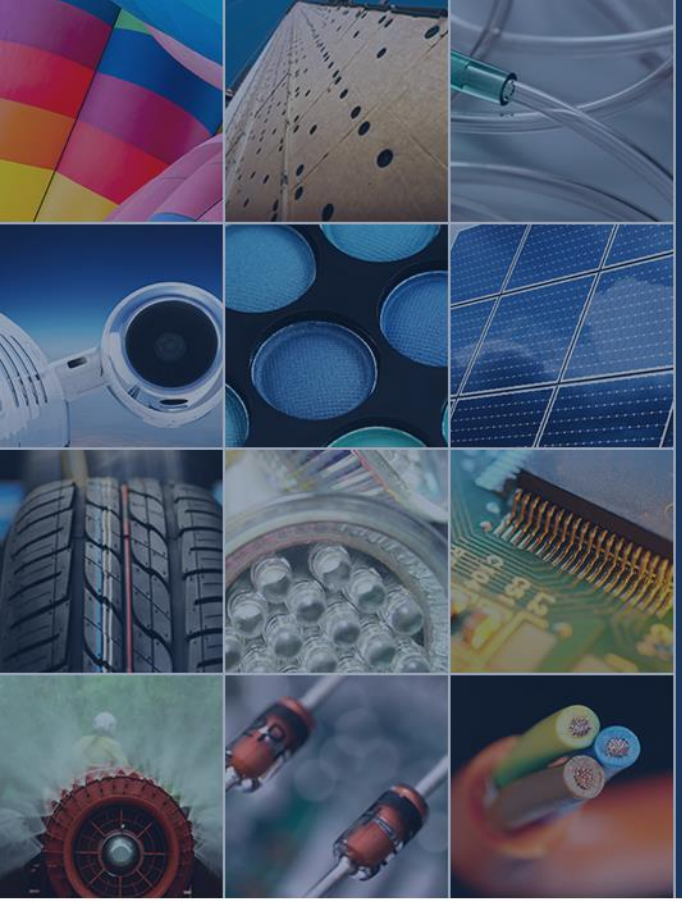

iMAPS New England 46th Symposium & Expo

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inventing possibilities

# Advancement in TPG* Graphite Based Thermal Management Technology for High Power Microelectronics

***Wei Fan***, *Liu Xiang, Brian Kozak, Kristi Scherler and Greg Shaffer*
*Momentive Performance Materials Inc.*
***Garry Wexler***
*Henkel Corp.*

Contact: wei.fan@momentive.com / (440) 878-5703

# Momentive Products in the Semiconductor Process


***Quartz materials also sold at multiple steps in the Silicon Semi Cycle***



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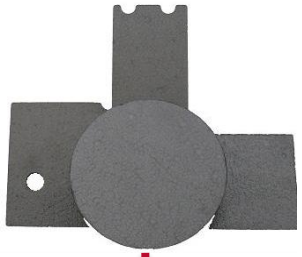
# Tailored Thermal Management Products (TMP) to Meet Specific Challenges

## TPG* Graphite



- High Thermal Conductive
- Light Weight

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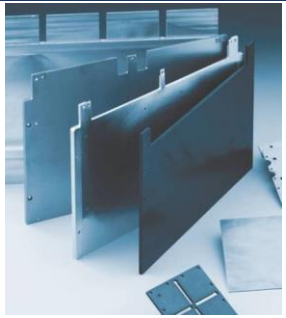
### TC1050* Heat Spreader

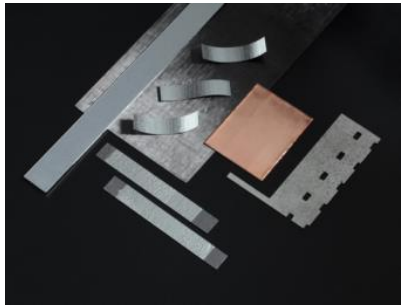


- Board level
- 2-D and 3-D shapes possible

### TMP-EX Heat Sink

- Chip level
- CTE matching

### TMP-FX Thermal Strap



- Low profile
- Flexible

*TC1050 and TPG are trademarks of Momentive Performance Materials Inc.



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# What Challenge Do You Face?
# Customized to Unlock Your Products Potential!







Increased power input or output?

Field Reliability?

Limited design space?

Reduced weight?

Too Hot?

***TMP Application Examples***

- 60% more power loading
- 90% temperature reduction
- 46% weight reduction
- 5x heat dissipation power of aluminum



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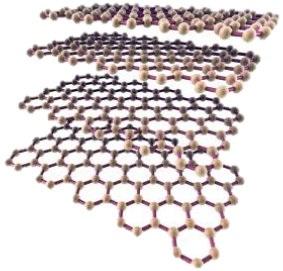
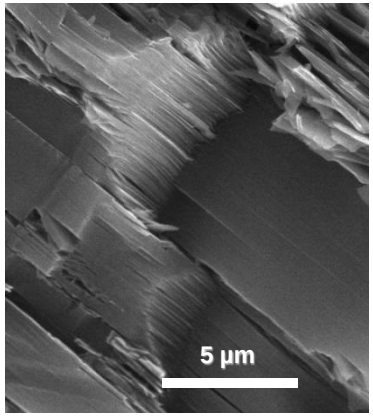
# The Core Benefits of Thermal Management Products (TMP) Based on TPG*

- Thermal Pyrolytic Graphite (TPG) is a highly crystalline graphite with well aligned graphene planes
- TPG has a **thermal conductivity 7x of aluminum**, but with **83% of aluminum's weight**






| Material | In-Plane TC (W/m-K) | In-Plane CTE (ppm/°C) | Specific Gravity |
|---|---|---|---|
| Aluminum | 210 | 24 | 2.7 |
| Copper | 400 | 16 | 8.9 |
| AlSiC | 180 | 9.5 | 3.0 |
| WCu | 190 | 8.3 | 15.6 |
| MoCu | 170 | 9.0 | 9.8 |
| TPG | 1500+ | -1 | 2.3 |

TC = thermal conductivity
CTE = coefficient of thermal expansion

Typical Properties are average data and are not to be used as or to develop specifications.

*TPG is a trademark of Momentive Performance Materials Inc.



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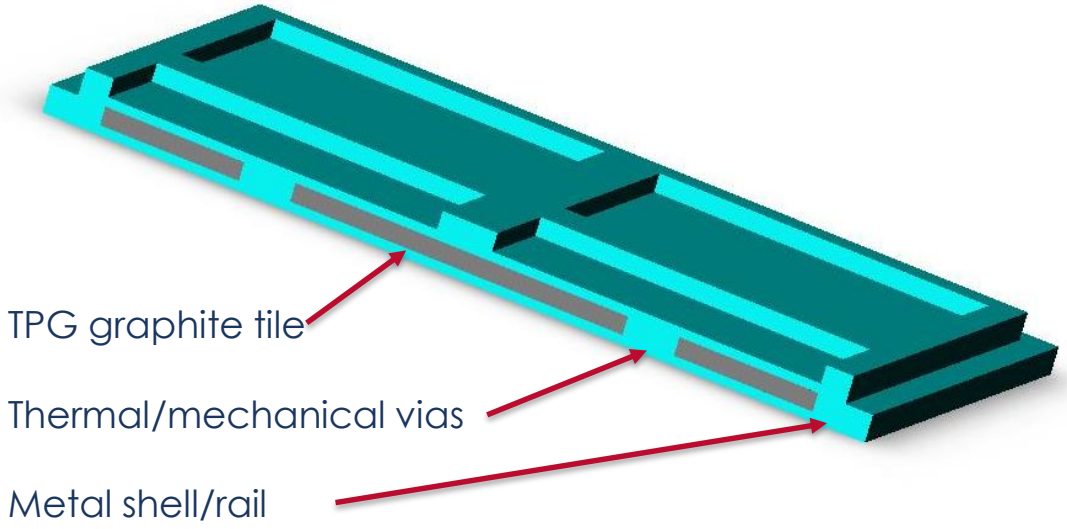
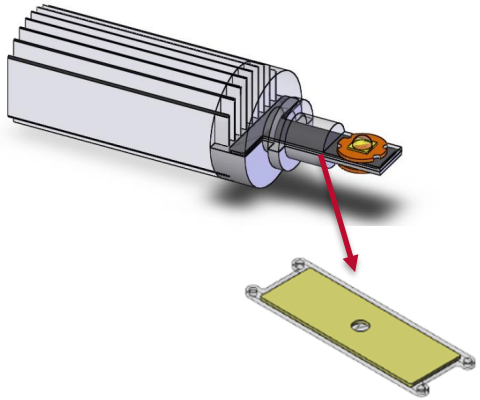
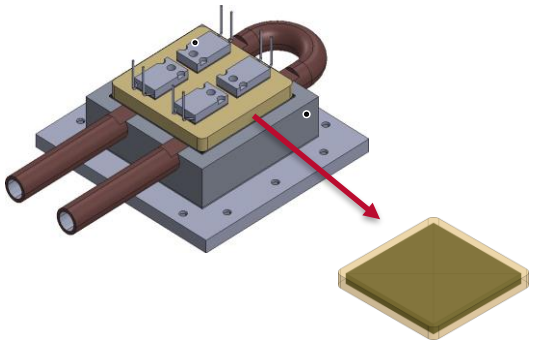
# Momentive's Proprietary Encapsulation Technology Enables Plug-n-Play Solutions

Our Heat Sinks are Engineered as if a Monolithic Metal Piece, but with the Performance of a World-class Thermal Designs:




**Cross Section of TPG Graphite-Metal Composite Heat Sink**





## Design Flexibility

- High thermal conductivity
- Low density
- CTE matching
- Strong
- Hermetic
- Reliable
- Platable
- Machinable



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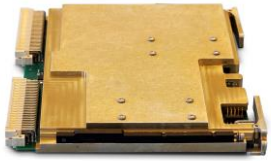
# Integrated TPG and IMS Technologies

**TC1050 + PCB**

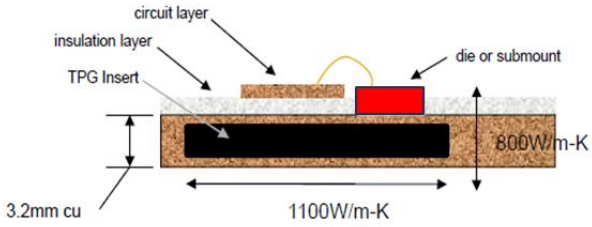


**TMP-EX + DBC**

**Challenges:**

- Complex design
- Many interfaces
- High assembling cost

## GEN I – Single Side Circuit (Low Voltage)

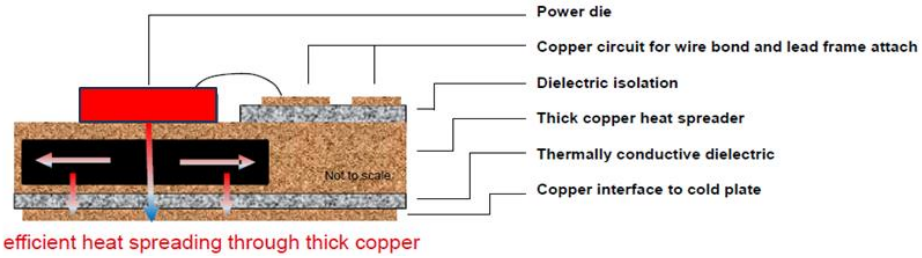




**Advantages:**

- Integrated IMS and TPG technologies
- Improve thermal performance
- Improve reliability
- Maximize GaN/SiC device capacity
- Reduce module complexity
- Reduce weight

## GEN II – Double Side Circuit (High Voltage)



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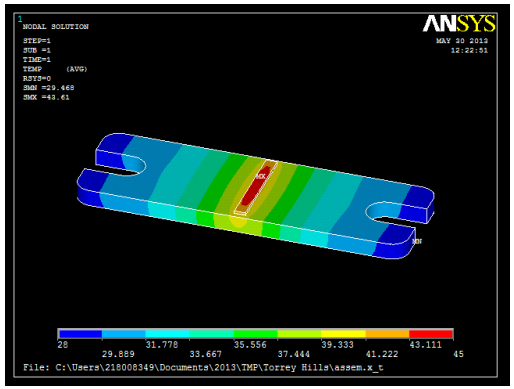
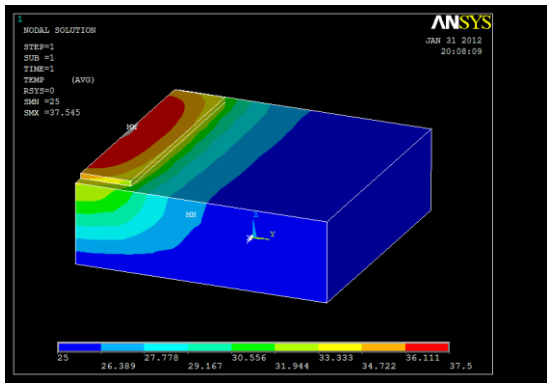
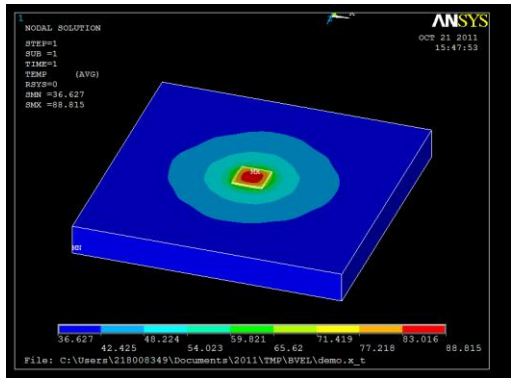
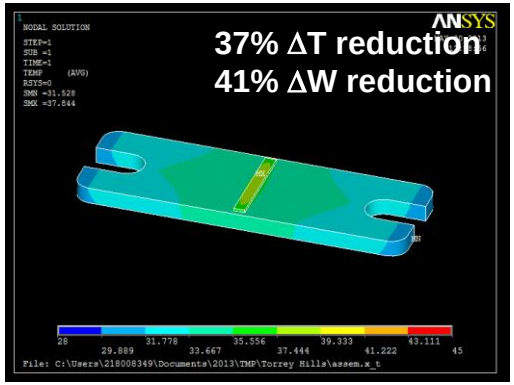
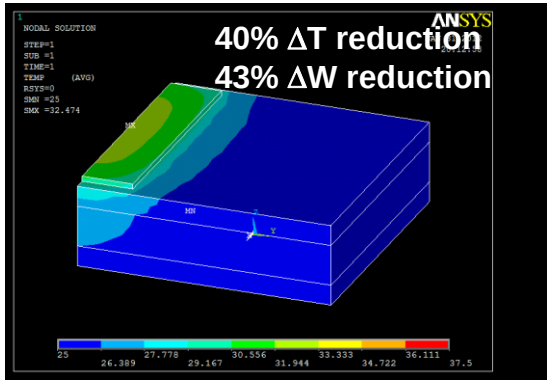
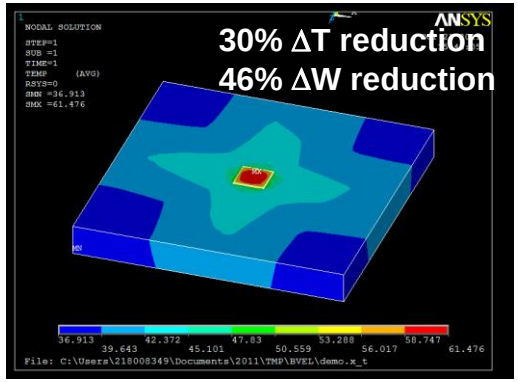
# TPG Metal Composite Outperforms the Monolithic Incumbents

| Material* | In-Plane TC (W/m-K) | Thru-Plane TC** (W/m-K) | Density ($gm/cm^3$) |
|---|---|---|---|
| Aluminum | 210 | 210 | 2.7 |
| TPG + Aluminum | 1073 | 507 | 2.4 |
| Copper | 400 | 400 | 8.9 |
| TPG + Copper | 1133 | 783 | 4.5 |
| AlSiC12 | 180 | 180 | 3.0 |
| TPG + AlSiC12 | 1060 | 435 | 2.5 |
| W85Cu | 190 | 190 | 15.6 |
| TPG + W85Cu | 1063 | 455 | 6.7 |
| Mo70Cu | 170 | 170 | 9.8 |
| TPG + Mo70Cu | 1057 | 416 | 4.8 |

* Estimated values based upon calculation using published information and should not be used as or to develop specifications. Actual values may vary.

** TPG graphene plane is perpendicular to the metal surface for this calculation.

# Thermal Simulation Shows Significant Improvement Over Incumbent

| | Center-mounted RF device | Edge-mounted laser diode | Center-mounted power device |
|---|---|---|---|
| Monolithic WCu heat sink |  |  |  |
| TPG-EX heat sink |   |   |   |

* Estimated values based upon simulation using published information and should not be used as or to develop specifications. Actual values may vary.



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# Characterization Capabilities and Qualification Standards

## Internal Capability

- **Thermal Conductivity**

Netzsch Nanoflash

- **Bonding Strength**

Instron

- **Thermal Expansion**

Anter Unitherm

- **Hermeticity**

Inficon He Detector

- **Dimension**

Zeiss CMM

## Packaging Qualification Standards*

- Thermal Shock: MIL-STD-883H-1010.8
- Mechanical Shock: MIL-STD-883H-2005.2
- Mechanical Vibration: MIL-STD-883H-2002.5
- Hermeticity: MIL-STD-883H-1014.13
- Coating:
  - Ni Plating – ASTM B733
  - Au Plating – ASTM B488-01
  - Chemical Conversion – MIL-DTL-5541
  - Sulfuric Acid Anodize – MIL-A-8625

* Typical standards. Test performed on stock products.

## External Testing Facilities

The Richard Desich SMART Commercialization Center for Microsystems

TPRL, Inc.

EWI

Tektronix®



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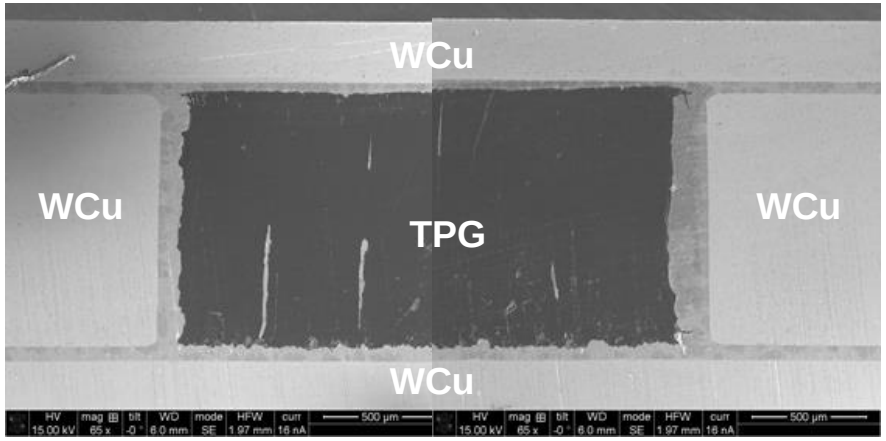
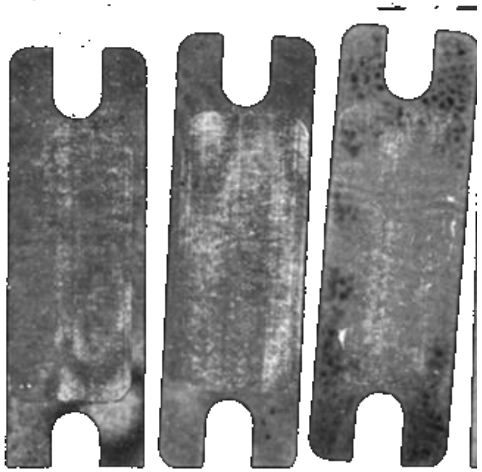
# Mechanically Strong and Thermally Conductive TPG-Metal Bonding Interface

**SEM of Cross Section**




**Ultrasonic Image of Bonding Interface**



* Imaged by Sonoscan Gen5 C-SAM

Intimate void-free contact is the key to:

- Low thermal resistance
- Strong structure
- Hermetic seal
- High reliability



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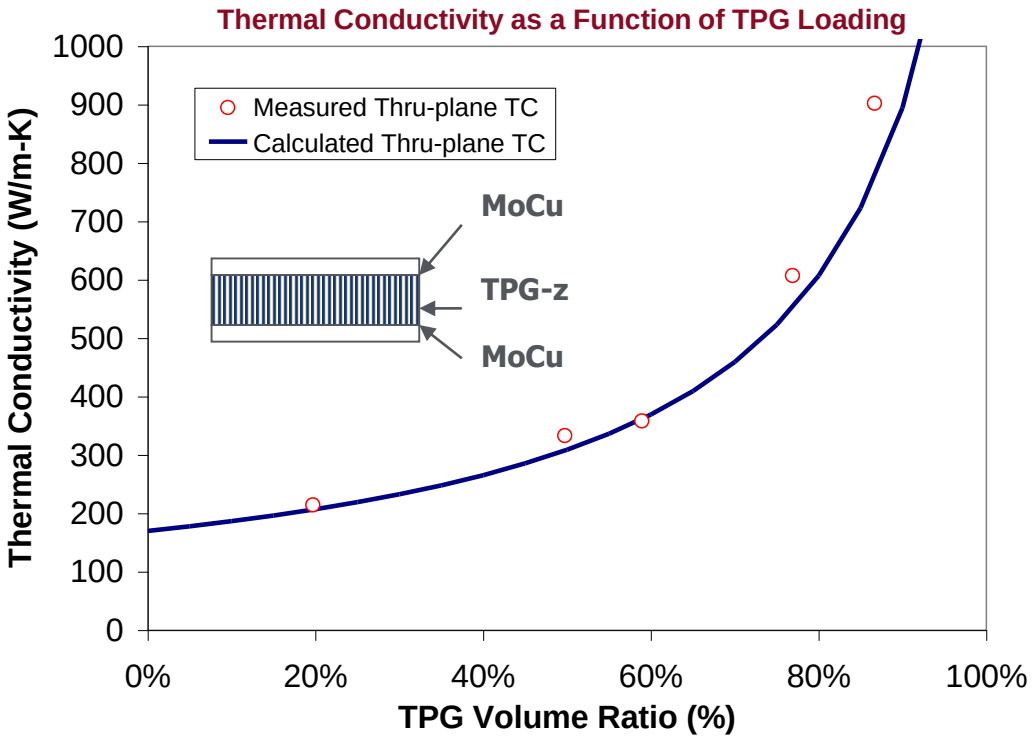
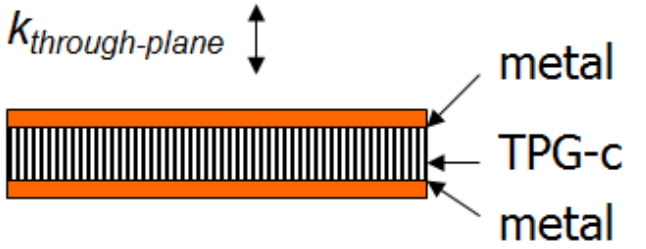
# Thermal Conductivity Matches Predicted Value




* *k* measured by Netzsch Nanoflash LFA447

** Tested data. Actual results may vary.

**TPG-c encapsulation**




$$k_{through-plane} = \frac{t_{total}}{\frac{t_{TPG}}{k_{TPG}} + \frac{t_{metal}}{k_{metal}}}$$

*t = thickness*
*k = thermal conductivity*

- Through-plane thermal conductivity EXTREMELY sensitive to defects.
- Thermal Conductivity matches predicted value.



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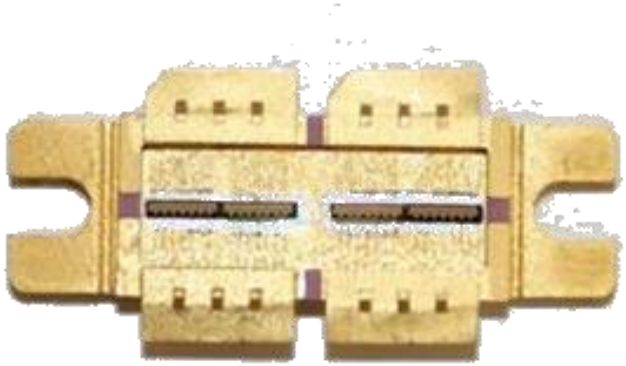
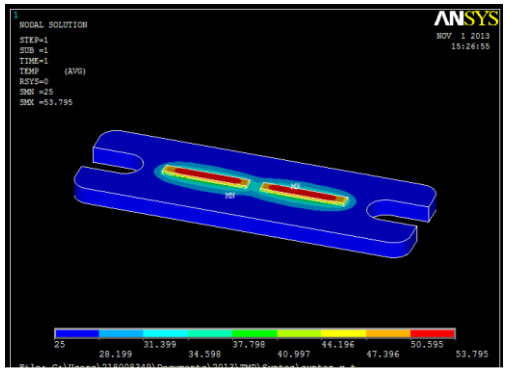
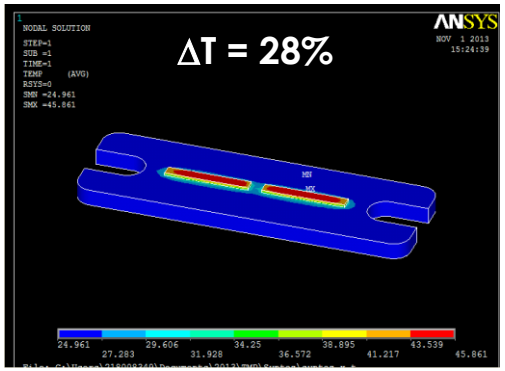
# Application 1 – TMP-EX Flange for RF Package



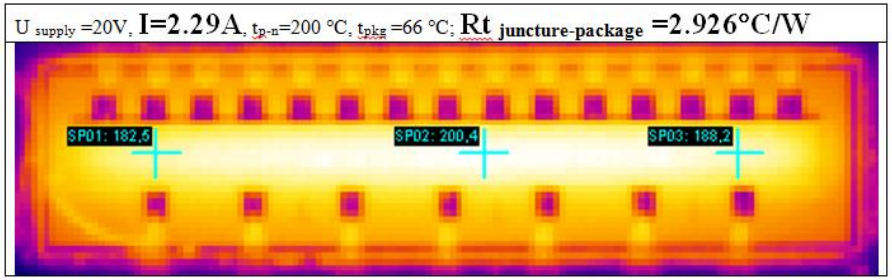
**W85Cu Heat Sink**



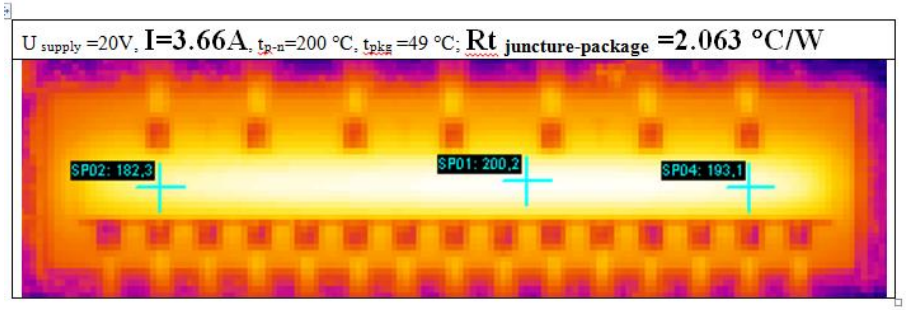

**TMP-EX Heat Sink**




**WCu Heat Sink**




**TMP-EX Heat Sink**




- Simulation matched experiment showed 30% reduction in thermal resistance
- Dies could be operated with 60% more power

* Used with permission from ZAO Syntez Microsystems
Note: Test data. Actual results may vary.



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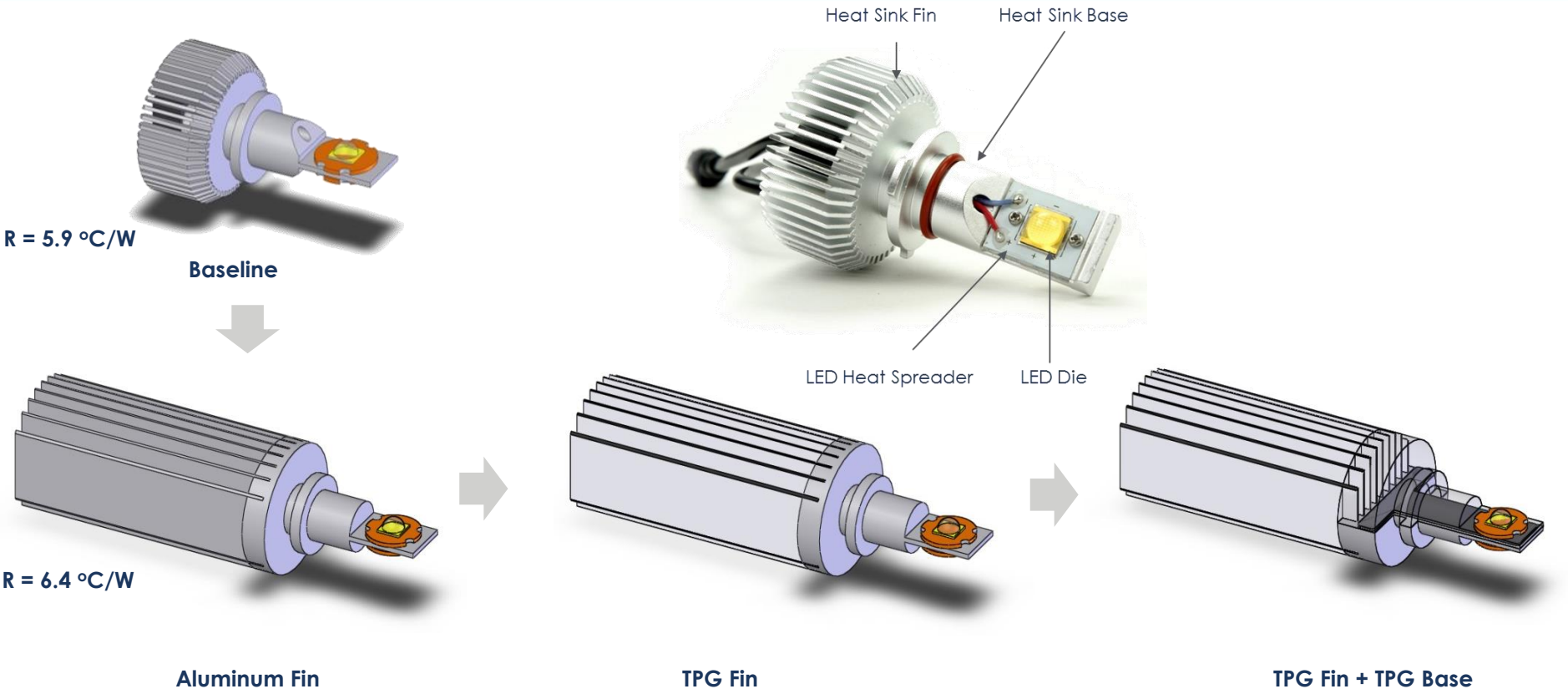
# Application 2 - Integrated TPG* Solution for LED Assembly




Integrate *TMP-FX Laminate* and *TC1050* Heat Spreader* into the LED headlight assembly using Momentive's proprietary bonding technologies.

*TPG and TC1050 are trademarks of Momentive Performance Materials Inc.



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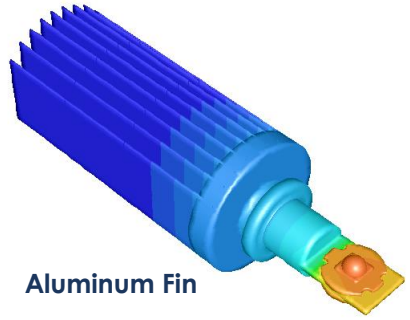
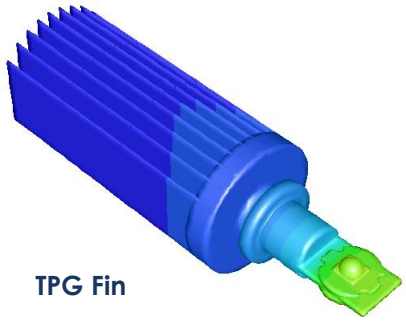
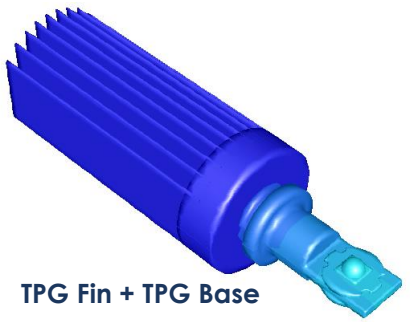
# Significant Temperature Reduction Observed in both Experiment and Simulation

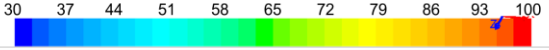



Note: Test data. Actual results may vary.




Total system thermal resistance was reduced by:

1. 27% with TPG* graphite fins
2. 24% with TPG* graphite base

*TPG is a trademark of Momentive Performance Materials Inc.



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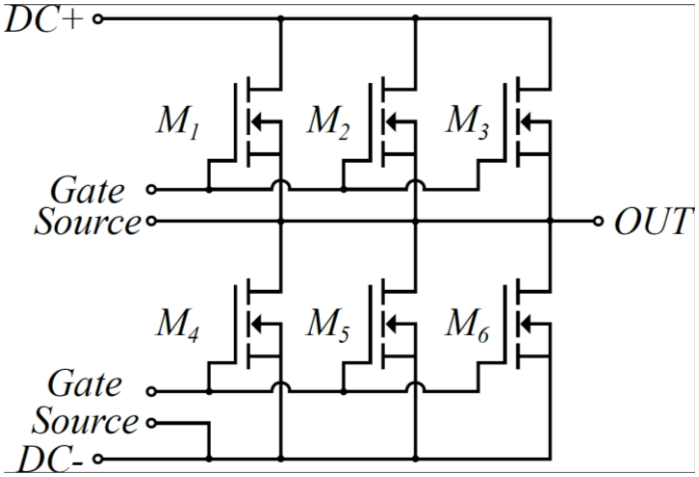
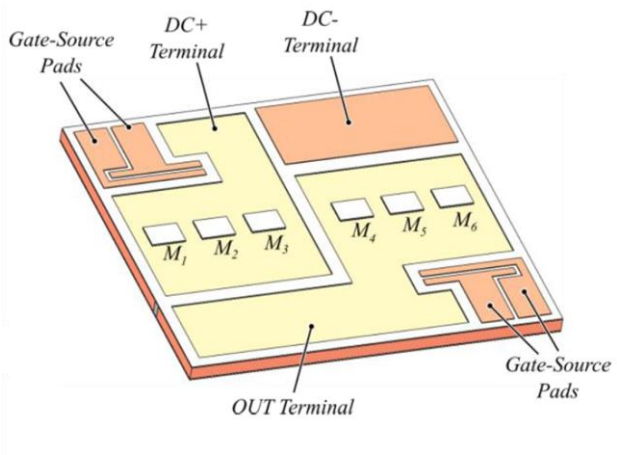
# Application 3 - TPG-Core IMS for SiC Power Module

**Half-bridge Module**

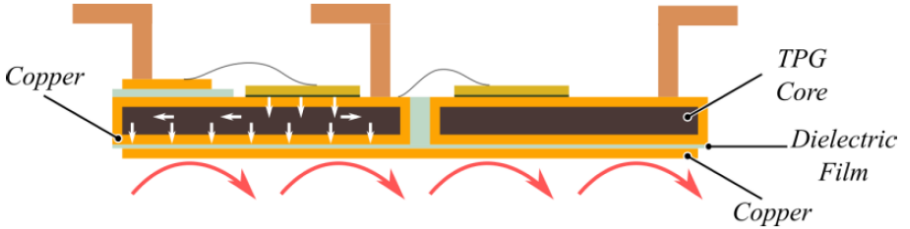



**IMS Layout**




- Two identical TPG cores are mounted directly underneath SiC dies and electrically isolated from each other.
- TPG cores assist heat spreading laterally and vertically.

**TPG-core Structure**



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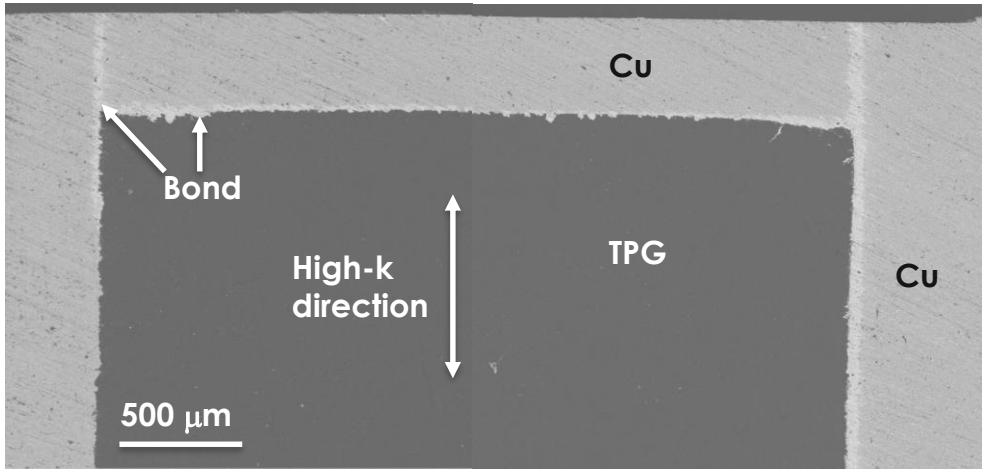
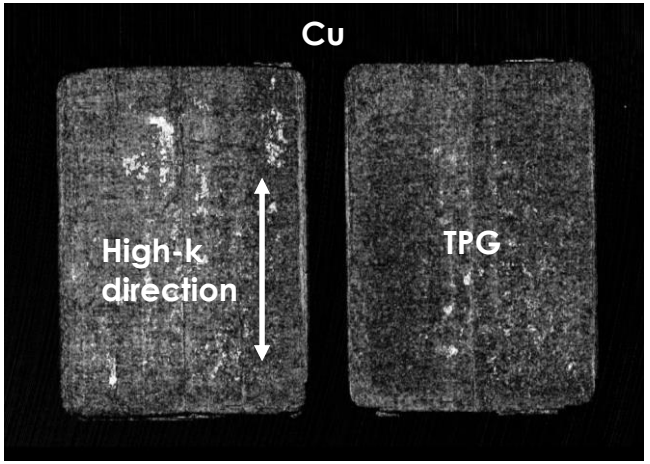
# TPG-Cu Joints for Thermal and Mechanical Excellence

**SEM Cross Section**




**C-Scan Top View**




- Nearly void-free TPG-meal interface was achieved with proprietary bonding technology.
- Through-thickness (Cu/TPG/Cu) thermal conductivity of 760 W/m-K was measured.



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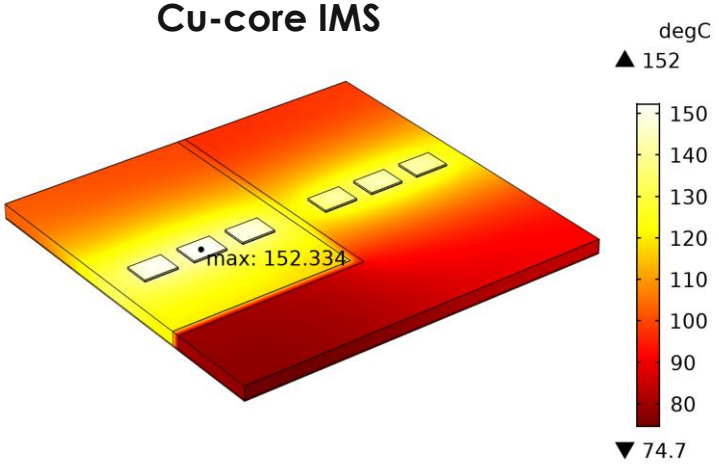
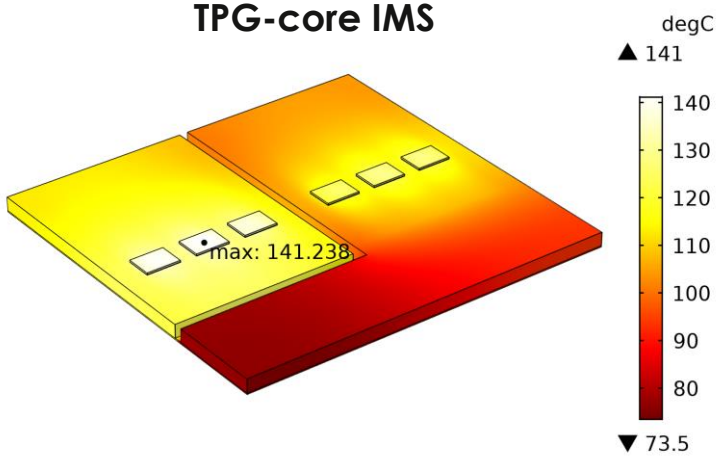
# Performance Comparison of SiC Power Modules Using Cu- and TPG-Core IMS

**Cu-core IMS**




**TPG-core IMS**




| | Thermal Conductivity (W/m-K) | | | Junction Temperature $T_{max}$ | | Junction Temperature Variation |
|---|---|---|---|---|---|---|
| | x | y | z | @ steady state | @ power cycle | @ power cycle |
| Cu-core IMS | 395 | 395 | 395 | 152°C | 109°C | 4.8~5.0°C |
| TPG-core IMS | 1155 | 130 | 760 | 141°C | 103°C | 3.9~4.2°C |



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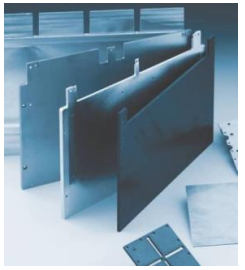
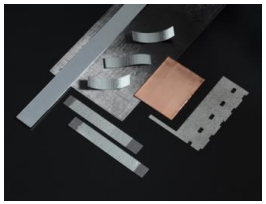
# Momentive Thermal Management Product Line

- TPG based thermal management products with light weight and high thermal conductivity (TC)
- Benefits to high-power electronics: more power, increasing reliability, extend life, and reduce cooling cost.
- 25 years of serving Telecommunication & Satellites, Military Aircraft, Radar Systems, and Unmanned Aerial Vehicles
- Recipient of Boeing's Gold Supplier award and L-3's Top 10 Supplier for quality and delivery
- AS9100 certified

TOSHIBA
L3
BOEING
LOCKHEED MARTIN
intel
NORTHROP GRUMMAN
Raytheon
aselsan







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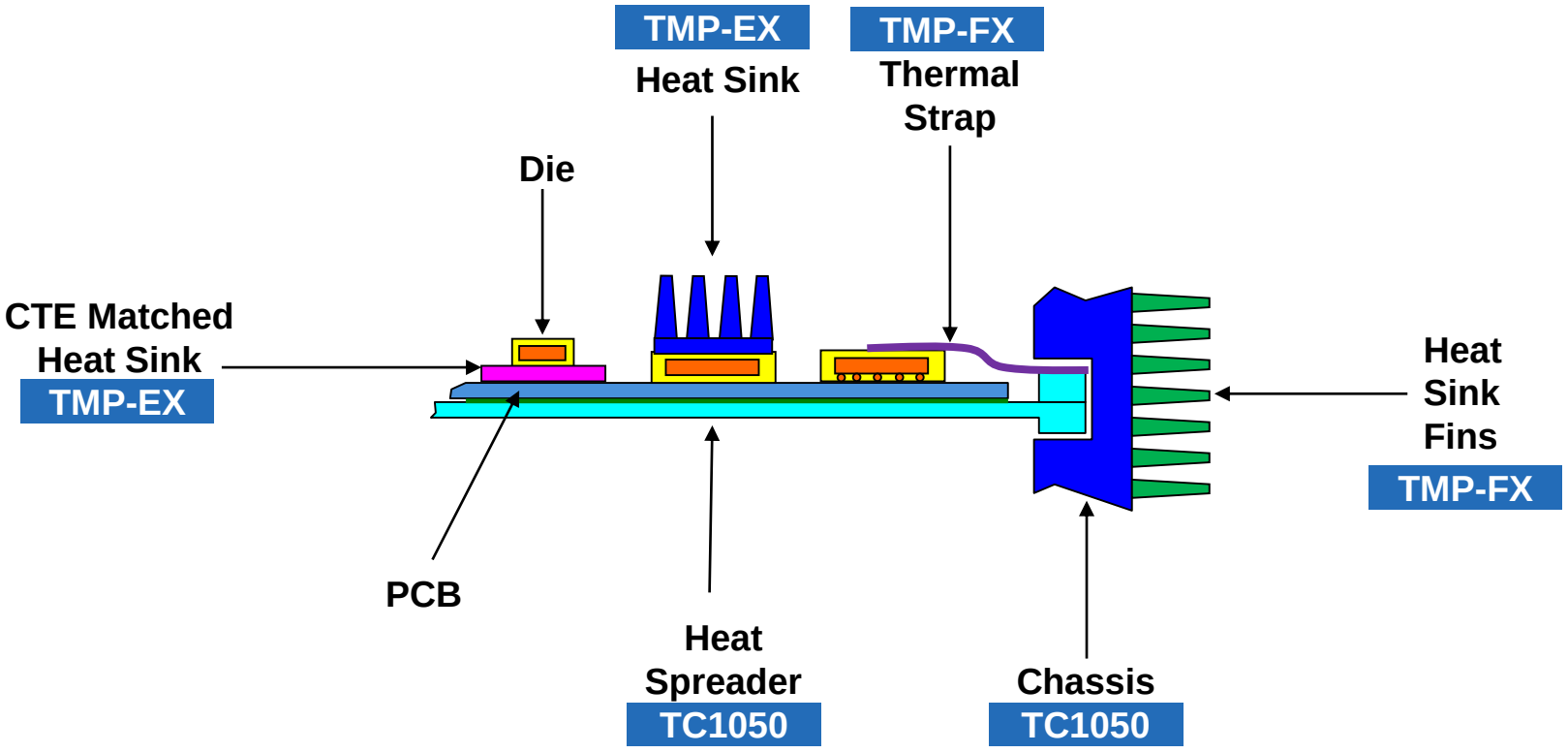
# How Can TMP Remove Critical Heat in Your Next Design?




A total heat dissipation solution can be engineered and supported by Momentive.



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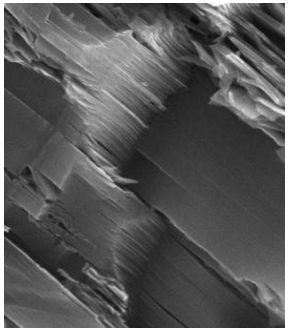
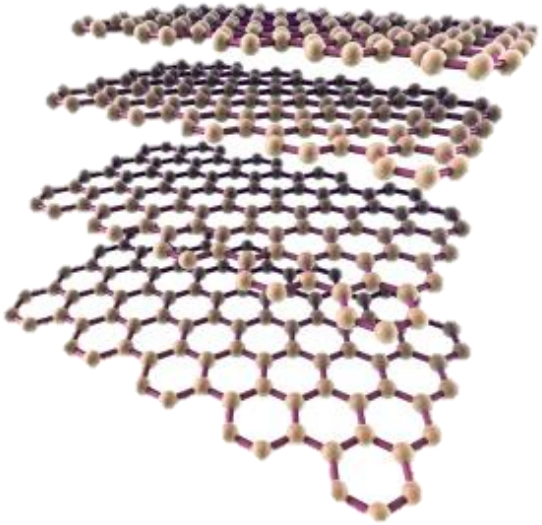
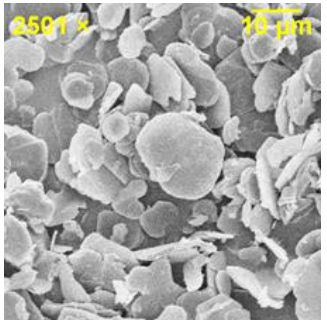
# *Thank You!*

**TPG* Graphite**

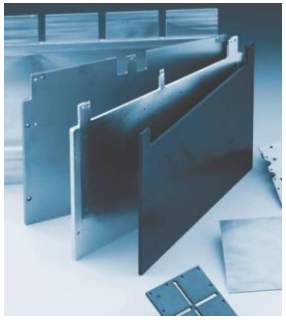




**BN Powders**

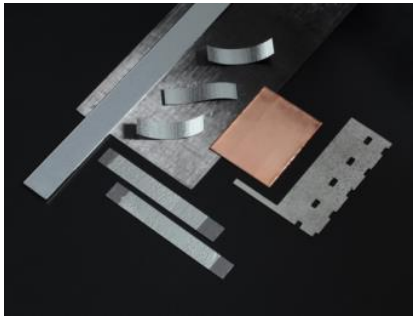



**TC1050* Heat Spreader**



**TMP-EX Heat Sink**

**TMP-FX Laminate**



**Cool*FX*® Modifiers**

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# Contact Us


**USA (East)**

Robert Bell
Ohio
+1 704 846 5672
Robert.Bell@Momentive.com

**USA (West)**

Roland McGoodwin
Ohio
+1 440 787 6334
Roland.McGoodwin@Momentive.com

**Europe**

Bruno Balland
France
+33 (0)1 60 71 56 20
Bruno.Balland@Momentive.com

**China**

Fred Wang
Shanghai
+86 21 3860 4807
Fred.Wang@Momentive.com

**Japan**

Akinobu Otaka
Osaka
+81 6 6398 0135
Akinobu.Otaka@Momentive.com

**Korea**

Sung-Il Chang
Seoul
+82 2 6201 4704
SungIl.Chang@Momentive.com




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