IGBT Power Module for HEV and EV

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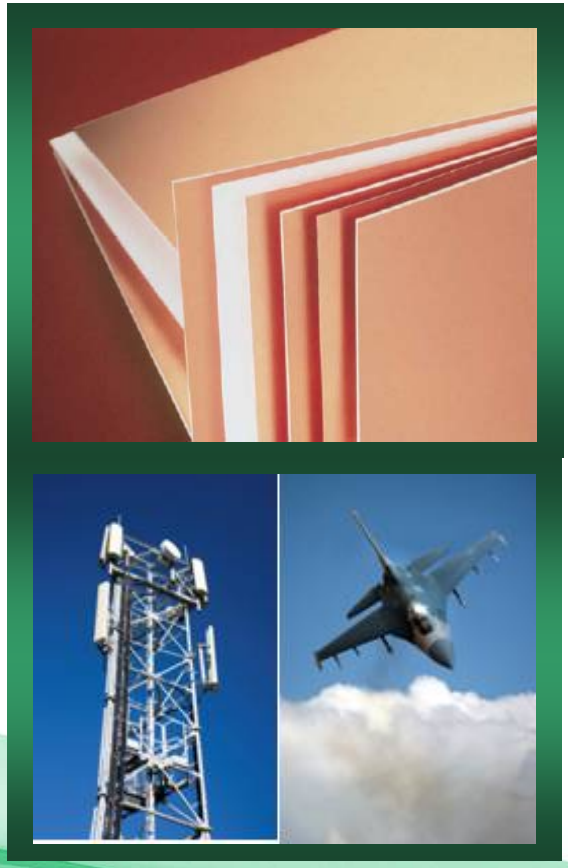
Printed Circuit Materials



High Performance Foams

Power Electronic Solutions

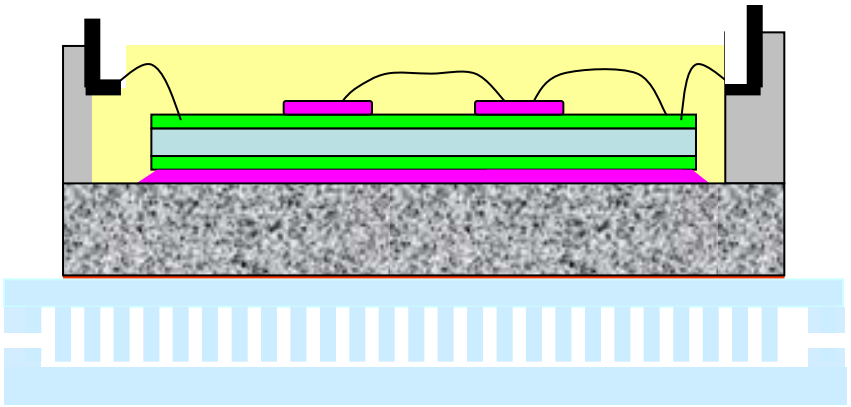
INTRODUCTION

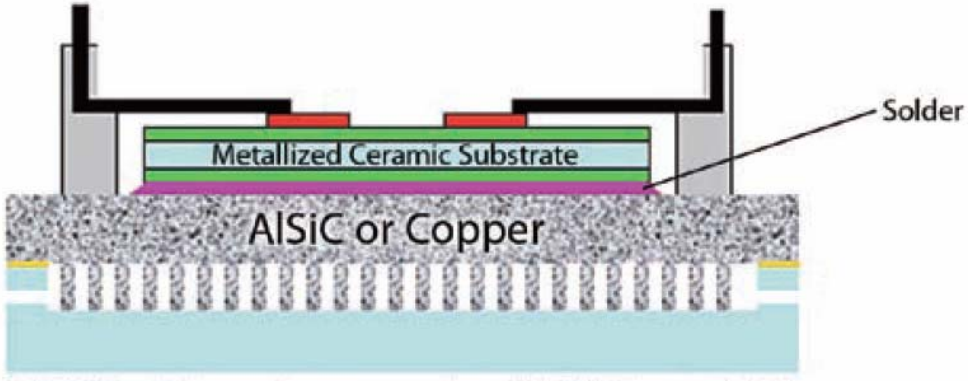
- HEV/EV Market and Motivation
- Engineered Materials Developed for IGBT Power Module Cooling
  - Baseplate selection
  - Cooling systems
  - Joining processes in Power Module manufacturing
    - Pin Heat sink/Baseplate Plating/Coating Options
    - Solder Selection
    - Joining
- Summary

EV/HEV Motivation

- Reduced Fuel Consumption
  - Electric motor assists the Internal Combustion Engine (ICE) to reduce fuel consumption as vehicle starts & accelerates.
  - No ICE in EV
- Improved Performance
  - Electric motors deliver maximum torque from zero rpm for powerful start and added power for acceleration.
- Environmental Performance
  - Reduced or eliminated CO_2 emissions improves environmental performance through reduced fuel consumption.

Improvements Implemented by HEV/EV Power Module Technology





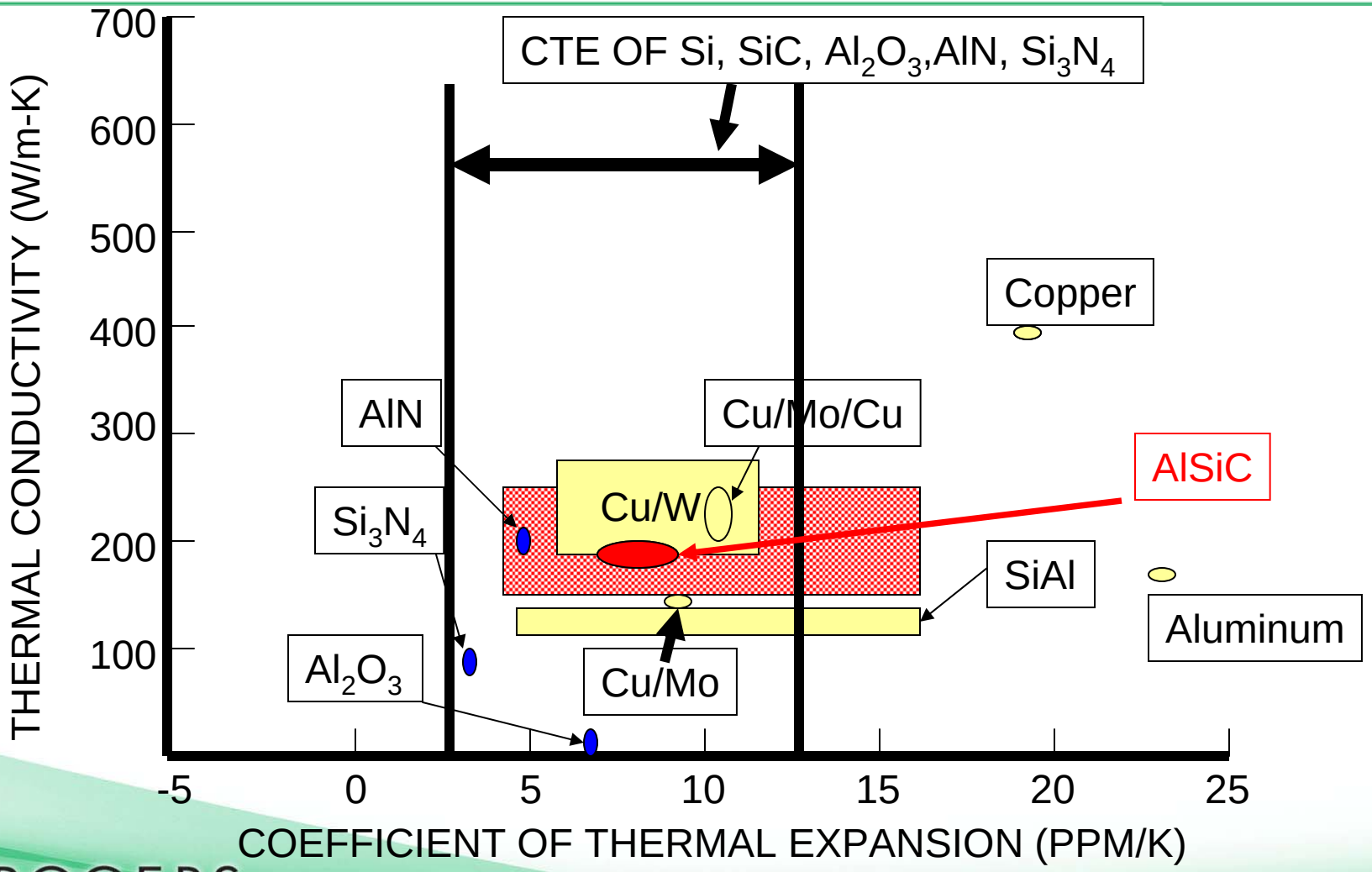
Traction Type Power Module

- 5 mm AlSiC baseplate
- Lead free solder preform
- Vacuum Soldering
- Grease interface between baseplate and Heat sink
- Nickel plating

Automotive Power Module

- 3mm AlSiC pin heat sink
- Lead free solder paste
- Eliminate vacuum soldering
- Eliminated grease interface
- Ni plating or copper cold gas coating

Materials Used to Remove Heat in IGBT Modules

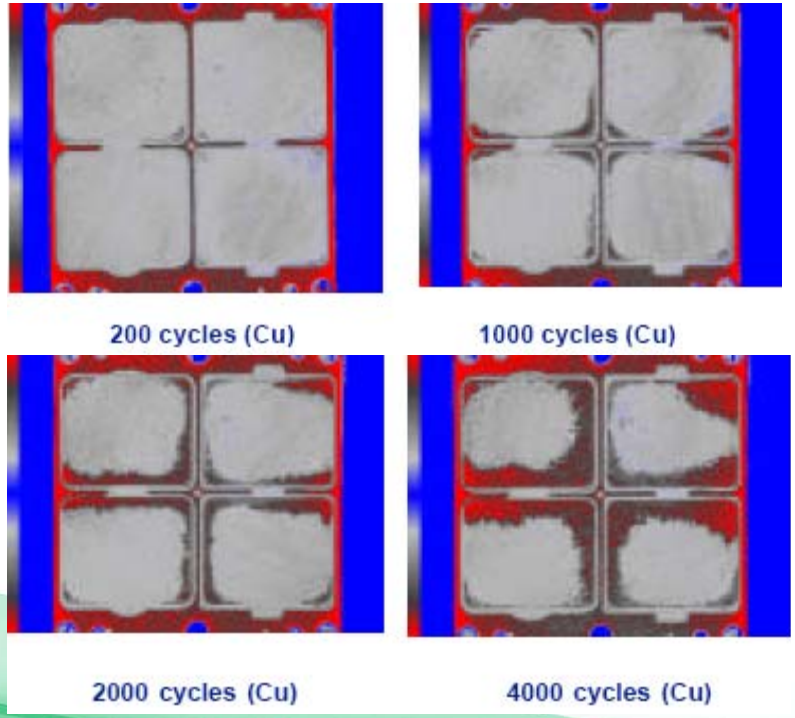


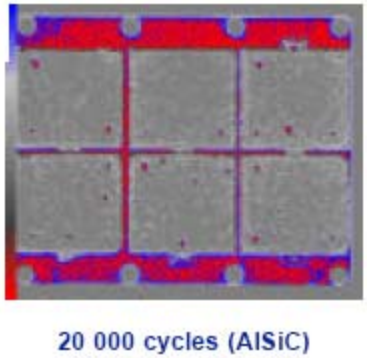
Copper Heat Sink vs AlSiC Heat Sink in HEV/EV IGBT Power Module

	AlSiC Pin Heat Sink	Copper Pin Heat Sink
Manufacturing process	Pressure Infiltration casting	Metal Injection Molding
Substrate	Aluminum Nitride	Aluminum Oxide
Performance	AlSiC Pin Heat Sink/AlN combination has better performance than Copper Heatsink/Alumina Combination	
Pin Shape	Round, Diamond & more	Round, Diamond & more
Pin density	More Pin density in copper	
Pin Height	3.5 mm	7 mm
Thermal Conductivity (W/m-K)	180-240	400
CTE (ppm/K)	8	17
Density	3 g/cc	8.9 g/cc
Weight 213mmx92mmx3mm 3.5mm pin height	245 g	726 g

Effect of Thermal Cycling

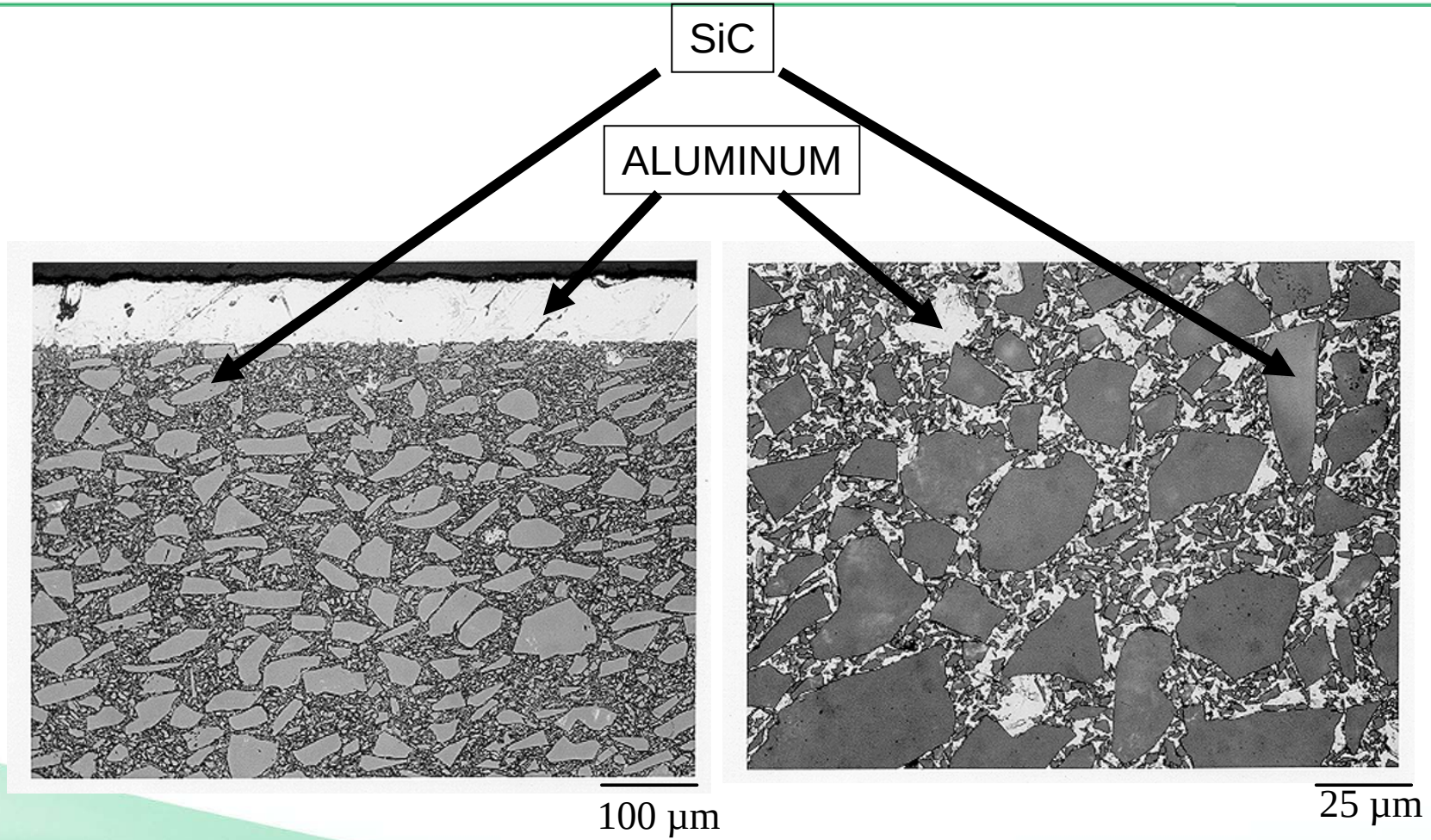
- Due to closer match of CTE's between AlSiC (CTE=7 ppm/K) and AlN (CTE=4.5 ppm/K) no delamination is observed in the solder layer between ceramic substrate and AlSiC baseplate even after 20000 thermal cycles ($\Delta T=80^{o}C$), while clear solder failure is observed when the baseplate is copper (CTE=17 ppm/K)



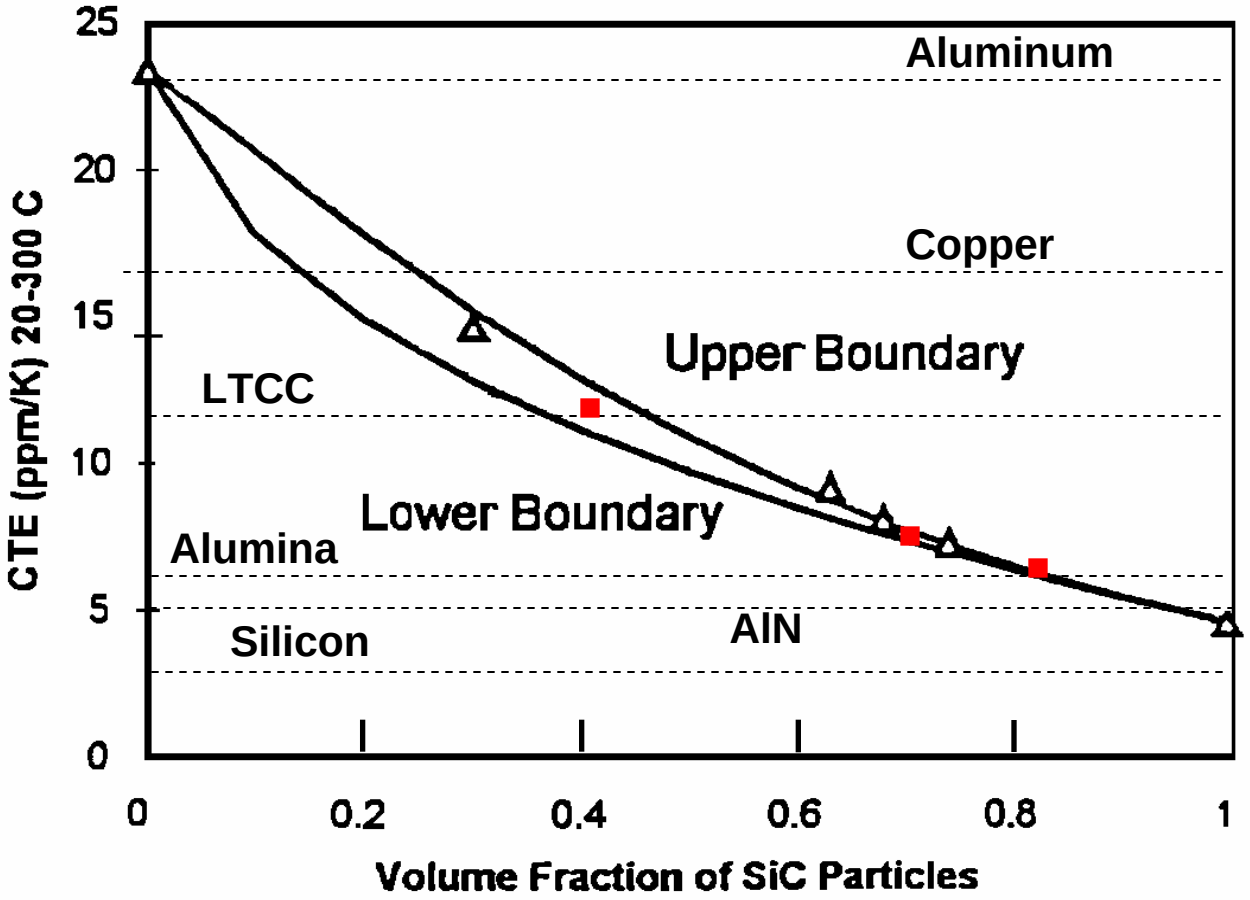


Courtesy of Infineon Technologies AG

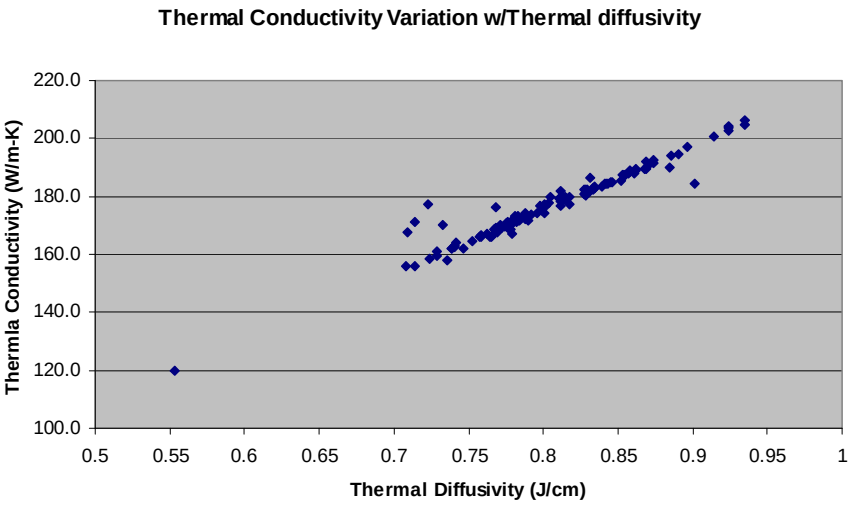
HEATWAVE™ AlSiC Microstructure Used in Current IGBT Modules

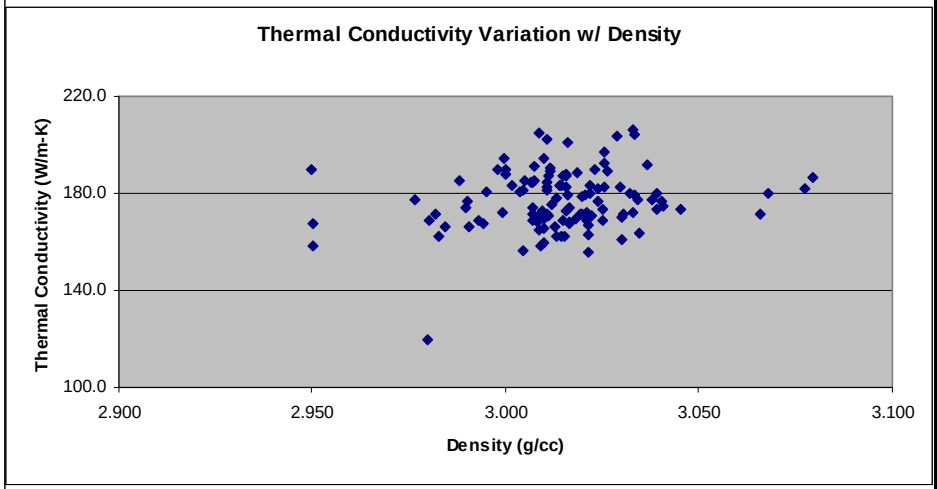


AlSiC CTE Model



AlSiC Thermal Conductivity

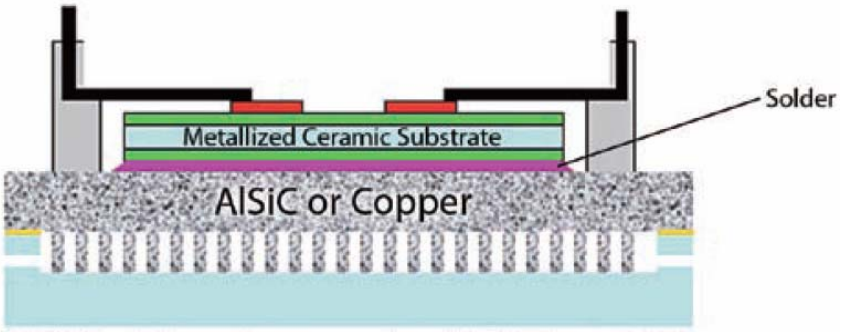


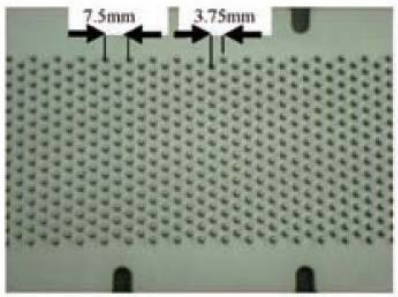


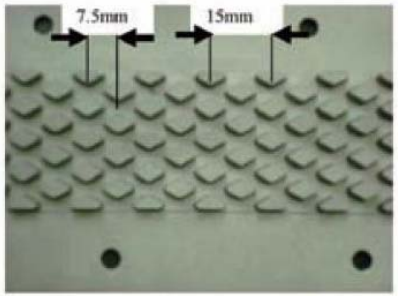
Liquid Cooling Systems

- Cold Plates
  - Machined or extruded aluminum plates with or without inserted copper tubes
  - Need to use grease as thermal interface materials
- Pin Fins
  - Copper, AlSiC or aluminum pin heat sinks with various pin geometries
  - Eliminates the need for thermal interface materials
- ShowerPower
  - Eliminates the need for pin fin
  - More homogeneous cooling
  - Bulging of baseplates is a problem when high pressure is required
- Liquid Cooled DBC Substrate
  - Cooling channels are integrated directly to DBC
  - Eliminates baseplate
  - Produced by joining various copper layers with different hole pattern to DBC

Pin Fin Cooling

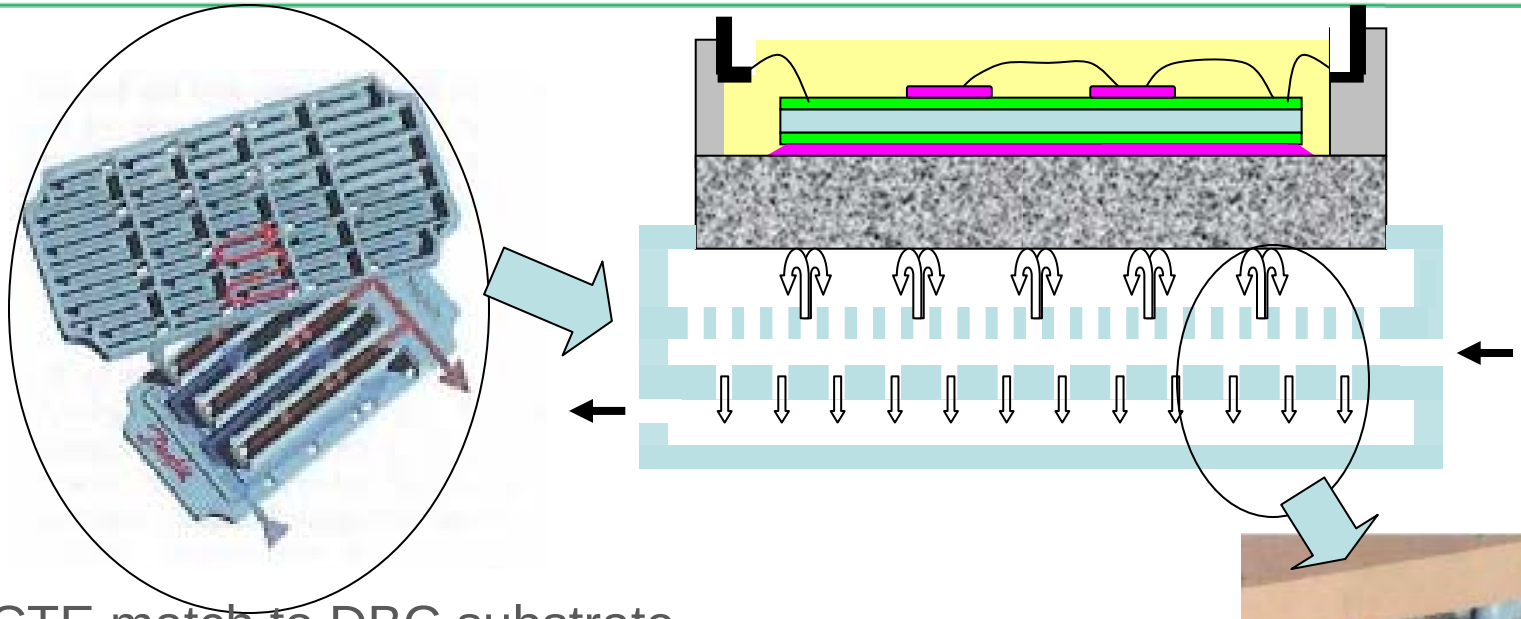






- Efficient cooling system
- Broad variety of pin geometries
- CTE Match to DBC Substrate
- High thermal conductivity for heat dissipation
- Tight dimensional tolerances without machining

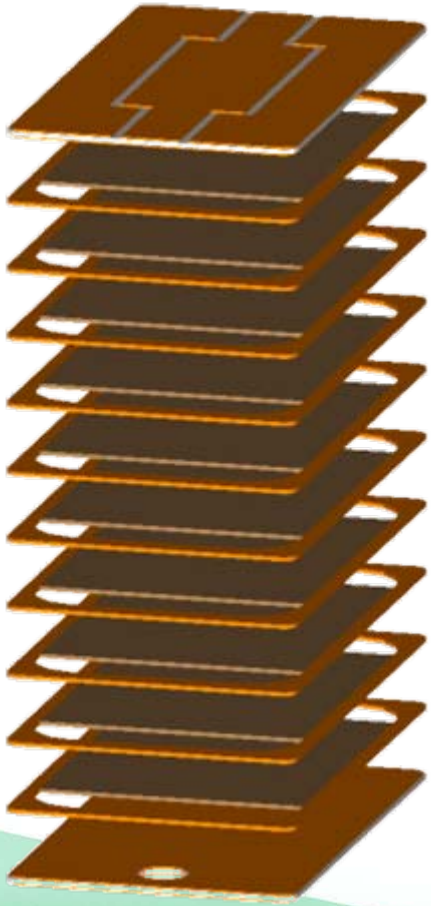
Danfoss ShowerPower®

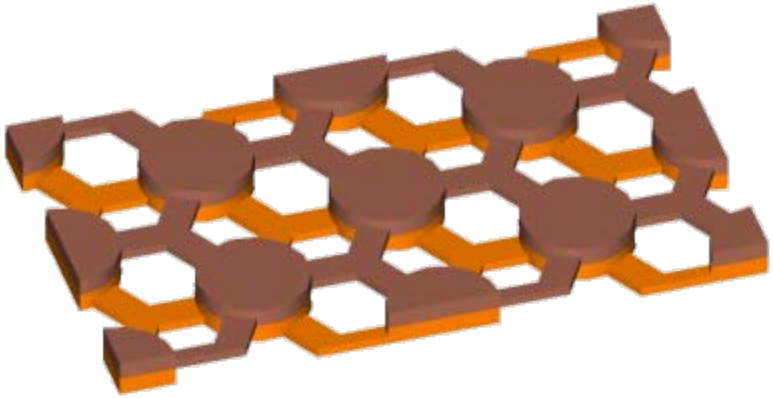


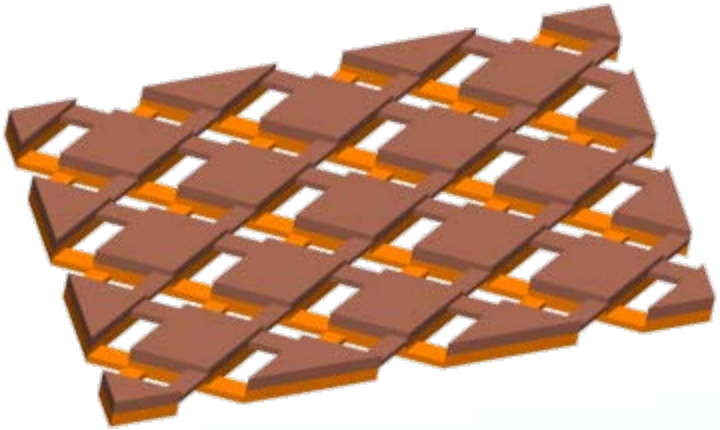
- CTE match to DBC substrate
- High thermal conductivity for heat dissipation
- Homogeneous cooling
- Cooling can be tailored
- Good thermal performance at a low pressure drop

Courtesy of Danfoss Silicon Power GmbH

Liquid Cooled DBC Substrate







Soldering AlSiC Baseplate to DBC

- Solder Options
  - Solder paste
  - Solder Preform
- Solder Compositions
  - Sn-37Pb
  - Sn-3.5Ag
  - Sn-3Ag-0.5Cu
- Soldering reflow Profile
  - 15^{o}C to 30^{o}C above the melting point of solder composition
- Baseplate surface Finish
  - Nickel plating
  - Copper Cold Gas Coating

Solder Preform versus Solder Paste

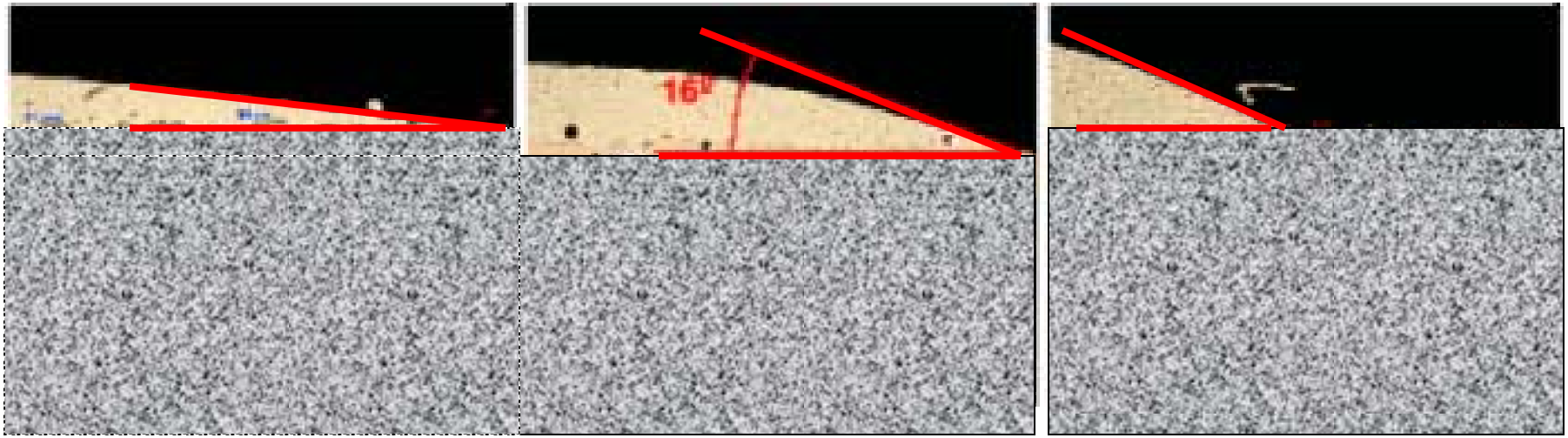
Solder Paste

- No fixture Required
- Low cost/Large Volume adaptable using screen printing
- Solder Void is >5%
- Requires cleaning in most cases
- Inert gas continuous soldering is possible
- Both Sn-Pb and lead free solder pastes are available
- Shelf life and specific Storage conditions exist

Solder preform

- Soldering fixture is required for locating preform
- Requires solder preform cutting/coining is required
- Solder void <5%
- Requires vacuum soldering and soldering is batch process
- Both Sn-Pb and Lead free solders are available
- No solder preform life issues

Criteria For Solder Joining to AlSiC Pin Heat Sink Using Wetting Angle

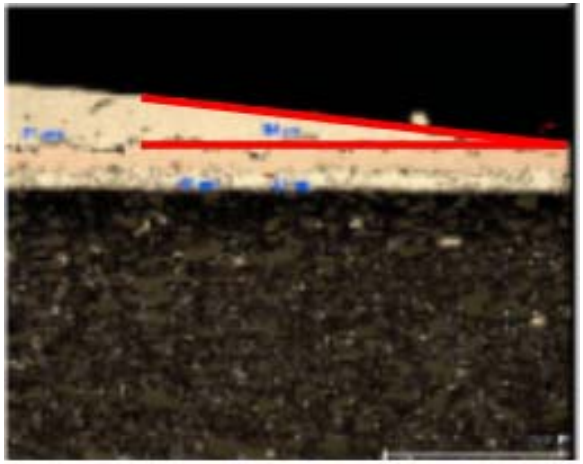


Very Good
Wetting angle <10°

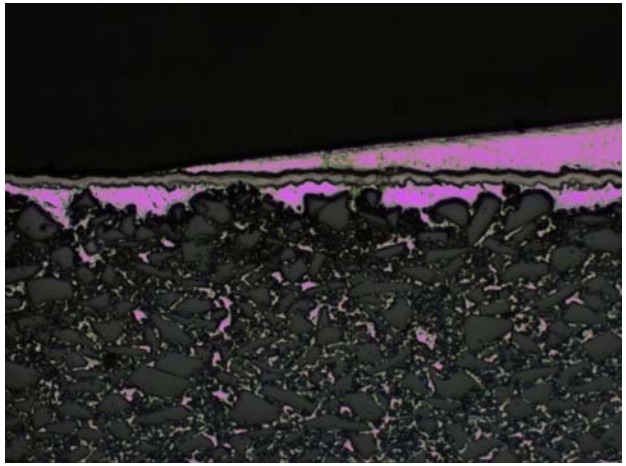
Very Good to Acceptable
Wetting angle =10°-20°

Not Acceptable
Wetting angle >20°

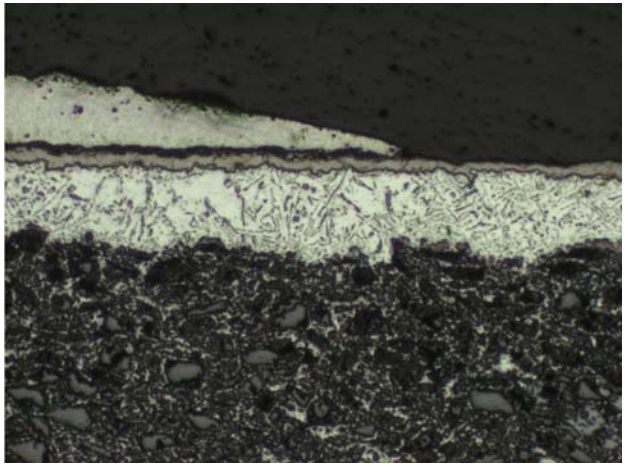
Solderability with various Solders



Copper Cold Gas Coating
Solder Paste-Sn-3Ag-0.5Cu
Contact Angle <10^{o}

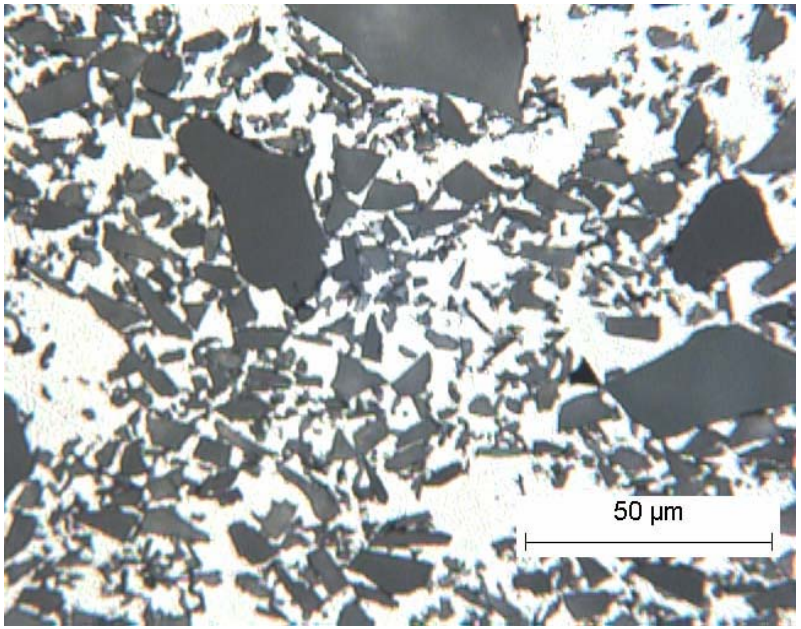


Electroless Ni Plating
Solder Preform-Sn-3Ag-0.5Cu
Contact Angle <10^{o}

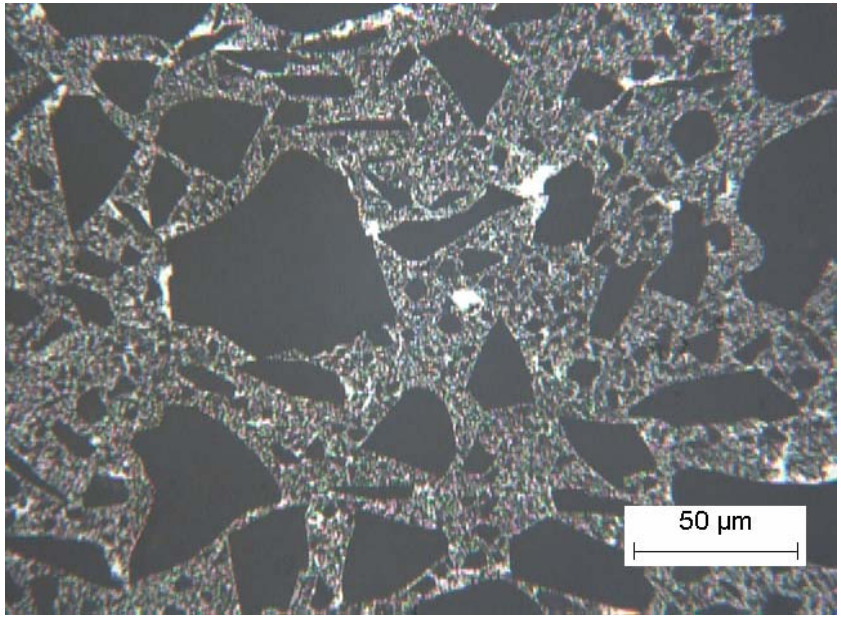


Electroless Ni Plating
Solder Preform-Sn-37Pb
Contact Angle <10^{o}

Alternative Available AlSiC Compositions

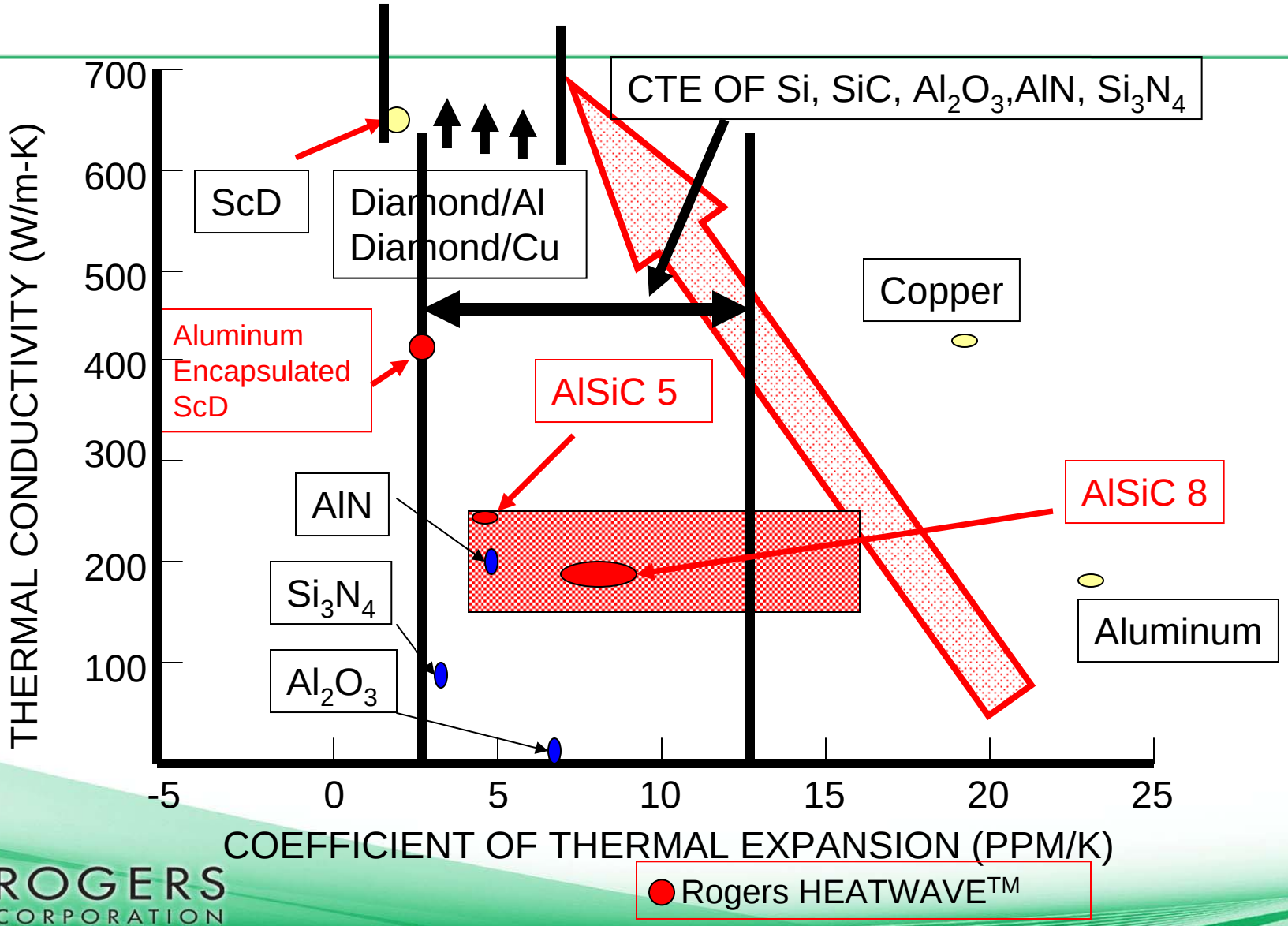


CTE = 12 ppm/K
TC = 183 W/m-K



CTE = 5.3 ppm/K
TC = 230 W/m-K

Thermal Management Materials Used in IGBT Modules



Continuous Improvement In IGBT Power Module design

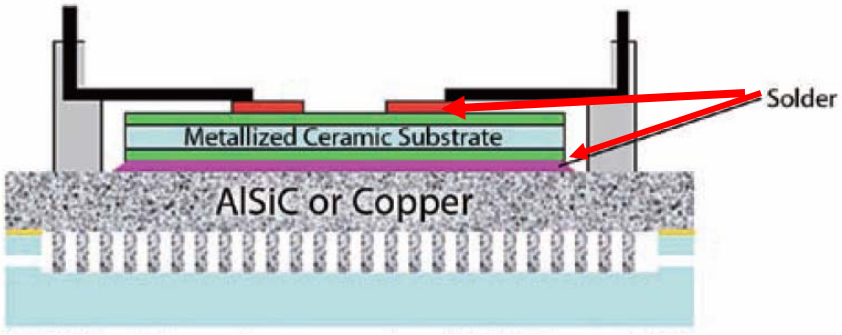
Performance Improvement

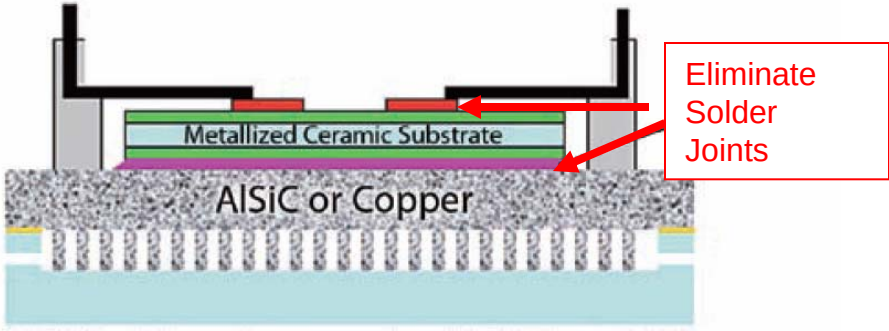
- IGBT semiconductor performance at junction temperature above 200ºC.
- Increasing $T_{j,op}$ from 125ºC to 175ºC allows to combustion engine coolant to cool the power electronics w/o need of a separate cooling circuit.
- Improved reliability in joining technologies. At $T_{j,op=}$175ºC, solder fatigue and wire bond lift-off failures limit power cycling/thermal shock lifetime.

Material Challenges

- Lower cost water cooled integrated heat sink
- High reliability MMC/ceramic combination with good thermal performance

Currrent

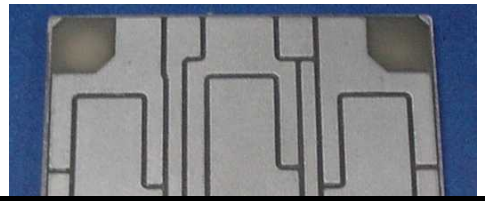




Future

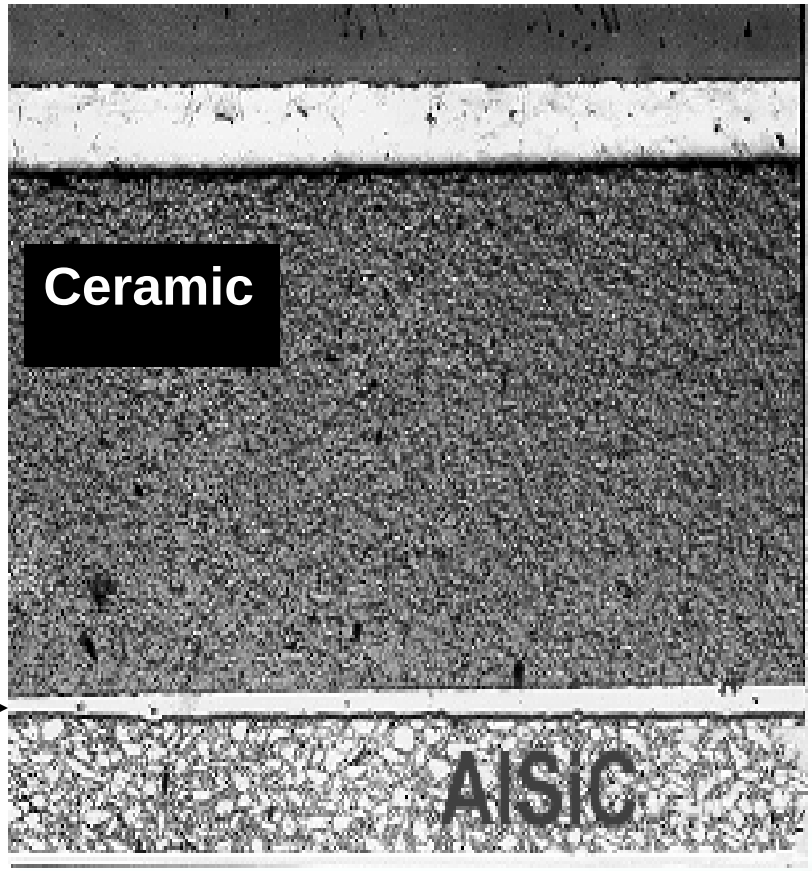
Hybrid Composites

AlN in-situ joined to AlSiC



Ceramics in-situ Joined to AlSiC

Aluminum Joint Between Ceramic and AlSiC



Summary

- HEATWAVE™ AlSiC CTE and Thermal Conductivity can be Tailored to Meet Application Requirements
  - CTE – 5 ppm/K to 15 ppm/K
  - TC – As High as 230 W/m-K
- HEATWAVE™ Hybrid Composites Allow Designers to use AlSiC for Applications Which Require Very High Heat Dissipation.
- Pressure Infiltration Process can be Utilized to Design Hybrid Composites for Various Unique Applications.