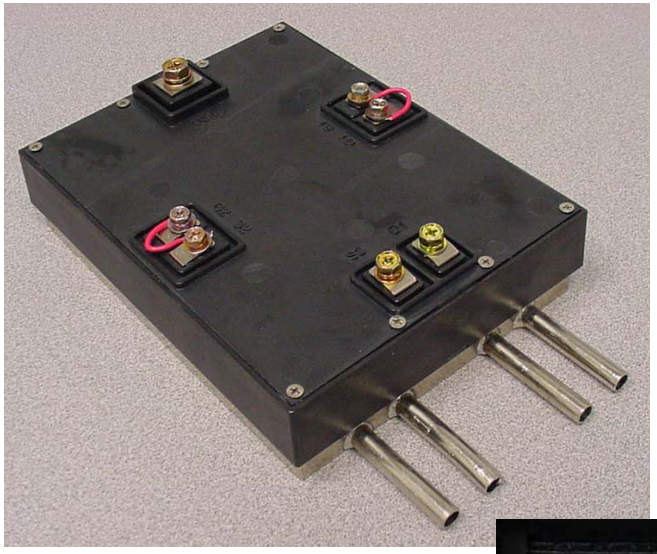
1200V Silicon IGBT

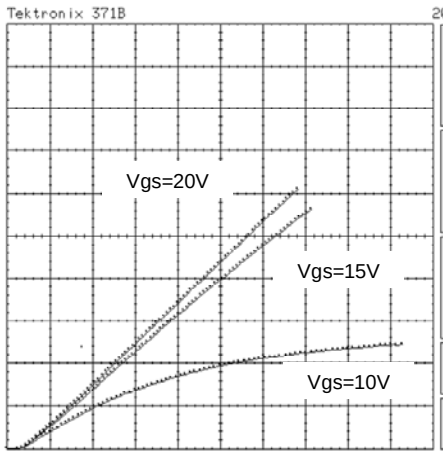


1200A -1200V Dual Si/SiC Hybrid Module

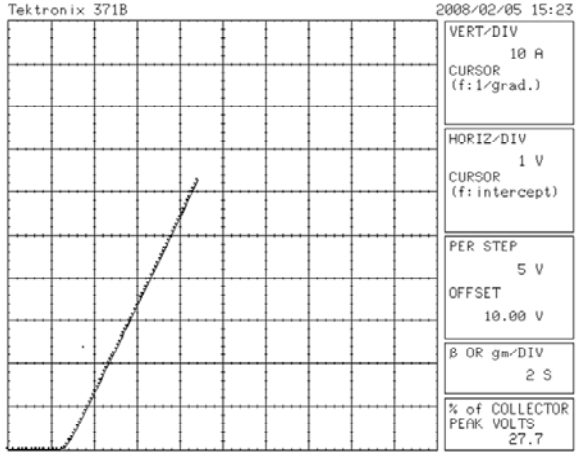
75A -1200V 3-**F** Si IGBT / SiC FW Diode Module

10kV, 50A SiC MOSFET/ SiC Schottky Half H-Bridge Module





Q1 MOSFET



Q1 JBS Diode

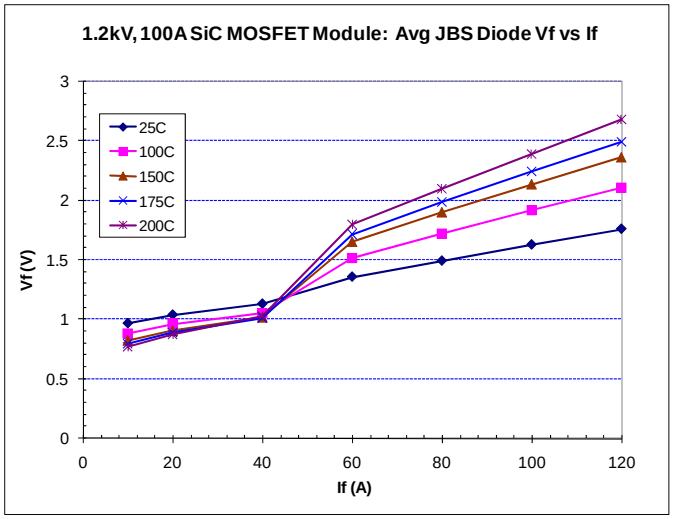
Test	Q1	Q2
Igs @ Vgs = 15V	2 uA	2 uA
Ids @ Vds = 3kV	0.6 uA	0.1 uA
Ids @ Vds = 5kV	2.6 uA	0.6 uA
Ids @ Vds = 6kV	5.1 uA	1.3 uA
Vds @ Ids = 50A Vgs = 15V	6.3 V	6.1 V
Vds @ Ids = 50A Vgs = 20V	5.6 V	5.5 V
JBS Diode Vf @ If = 50A	3.8 V	3.9 V

All Tests @ 25C

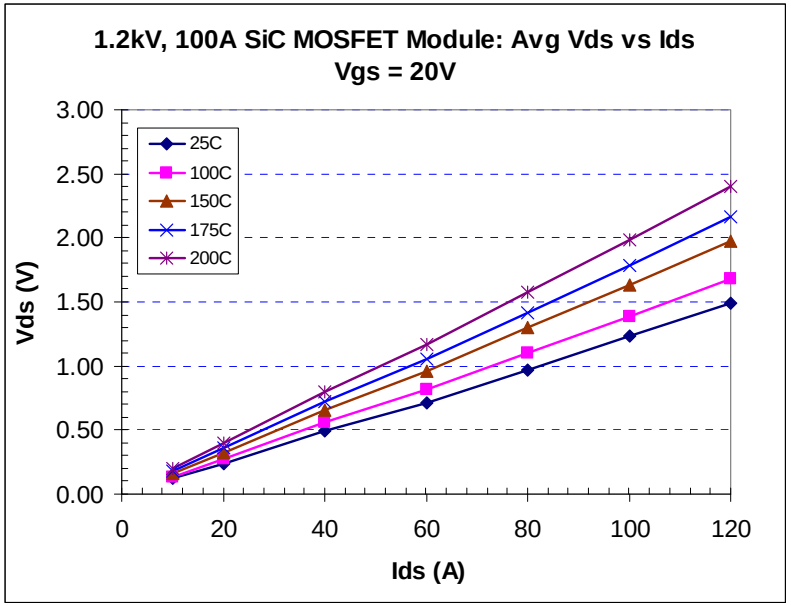
HPE Phase II Module

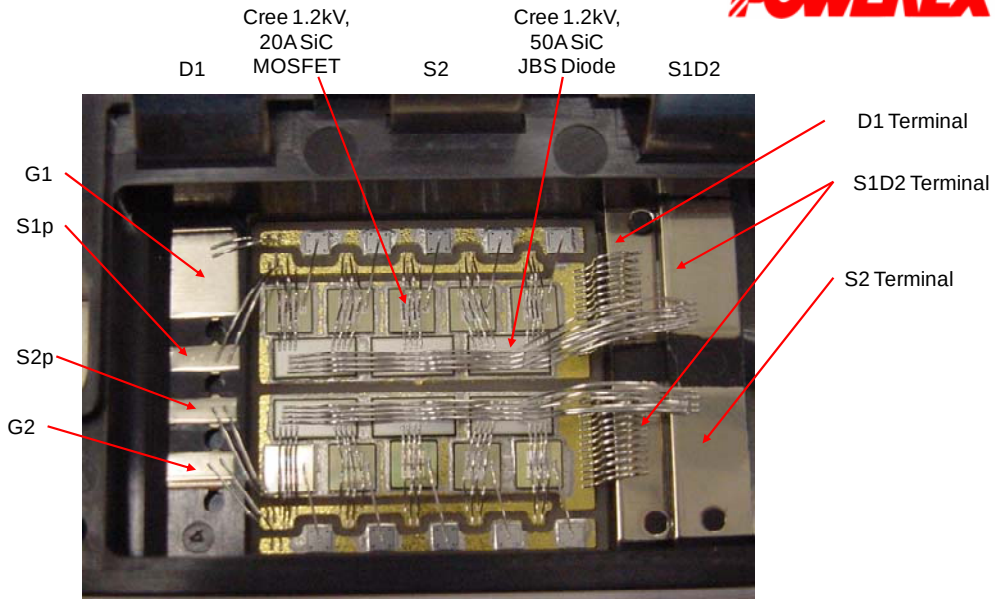
- 15kV Isolation
- Capable of 200C Operation
- Liquid Cooled

1.2kV, 100A SiC MOSFET/ SiC Schottky Half H-Bridge Module



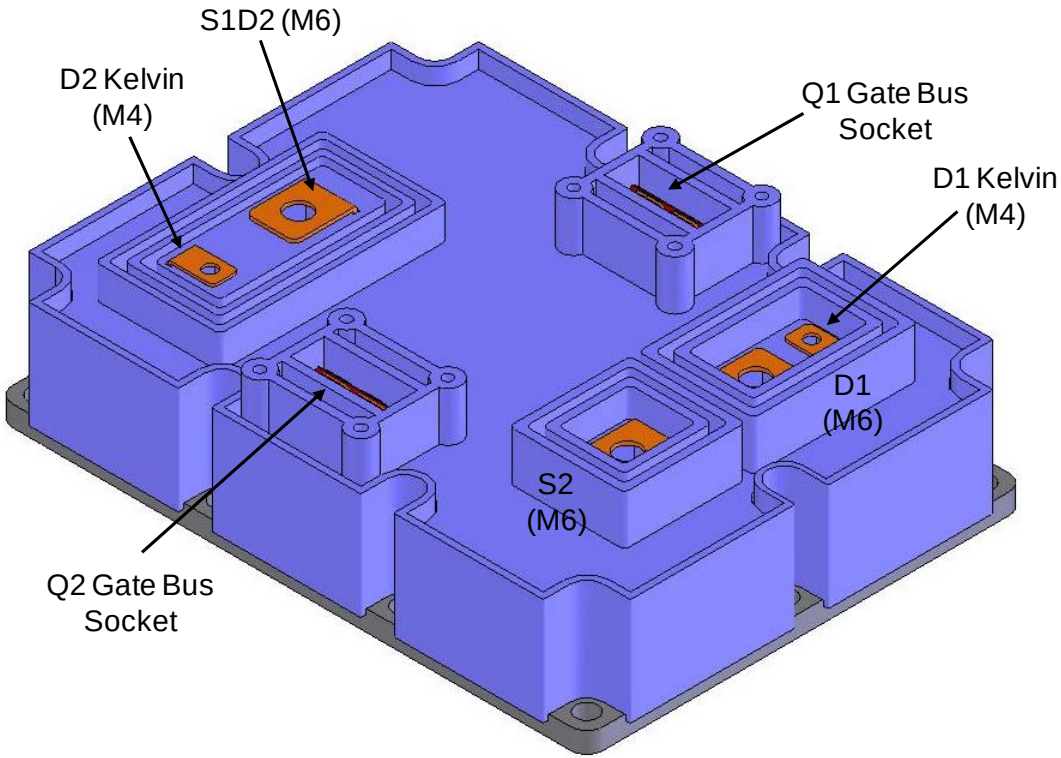
Capable of 200C Tj Operation





Technology Challenges for HV, HF Power Modules

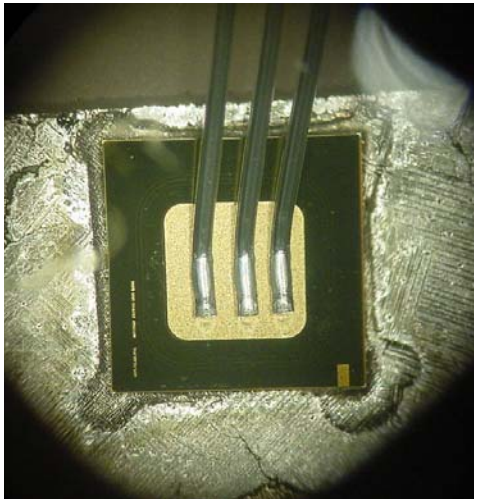
- External Voltage Strike & Creep
- Internal Dielectrics
  - Reliability & Losses
  - Corona/Partial Discharge
  - High Temperatures
- Low Inductance
  - Power Loop
  - Gate Loop
- Efficient Cooling
  - High Chip Power Densities
- Package Reliability

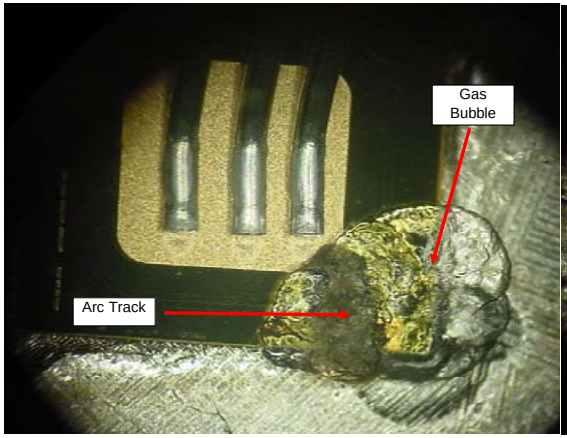


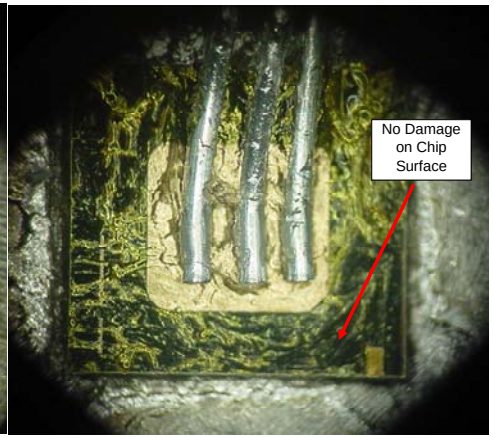
HPE Phase III SiC MOSFET Module:
10kV, 120A Half H-Bridge

Internal Package Dielectric Material Challenges for HV/HF Modules

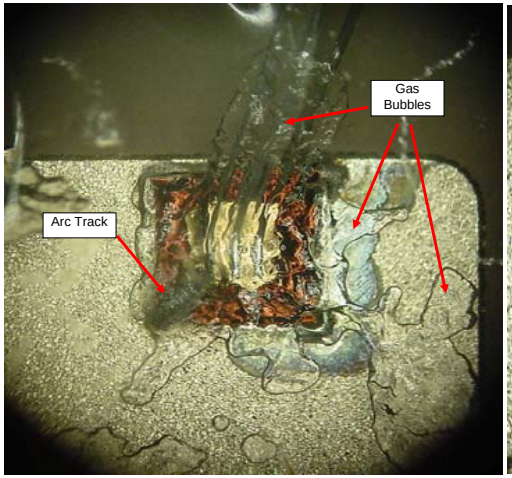
Start of HTRB Life Test

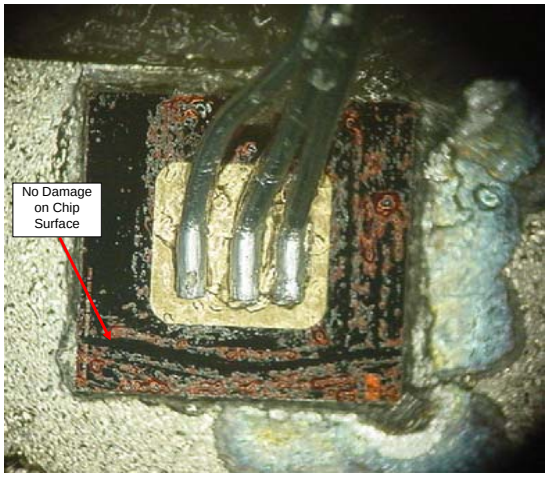






Gel Breakdown Failures Due to Bubble Formation

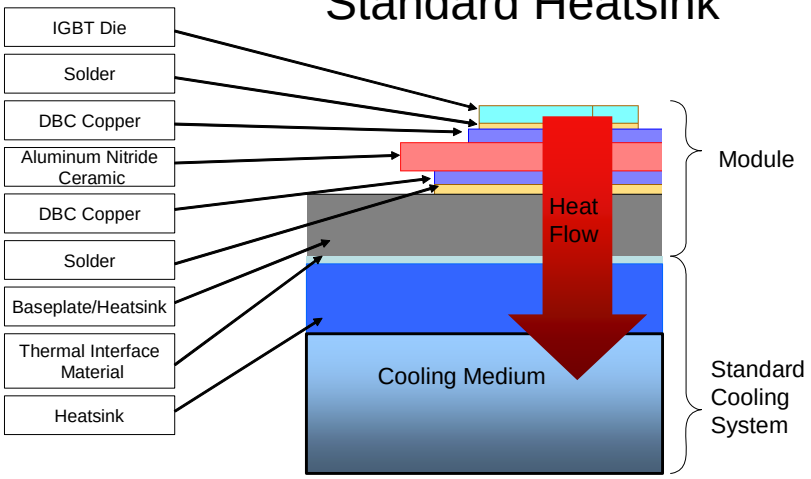


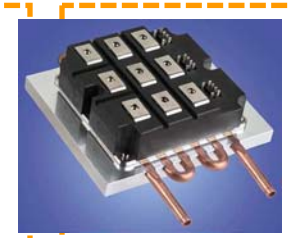


Program to Investigate & Improve Encapsulant Reliability Currently Funded by Navy MANTECH

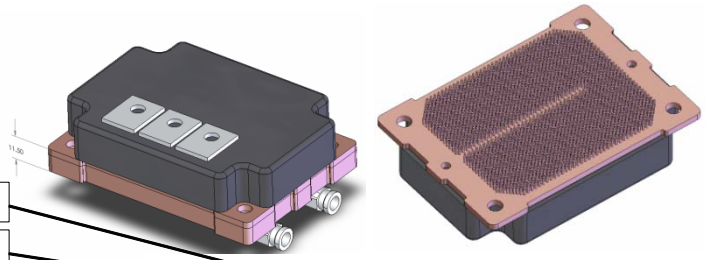
Cooling Challenges– Reducing the Heat Flow Path

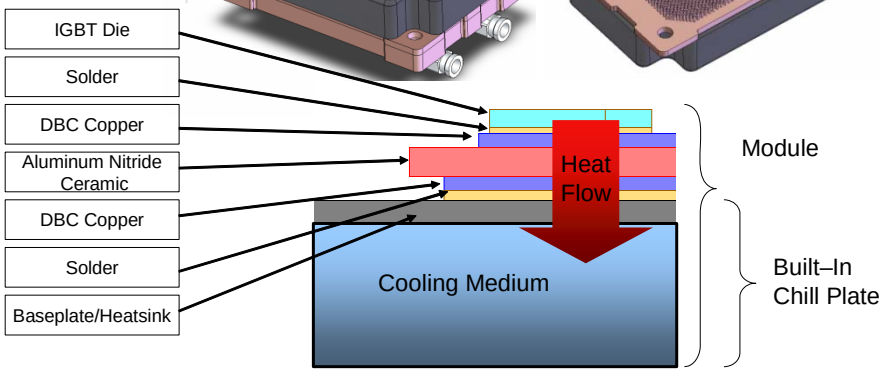
Standard Heatsink



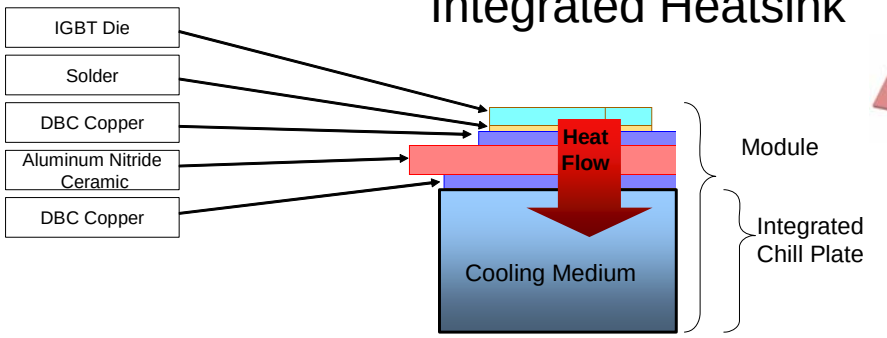


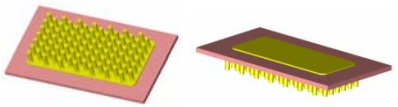
Built-In Heatsink

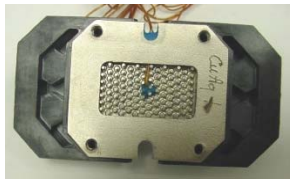




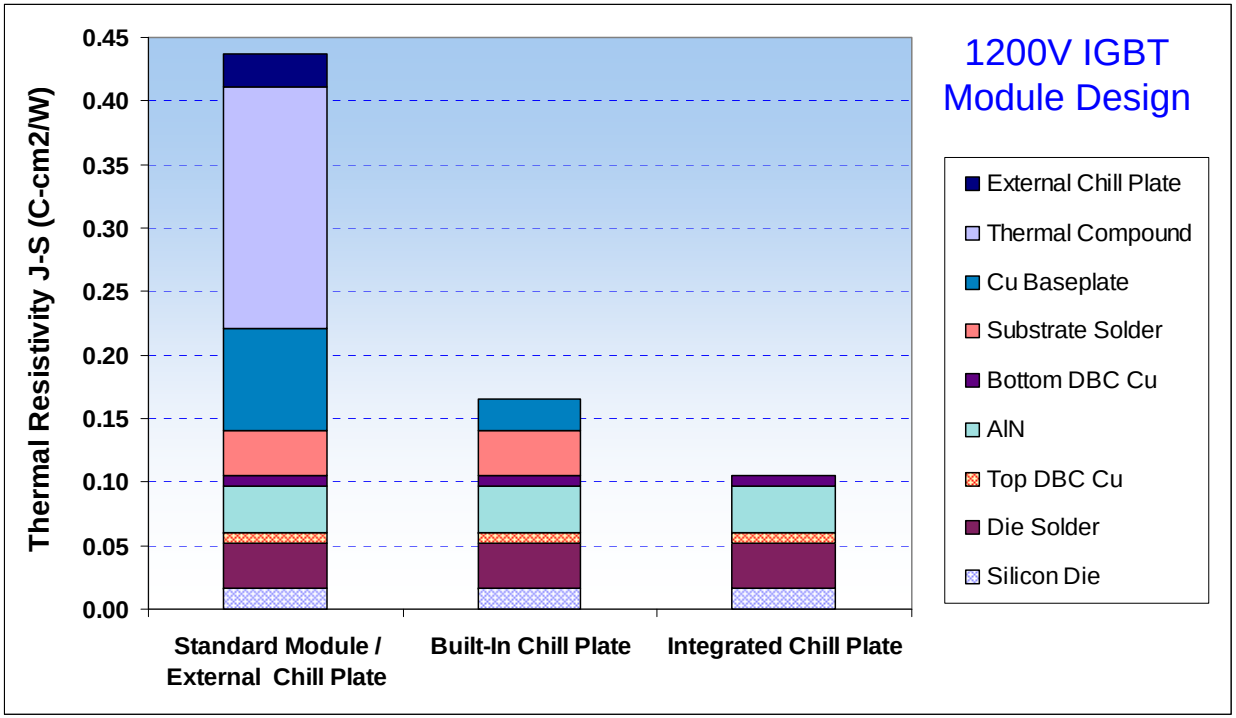
Integrated Heatsink



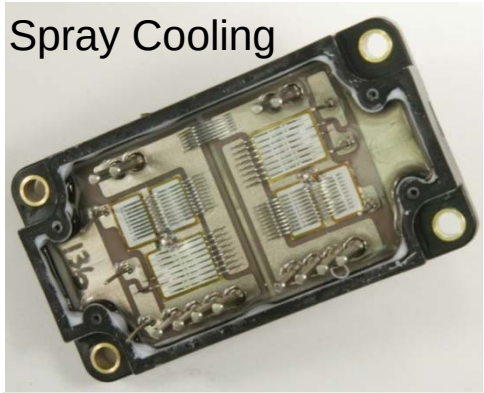


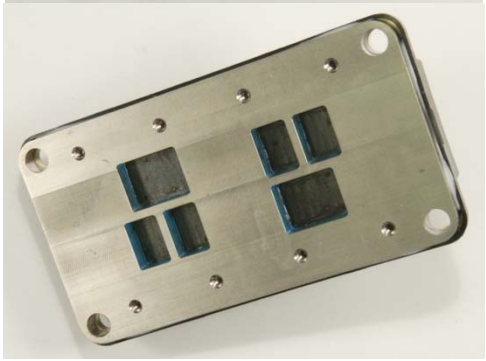


Thermal Resistivity Comparison of Paths to Cooling Medium

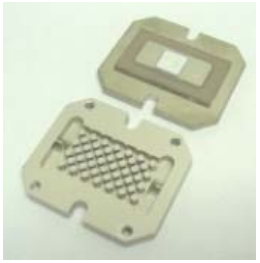


Spray Cooling





Programs Funded by DARPA, ONR, AFRL & DOE to Extend the State of the Art in Module Air & Liquid Cooling



Fins

Microchannels

Commercial Challenges For SiC-Based Modules

- SiC Chip Costs
  - High Material Cost
  - Low Yield
- Power Module Costs
  - Small SiC Die Sizes Leads to Lower Power Densities & Larger Modules

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