High Performance Pyrolytic Graphite Composite Heat Spreaders

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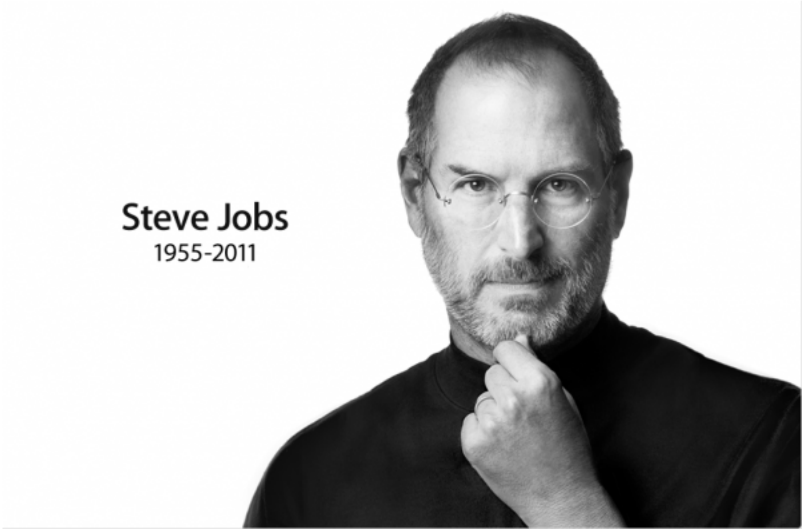
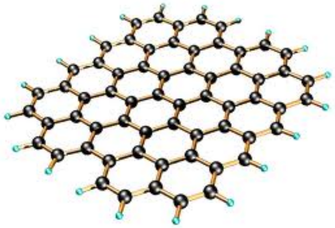
The glut of heat dissipation technologies notwithstanding, there is an urgent need for cost-effective, yet optimal solutions to thermal management

"I think this is the start of something really big. Sometimes that first step is the hardest one, and we've just taken it."



Production Scale 3D 'Graphene'



Agenda

Background
Pyroid HT Pyrolytic Graphite
Case Study: Two Dimensional Laser Diode
Composite Structures
Thermal Cycling Tests
CTE Analysis
Application Portfolio
Summary

Who Are We?

The Pyrogenics Group

Pyrogenics Mission:

Provide engineered carbon based products for key industries requiring innovative material solutions

Largest single source producer of pyrolytic graphite, thin films, and specialty carbon composites
Markets – Aerospace, Semiconductor/Electronics, Medical Imaging, Defense, Isothermal Forge, Glass

Winner of 2011 Top Twenty "Most Innovative Small Business Company Award" from the METI (Japanese Ministry of Economy, Trade and Industry)

Thermal Challenges are Driving a Serious Review of Graphite Spreader Material

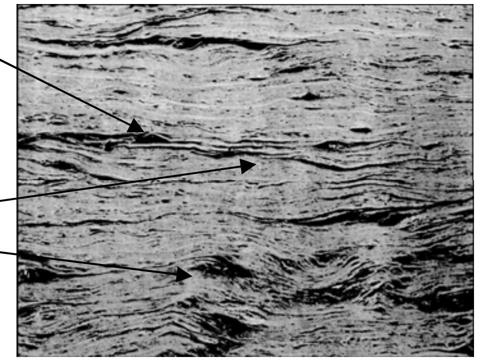
BUT NOT ALL GRAPHITES ARE THE SAME!

Natural Graphite Spreader micrograph

Natural graphite heat spreader material

Static imperfections

- limited columnar structure and alignment
- dislocations
- point defects



100 µm

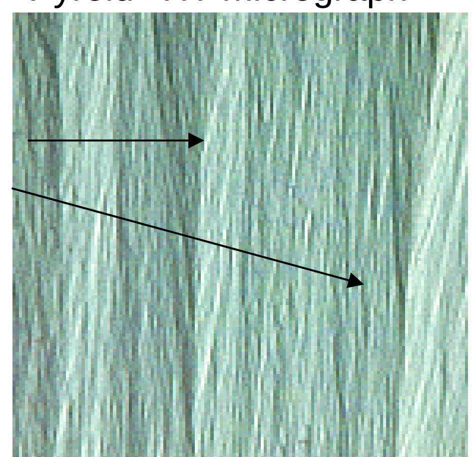
Pyroid® HT micrograph

Pyroid® HT Pyrolytic Graphite

- Light weight
- High purity (>99.999%)
- No porosity

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

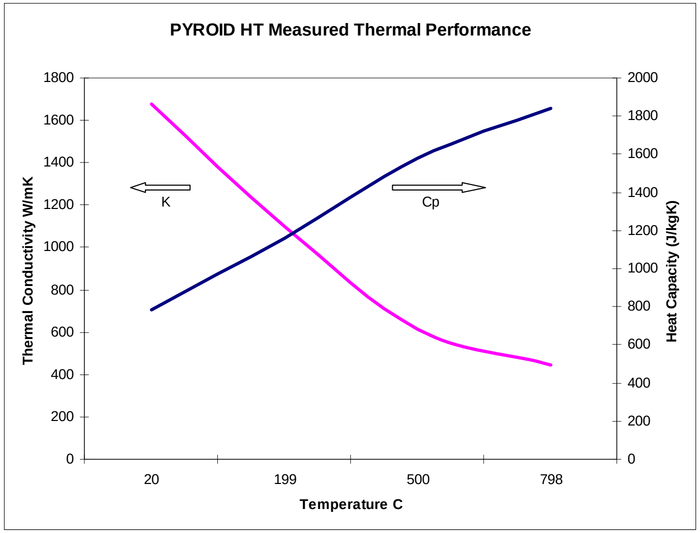
Approaches theoretical carbon density



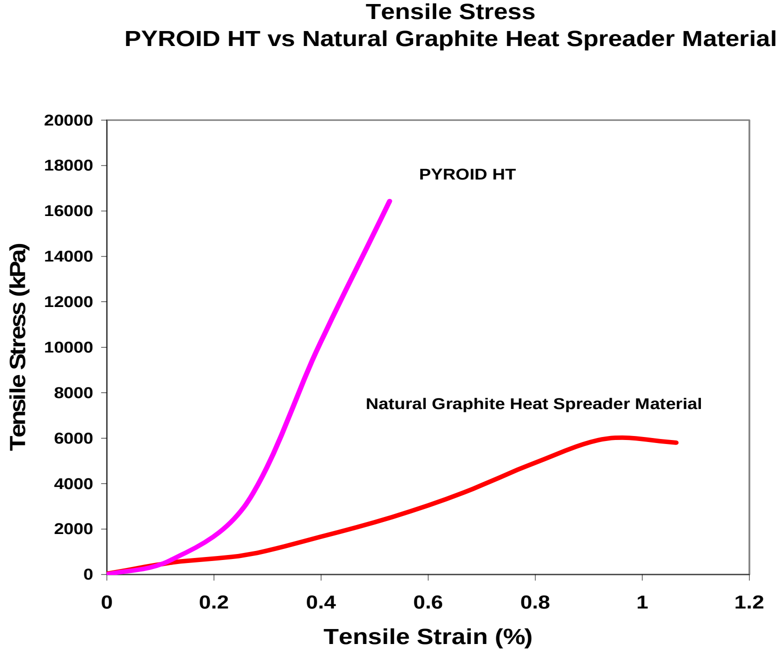
Pyroid® HT Pyrolytic Graphite thermal management material

Features

- High purity > 99.999% , crystalline structure
- Thermal Conductivity
  - 1700 W/m-K X-Y plane
  - 7 W/m-K Z plane
- Engineered material
- Density: 2.22 g/cc
- Thickness up to 3 cm
- Machined and prepare to mirror finish
- Metallization process technology



Pyroid® HT Pyrolytic Graphite thermal management material



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

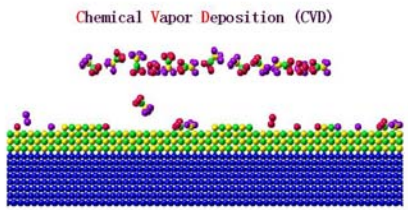
Natural Graphite = 8 GPa

Pyroid HT
- 4X Tensile
- 6X Elastic Modulus

than natural graphite heat spreader material

Pyroid® HT Pyrolytic Graphite Production Process

Large, High Temperature Vacuum Furnaces



Pyrolytic Graphite Deposition and HT conversion process

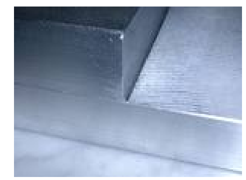
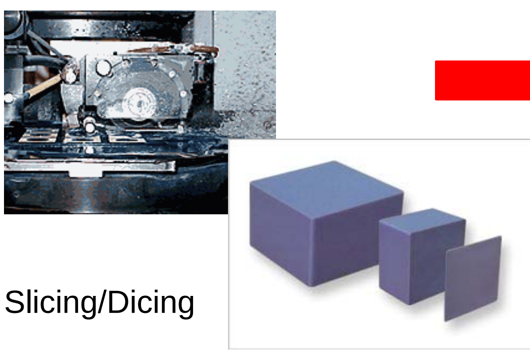
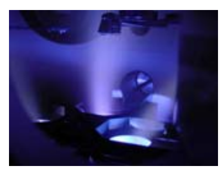


Plate Production Size (1200 sq. cm^2 sq up to 3 cm thick)



Slicing/Dicing

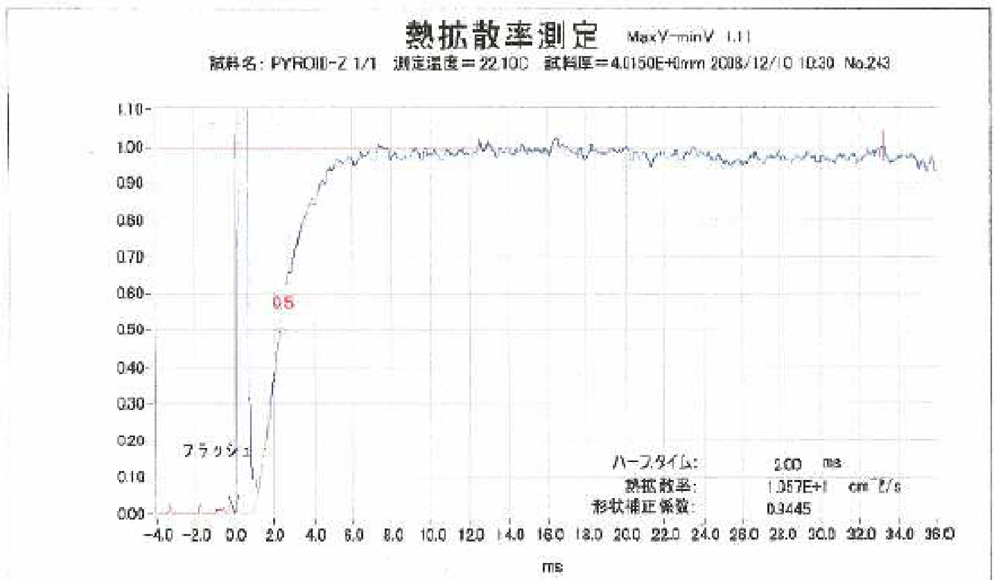


Bonding & Metallization

Form Factor Packaging

Various Thermal Conductivity Measurement Methods

Pyroid HT XY plane



Alvac TC-7000
Laser Flash Diffusivity

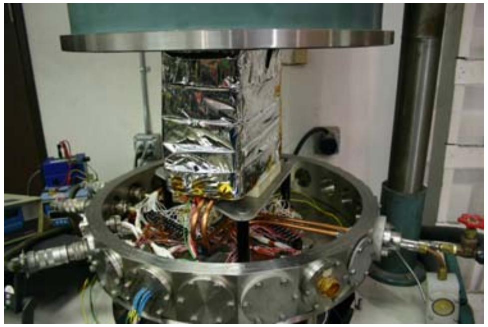
Thermal Diffusivity : 10.57 cm2 / sec = 1057 mm2 / sec
Specific Heat : 0.73 J/g.K
Density : 2,22g/cc
Thermal Conductivity : 1,057 x 0.73 x 2.22 = 1,713 W/mK

Various Thermal Conductivity Measurement Methods

Material Innovations Inc.

In-Plane Thermal Conductivity

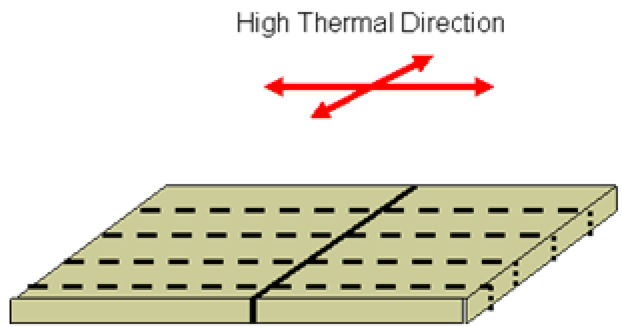
Multiple simultaneous thermal conductivity measurements via RTDs over a large area that determine the overall thermal performance of the component rather than assessing only localized values

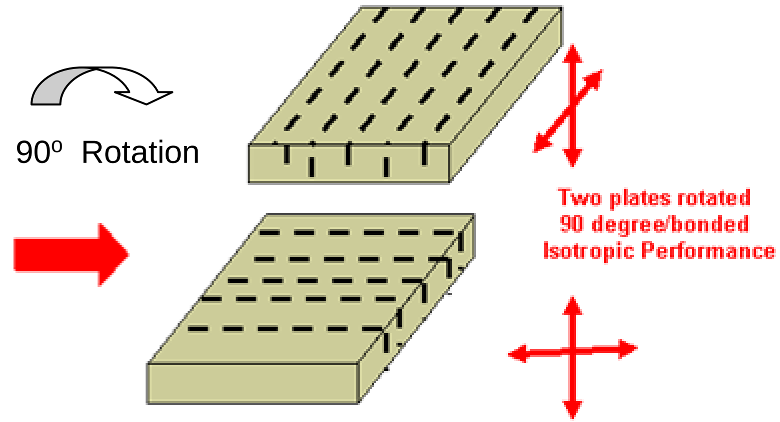


In-Plane Thermal Conductivity Results, X-Y Direction

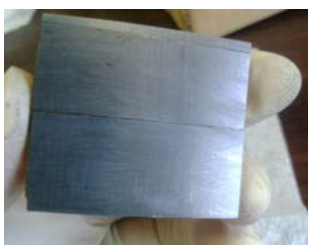
Thermal Conductivity @ 77°C → 1875 W/mK

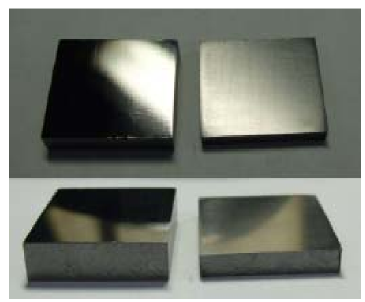
Pyroid® HT Pyrolytic Graphite Patented Near Isotropic Material





Isotropic Plate



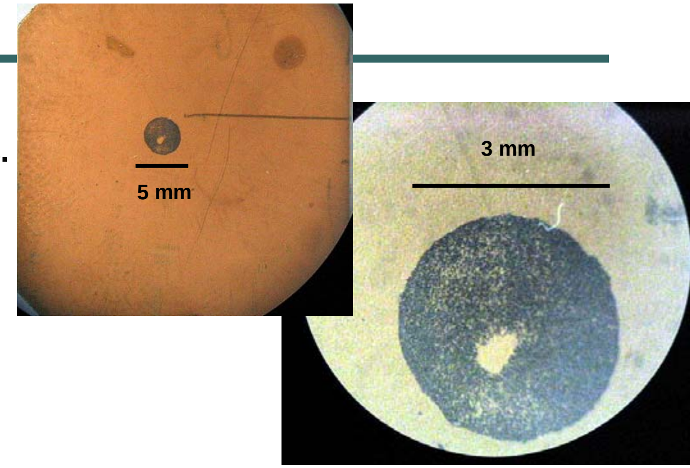


Z Thermal Conductivity 1,390 W/mK

Metallization Bond Strength Results

Summary of Sebastian pull test results for three metallization types.

Metallization type	Avg. fracture stress (Mpa)	Avg. shear failure load (Kg.)
Ti -1000 Å NiCr-1000 Å Au-3000 Å	26	15
Ti -1000 Å Ni-1000 Å Au- 3000 Å	31	14
Ti-1000 Å Pt-1000 Å Au-3000 Å	28	21



Compatibility of selected solder types with metallization

Sn (80Au/20 Sn)

Au Ag Sn

In Sn

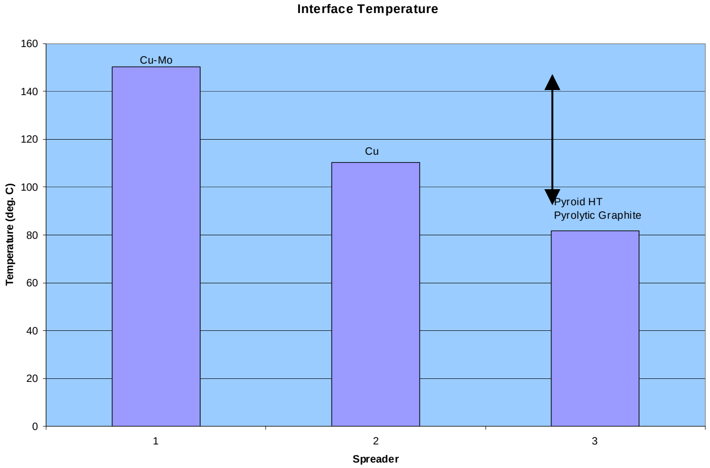
SAC 305

Failures in the material
Not in the metallization interface

Performance Example:

Pyroid HT thermal material test with laser diode

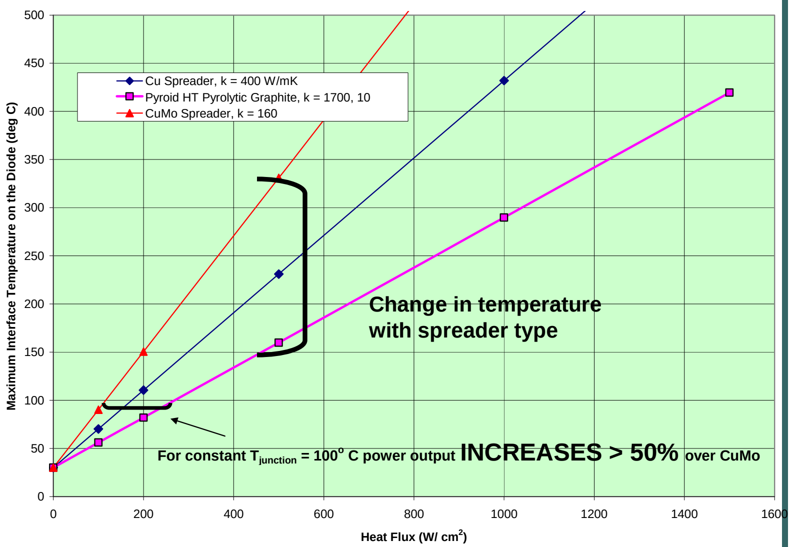
Laser Diode Application Experimental Results



Application:

Laser Diode
Power Input
200 W/cm^2 flux

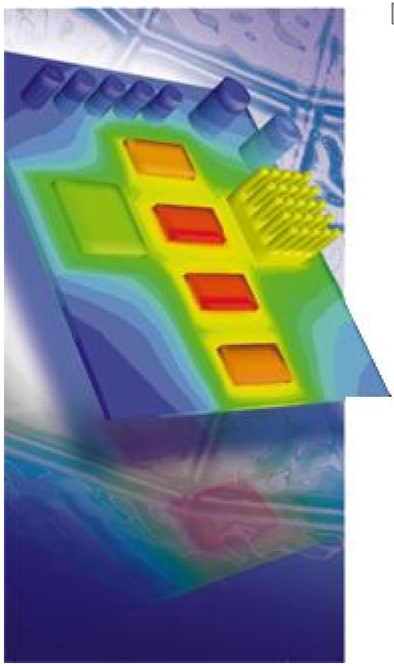
Resulting interface
Temperature reduction
Delta $T_{junction}$ = 70º C

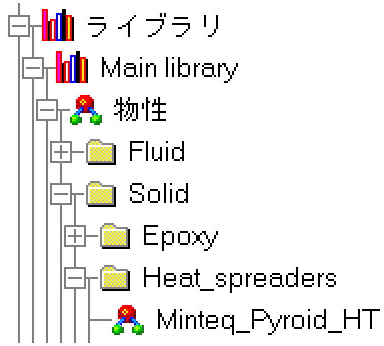


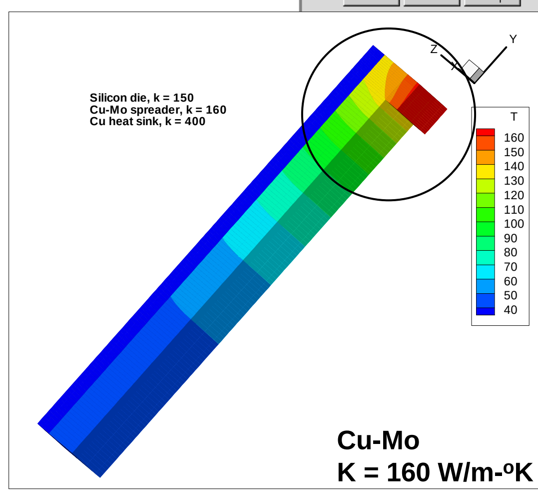
Conclusion 1) Reduction Tjunction temperature of 70º C

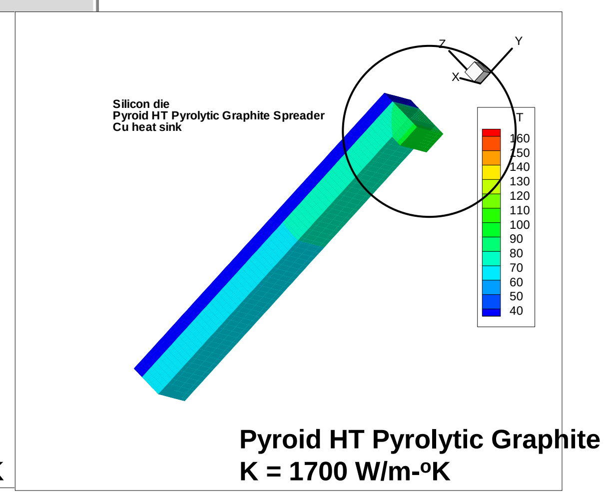
2) For constant Tjunction = 100º C power output INCREASES > 50% over CuMo

ANSYS® Icepak ® software provides powerful CFD for electronics thermal management









Resultant Temperature Contours for PYROID® HT Pyrolytic Graphite vs. CuMo heat spreaders for a laser diode heat flux of 200 W/cm ^{2}

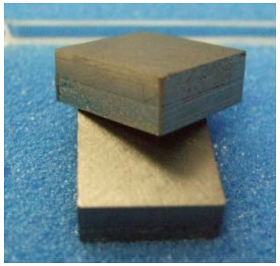
Pyroid® HT Pyrolytic Graphite Composite Structures

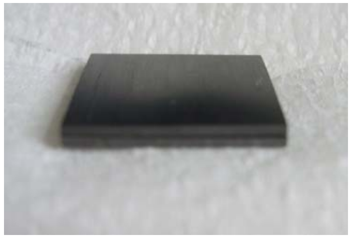
(patents pending)

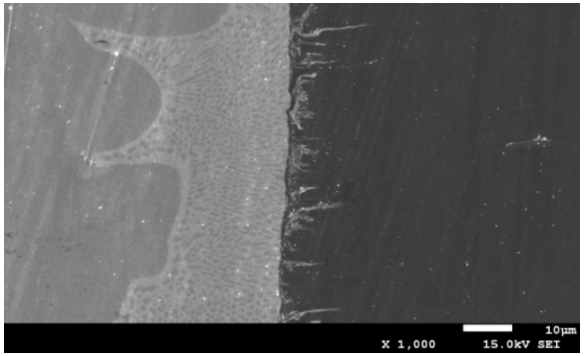
Composite structures from pyrolytic graphite bonded to a variety of substrates

Benefits

- ***Provides adequate bond strength to survive thermal cycles***
- ***Structural stability in demanding applications***
- ***Easily mass produced***

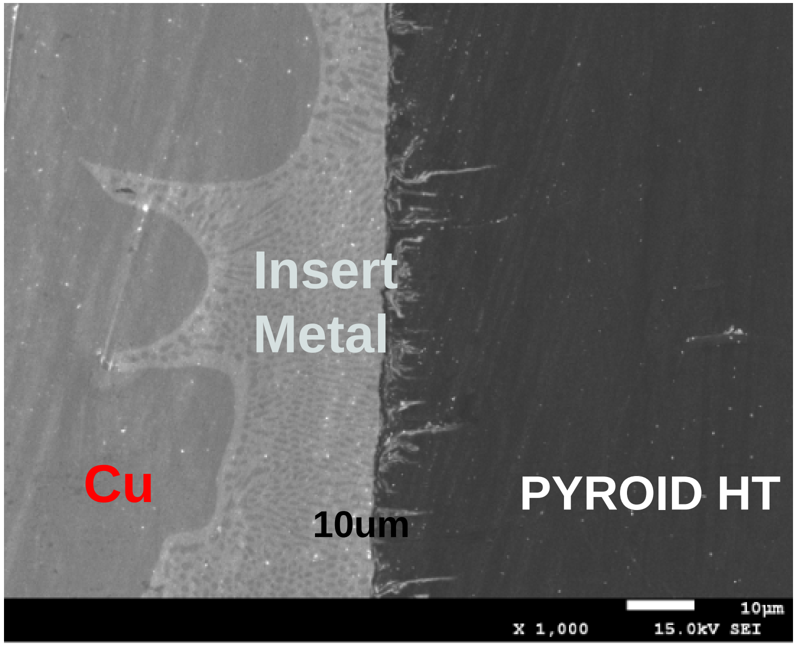


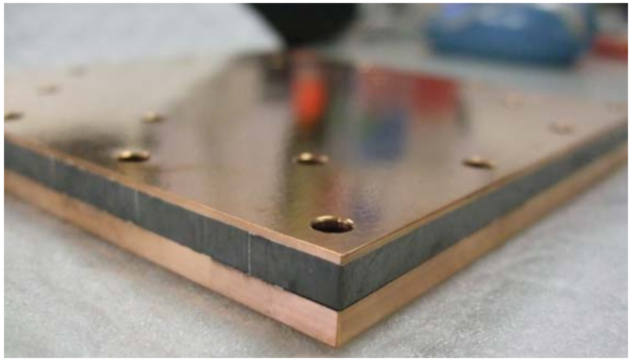




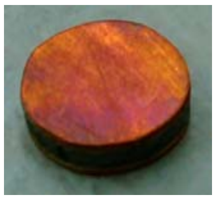
Pyroid® HT Pyrolytic Graphite Composite Structures

Pyroid® HT pyrolytic graphite plus bonded copper yields integrated thermal management composite material





Composite Structure Thermal Cycling Measurement Testing



Columnar shape samples

Configuration

- ASTM F96 - 77(2010) Standard Specification for Electronic Grade Alloys
- First and third layer - Cu thickness 0.3 mm
- Second layer - Pyroid HT thickness 0.3mm
- Test diameter - 10mm

Thermal Environmental Equipment:

Espec SH-241 Bench-Top Temperature & Humidity Chamber

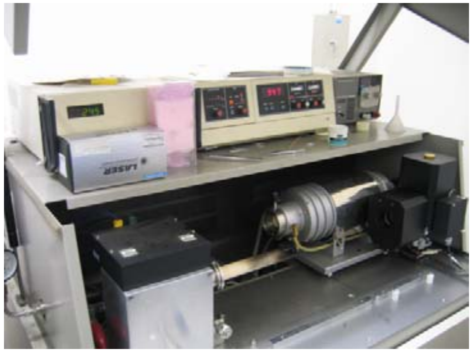
Test parameters

Temperature range: (-40°C to 150°C)
Heat ramp – 2 hrs
Hold time – 2 hrs
Cool down ramp – 2 hrs

Thermal Conductivity Measurement Equipment

ULVAC-RIKO TC7000 based on JIS R1611

Specifications	
Temperature range	1) R.T. to 1500 ºC
Sample size	Standard: 10mm dia. x 1 to 3 mm thick Substrate measurement method: 2.5 x 2.5 x 1 mm thick or less (option) Stepwise heating method: 30mm dia. x 3 to 5 mm thick (option)
Laser output	Nd glass laser (normal oscillation 10 J/pulse or more)
Measurement atmosphere	Vacuum or inert gas
Measurement accuracy	Thermal diffusivity: within ± 5%, specific heat capacity: ± 7%



Composite Structure 1000 Cycle Thermal Results

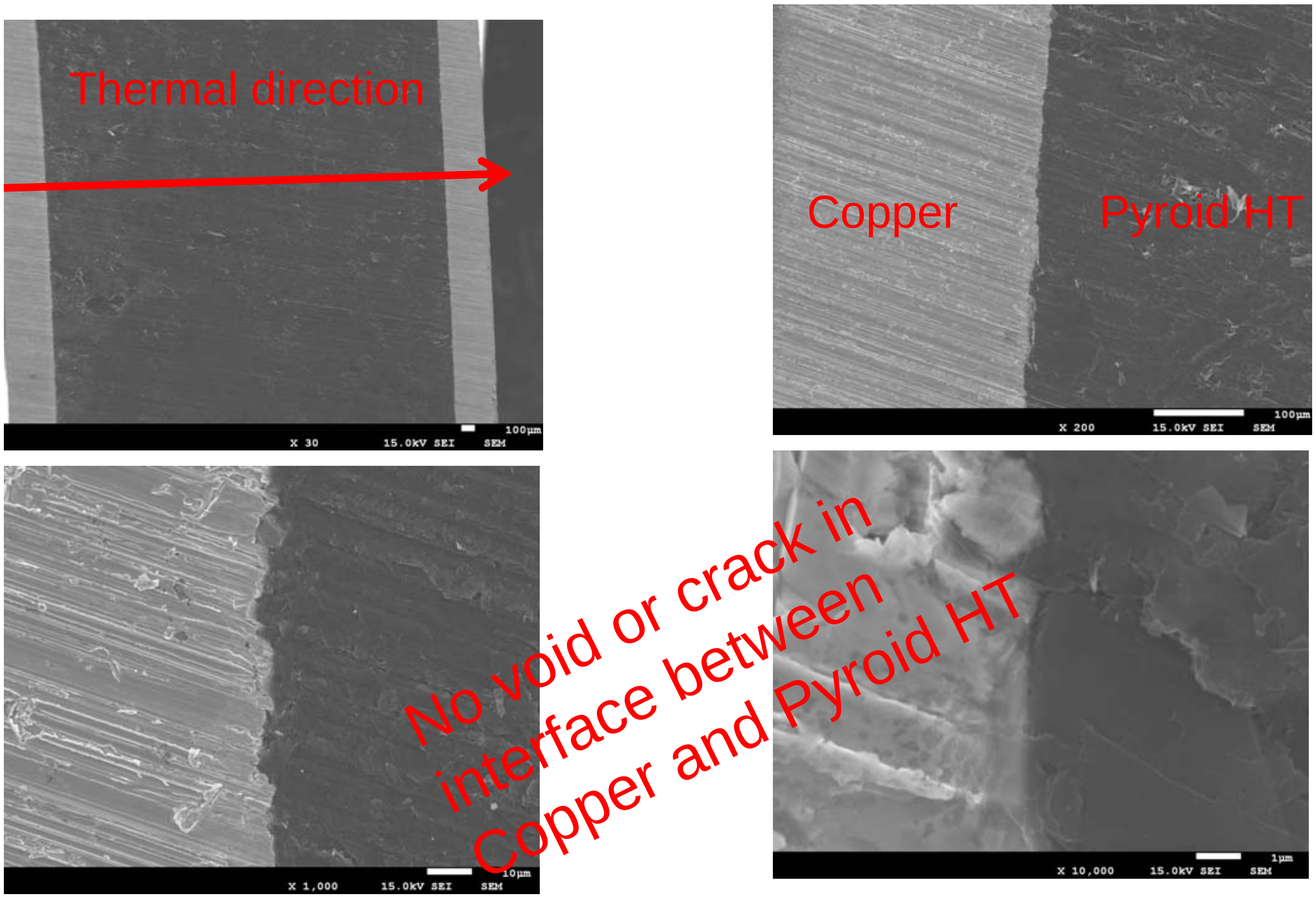
Each measurement value is average of 3 measurements

Before cycles density (g/cm3)	Thermal diffusion (cm2/sec)	Specific heat (J/g・deg)	Thermal conductivity (W/mk)
3.33	5.022	0.6029	1008
3.34	5.117	0.5555	949
3.37	4.880	0.5669	932

After 1000 cycles density (g/cm3)	Thermal diffusion (cm2/sec)	Specific heat (J/g・deg)	Thermal conductivity (W/mk)
3.32	5.572	0.5551	1023
3.41	5.364	0.5521	1010
3.43	4.996	0.5659	970

No Thermal Conductivity Degradation

Pyroid® HT Pyrolytic Graphite Cu Composite SEM Section after Thermal Cycling Results



Pyroid® HT Pyrolytic Graphite Composite Options
Engineered Thermal Performance

Pyroid HT	1.5mm	Ni+Au	**1,444 W/mK**
Pyroid HT	1.5mm	0.3 mm Cu	600 W/mK
Pyroid HT	1.5mm	0. 5 mmCu	510 W/mK
Pyroid HT	3.0mm	0.5 mm Cu	496 W/mK
Pyroid HT	3.0mm	0. 15mm AlN	1,240 W/mK
Pyroid HT / Pyroid HT	2.0mm / 2.0mm	0.635 mm AlN	600 W/mK
Pyroid HT / Pyroid HT	2.0mm / 2.0mm	1.0 mm AlN	514 W/mK
Pyroid HT / Pyroid HT	2.0mm / 2.0mm	0.32 mm SiN	519 W/mK
Pyroid HT	2.5mm	0. 5 mm Alumina	154 W/mK

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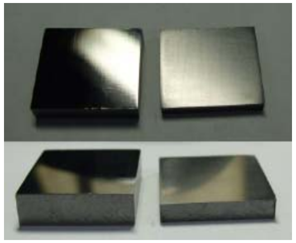
Near Isotropic CTE Stress Analysis:

Modulus of Elasticity is Key Material Property



Properties of die and spreader materials

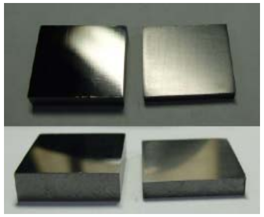
Material	CTE (1/ºC)	E, modulus of elasticity, (GPa)
Silicon	4.68×10^{-6}	110.3
PYROID® HT Pyrolytic Graphite	-0.5×10^{-6} ∥ 25×10^{-6} ⊥	< 50
Diamond	1.18×10^{-6}	700 - 1200
Copper	16.5×10^{-6}	110.3

For 200º C temperature excursion thermal stresses for various die/spreader materials

Resultant governing system equation:

$$\sigma = \frac{(\alpha_A - \alpha_B)\Delta T\, E_A E_B}{(E_A + E_B)}$$

Near Isotropic Pyroid HT Composite
CTE Stress Analysis Results



No damage after 1000 thermal cycling -40 to 150ºC

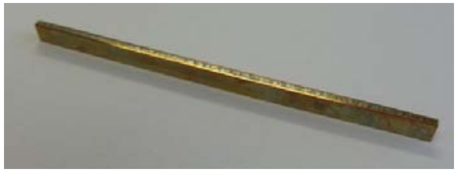
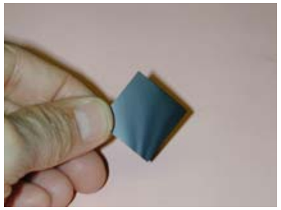
For 200º C temperature excursion thermal stresses for various die/spreader materials

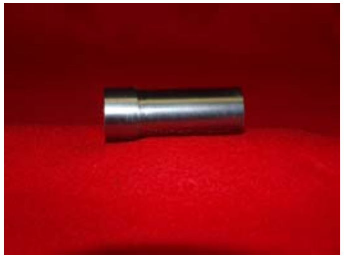
Die/spreader Materials	Stress, MPa (psi)
Silicon/Diamond	-71 (-10,260) (die compression)
Silicon/Copper	130 (18,900) (die tension)
Silicon/PYROID HT® Pyrolytic Graphite ∥	4.8 (697) (die tension)
Silicon/PYROID HT® Pyrolytic Graphite ⊥	-11 (-1600) (die compression)

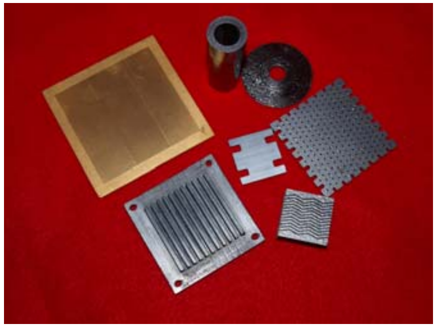
Order magnitude lower than diamond or copper

Pyroid HT/Cu = 50 MPa tension

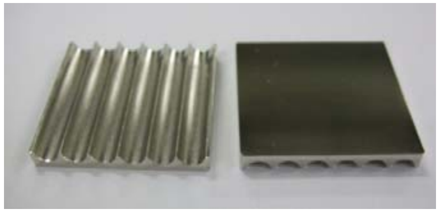
Examples of Pyroid® HT Pyrolytic Graphite Product Application Portfolio

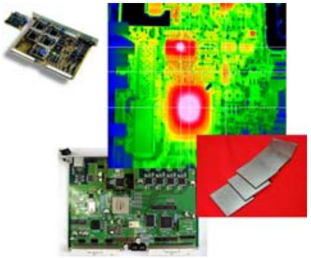








Conclusions



- **Optimization Models** available for **"<u>engineered" orientation</u>** Pyroid® HT Pyrolytic Graphite heat spreader designs
- **Pyrolytic Graphite <u>Composite Structures</u>** provide additional thermal management design freedom
- **Elastic Modulus** is just as important as CTE to mechanical compatibility between spreader and dissimilar materials
- **Pyroid® HT Pyrolytic Graphite** Heat Spreaders and Composites provide exceptional thermal performance and are a cost effective alternatives to other heat spreaders

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