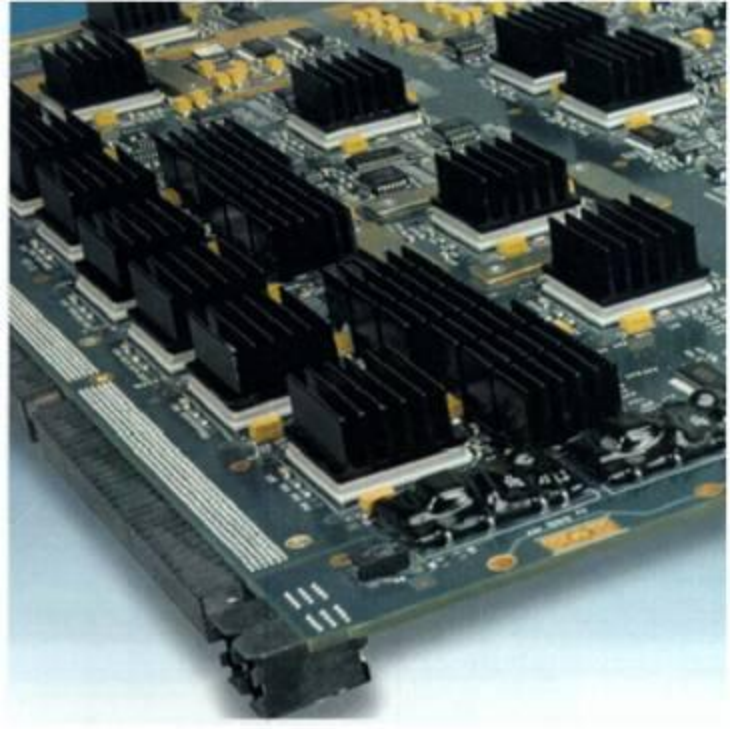

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TPG* (Thermal Pyrolytic Graphite) and TC1050* Thermal Management Materials

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Industry Manager – Thermal Management
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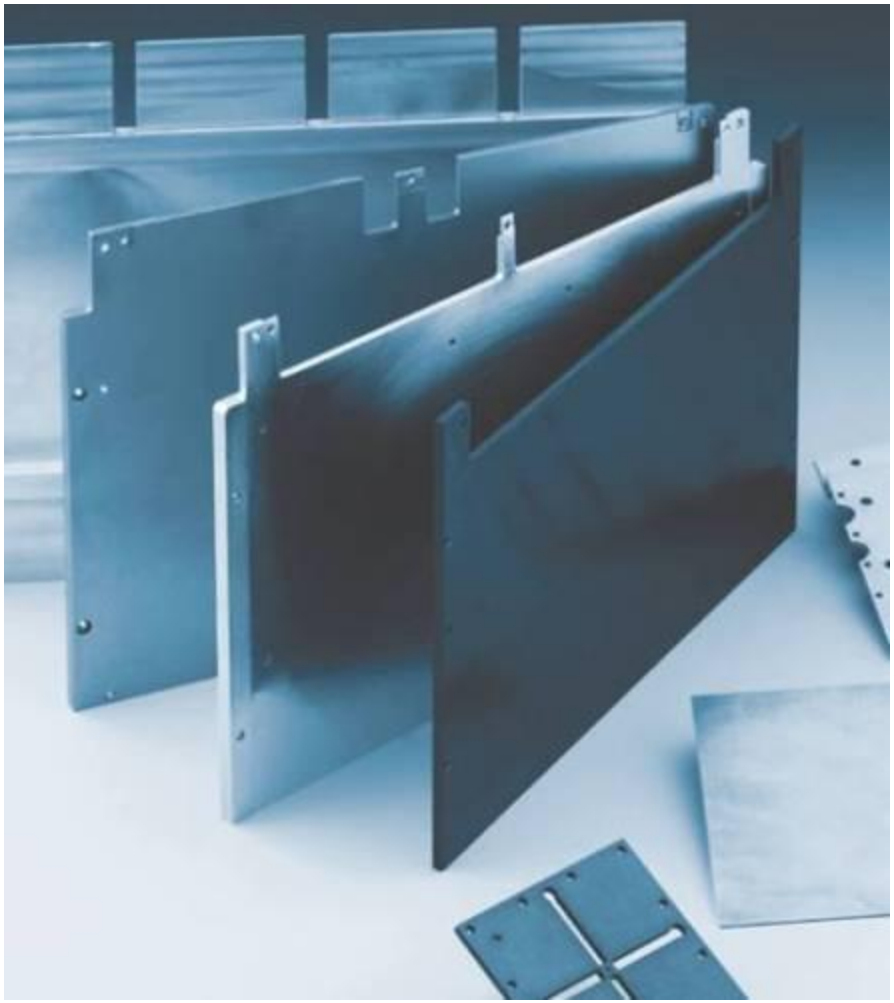
TPG* and TC1050* Composites

- What is this highly conductive material (T_c > 1000 W/m-K)
- Differences, properties, and capabilities
- Composites using TPG
- Applications in high power electronics
- Specific examples of its use



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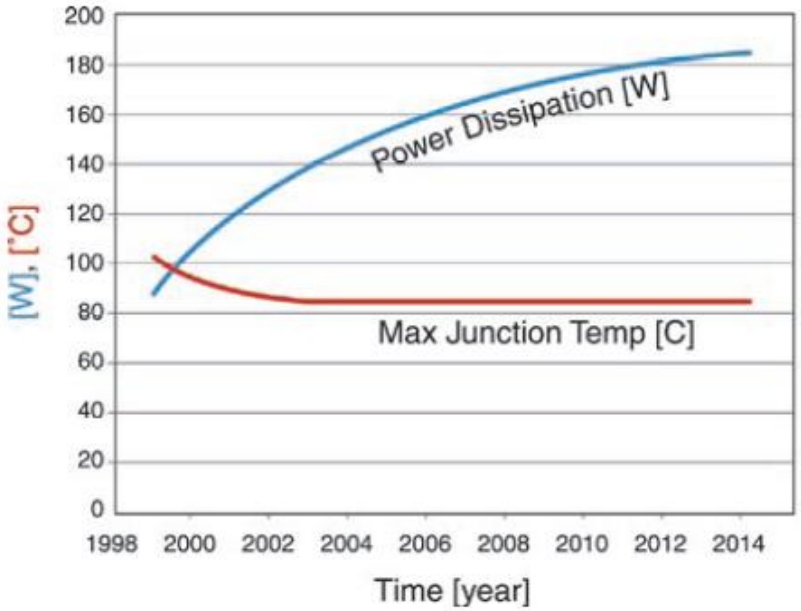
Device power requirements continue climbing



- Increased power requirements
- Increased power dissipation (heat) needs
- At constant junction temperatures

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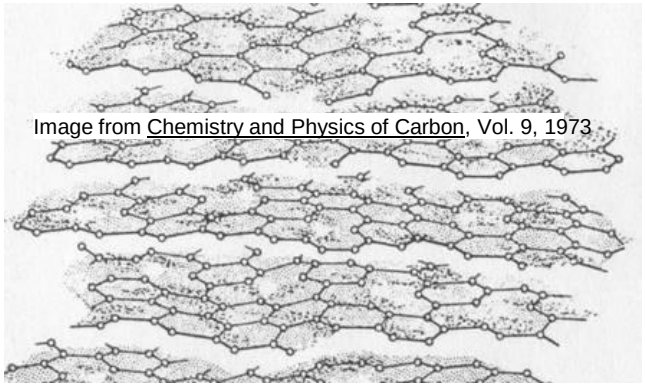
Source: Thomas Perazzo, "Expanding the limits of air cooled technology"

Synthesis of Highly Conductive TPG*

Turbostratic PG
"as deposited"

Limited conductivity

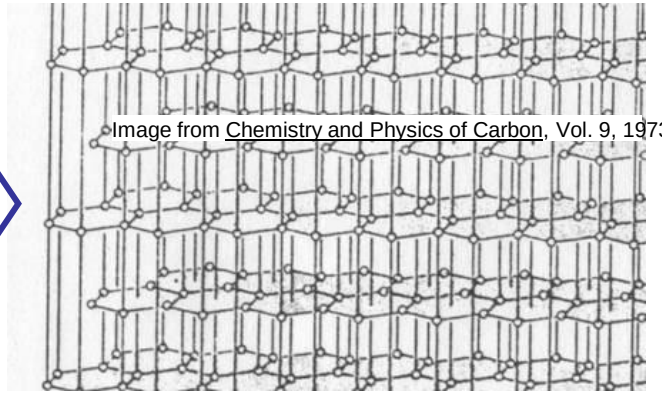


- Formed from methane via CVD
- Classic 2-D, hexagonally ordered crystal structure
- 3rd dimension is DISORDERED
- Density 2.2 gm/cc
- Thermal conductivity 200-400 W/m-K

PG subject to heat treatment

Oriented TPG Graphite
"heat treated"

High conductivity



- Additional ordering of 2-D structure
- ORDERED 3D crystal structure
- Phonon transfer (thermal conductivity) dramatically enhanced
- Lighter than Al - density 2.2 gm/cc
- Thermal conductivity >1500 W/m-K

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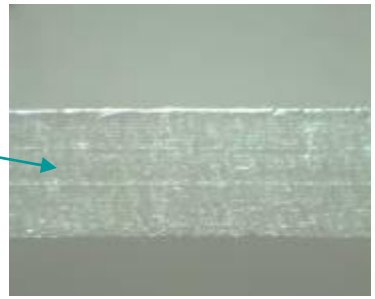
* TPG is a trademark of Momentive Performance Materials, Inc.

Three Grades of Pyrolytic graphite

Type	Grade	T_c (W/m-K)	Typical Use
Pyrolytic Graphite	(PG)	200-400	Sputtering targets Rocket nozzles
Thermal Pyrolytic Graphite	(TPG*)	>1500	Thermal Management High Power assemblies/devices
Highly Oriented Pyrolytic Graphite	(HOPG)	>1700	Monochromators for XRD and Neutron Scattering

TPG surface 10X

TPG cross section
X-Y layers 30X



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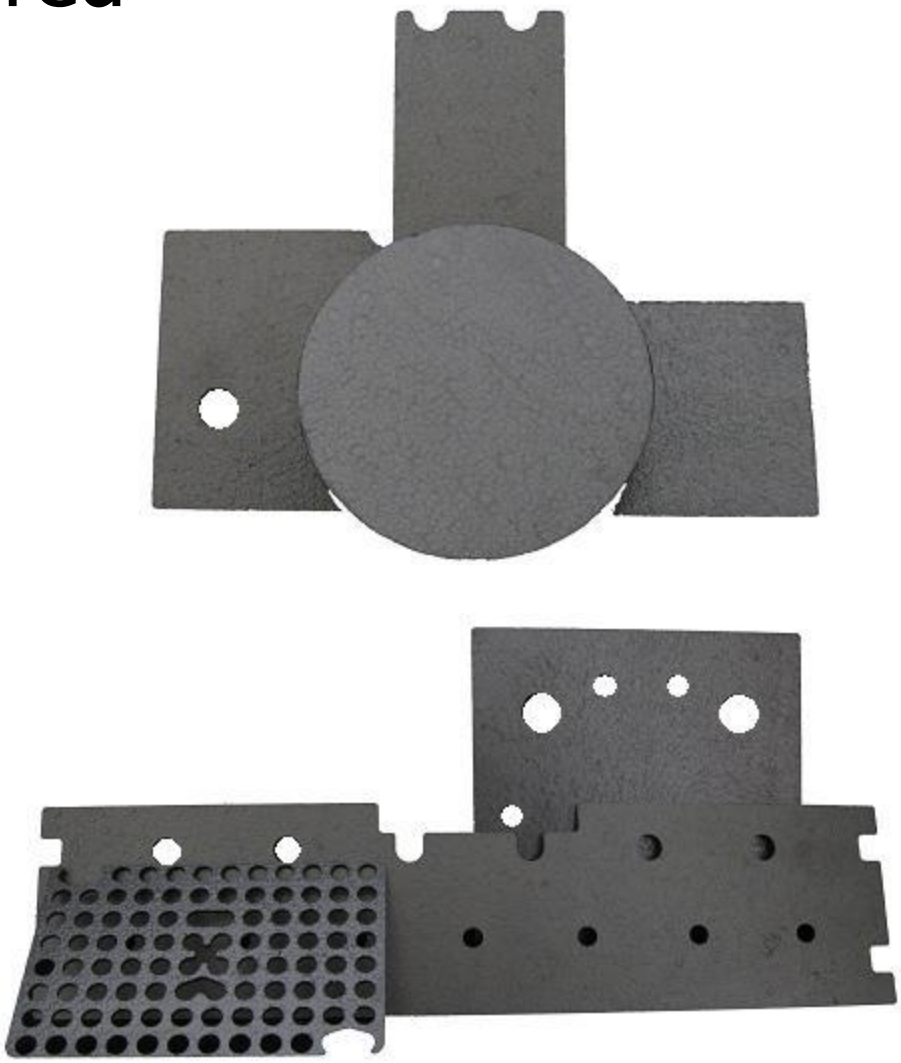
TPG* is easily configured

- Available in a variety of shapes and sizes
- Capability from simple to complex
- Machines similar to typical ceramics
- Multiple tiles configured for large / thick component requirements



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Comparison of TPG* material to other advanced thermal materials

Material	In-Plane TC (W/m-K)	Thru-Plane TC (W/m-K)	In-Plane CTE (ppm/°C)	Specific Gravity	Specific In-Plane TC[1]
Aluminum	218	218	23	2.7	81
Copper	400	400	17	8.9	45
AlSiC-12	180	180	11	2.9	62
CuW	185	185	8.3	15.2	12
Carbon/Carbon	400	40	-1.0	1.9	210
CVD Diamond	1100-1800	1100-1800	1-2	3.5	310-510
TPG Graphite	1500+	10	-1	2.3	650

[1] In-plane thermal conductivity / specific gravity
Sources: Carl Zweben, Thermal Consultant

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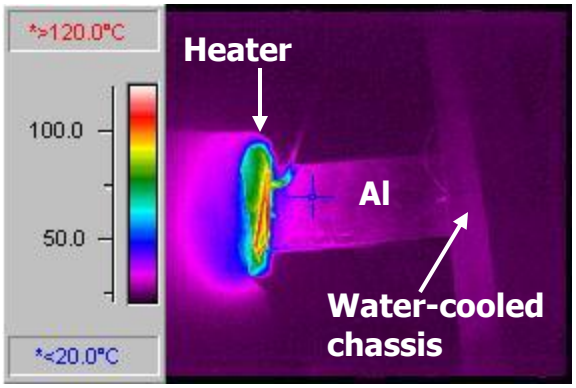
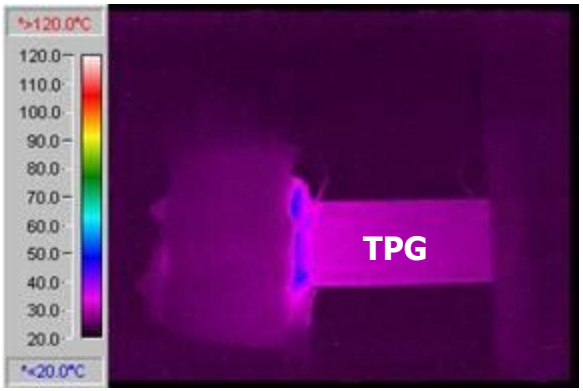
TPG* High Thermal Performance



6061 Aluminum
T_{max} = 115 °C

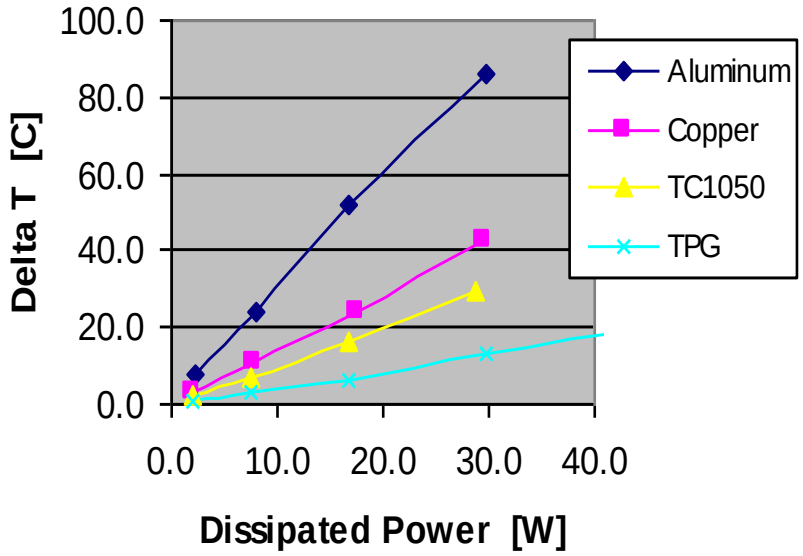


TPG™
T_{max} = 44 °C

0.125" x 1.875" x 4.875" bar

Kapton™ 30 watt heater at one end, water-cooled chassis at other (1-dimensional flow)

Typical Thermal Performance



TPG graphite shows > 5X the power dissipation capability of Al

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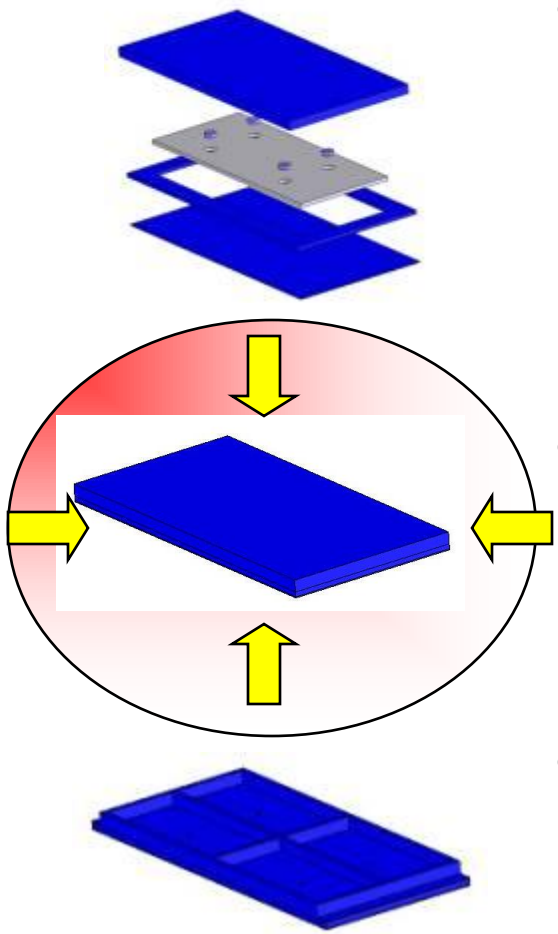
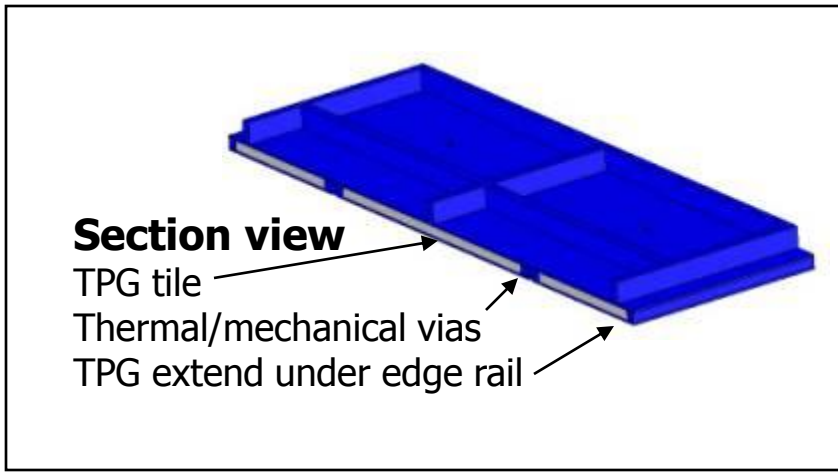
TC1050* Composite Manufacturing



- Kit
  - Top metal face, with thickness for features
  - Via "buttons"
  - TPG* tile
  - Frame
  - Bottom metal face
- Diffusion bond
  - High pressure
  - High temperature
- Machine finished form
  - TPG fully encapsulate
  - TPG extends into contact area on edges



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Product Capabilities

		TPG*	TC1050*
Size (in)	Min.	0.100 x 0.100	0.50 x 0.50
	Max.	5.5 x 10.0	14 x 14
Thickness (in.)	Min.	0.010	0.060
	Max.	0.375	> 0.50
Machinability		Conventional	T(0) capability
Flatness^ (in./in.)		0.020	0.002
Dimensions^ (in.)		0.005	0.005
Positional^ (in.)		0.005	0.005
CTE (ppm/°C)		xy= –1 | z=26	17-26
Hermetic		-	Yes
Coatings		-	Yes

^ Standard Tolerances and geometry dependent

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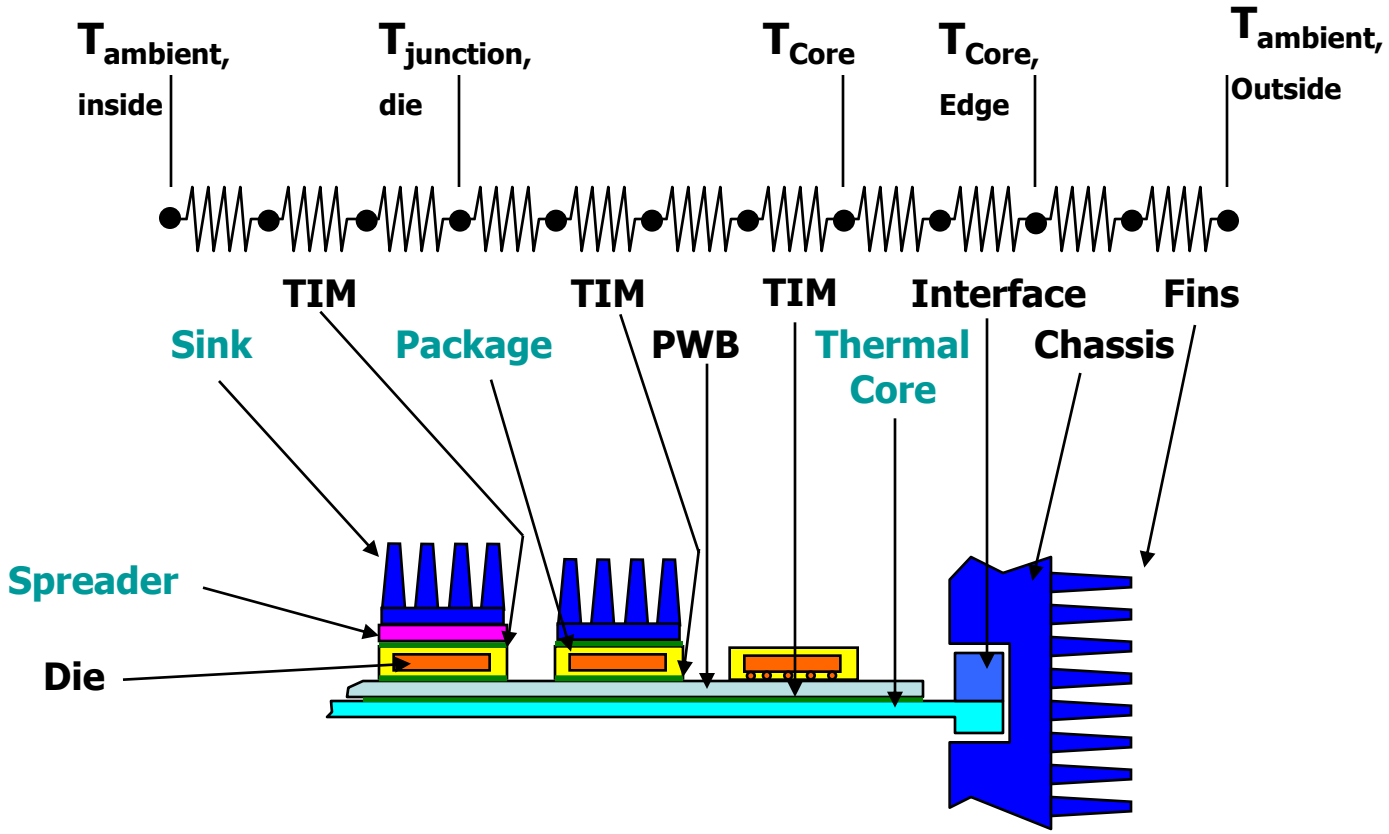
TPG* and TC1050* Material Applications in Thermal Management



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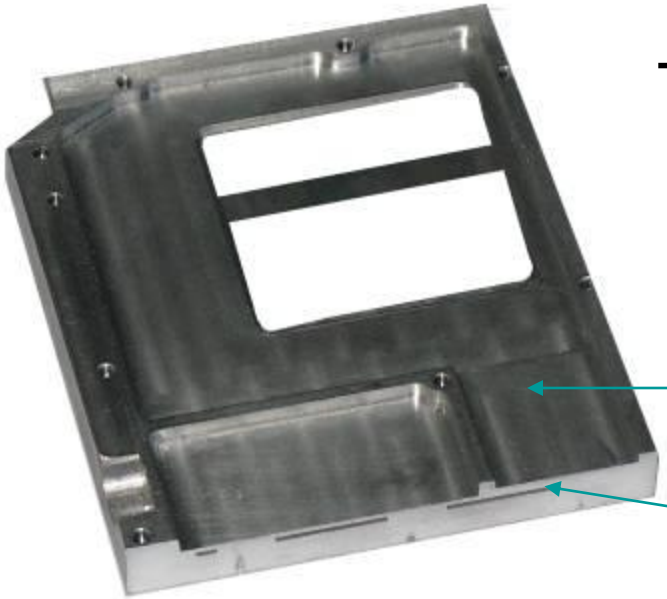
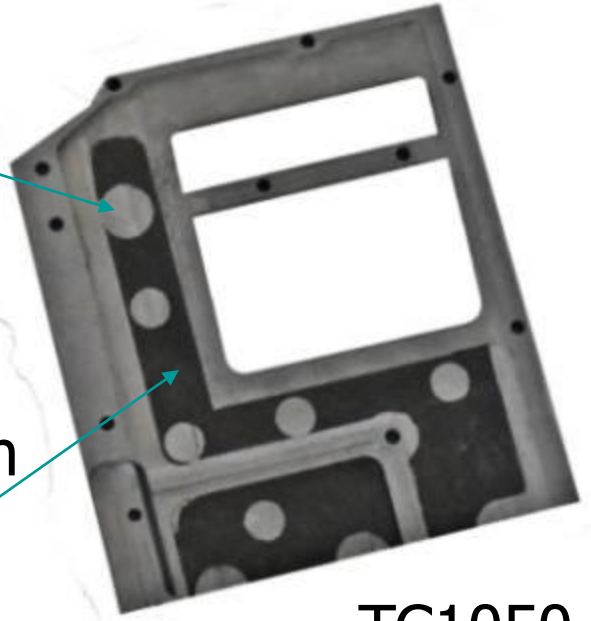
TC1050* Thermal Core



TC1050



TC1050 "Revealed"

- Aluminum or copper encapsulation
- Other innovative encapsulations
  - Aluminum-Silicon-Carbide (AlSiC)
  - Carbon-fiber composites
- Thermal vias significantly improve "c-axis" conductivity and mechanical integrity

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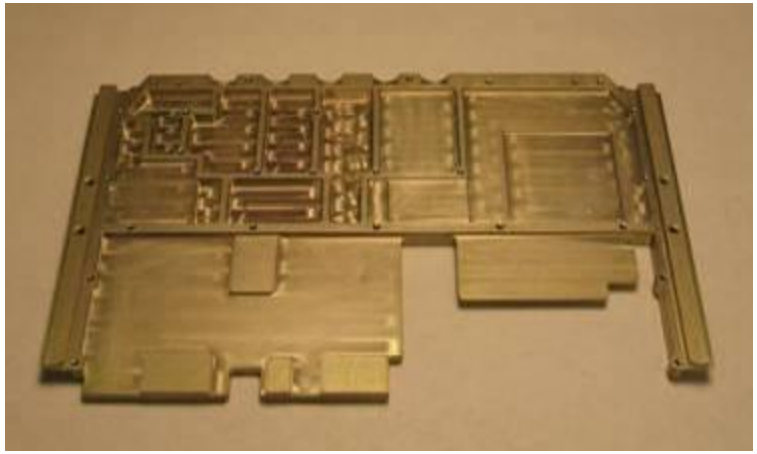
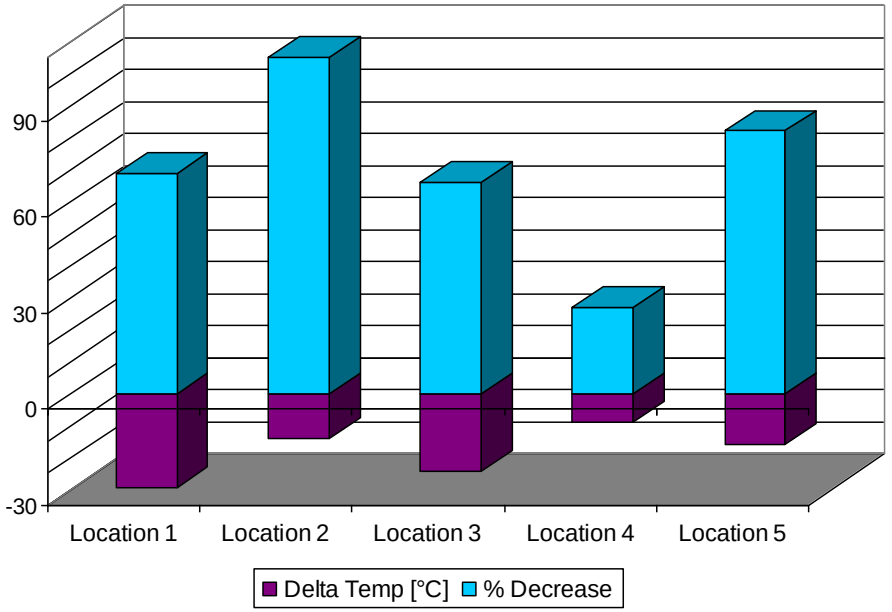
TC1050* vs. Aluminum Frame For 6U CPCI module



Source: Customer in-house test results 4/2006



- **Conduction cooled 6U CPCI Format module**
- **60 Watts total Heat Dissipation**
- **TC1050/Aluminum Frame Design -- 3D Features**
- **Designed for rugged airborne and ground applications**

Results:

- **Significant improvement in heat removal and cooling of the heat sources**
- **Significant temperature reductions utilizing TC1050 over Aluminum in a heat spreader for a 6U CPCI module that is conduction cooled.**

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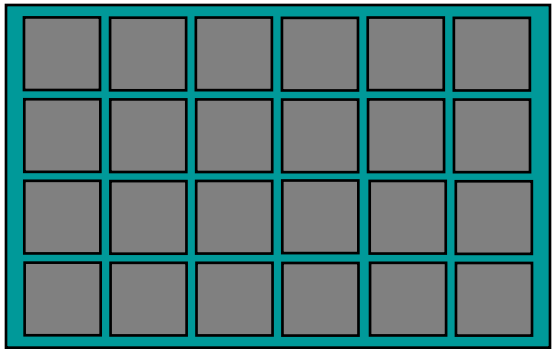
Standardized TC1050*

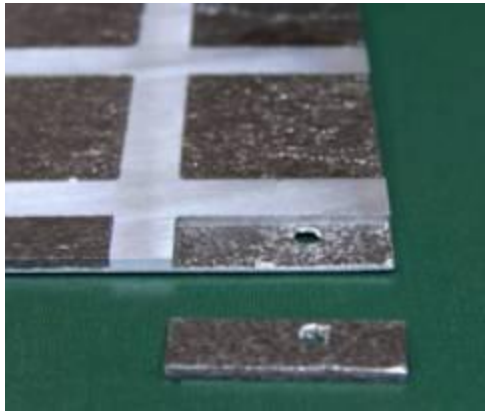
Concept: Standardized TC1050 boards manufactured with small TPG*tiles encapsulated in metal matrix

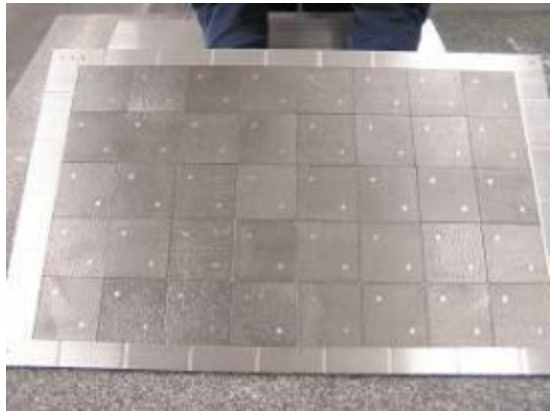
	Traditional	Standardized Board
Thermal conductivity	1050 W/mK	Target 700-1000 W/mK
Lead time	>10 wks	off the shelf ~2 wks
TPG	Customized shape	Small standardized shape
Hermiticity	Fully sealed	As Needed

Advantage

Under further development







TPG and Al dimension can be tailored to optimize performance/cost to meet customer requirements

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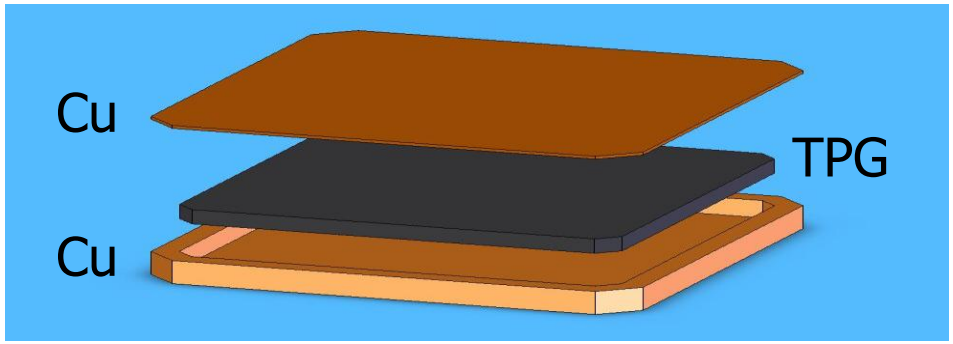
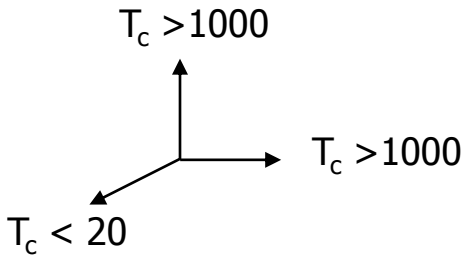
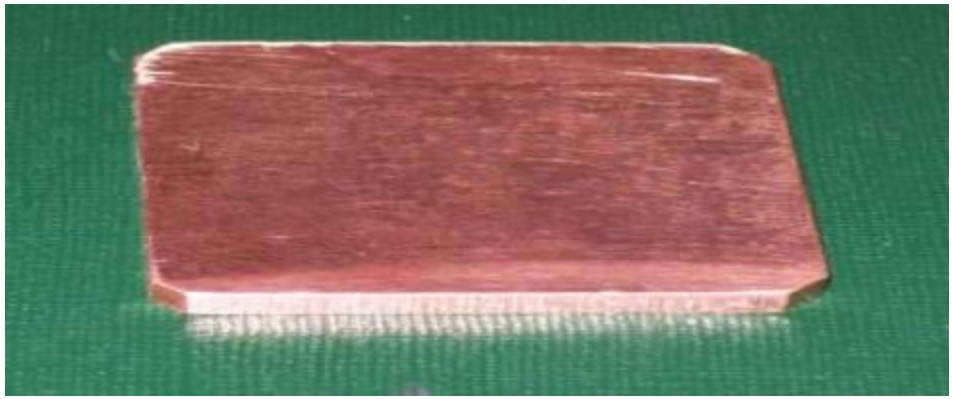
Package heat spreaders

Copper Chip Module Heatspreader

TC1050* with TPG*rotated 90° in Z direction







- TPG min. thickness .050 inch
- x-y max is 1.0 inch today

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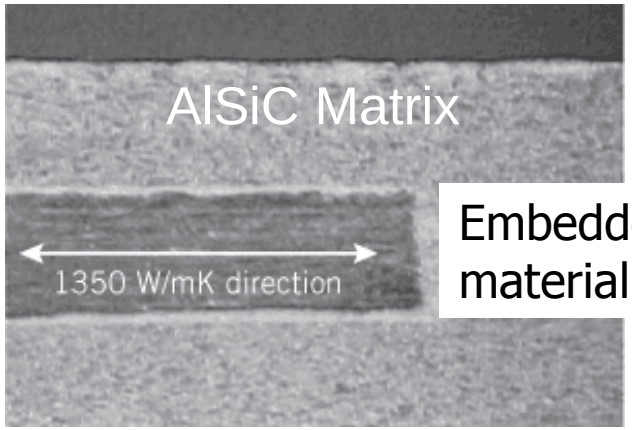
Chip level applications

AlSiC Flip Chip Lids with Embedded TPG* material

- 23 mm SQ x 0.5mm
- 1350 W/m-K xy-axis 10 W/m-K z-axis



Source: Ceramic Process Systems

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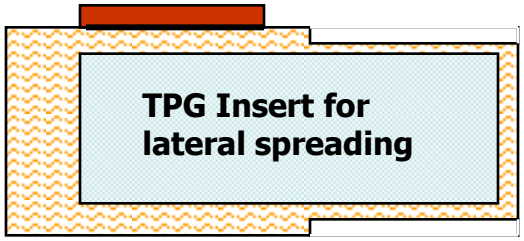
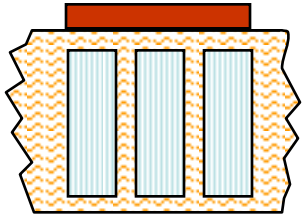
Chip level applications

- Other Composites with In-Situ Cast TPG*
- CTE tunable for Power Packaging Applications

Copper graphite skin
CTE 4 ppm/°C
TPG inserts (un-plated)





TPG Inserts for through thickness heat sinking

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Source: Metal Matrix Cast Composites

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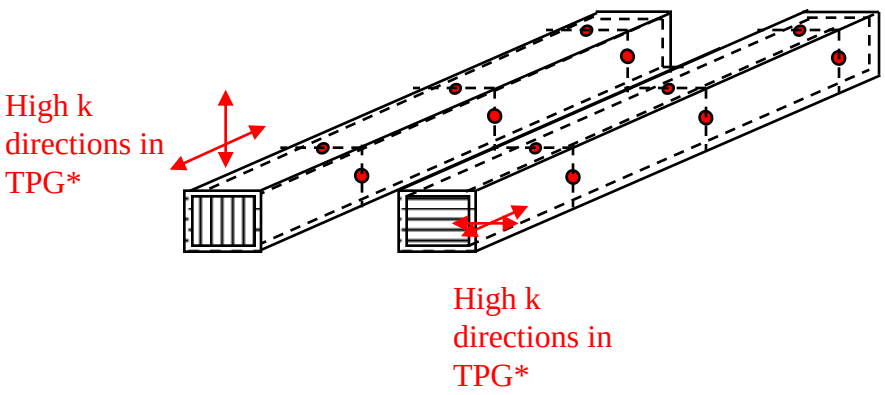
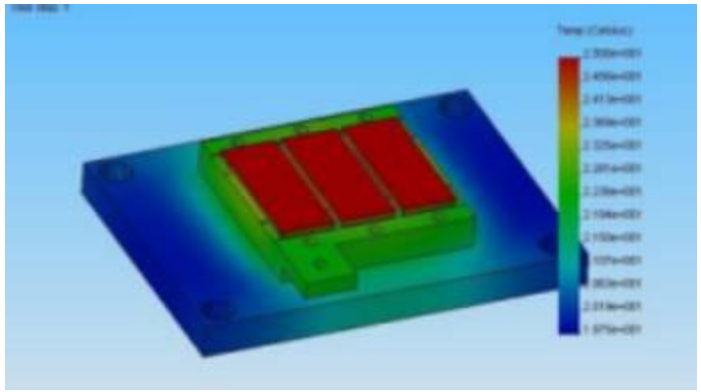
Thermal Conductivity - TPG*with Cu Composite





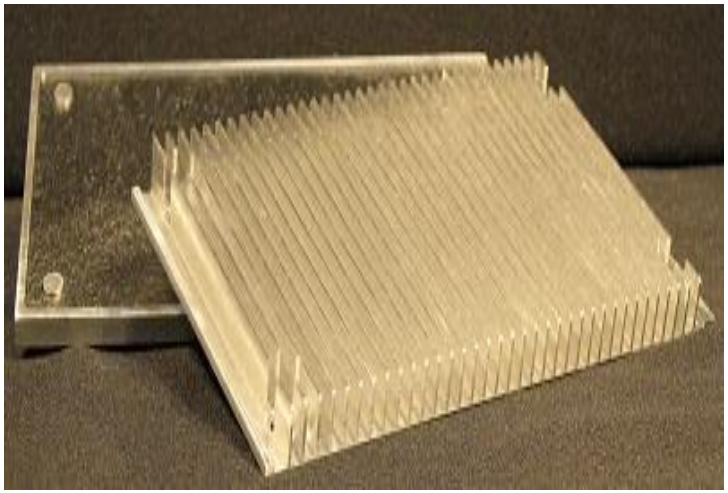
	T_C Composite	T_C of TPG Insert
Cu Composite w/ TPG	>1000*	~1700

Actual T_C will vary depending on Cu composite thickness

Source: Metal Matrix Cast Composites

Heat Sink Application

TC1050* to improve standard heat sink performance



- Improve heat spreading in the base
- Reduce over all hot spot(s) temperature
- Increase fin efficiency

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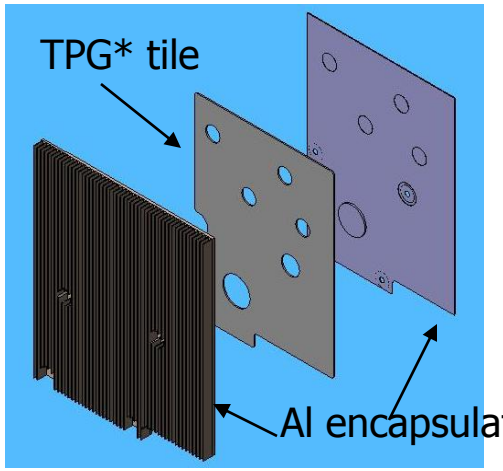
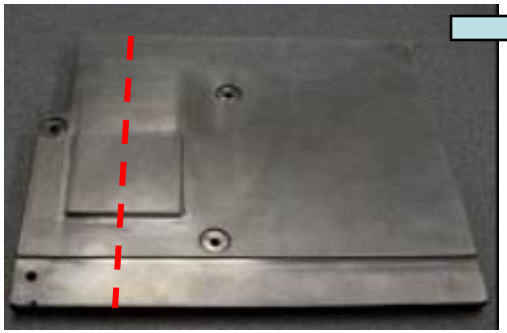
Heat Sink Constructions

- Standard aluminum heat sink

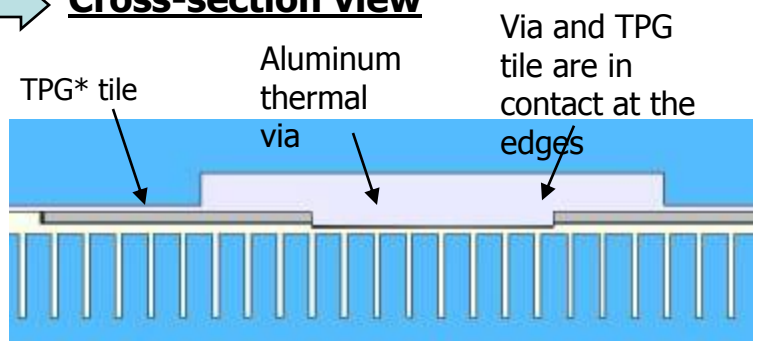


Exploded view

- TC1050* prototype heat sink



Cross-section view



Same dimensions as standard heat sink, TPG and aluminum parts are bonded with epoxy.

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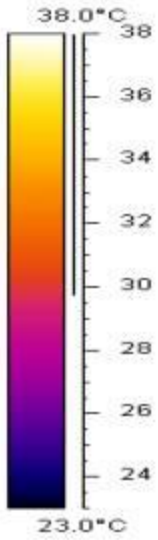
Prototype heat sink results

	CPU Average T (°C) 100% stressed
Baseline Aluminum heat sink	**53.5**
TC1050 prototype heat sink	**49.0**

Baseline

TC1050



△ T = 5.8C

△ T = 4.7C

- CPU temperature reduced 4.5°C in 100% stressed condition versus the standard aluminum heat sink
- By upgrading the prototype from an epoxy bond to diffusion bond, further improvement on TC1050* heat sink may be possible.

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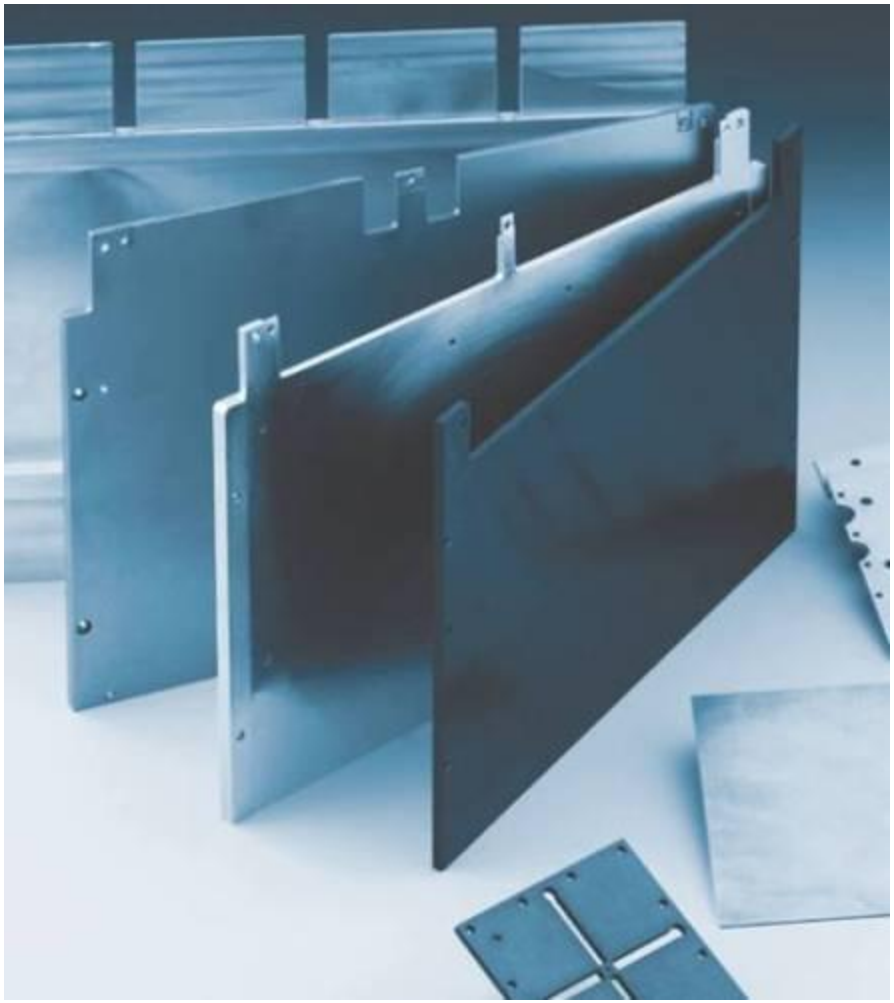
TPG* and TC1050* Composites

- Thermal conductivity > 1000 W/m-K
- A passive solution in a wide range of geometries
- Military qualified
- Hermetically sealed package
- Industry proven for > 12 years



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Thank You!