High Temperature, High Performance SiC Power Modules for Next Generation Vehicles

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APEC®

presented by…

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Introduction & Outline

CAD Modeling Techniques

Simulation Process

Example Simulation Results

Hermetic Power Module

Packaging Overview

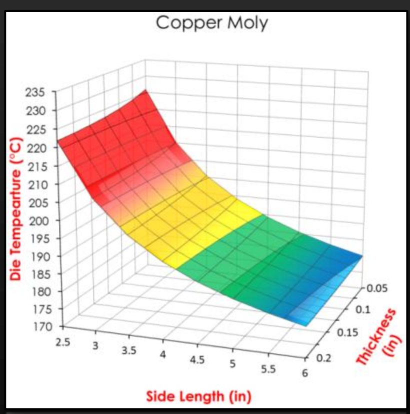
Inverter Testing

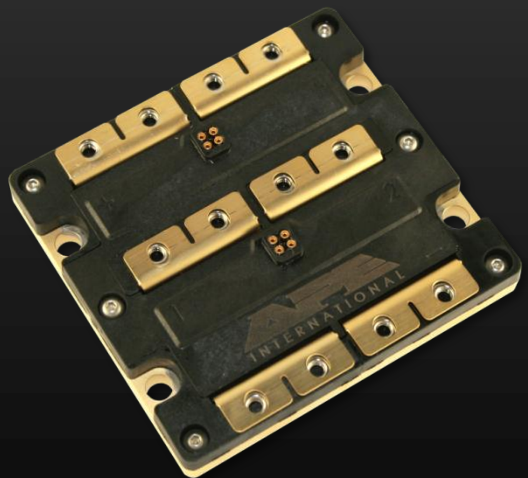
High Performance Modules

Packaging Overview

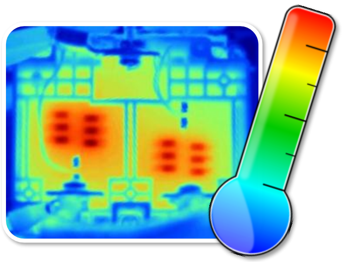
Characterization & Switching Loss

JFET, DMOS, TMOS

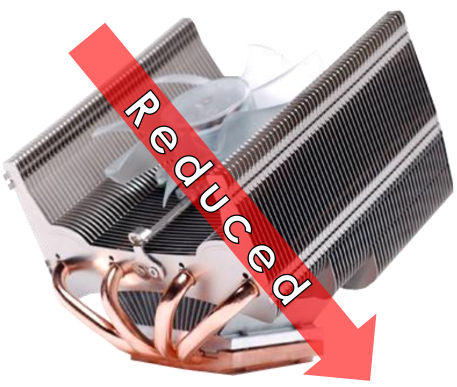




Why High Temperature?



What if temperature was *not a limitation*?

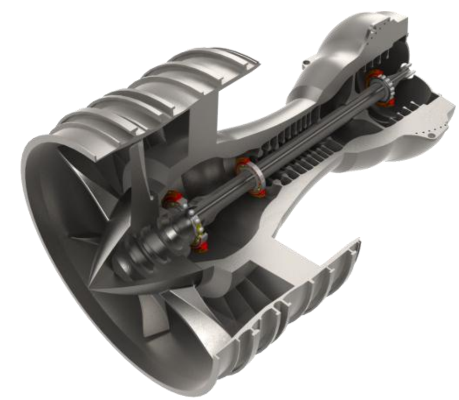


Cooling Systems

Thermal Shielding

- *Efficiency*
- *Power Density*
- *Size & Weight*
- *Complexity*
- *Cost*

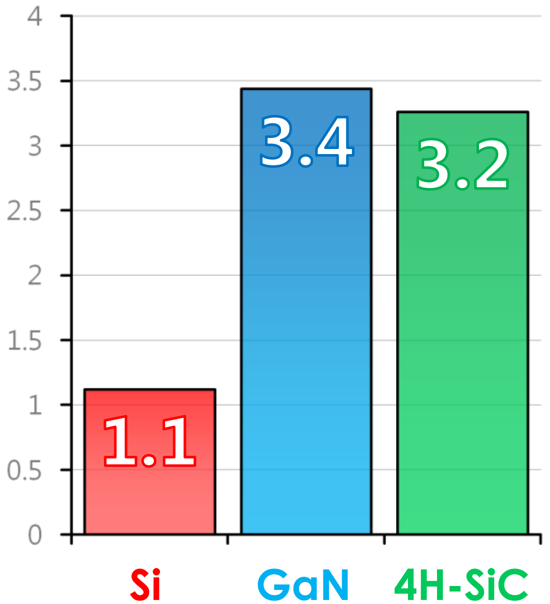
Design Tradeoffs



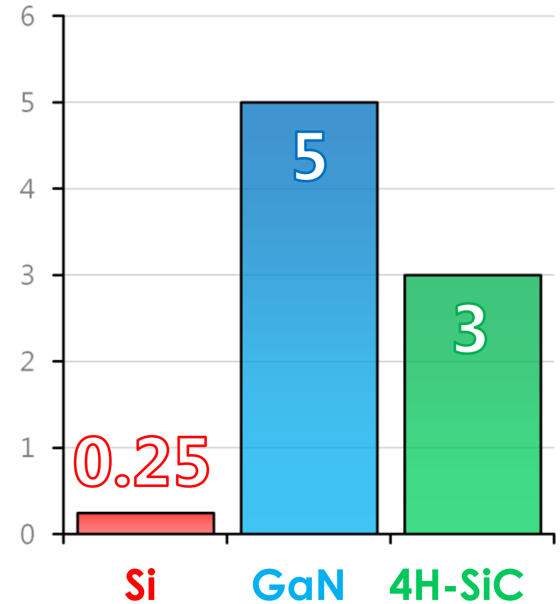
Extreme Environments

Wide Band Gap Semiconductors

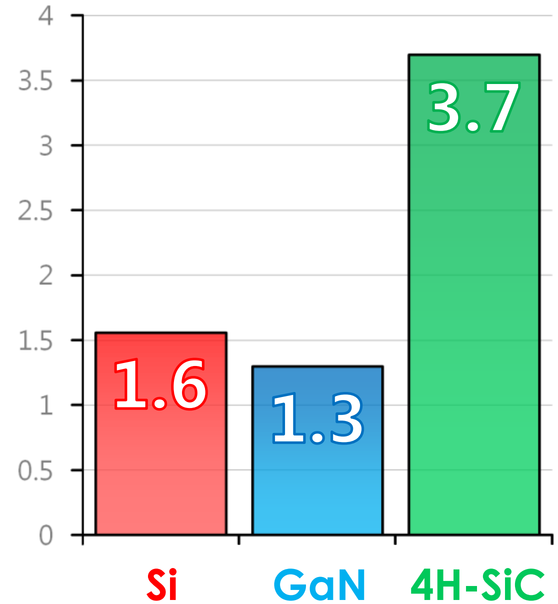
Band Gap
(eV)



Breakdown Electric Field
(MV/cm)



Thermal Conductivity
(W/cm•K)



larger band gaps mean...

- ⬇ ***Intrinsic Carriers***
- ⬆ ***Operating Temperature***

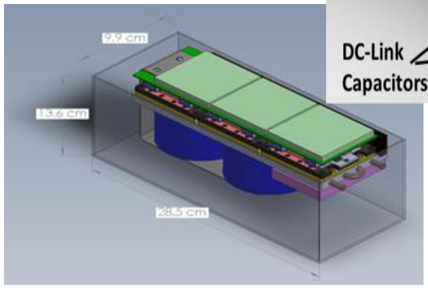
higher critical fields result in...

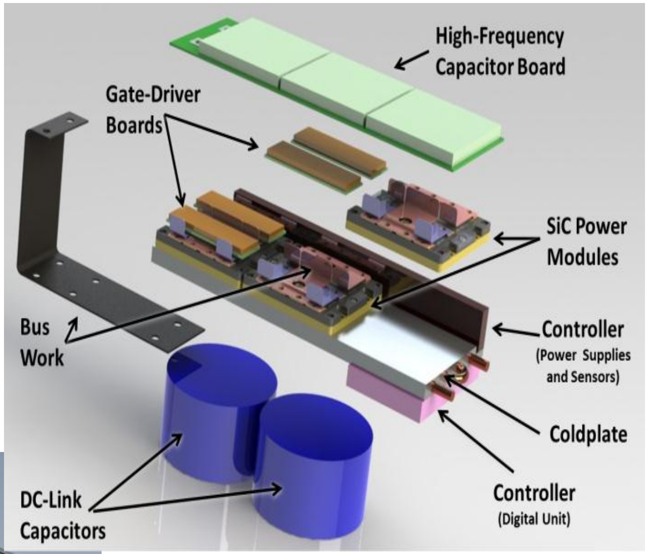
- ⬆ ***Blocking Voltages***
- ⬇ ***On-Resistance***
- ⬆ ***Switching Speed***

increased thermal cond. allows...

- ⬆ ***Heat Dissipation***
- ⬆ ***Power Density***

Military Vehicle Applications

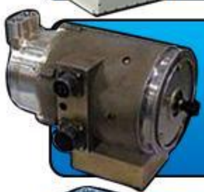




More Electric Aircraft Applications

Inverter / Converter / Controller

Conditioned power to flight critical actuation system



Emergency Generator

Independent source of electrical power

DC Battery

Uninterruptible, flight critical power

Starter / Generator

Source for redundant, flight critical power

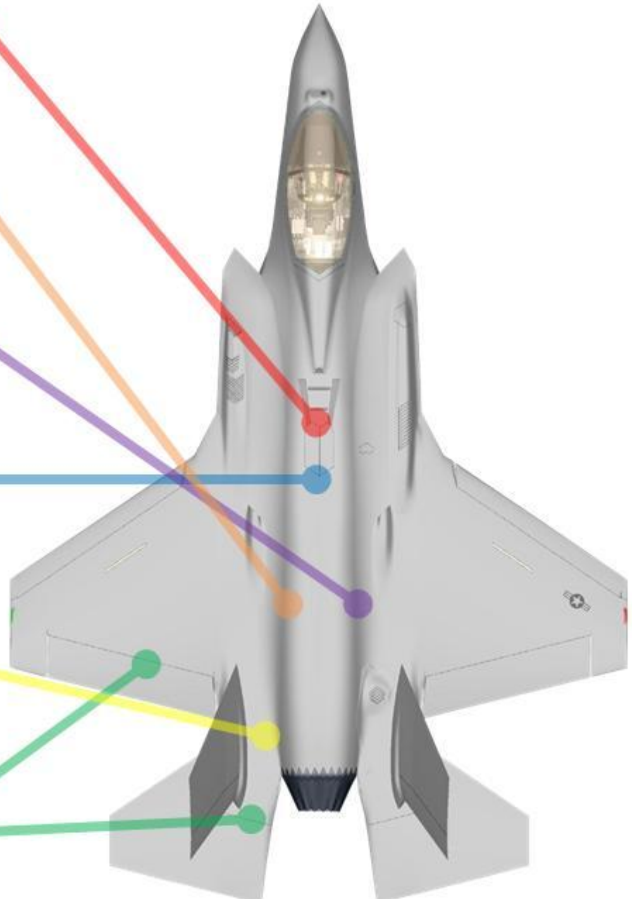
Power Drive Electronics

Modulated power to flight control actuators

Electro-Hydrostatic Actuators

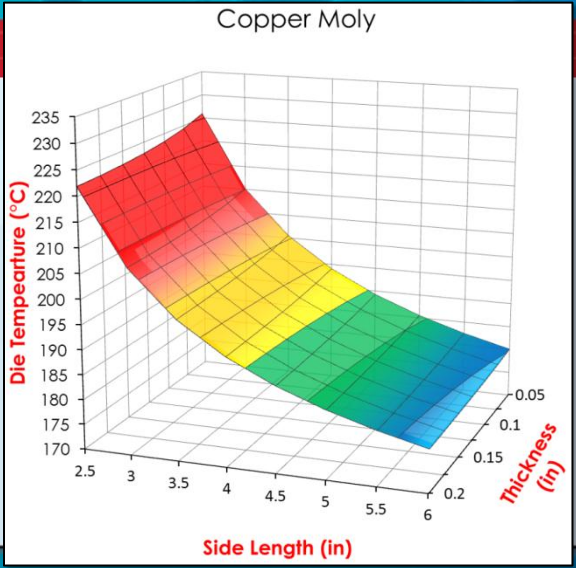
Redundant control power at each control surface

More Electric Aircraft (MEA) such as the F-35 could find SiC power electronics usage in or with:



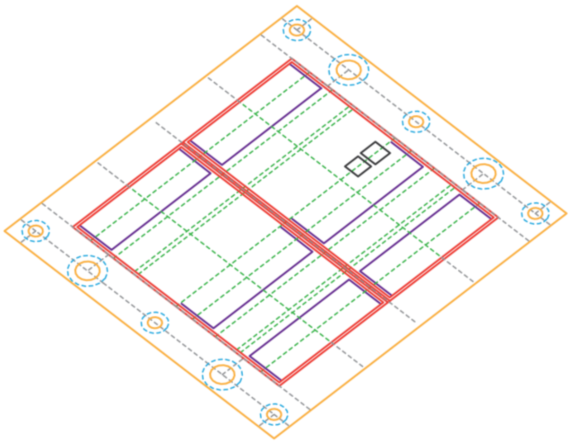
Design

philosophy and processes



Adaptive CAD Modeling

Technique which allows for rapid configuration of a design with minimal user input.



Reference Sketches

Geometry is driven by relationships, equations, and named variables.

Assembly

Components are defined in context and driven by the referenced design variables.

Configurations

Thousands of variations may be rapidly analyzed with this process.

Adaptive Simulation

Using an adaptive CAD model and FEA simulation software, thousands of configurations may be investigated.

Base Plate
material
geometry

Power Substrate
ceramic type
ceramic thickness
metal type
metal thickness

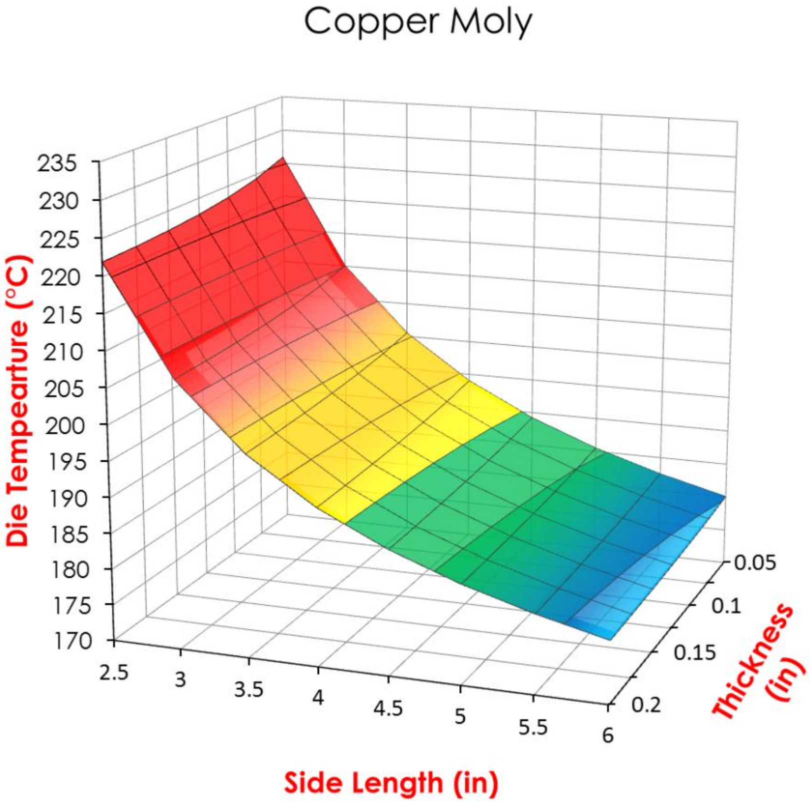
Die Attach
material
thickness

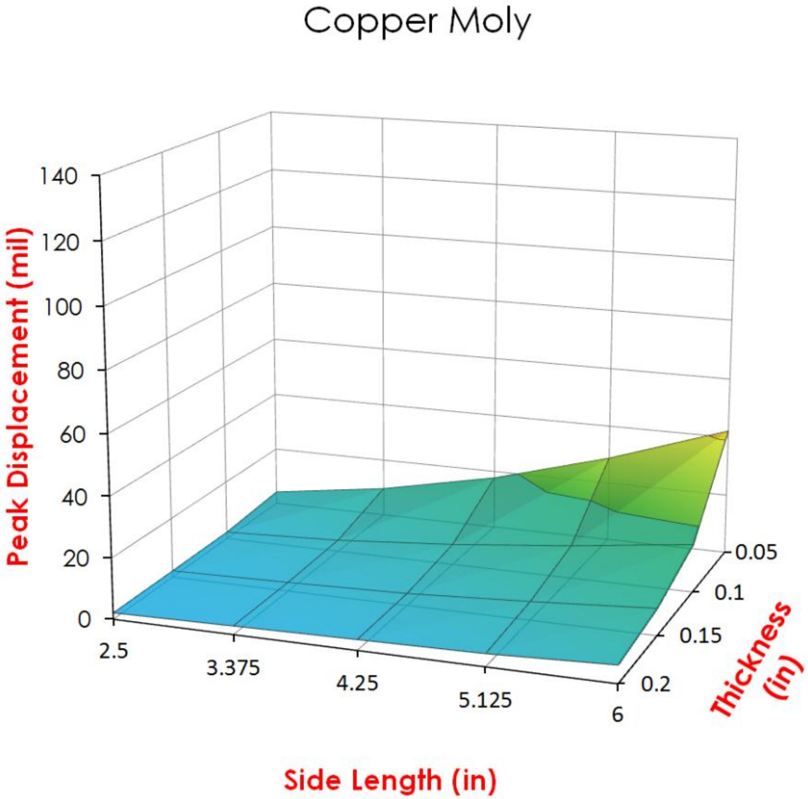
Spacing
die to die
die to edge
substrate to base plate
substrate etch lines
clearances
tolerances

Tradeoffs
thermal performance
stress & displacement
weight vs. performance
volume vs. performance
plastic reinforcements

Example Base Plate Analysis

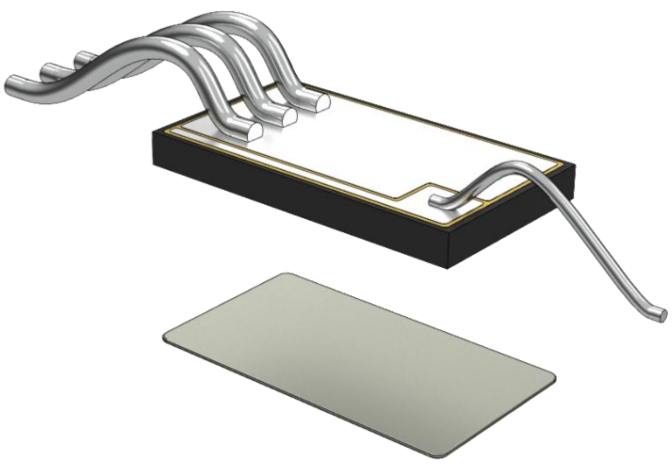
Simulation data is extracted and organized into design surfaces. Tradeoffs are identified and visualized.

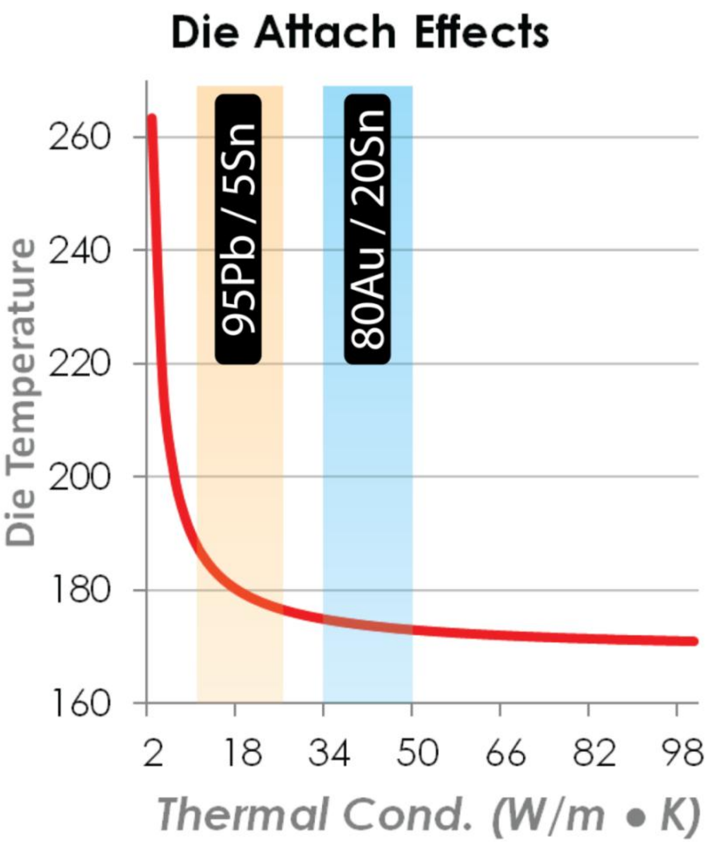




Example Die Attach Analysis

The thermal conductivity of the die attach exhibits diminishing returns.



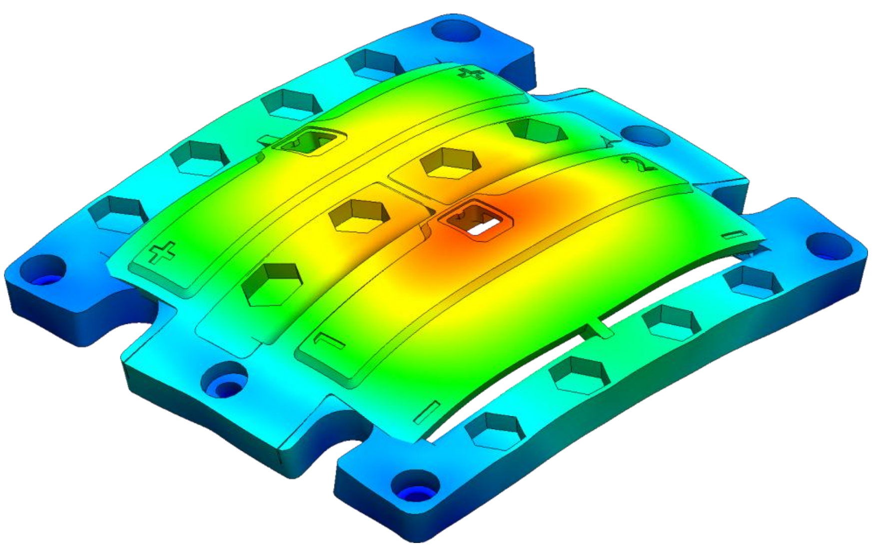


Example Housing Analysis

Plastic reinforcing features are carefully designed for minimal stress & displacement.

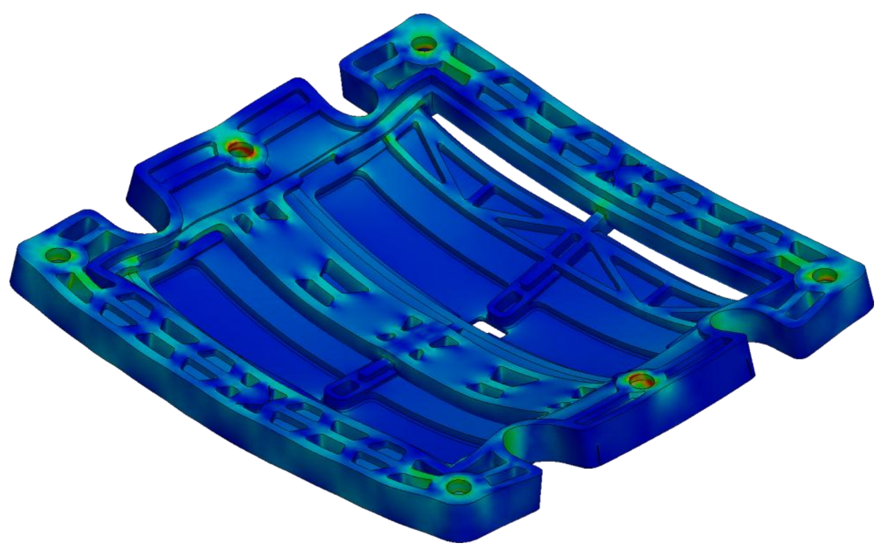
Displacement @ 200°C

0 mil *(0 mm)* — **0.9 mil** *(0.023 mm)*



Von Mises Stress @ 200°C

0 MPa — **2 MPa**



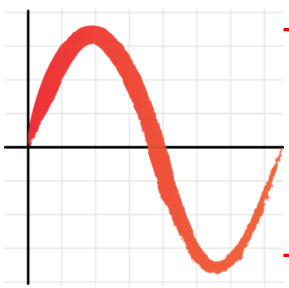
Hermetic Modules

design and features

Hermetic Sealed Modules

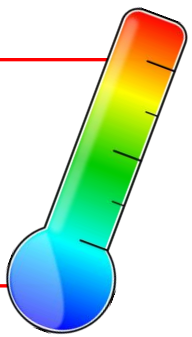
Extreme environment, high frequency all SiC half-bridge power stage.

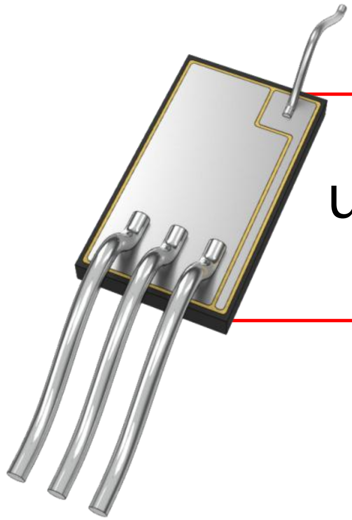


Ratings
1200V
≤100A

Temperature
300°C peak
(packaging)

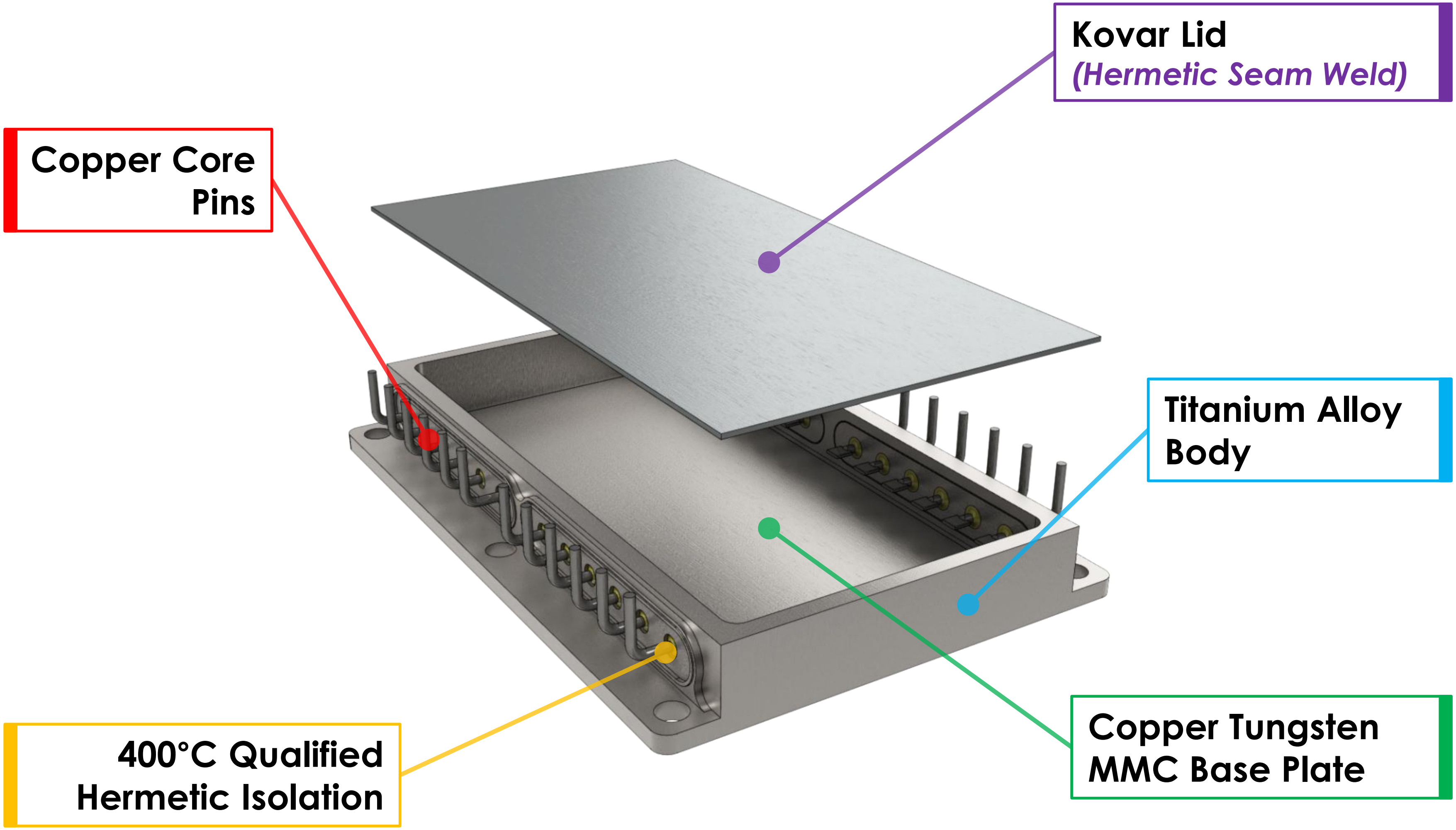




Devices
up to 10 die in parallel
per switch position

**** pictured: SemiSouth 50mΩ JFET (SJEC120R050)***

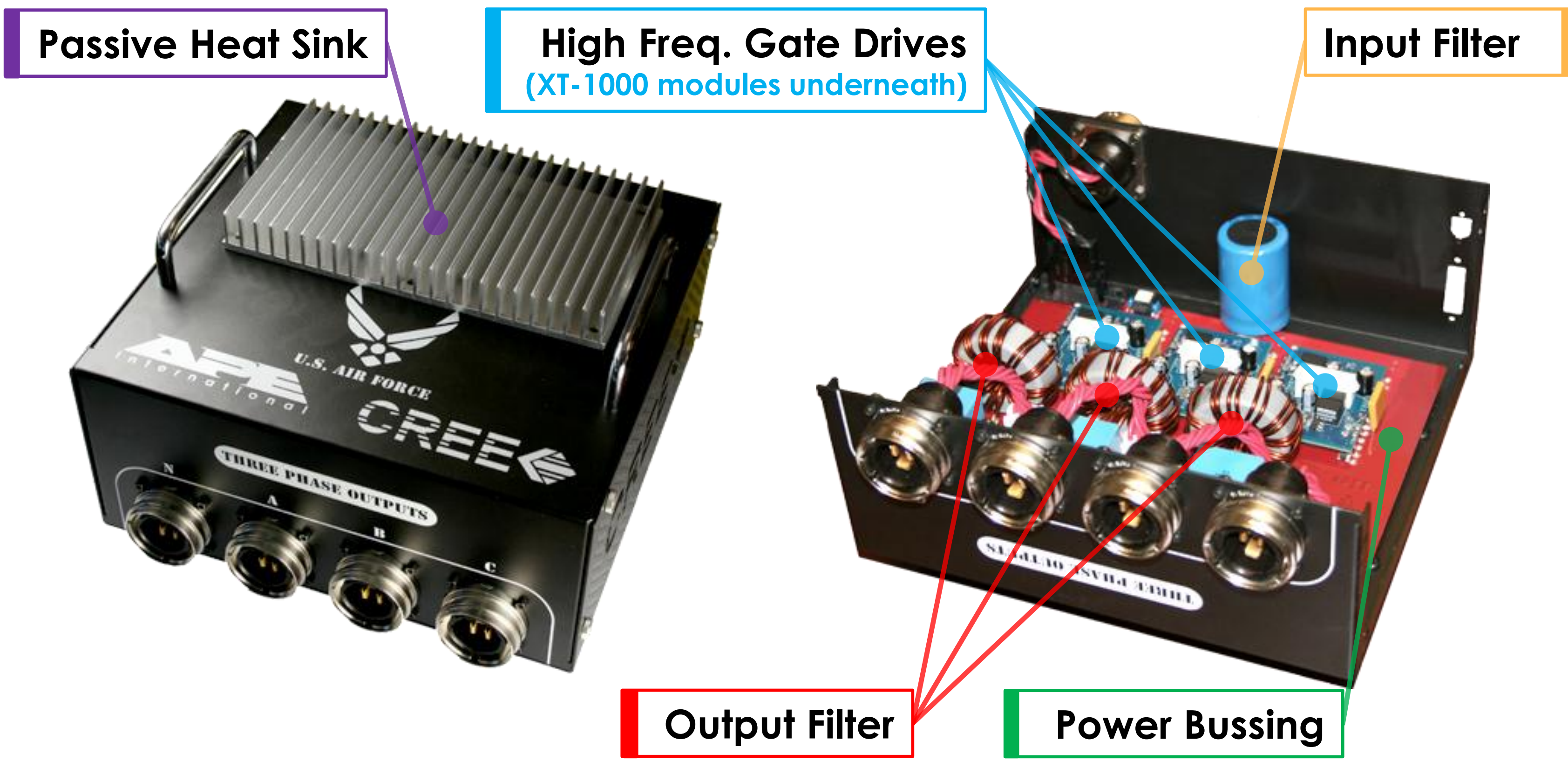
Packaging


Kovar Lid
(Hermetic Seam Weld)
Copper Core Pins
Titanium Alloy Body
400°C Qualified Hermetic Isolation
Copper Tungsten MMC Base Plate

Inverter System

A high performance *3-phase* inverter was designed and fabricated with hermetic modules.

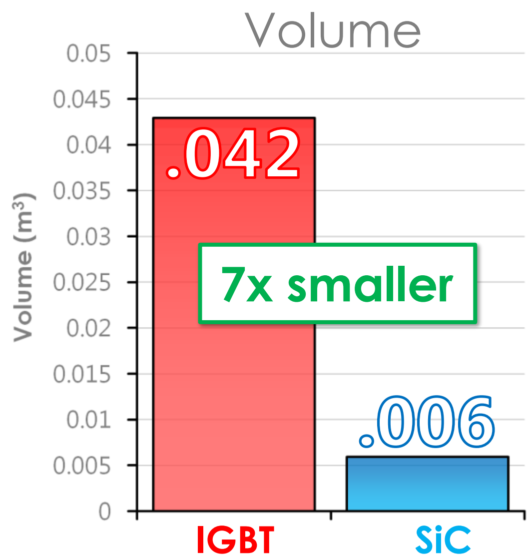
Maximum Power	Switching Freq.	Peak Junction Temp.
5 kW	50 kHz	200°C

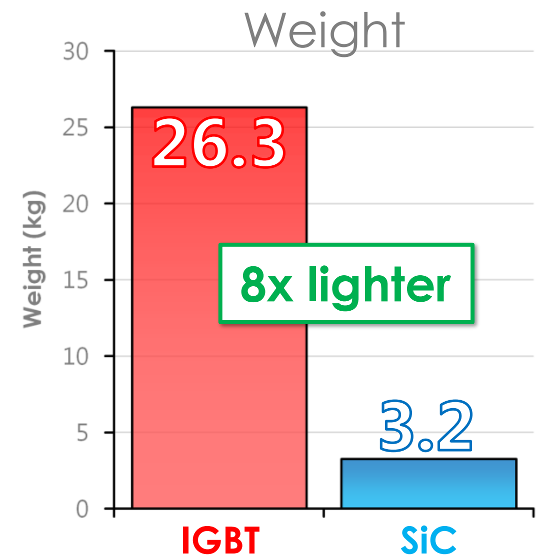


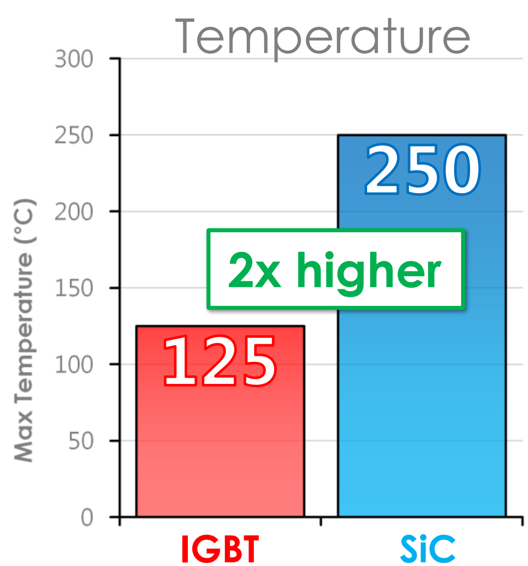
System Comparison

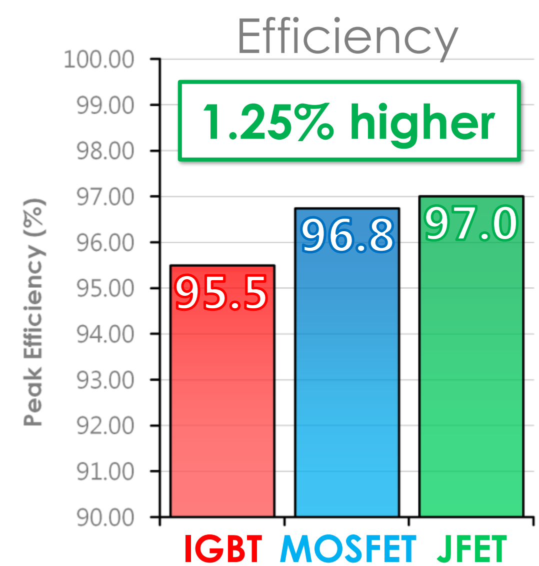
Comparison Inverter
IGBT Based (5kW)

APEI, Inc. Inverter
SiC Based (5kW)



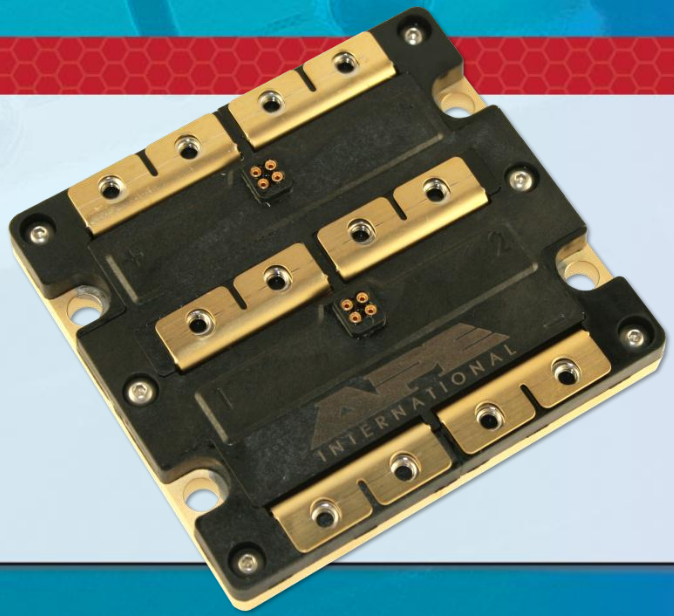




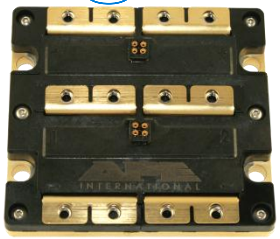


High Performance Modules

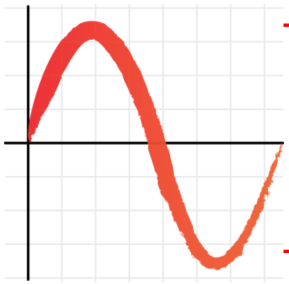
design and features



High Performance Modules

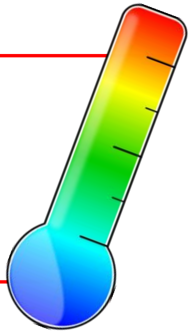


High temperature, high frequency, high power density all SiC half or full-bridge power stage.



Ratings
1200V
>150A

Temperature
250°C peak
(packaging)



Devices
up to 16 die in parallel
per switch position

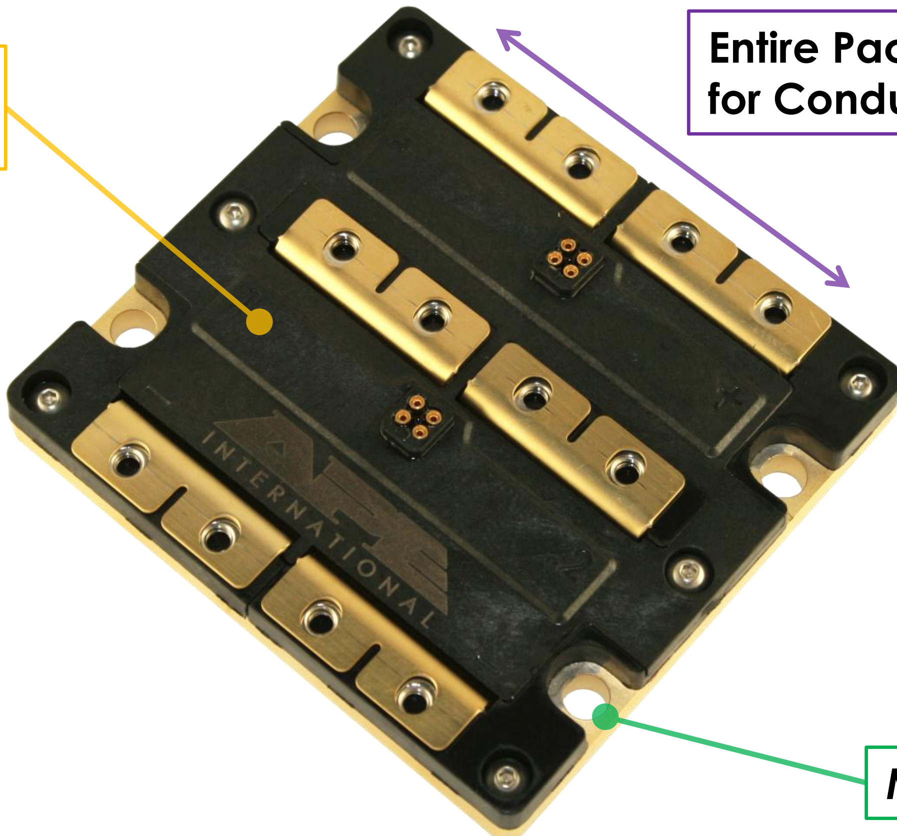
**** pictured: SemiSouth 50mΩ JFET (SJEC120R050)***

Packaging

Multiple Material Choices Based on Application

High Temp. Plastic Housing

Very Low Profile
0.43 in (10.9 mm)



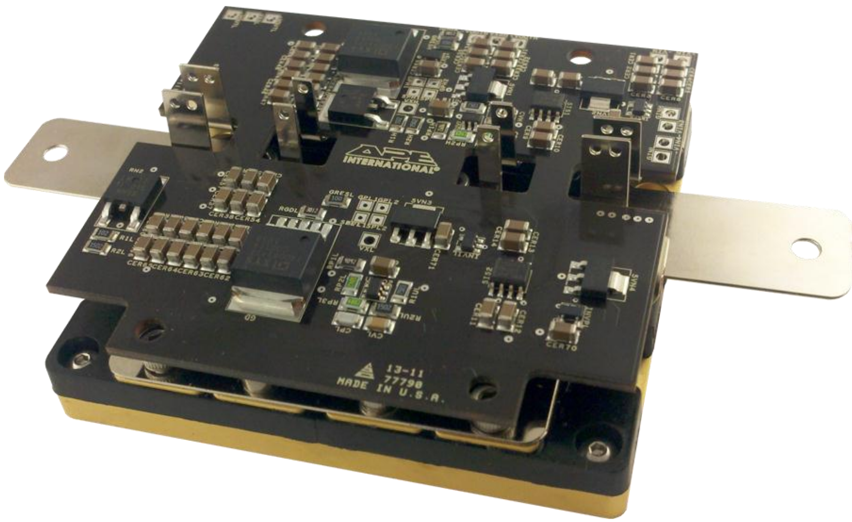
Entire Package Width Used for Conduction

Completely Flux Free Assembly

MMC Base Plate

Full Systems

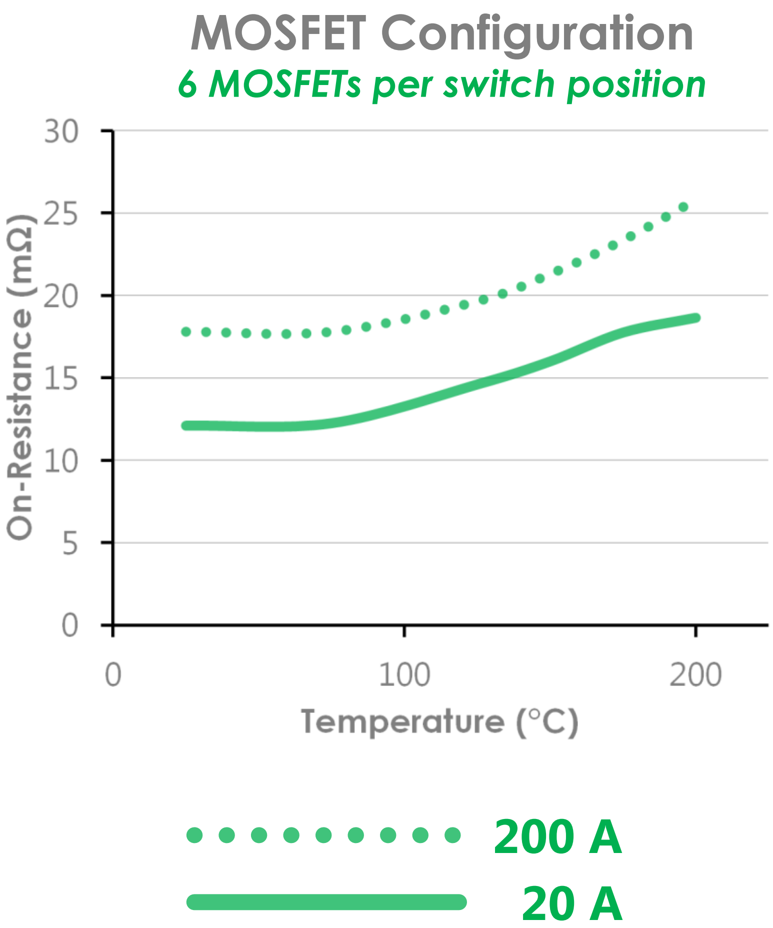
Modules have custom bussing and gate drives to achieve high performance switching

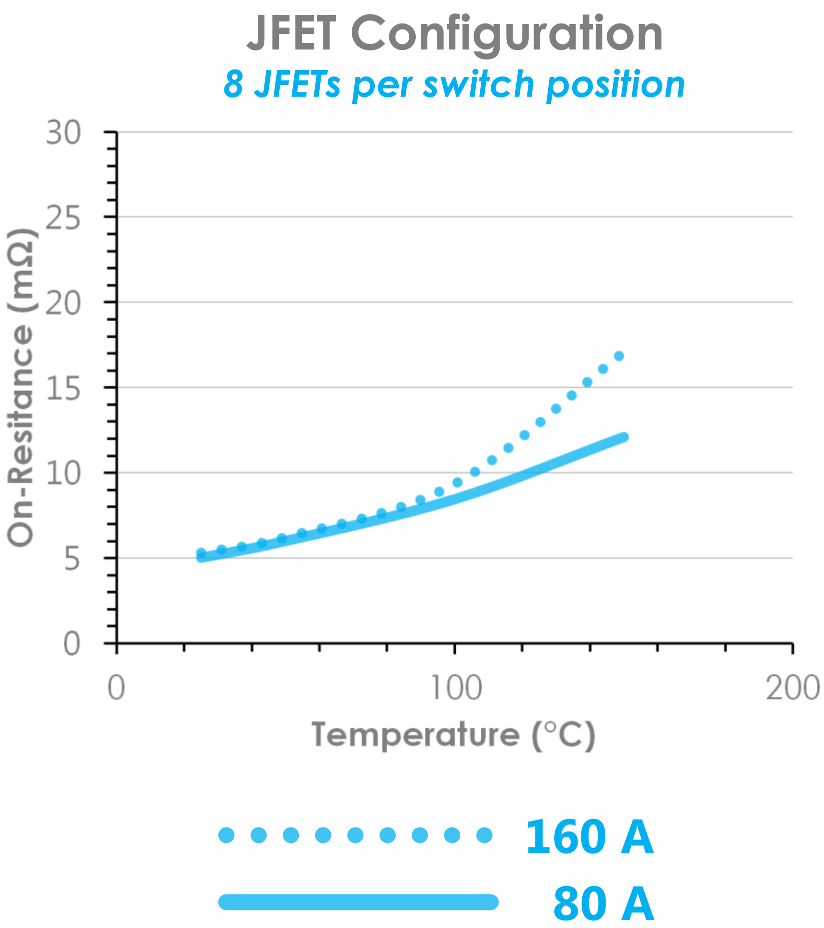


High Frequency
Gate Drive With Bussing

Characterization

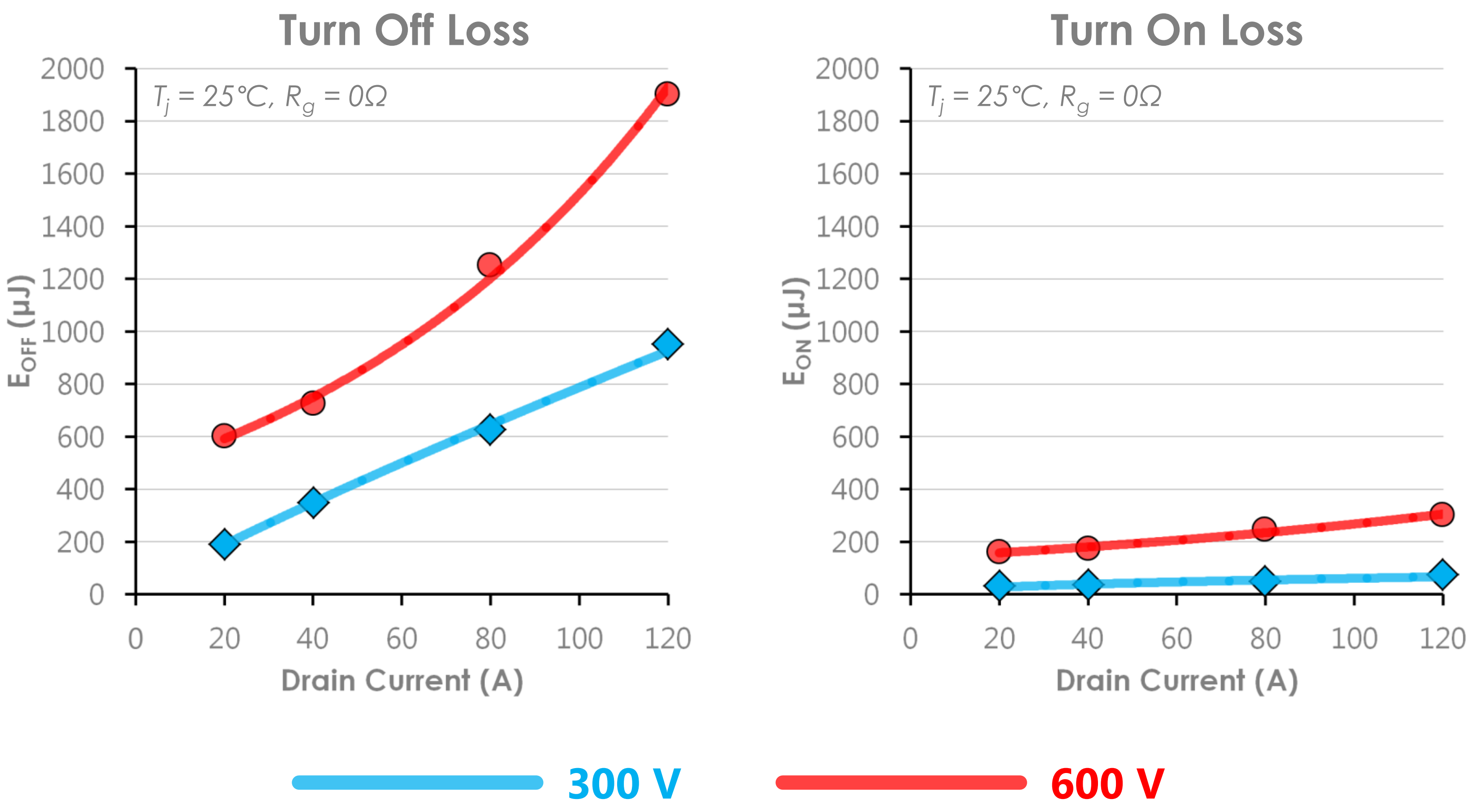
The paralleled switch positions exhibit very low on state resistances, even at high temperature.



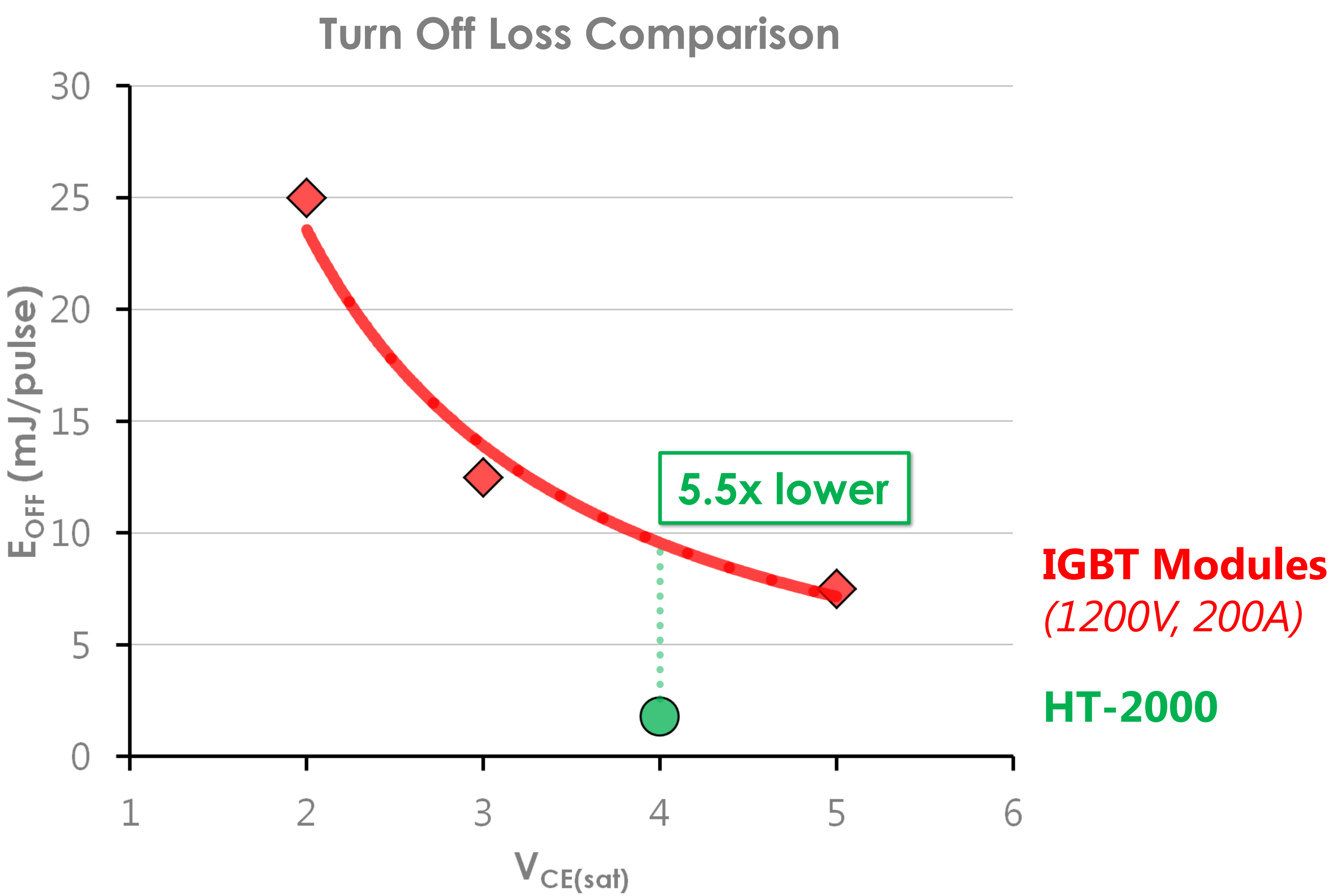


Switching Energy

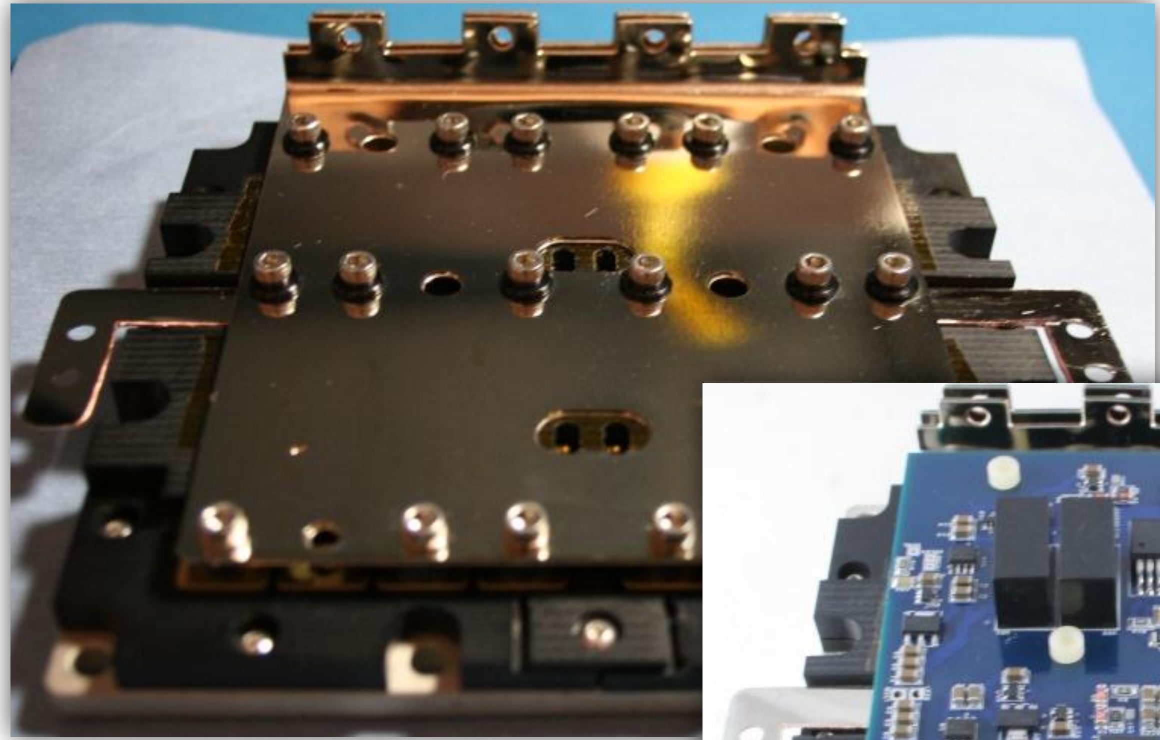
Extremely low switching losses may be achieved with simultaneous switching events and high freq. gate drives.

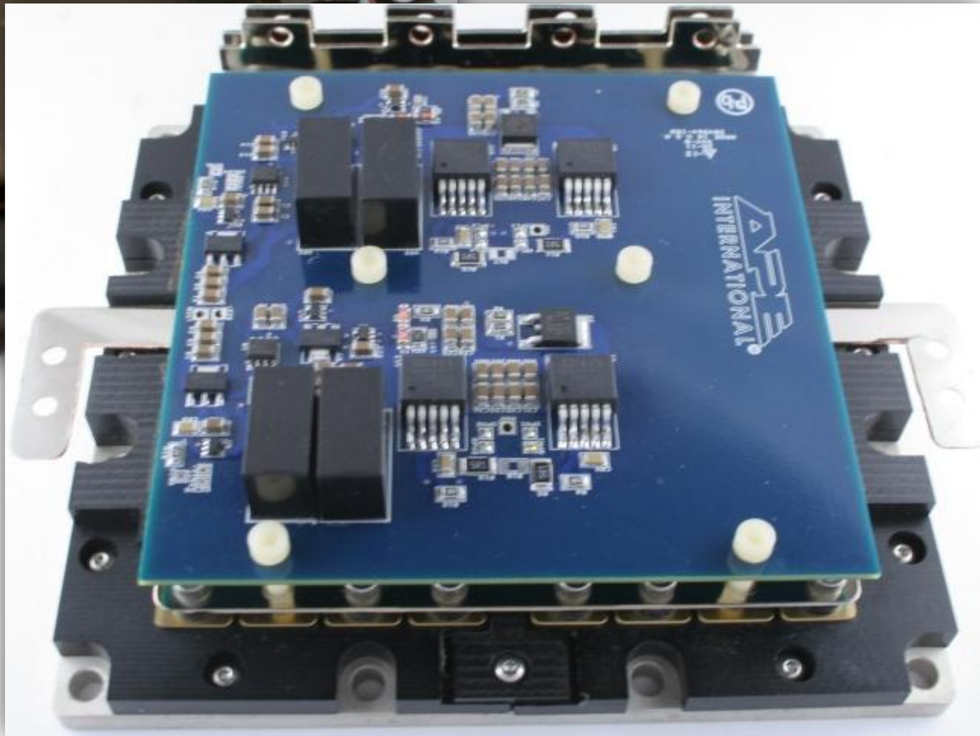


Switching Loss *(vs. IGBT)*

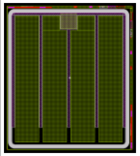


High Performance Module (Cree MOSFET)



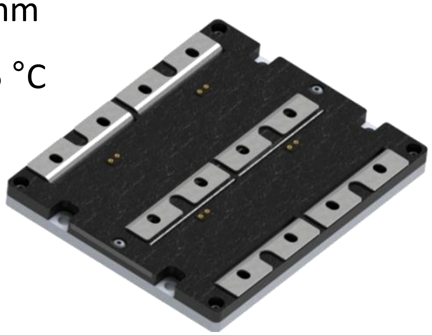


High Performance Module (Cree MOSFET)



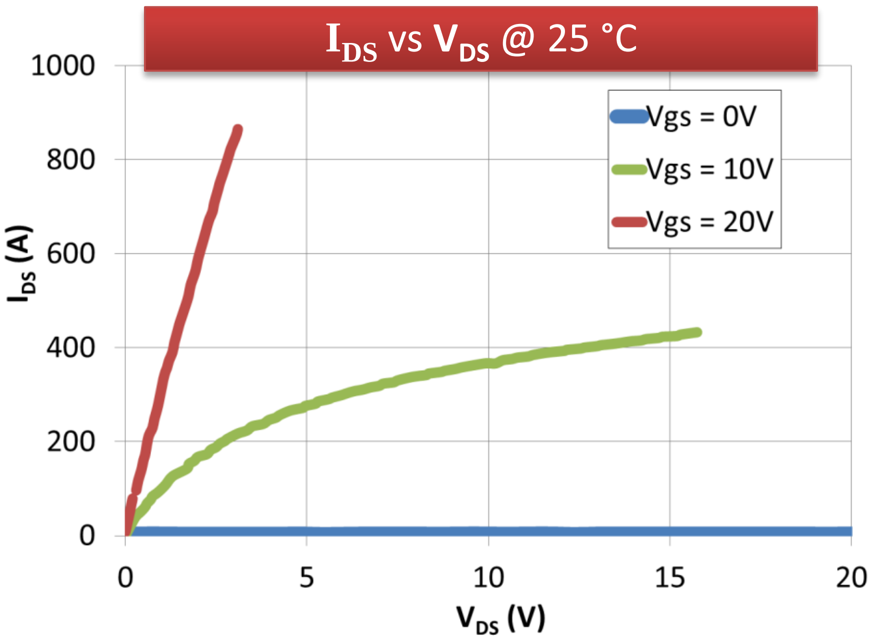
DEVICE INFO:

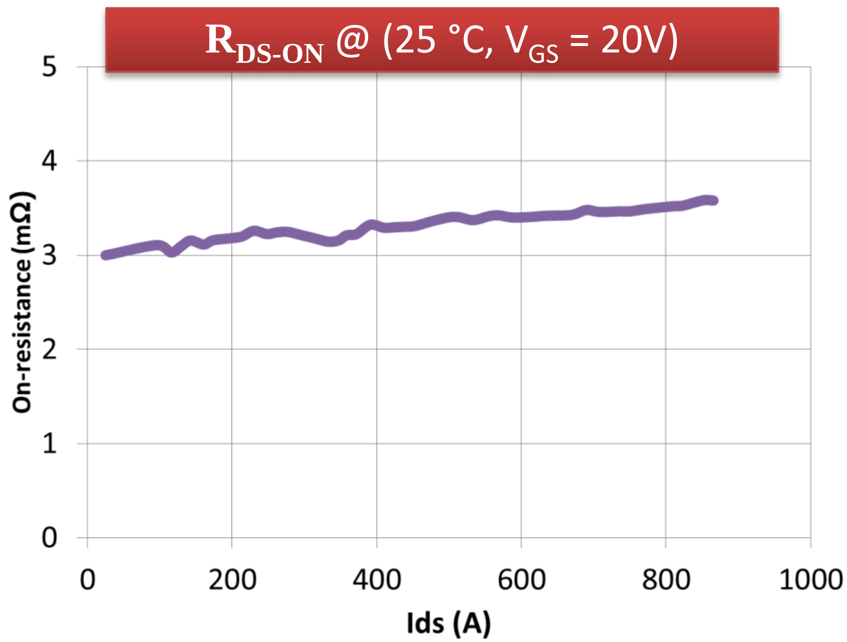
- Chip Dimensions: 7.0 mm x 8.0 mm
- R_{DS-ON} per chip =24 mOhms @ 25 °C
- 1200 V



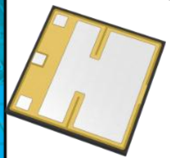
MODULE INFO:

- 16 Cree DMOSFETs
- 8 DMOSFETs per switch position
- R_{DS-ON} Module ~3 mOhms @ 25 °C
- 1200 V, ~500 A
- Wire Bondless Packaging Technology



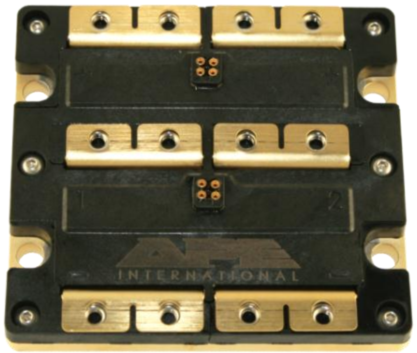


High Performance Module (Rohm TMOS)



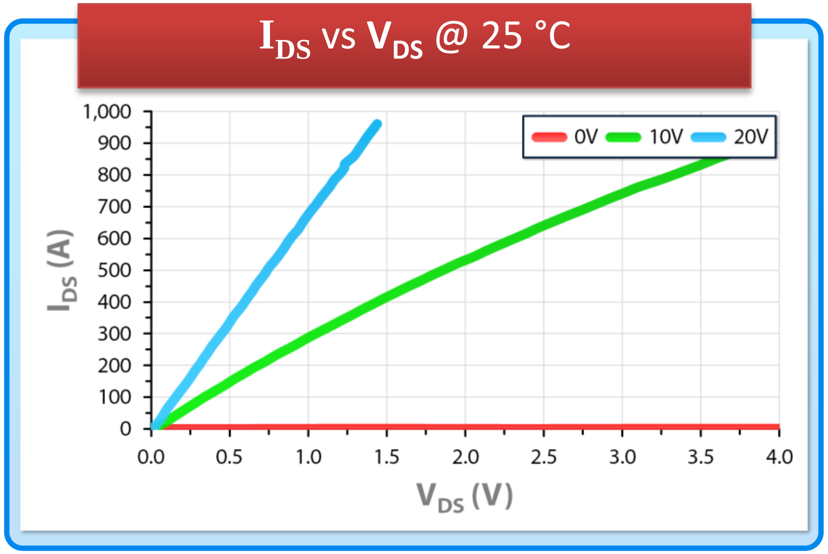
DEVICE INFO:

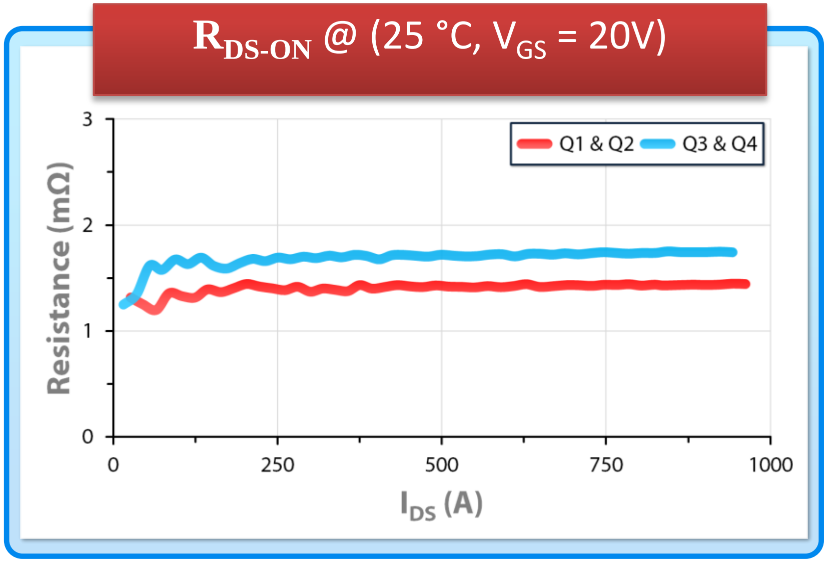
- Chip Dimensions: 4.8 mm x 4.8 mm
- $R_{DS\text{-}ON}$ per chip =12 mOhms @ 25 °C
- 600 V



MODULE INFO:

- 16 Rohm TMOSFETs
- 8 Trench MOSFETs per switch position
- $R_{DS\text{-}ON}$ Module =1.5 mOhms @ 25 °C
- 600 V, 1000 A

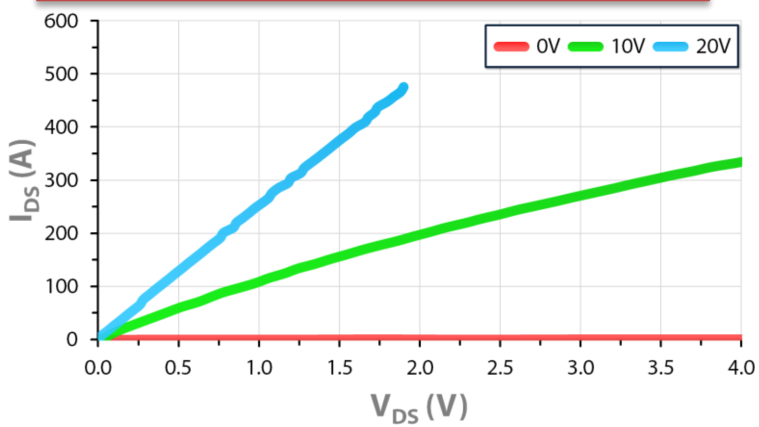




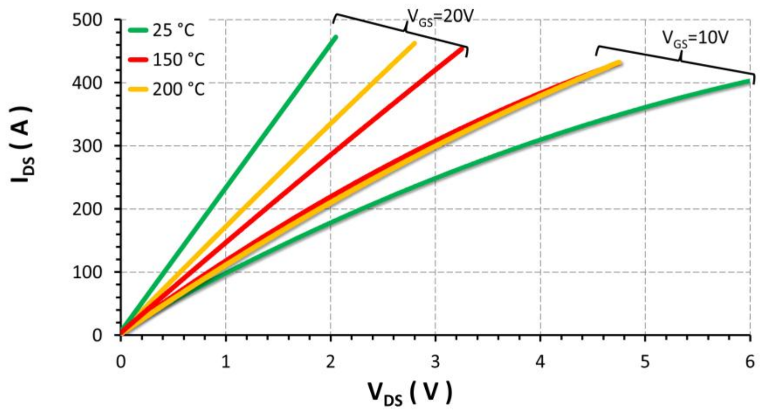
High Performance Module (Rohm TMOS)

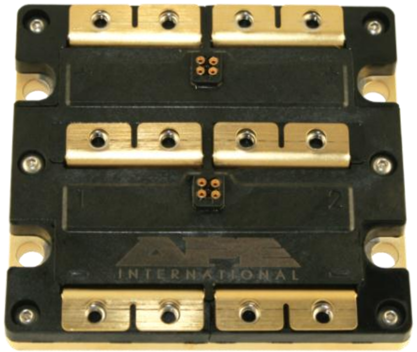
3 devices in parallel

I_{DS} vs V_{DS} @ 25 °C



I_{DS} vs V_{DS} @ 25, 150, & 200 °C





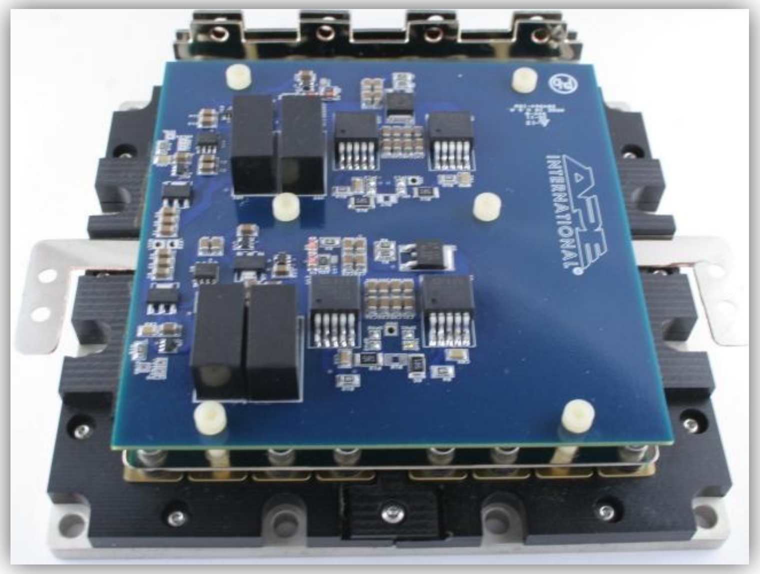
Conclusions

These newly developed high performance SiC power modules can provide substantial system benefits, including:

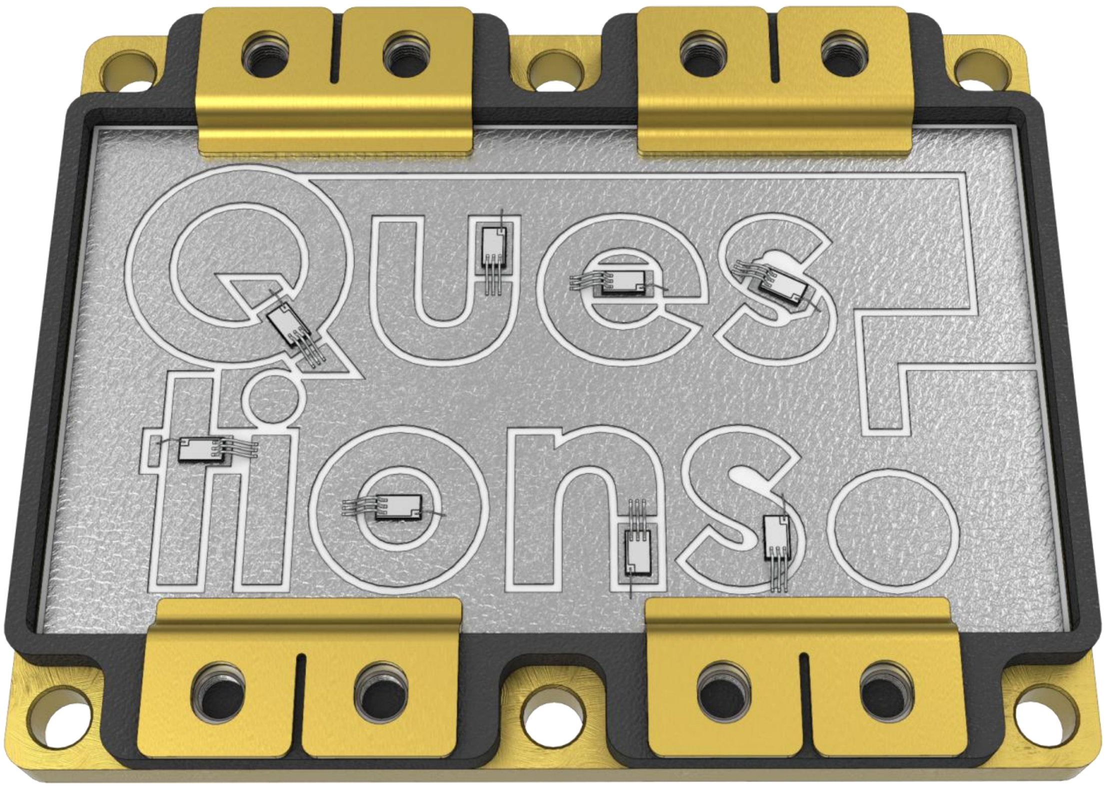
Increased
efficiency
power density

Reduced
volume
weight

Higher
junction temperatures
ambient temperatures



Thank You!



Acknowledgements

This material is based upon work supported by the Army Research Laboratories, the Air Force Research Laboratory (AFRL), the U.S. Army TACOM, the Department of Energy (Energy Storage Program), SAIC, Cree, Inc., Semisouth Laboratories, Inc., and Rohm Semiconductor.