IMPROVED THERMAL MANAGEMENT IN EV POWER ELECTRONICS WITH BORON NITRIDE FILLED POTTING COMPOUNDS

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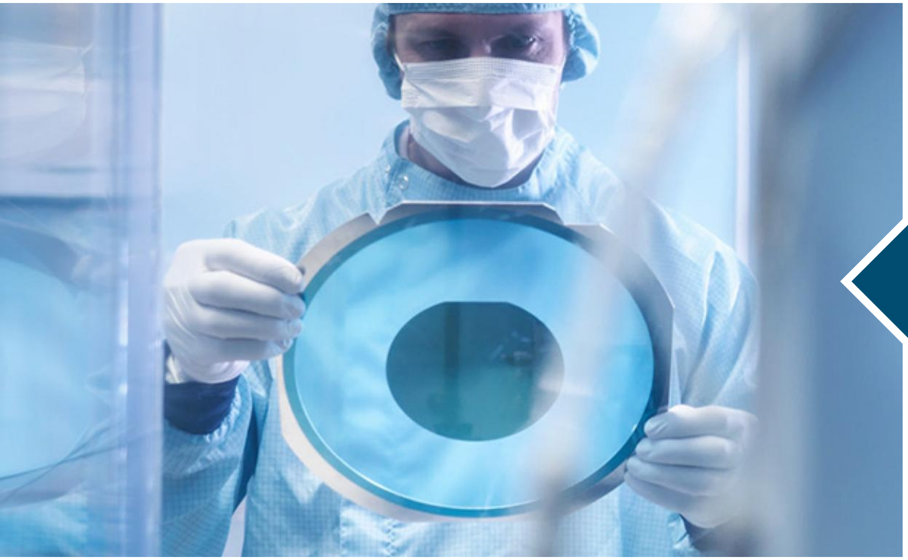

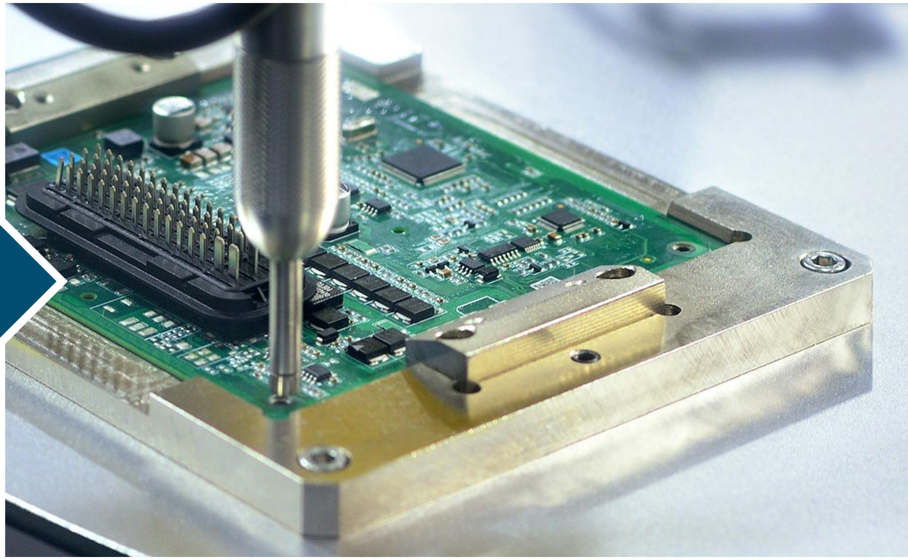

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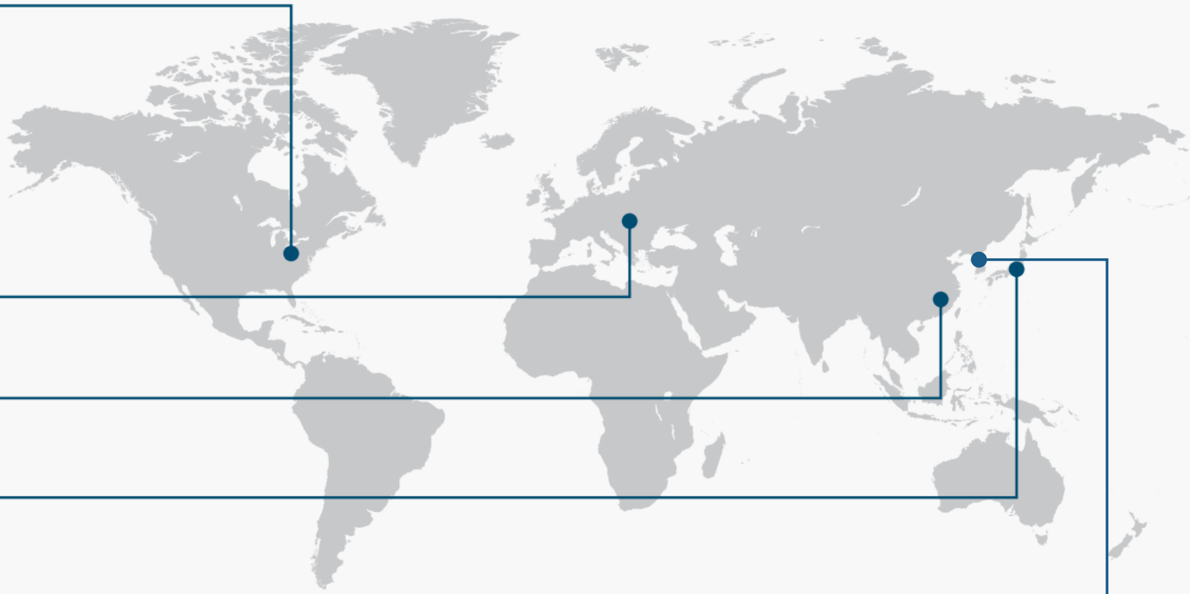
GLOBAL MANUFACTURING AND TECHNICAL SERVICE FOOTPRINT



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CERAMICS PORTFOLIO

CVD COATINGS

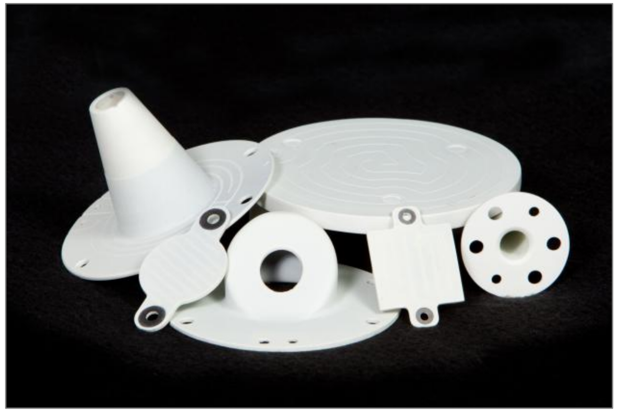
- **Tantalum Carbide**
- **Pyrolytic Boron Nitride**
- **Pyrolytic Graphite**

PRESSED & SINTERED SOLIDS

- **Hot-Pressed Boron Nitride Shapes**

POWDERS

- **Boron Nitride**
- **Boron Nitride-Based Paints**
- **Spherical Alumina**
- **Spherical Silica**
- **Titanium Diboride**

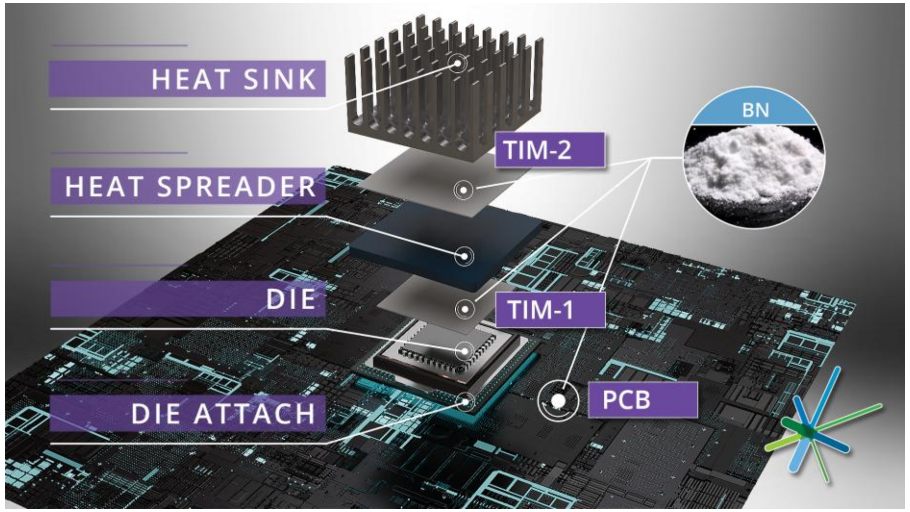


HEATERS & ELECTRO-STATIC CHUCKS

- **Pyrolytic Boron Nitride**
- **Assemblies**

HEXAGONAL BORON NITRIDE

- **High Thermal Conductivity**
- **High Electrical Resistivity**
- **High Thermal Stability**
- **Low Dielectric Constant and Loss**

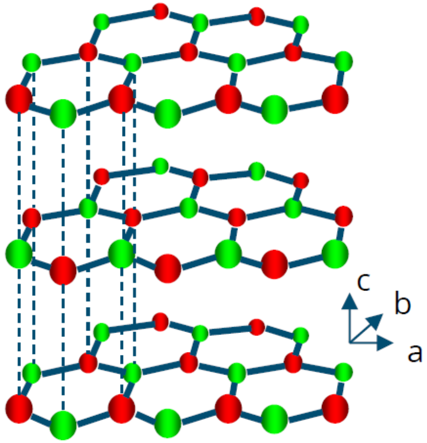


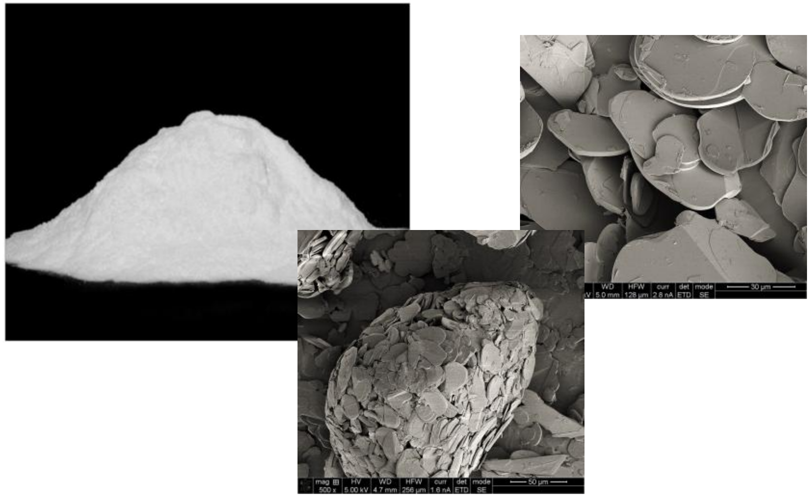
Typical Properties of Hexagonal Boron Nitride (h-BN)

Property	Typical value*
Theoretical Density	2.25 g/cc
Thermal Conductivity	300 W/mK†
Volume Resistivity	10^{15} Ohm-cm
Dielectric Constant	3.9
Mohs Hardness	1.5

*Typical properties are average data and are not to be used as, or to develop specifications

† In-plane conductivity in the a-b plane of the crystal

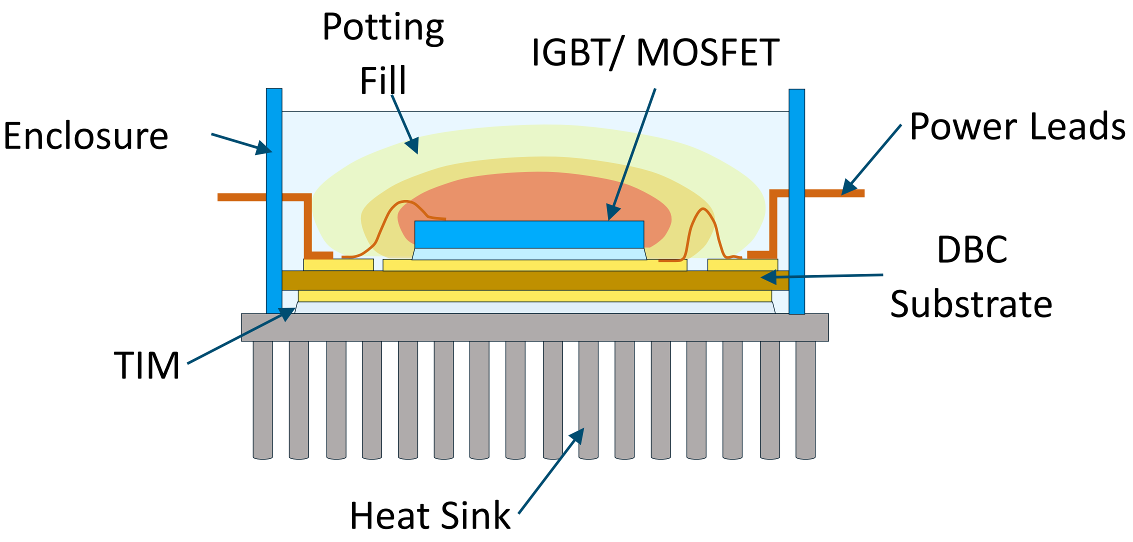




POWER MODULES AND THERMAL MANAGEMENT

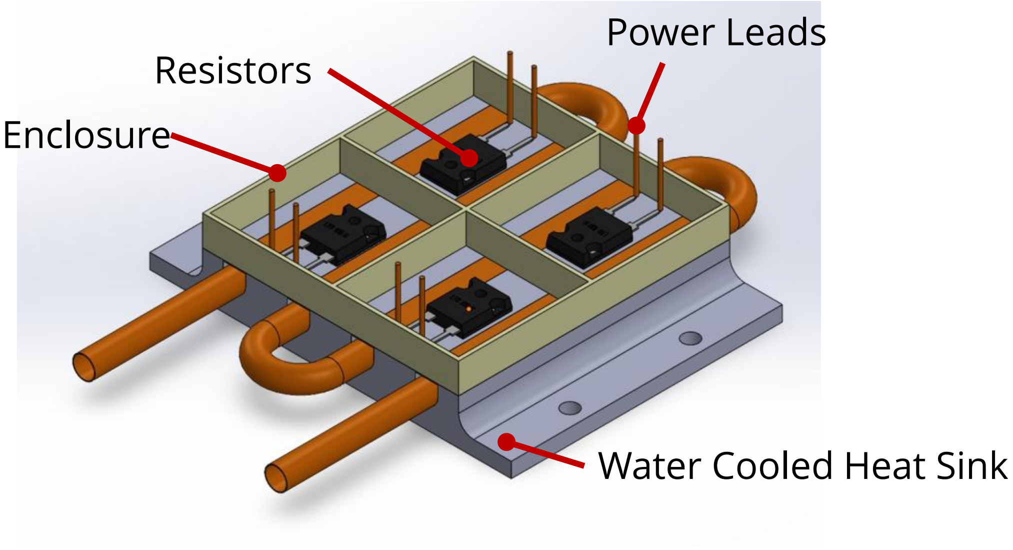
Most Power Modules (Half bridge/ full bridge, single side cooled devices):

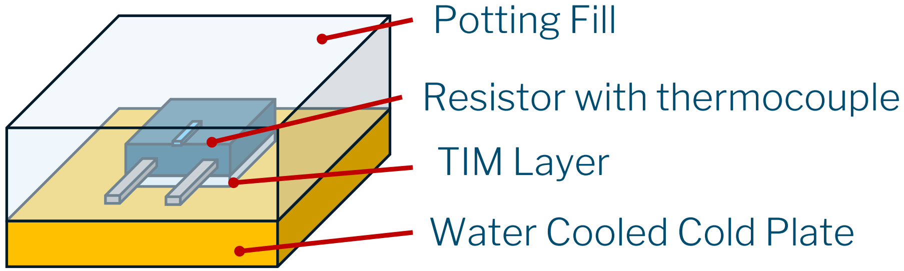
- **Heat Extraction from the bottom side (least thermal resistance)**
- **Top side potting generally with neat resin. So, not much top side heat removal.**



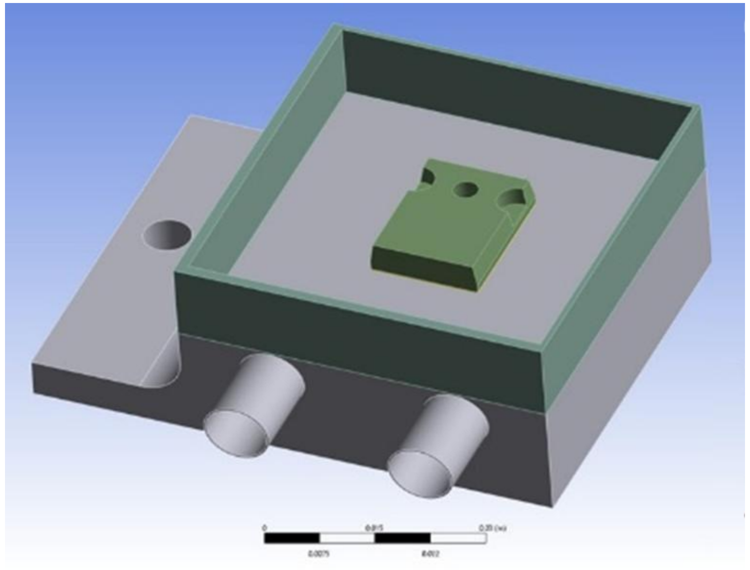
Simplified IGBT/ MOSFET cross section

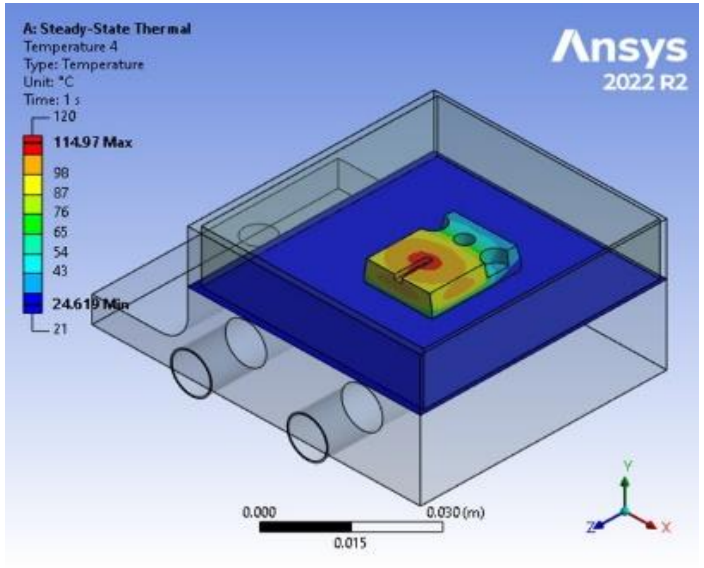
Demonstrator with resistors to Mimic IGBTs/MOSFETs



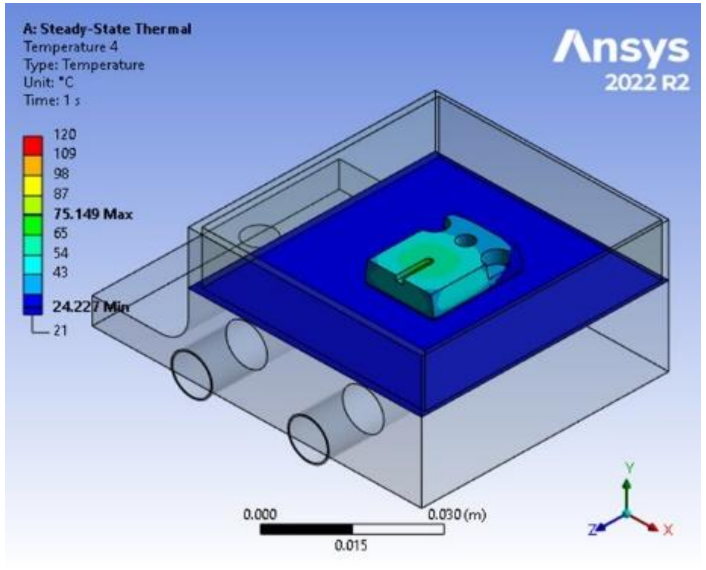


FINITE ELEMENT SIMULATIONS AND MODELING





Pure Silicone Potting

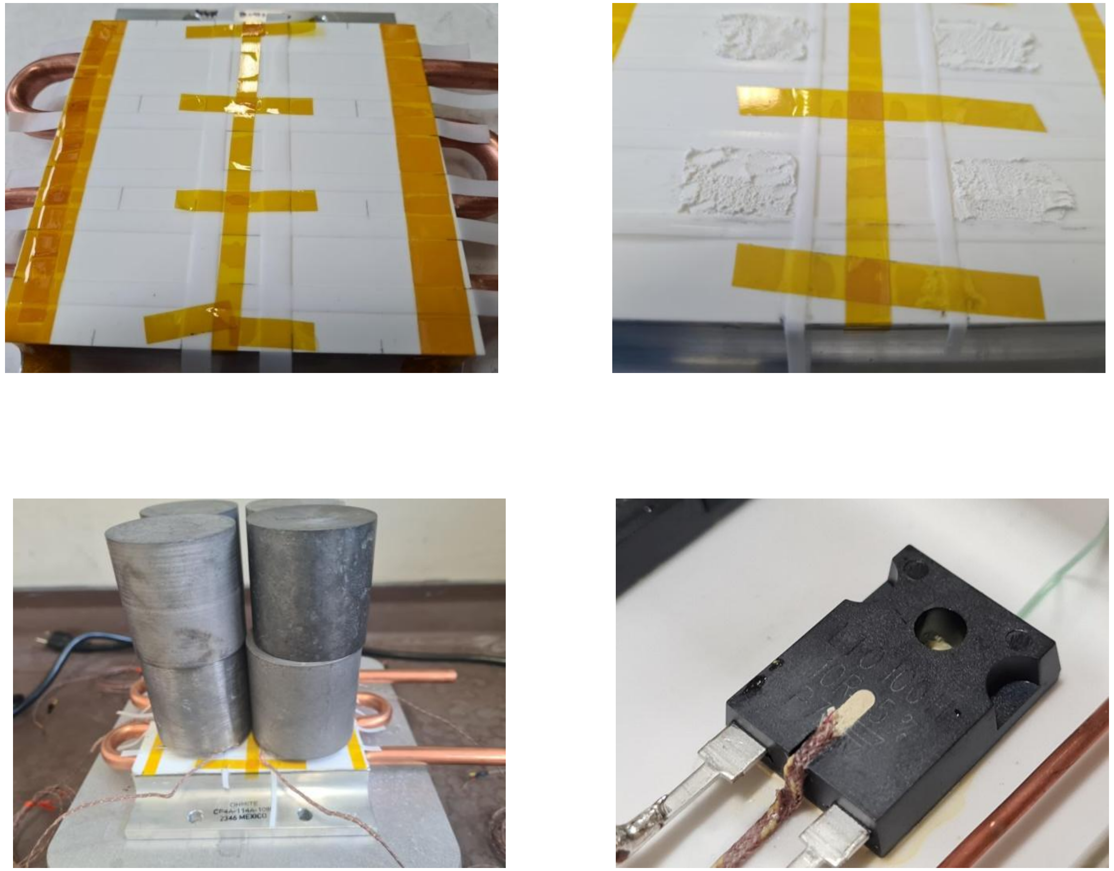


With BN Potting

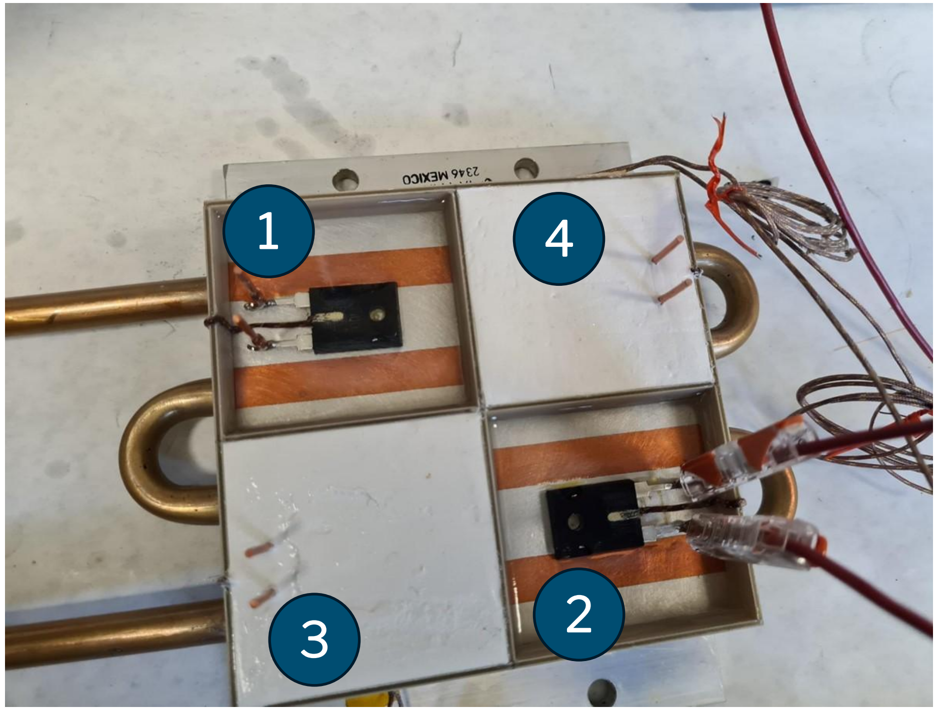
- Boundary conditions were matched to experiment. Material properties as measured.
- No additional assumptions or empirical corrections used

a) Modeling ¼ of the device (one resistor) was sufficient
b) Temperature contour map of pure silicone potting at 100 Watts,
c) With BN Potting

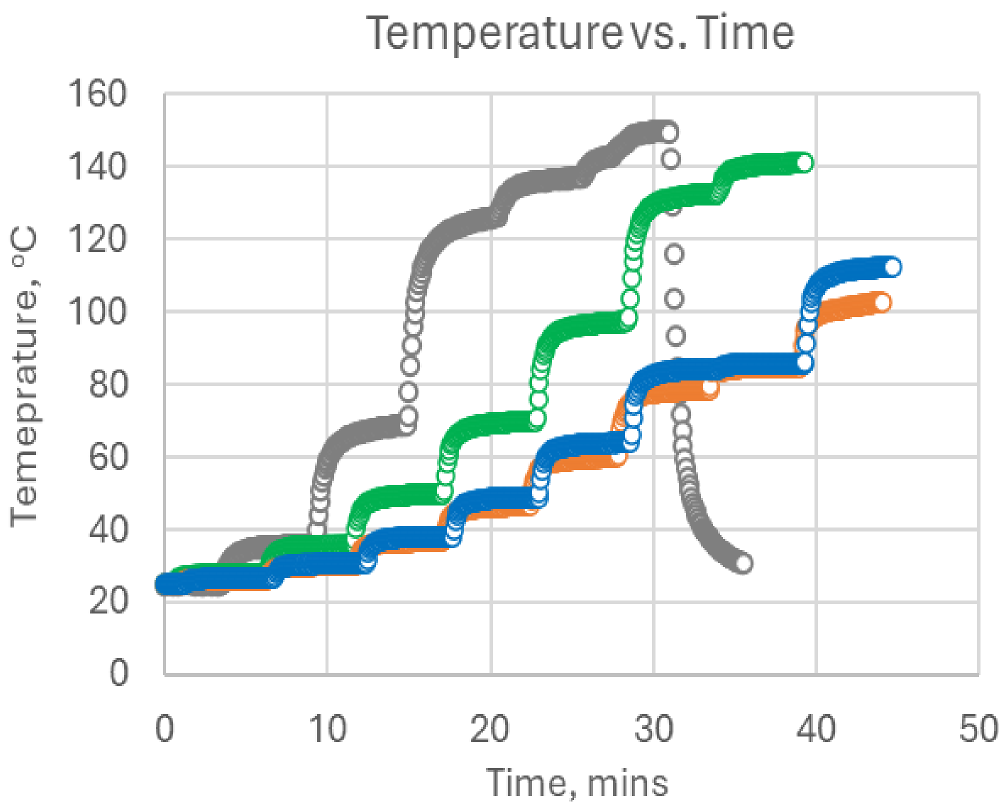
DEMO MODULE CONSTRUCTION

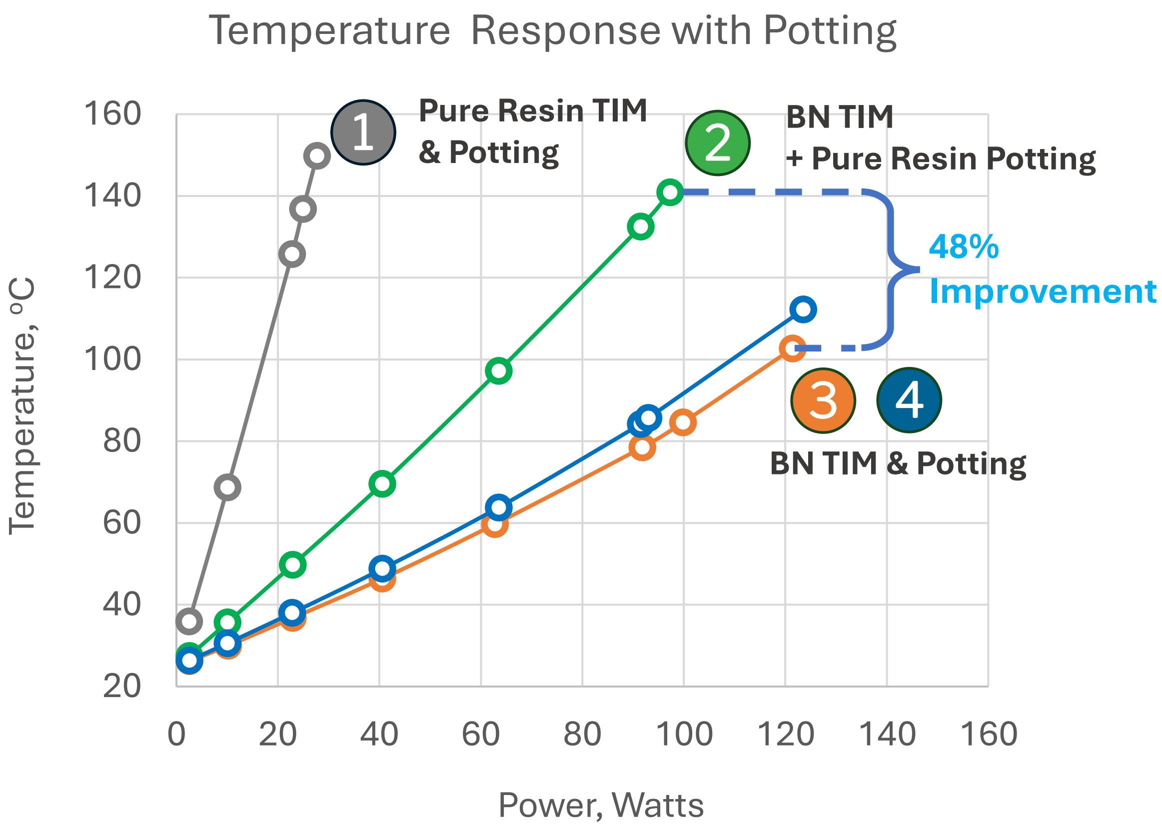


- **Case 1: Pure Resin in TIM and Potting (worst case)**
- **Case 2: BN TIM, Pure Resin Potting**
- **Case 3 & 4: BN TIM and BN Potting**



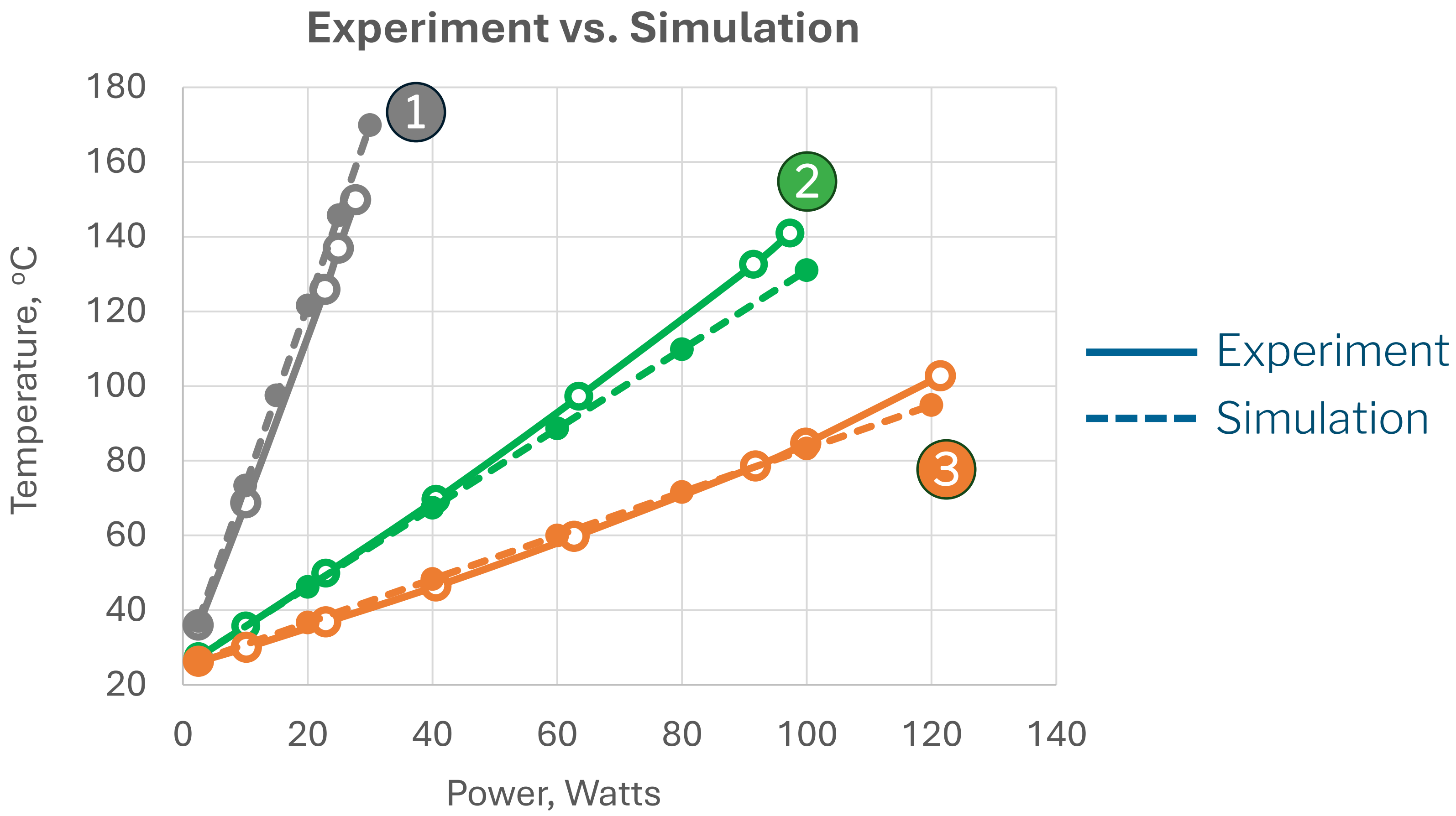
DEMO MODULE TESTING





- Resistors tested individually at various power settings till steady state
- Case 3 and 4 could be over driven to **~120%** of rated power due to improved thermal management

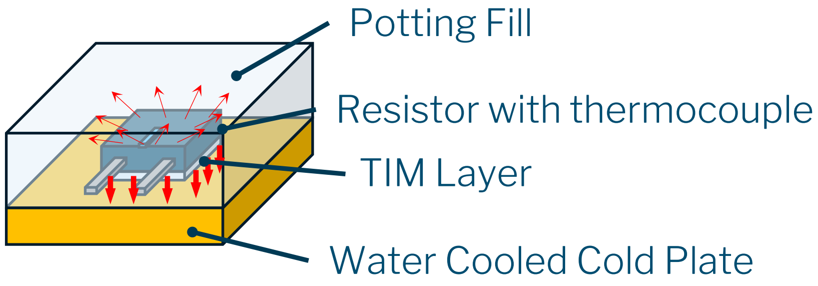
COMPARISON BETWEEN SIMULATION AND EXPERIMENT

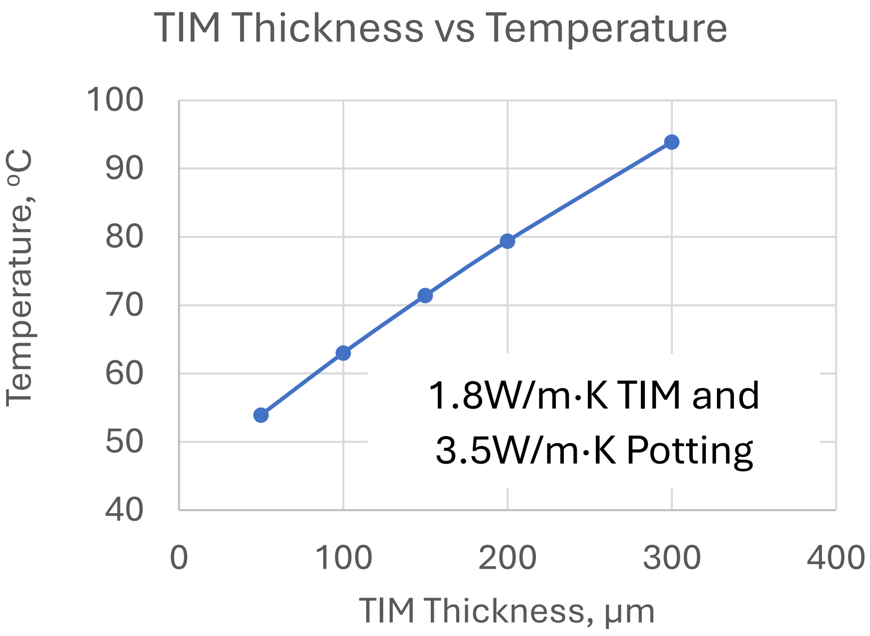


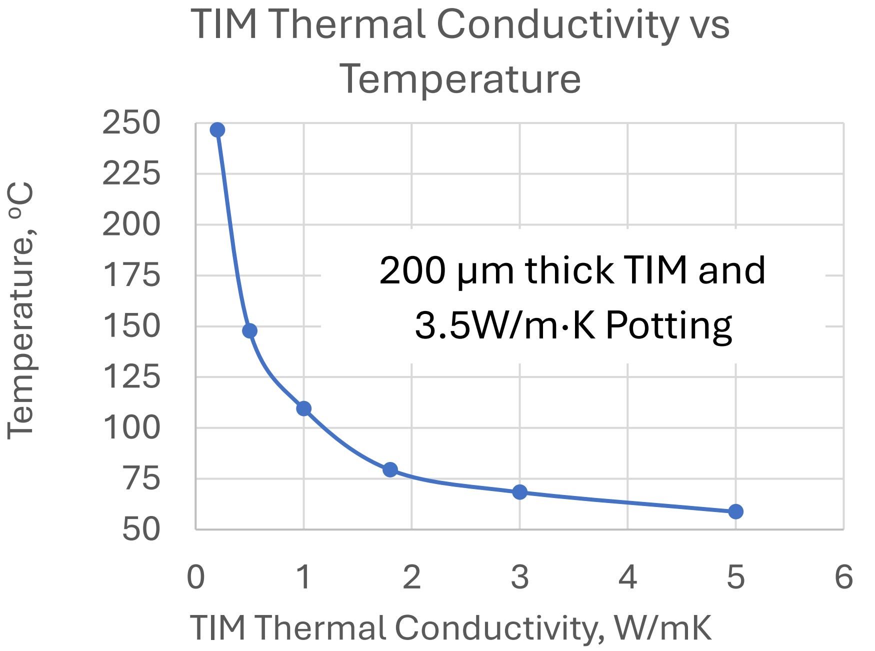
- Simulation showed excellent agreement with trials
- Significant hot spot temperature reduction at the chip
- Even with industry leading TIM at the bottom!

FACTORS AFFECTING HEAT DISSIPATION

- TIM Layer thickness and TIM thermal conductivity play a very important role

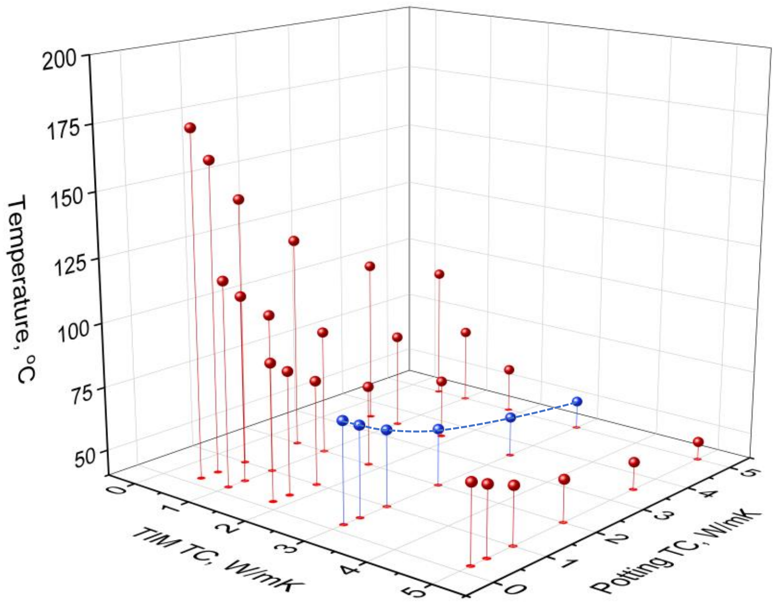


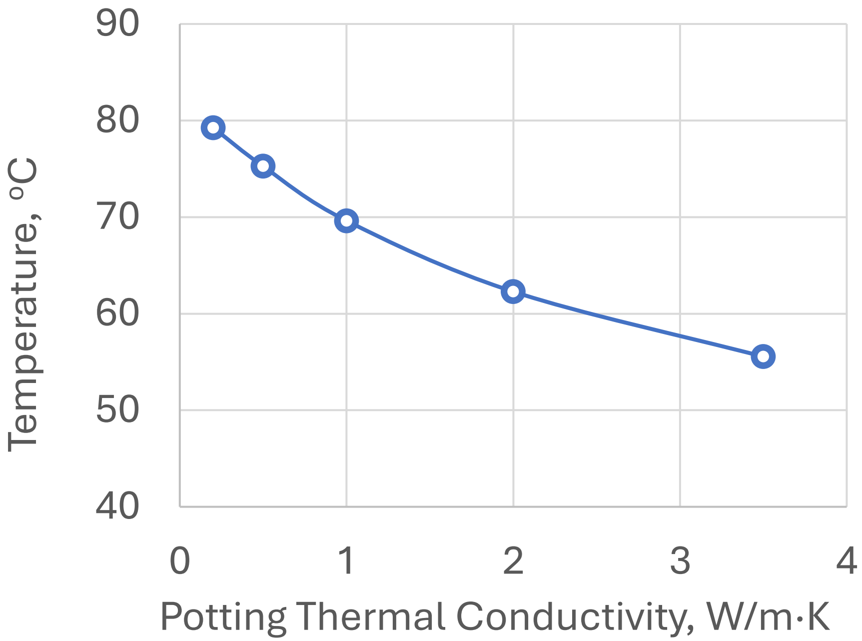




WHAT IF'S

How much benefit will we get **despite** aggressive bottom side cooling?





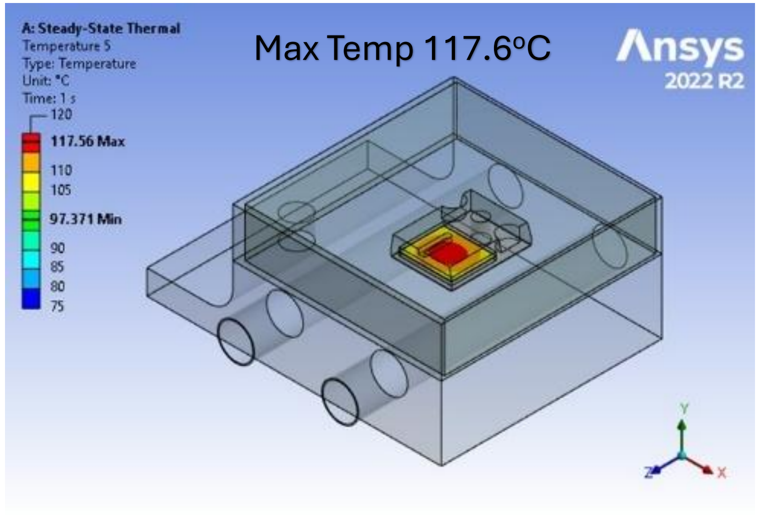
- **Significant reduction in resistor temperature even at premium TIM layer properties.**
- Blue pins in left has 3W/m·K TIM with 100 μm thickness. Plotted separately on the right.

WHAT IF'S

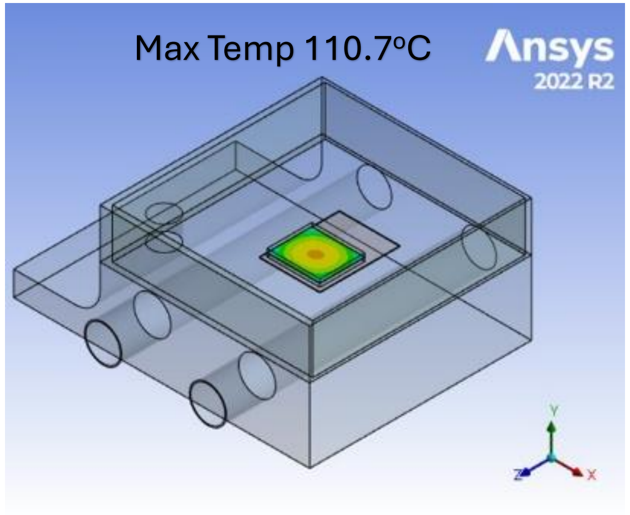
Effect of Epoxy Molding Compounds

Current Resistor ~1 W/m·k

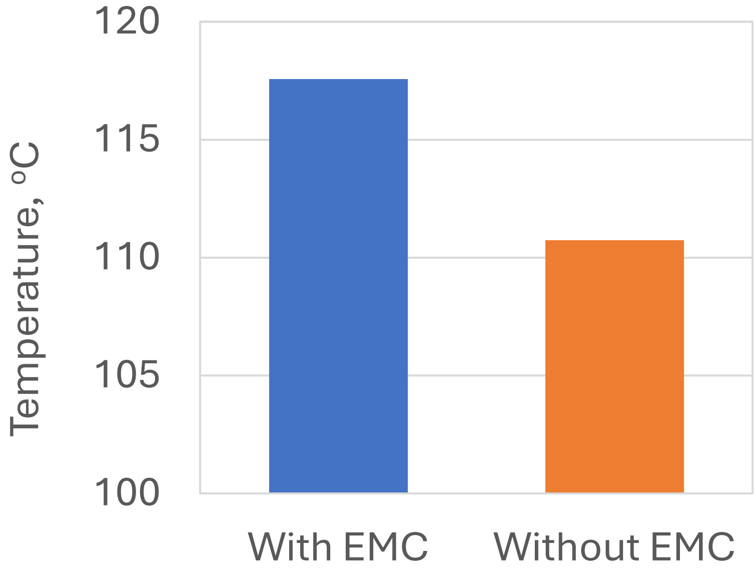
Actual MOSFETs can be up to ~3 W/m·k



With EMC



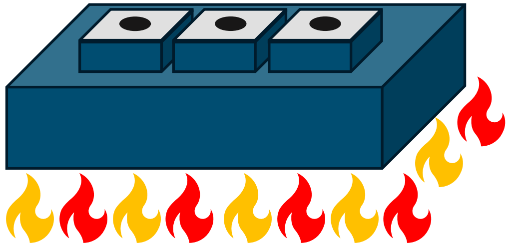
Without EMC



- Hottest temperature is at the resistor core
- If there were no EMC casing, the temperatures could be improved further

CONCLUSIONS

- Thermally conductive potting compounds such as BN fillers can significantly increase heat removal in power electronics
- Bottom side heat extraction may not be always sufficient in single sided power modules as demands increase
- Already critical thermal design in power electronics will further increase with expanded use
- BN's thermal conductivity, coupled with electrical insulation and low loss characteristics are attractive in high power, high frequency applications



THANK YOU