Pyrolytic Graphite Heat Spreader Options for High Performance Embedded Components and Systems

Richard Lemak
Director Business Development
MINTEQ International, Inc. Easton, PA USA

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Agenda

Background

Graphite Heat Spreader Materials

Physical and Thermal Characteristics

Heat Spreader Design Options

Conclusion

M I N E R A L S T E C H N O L O G I E S I N C.

MINERALS TECHNOLOGIES IS A RESOURCE- AND TECHNOLOGY-BASED GROWTH COMPANY THAT DEVELOPS, PRODUCES AND MARKETS, WORLDWIDE, A BROAD RANGE OF SPECIALTY MINERALS, MINERAL BASED AND SYNTHETIC MINERAL PRODUCTS AND RELATED SYSTEMS AND SERVICES.

$1B 2005 Sales

SPECIALTY MINERALS INC

The Leading Producer and Supplier of Precipitated Calcium Carbonate (PCC) to the Worldwide Paper Industry
Processed Minerals – Mines and Produce Natural Mineral and Mineral-Based Products

MINTEQ INTERNATIONAL INC

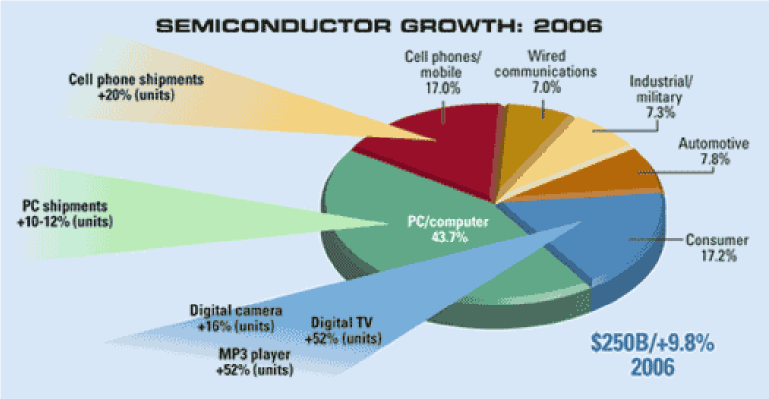
Refractory Products – One of the World's Leading Developers and Marketers of Mineral-Based Monolithic Refractory and ceramic materials

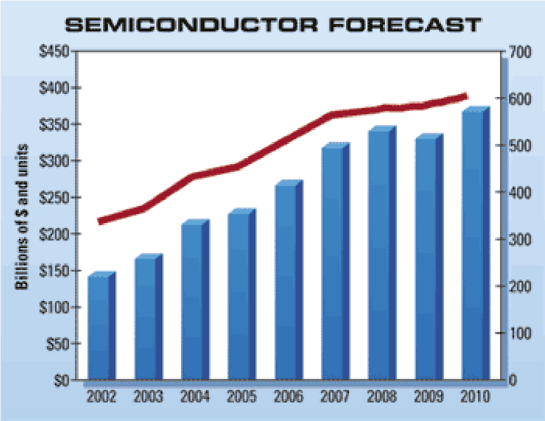
Largest single source producer of pyrolytic graphite and specialty carbon composites

Markets – Aerospace, Electronic (ion implant), Medical Device, Glass

Experts predict semiconductor processing and devices to grow 8-10 % long term growth (1)

Where the growth is coming from (2) :





Explosive increase of processing power is required now and into the future.

Unconstrained power density projections.

ITRS 2005 predicts continuing rise in high performance processors from 365 W to 515 W by 2011. (3)

Device manufactures are feeling pressure on energy consumption.

Reference:

(1) Semico Rsearch Corp./Semiconductor International (8/2006)

(2) Semico/Gartner/IDC/Strategy Analytics/SIA Frecast/Semiconductor International (8/2006)

(3) System Drivers 2005 International Technology Roadmap for Semiconductors (ITRS)

Thermal Management Design Engineer Ideals:

- Materials that optimize new, state of the art cooling and tight packaging needs meeting functionality and commonality requirements
- Flexible package solution that can be used for different applications
- Isotropic spreader material with thermal conductivity greater than copper and minimum material conductivity of 1000 W/mK
  - High in plane (x-y) for efficient spreader thermal conductivity
  - High through plane (z) thermal conductivity for heat flux “hot” spots

Yielding maximum thermal performance for power intensive applications

- Low, tailorable coefficients of thermal expansion
- Low density, low weight to minimize shock loads
- Economical cost, near net shape, high volume capable manufacturing
- High structural strength and stiffness

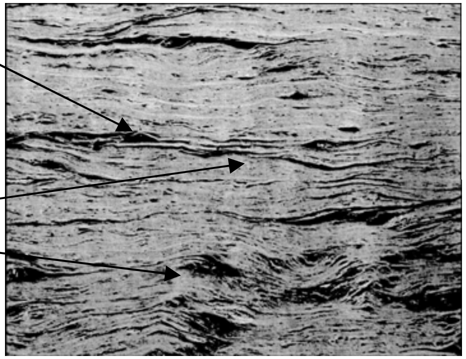
Thermal Challenges are Driving a Serious Review of Graphite Spreader Material

BUT NOT ALL GRAPHITES ARE THE SAME!

Natural graphite heat spreader material

- Large flexible sheets from soft flakes
- In plane thermal conduction at 440 – 500 W/mK
- Density ~1.9 g/cc

Natural Graphite Spreader micrograph



Static imperfections

- limited columnar structure and alignment
- dislocations
- point defects

100 µm

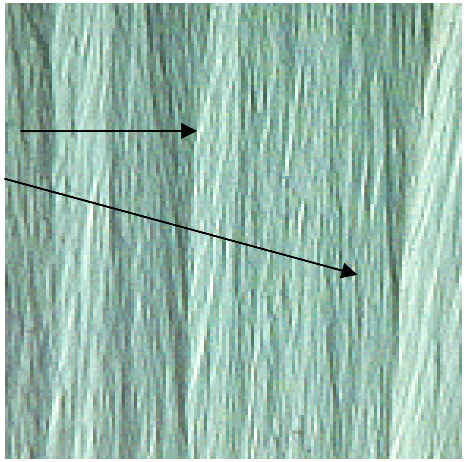
Issues:

- Thermal conduction values that are affected by imperfections
- Limited thickness to 1.5 mm
- Physical strength limitations

PYROID® HT Pyrolytic Graphite

- Light weight
- High purity (>99.999%)
- No outgassing and biocompatible
- Tailored thermal conduction from 450 -2000 W/m°K
- Anisotropic conduction and CTE but can be oriented to match application

PYROID® HT micrograph



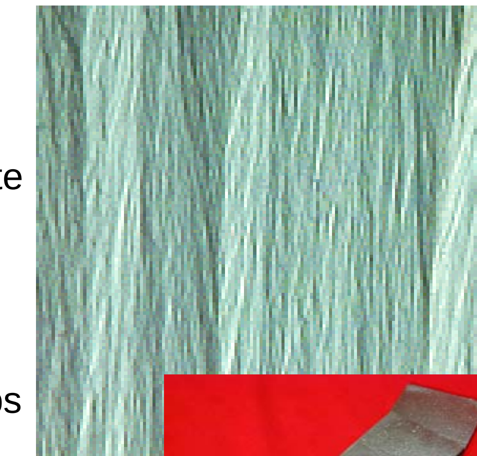
- Substantial columnar structure
- High purity with no point defects
- Well aligned, hexagonal atoms
- Single crystalline structure

Approaches theoretical carbon density

PYROID® HT Pyrolytic Graphite Characteristics

MINTEQ International's Pyrogenics Group has Decades of Experience Perfecting the Chemical Vapor Deposition Processing of Pyrolytic Graphite

- High purity > 99.999%
- Single crystalline structure
- Thermal Conductivity
  - 2000 W/mK (maximum) function of controlled annealing steps
  - 1200 – 1400 W/mK (typical) matching CVD diamond
- Density: 2.25 g/cc
- CTE: -0.6 to 25 ppm/ °C (plane dependent)
- Plate and wafer production
  - > 30 cm wide x 3 meter long
  - tailored thickness up to 1.3 cm (thicker on case by case basis)
  - easily cut, diced and lapped
  - compatible with active solder bonding techniques
  - high volume production and capable of integration to volume packaging requirements



Physical Measurement Testing

5569 Instron Materials Testing Machine

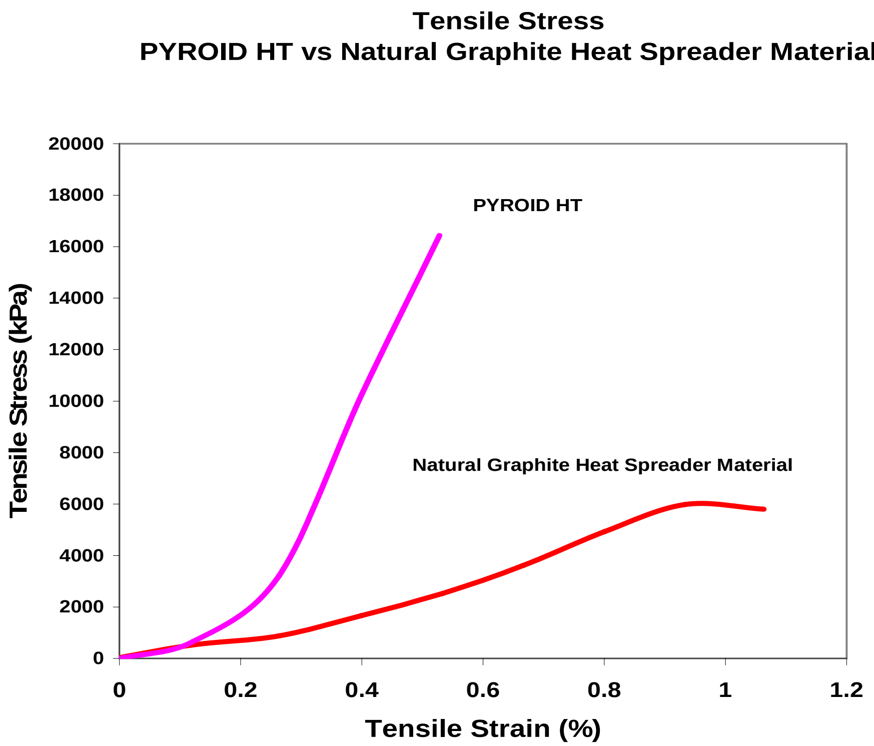
Samples

- Natural graphite heat spreader material
- PYROID HT typical production sample designed for thermal management applications
- Thickness of 1.5 mm all specimens

Standards and Procedures

ASTM D790-71 3 Point Flexural
ASTM C749 & D412 Tensile Stress Strain

Measurements of basic material without benefit of composite augmentation



Physical Test Results (x-y plane)

Tensile stress at maximum load

PYROID HT = 28,900 kPa

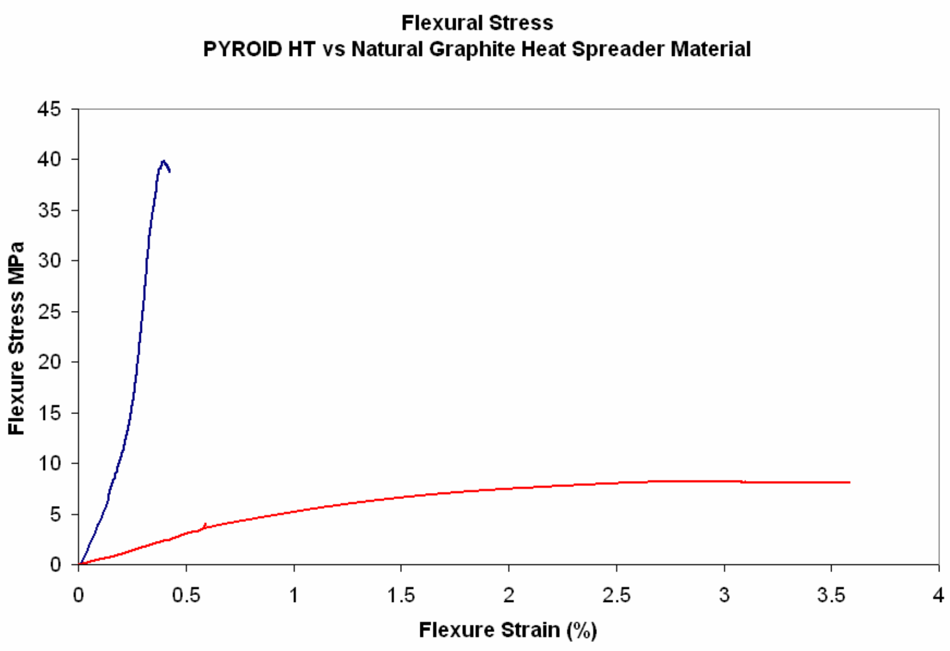
Natural Graphite = 7,300 kPa

Young's Elastic Modulus

PYROID HT = 50 GPa

Natural Graphite = 8 GPa

PYROID HT exhibited 4 times the ability to sustain tensile load than natural graphite heat spreader material and 6 times the Elastic Modulus



Physical Test Results (x-y plane)

Flexural Strength

PYROID HT = 43 MPa
Natural Graphite = 9 MPa

Flexural Modulus

PYROID HT = 33,200 MPa
Natural Graphite = 372 MPa

PYROID HT exhibited nearly 5 times the ability to sustain flexural load and nearly 90 times the Flexural Modulus than natural graphite heat spreader material

Thermal Conductivity Measurement

Holometrix µFLASH

Standards and Procedures

ASTM D792-00 Density and Specific Gravity
ASTM E1269-01 Specific Heat
ASTM E1461-01Thermal Diffusivity Laser Flash Method

Measurements of basic material without benefit of composite augmentation

PYROID HT Density - 2.2614 g/cc

Close to the theoretical density of carbon

Specific Heat Measurement
(x-y plane)

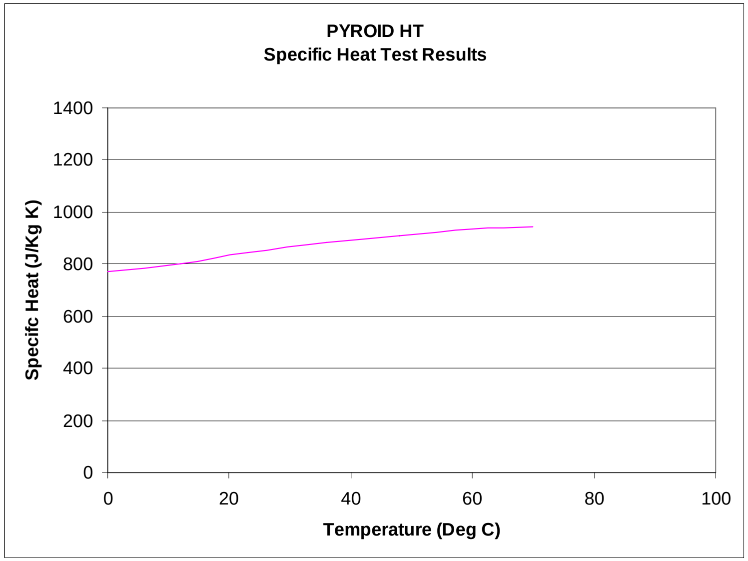
772 J/Kg ºK at 23 ºC
945 J/Kg ºK at 80 ºC

Thermal Diffusivity Measurement

Plane	Thermal Diffusivity (M^2/S)
X-Y	1.0093×10^{-3}
Z	3.662×10^{-6}

Regular Pyrolytic Graphite

X-Y	2.349×10^{-4}
Z	1.009×10^{-6}



Thermal Conductivity Calculation

Natural Graphite Heat Spreader Material 440 – 500 W/mK

PYROID HT

X-Y Plane	1,929 W/mK
Z Plane	7 W/mK

Standard Pyrolytic Graphite

X-Y Plane	449 W/mK
Z Plane	1.9 W/mK

PYROID HT exhibits 4 times the thermal conduction as natural graphite heat spreader material

Holometrix µFLASH

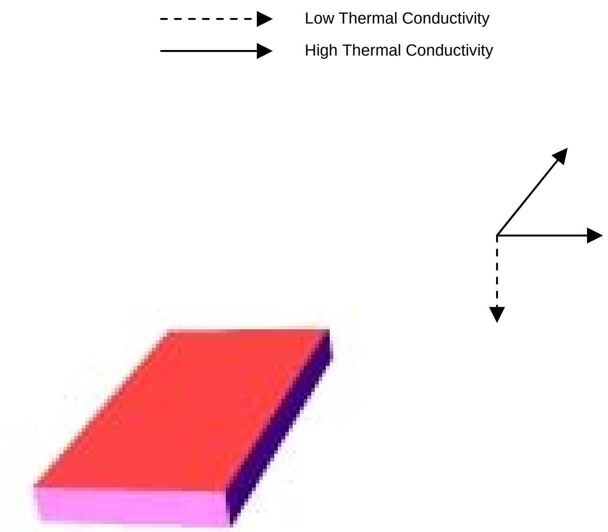
PYROID HT Heat Spreader Design Options

Two Dimensional Spreader Options

PYROID HT dimensions of 30 cm x 30 cm and thickness as thin as 0.2 mm

Results:

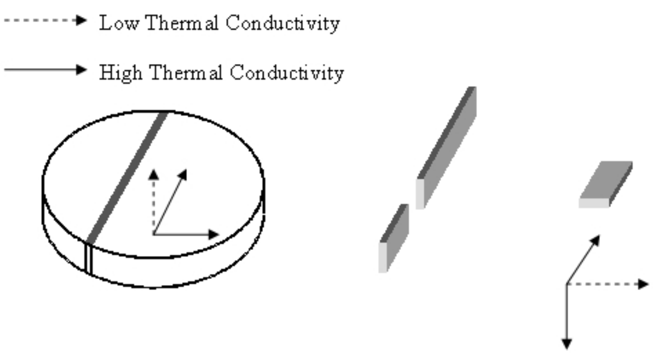
Rapid, high heat flux (>1,200 W/mK) transport across the spreader away form the heat source in the high conductivity plane direction



Two Dimensional Spreader Options

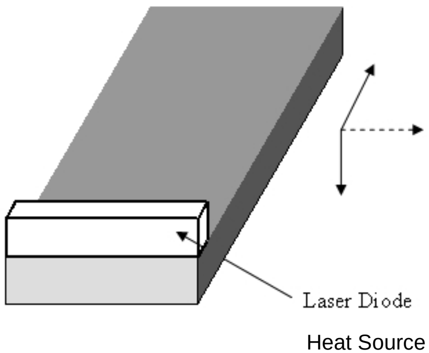
Spreader width dimensions of < 1.3 cm

- PYROID HT plate (30 cm x 3 m x 1.3 cm)
- Dice material into planes of desired thickness
- Orient material 90º



Results:

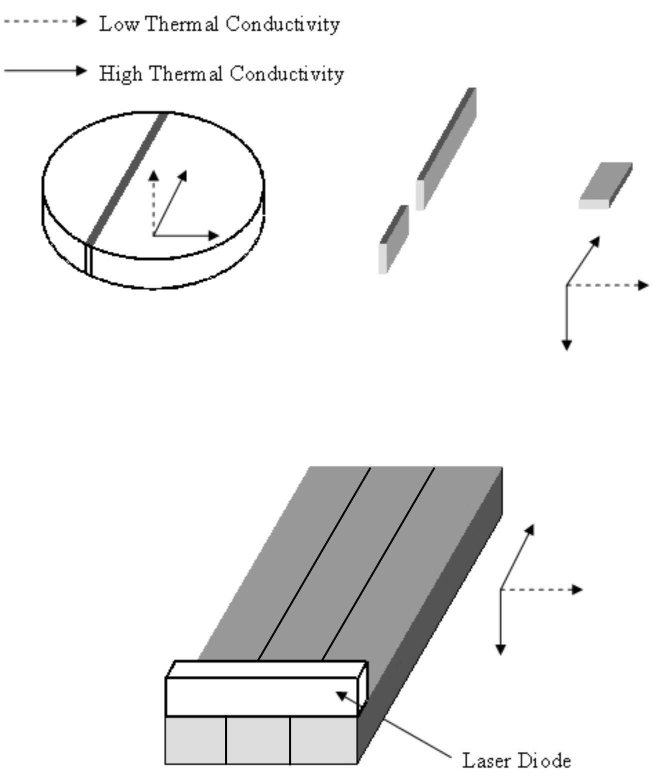
Rapid, high heat flux (>1,200 W/mK) transport across the spreader away form the heat source and normal into the appropriate heat sink



Two Dimensional Spreader Options

Spreader width dimensions of > 1.3 cm

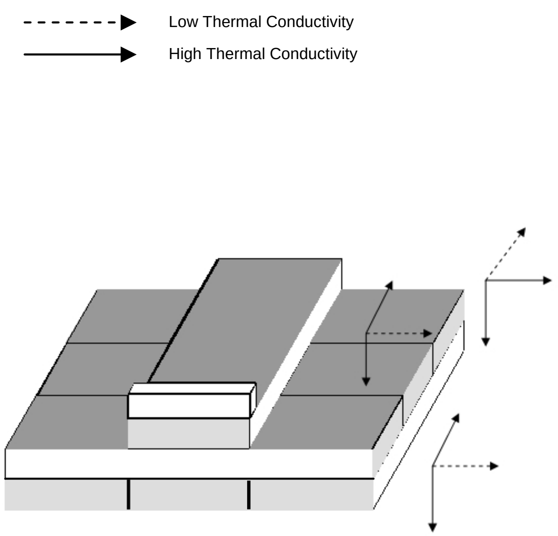
- PYROID HT plate (30 cm x 3 m x 1.3 cm)
- Dice material into planes of desired thickness
- Orient material 90º
- Controlled bonding using active solder techniques to match width requirement
- Thermal resistance of thin bonds are minimal since thermal flux requirement is along length of spreader



Results:

Rapid, high (>1,200 W/mK) heat flux transport across the spreader away form the heat source and normal into the appropriate heat sink

Three Dimensional Spreader Options



- Formed by stacking and active solder bonding two dimensional spreaders in alternate layers
- Very thin active bonds result in minimal thermal resistance
- Engineered tailoring of plane orientation and thickness for CTE consideration

Results:

High conductivity material with near isotropic conduction

Rapid, high (>1,200 W/mK) heat flux transport across the spreader in all dimensions from the heat source and into the appropriate heat sink

Hot Spot Issues

Hot spots are handled with a two dimensional HT spreader material to maximize normal direction conductivity

Or

Inserting HT material vias into spreader body bonding with active solder techniques for discrete hot spots solutions

Results:

Rapid, high (>1,200 W/mK) heat flux transport across the spreader in two directions from the heat source

HT thermal vias (>1,200 W/mK) into spreader body for added normal direction discrete heat source transport away form the heat source

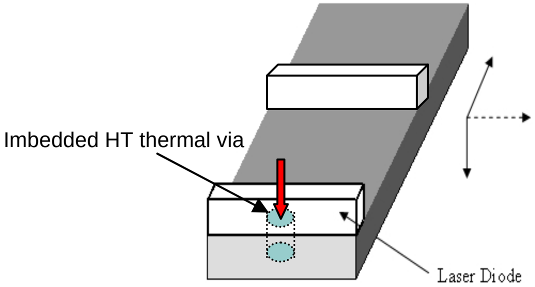
Low Thermal Conductivity

High Thermal Conductivity

Options:

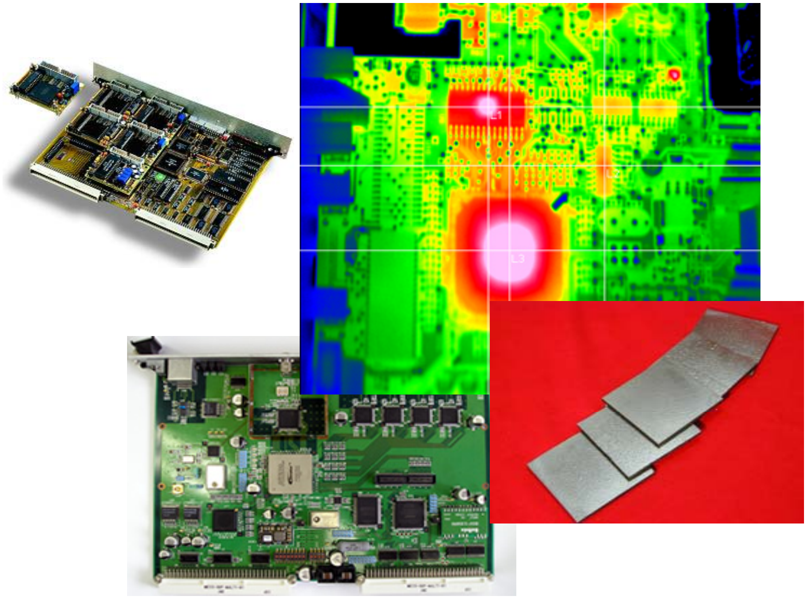
Thin 1.5 mm thickness (or less) PYROID HT (x-y plane) conduction for point heat source issues

Or two dimension spreader geometries with imbedded HT vias of varying depths for point heat source issues



PYROID HT heat spreader material for

- Wide band gap
- RF and MW
- Insulated Gate Bipolar Transistors (IGBT)
- Power amplifiers
- High-brightness LEDs
- Laser diodes
- Processors, ASICs, other
- Light weight applications
- Confined enclosures



Summary

- A review of graphite heat spreader solutions indicates not all graphites materials are the same.
- A comparison of measured physical and thermal conduction properties indicates PYROID HT Pyrolytic Graphite heat spreader material offers higher physical properties and thermal conduction (due to its inherent single crystalline structure) over natural graphite spreader materials.
- Varying configurations of heat spreader solutions are easily obtained and capable of being oriented to best suit the application.
- Thermal vias of PYROID HT material offer high heat conductivity to handle discrete hot spot issues.
- PYROID HT is currently produced at high volume and capable of being integrated into flexible packaging manufacturing options.
- PYROID HT thermal spreader material is at home in extreme environments and able to leverage its inherent properties to function in confined enclosures with next generation air, liquid, hybrid cooling solutions.

Contact Information

Richard Lemak

Director, Business Development

MINTEQ International Inc.

Pyrogenics Group

640 N. 13th Street

Easton, PA 18042 USA

Tel: 610-250-3349

FAX: 610-250-3325

Email: richard.lemak@minteq.com

Website: www.pyrographite.com