High Performance Pyrolytic Graphite Heat Spreaders: Near Isotropic Structures and Metallization

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Agenda

Background

Metallization

Case Study – Two Dimensional Laser Diode Application

Case Study - Three Dimensional Heat Spreader Applications

- T/R Module
- CTE Analysis

Conclusions

Who Are We?

GLOBAL RESOURCE AND TECHNOLOGY BASED GROWTH COMPANY THAT DEVELOPS, PRODUCES AND MARKETS, SPECIALTY MINERALS, SYNTHETIC MINERAL PRODUCTS, SYSTEMS AND SERVICES.

$1.1B 2007 Sales
MTX NYSE

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

The Pyrogenics Group

Pyrogenics Mission:

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

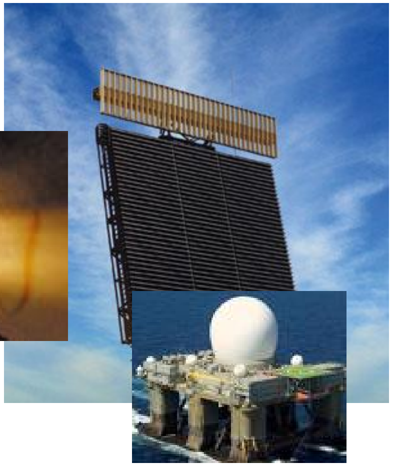
Largest single source producer of pyrolytic graphite, thin films, and specialty carbon composites
Markets – Aerospace, Semiconductor/ Electronics, Medical Imaging, Isothermal Forge, Glass

omega piezo

Leading manufacture of high quality piezoelectric, alumina and specialized thermal management components/systems for thermally constrained circuitry for military applications, as well as alternative energy systems

An Effective Thermal Management Solution is Key to Continued Growth

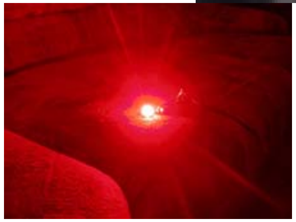
Widespread growth of smaller packages forcing increased power density for applications found in:



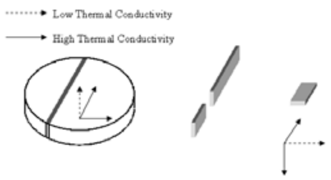
Defense/Military
Commercial Industry

Need performance thermal management solutions for:

- Laser Diodes
- T/R Radar Modules
- LED Lighting
- OLED/COLED
- All High Power Devices

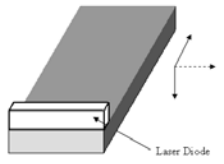


PYROID® HT Pyrolytic Graphite
Thermal Management Enabling Material for the Next Decade

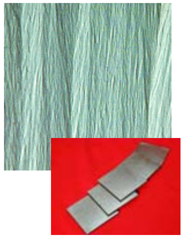


MINTEQ International's Pyrogenics Group has Decades of Experience Perfecting the Chemical Vapor Deposition Processing of Pyrolytic Graphite

- High purity > 99.999%
- Single crystalline structure
- Thermal Conductivity
  - 1700 W/mK matching CVD diamond
  - Anisotropic ("Engineered" 2 plane orientation)
- Density: 2.25 g/cc (only 25% of Copper)
- Plate and wafer production
  - > 30 cm wide x 3 meter long
  - Tailored thickness up to 2.5 cm
  - Easily cut, diced and lapped to mirror finish
  - High production, pick/place, capable of integration to volume packaging requirements

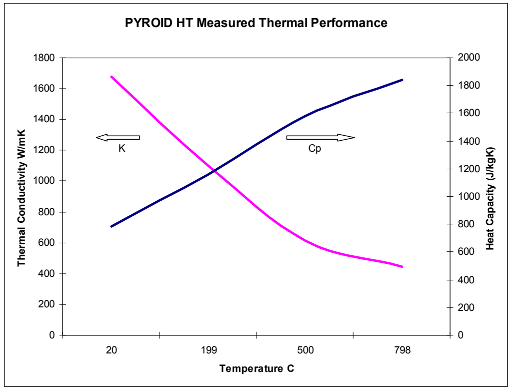


"Engineered" Z Orientation



Thermal Conductivity Flash Diffusivity Measurements

Holometrix µFLASH



PYROID® HT Conductivity (20° C)

X-Y Plane	1,700 W/mK
Z Plane	7 W/mK

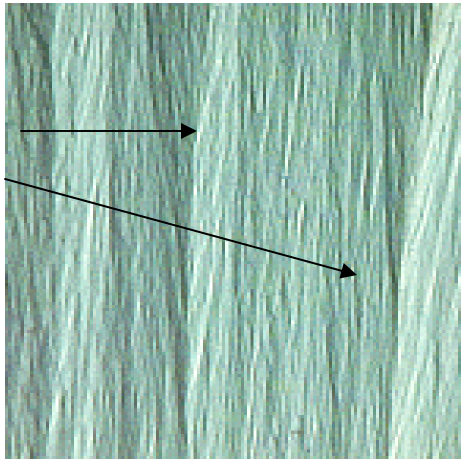
Standard Pyrolytic Graphite

X-Y Plane	440 W/mK
Z Plane	1.7 W/mK

PYROID HT

PYROID® HT micrograph

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



4X Thermal Conductivity of Copper

25% Weight of Copper

↑↑↑ Performance/Cost Over Diamond or Copper

Key Enabler for Use - Metallization Development

Metallization to PYROID® HT Pyrolytic Graphite must insure an acceptable bond strength

Sebastian Pull Test (semiconductor coating strength measurement)

- ✓ **Industrial standard test of adhesion strength**
- ✓ **Epoxy coated 2.69 mm metal stud bonded to sample**
- ✓ **Constant strain rate "pull" perpendicular to bonding plane**
- ✓ **3 metallization compositions**
- ✓ **Compatible tested with solder types (Pb-Sn, Au-Sn, Indium, etc.)**

Stud Pull Adherence Test

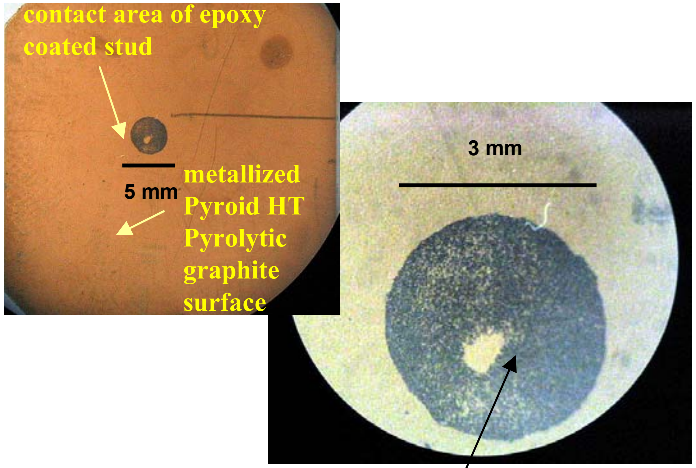
Shear test using MIL STD 883

Shear Test

Key Enabler for Use - Metallization Development

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



Failures in the material
Not in the metallization interface

Key Enabler for Use - Metallization Development

Conclusion:

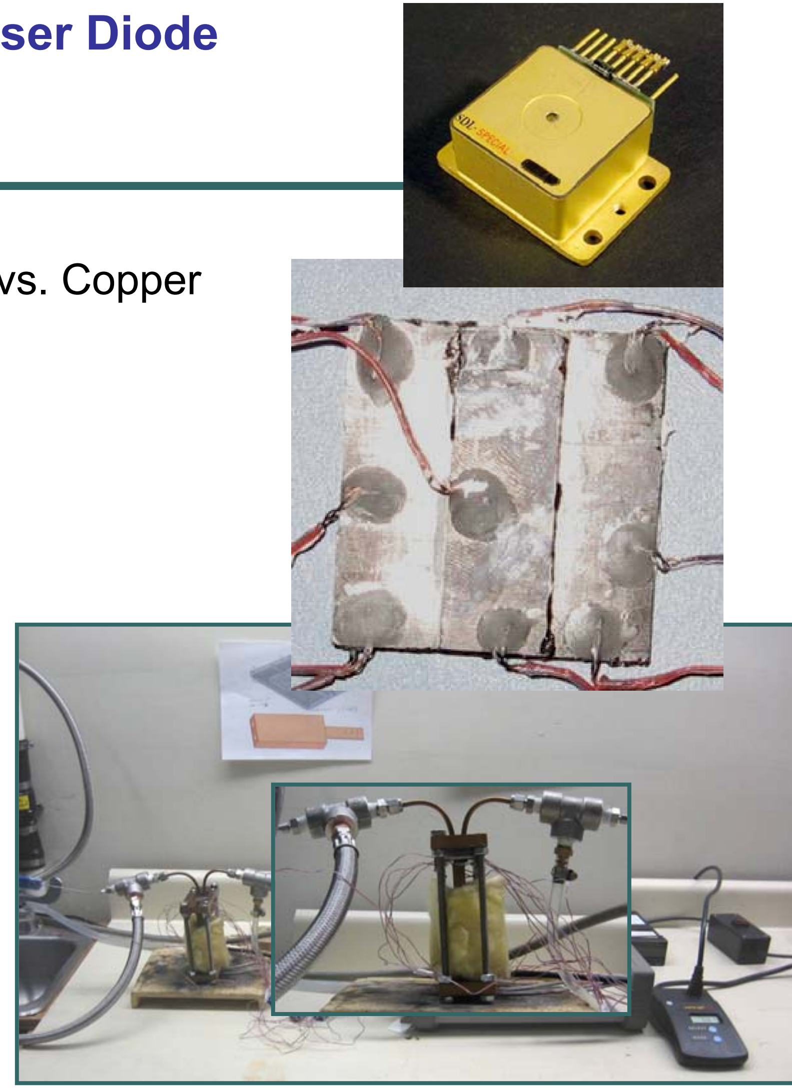
PYROID® HT metallization bond strength meets or exceeds semiconductor standards

Compatibility and wettability of selected solder types with metallization

- Au Sn (80Au/20 Sn) Hi temperature
- Ag Sn
- In Sn
- SAC 305
- traditional Sn Pb

Typical Au Sn solder wire Attachment

Case Study - Two Dimensional Laser Diode



Two dimensional PYROID® HT Heat Spreaders vs. Copper Laser Diode Application Experiments

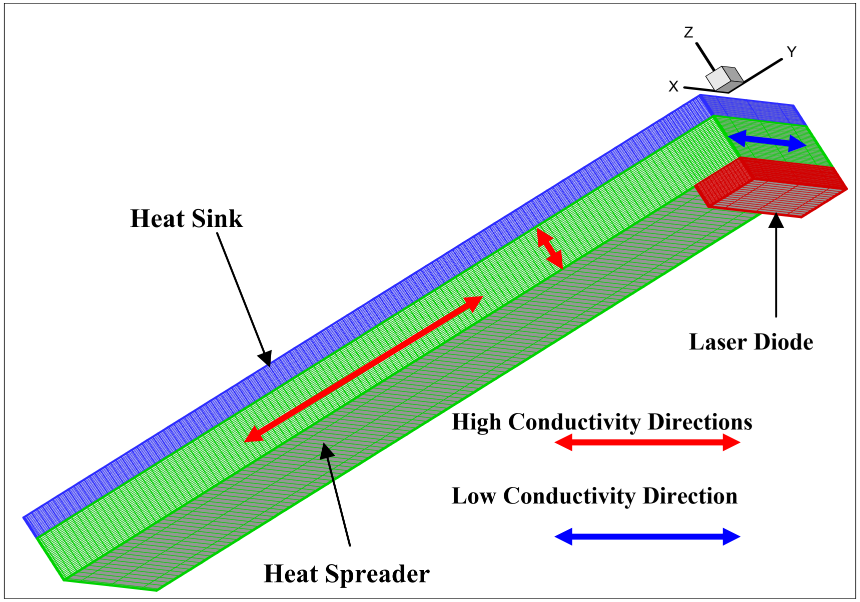
Objective:

Measure laser diode temperature and match to 3D Omega Piezo Technologies' finite control volume thermal conduction program

Materials tested and modeled

1. Copper-Molybdenum (industry accepted for CTE)
2. Copper
3. Pyroid® HT Pyrolytic Graphite

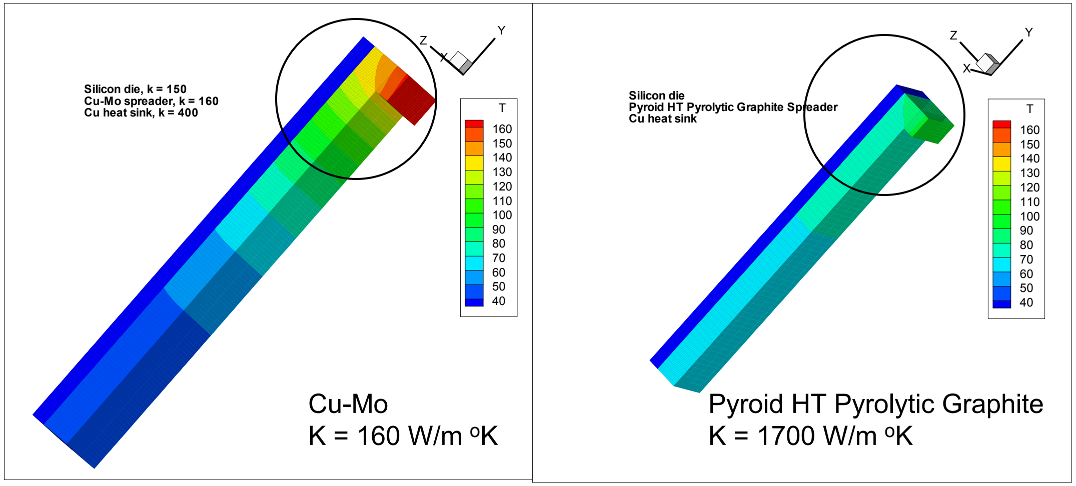
Case Study - Two Dimensional Laser Diode



Finite control volume computational grid with laser diode attached to the heat spreader end

- Two dimensional heat spreader configuration
- Low conductivity plane across diode
- High conductivity plane
- Constant heat flux 200 W/cm^2
- Copper heat sink temperature 30 ^oC

Case Study - Two Dimensional Laser Diode

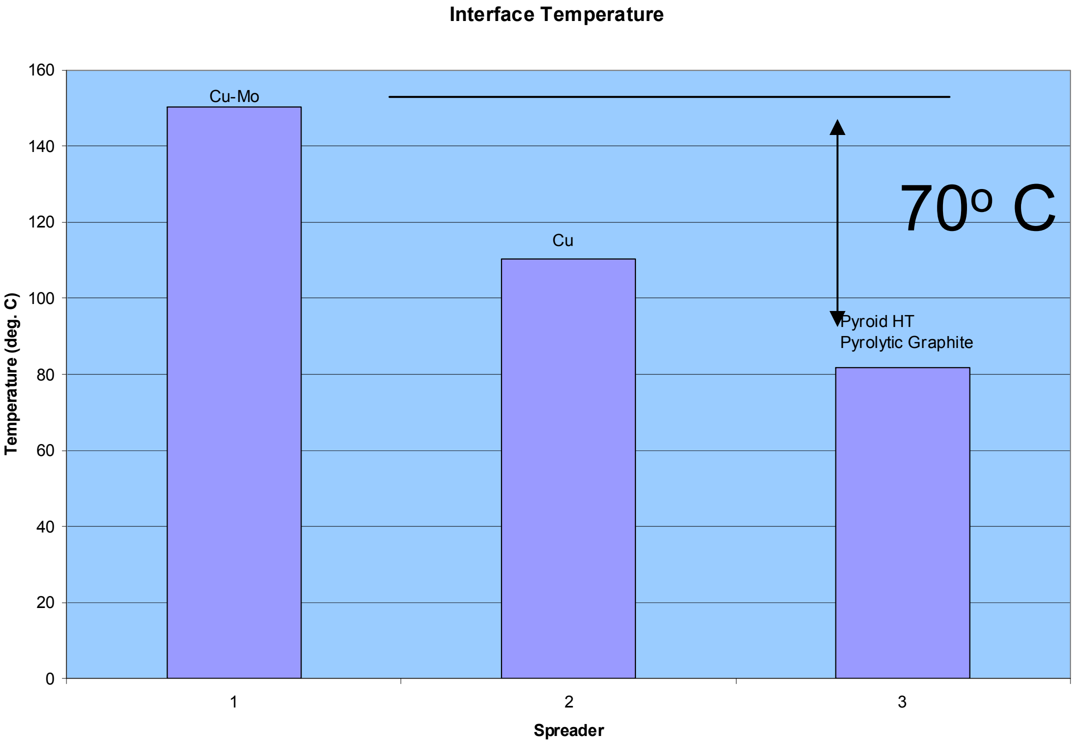


Resultant temperature Contours for CuMo vs PYROID® HT Pyrolytic Graphite heat spreaders for a heat flux of 200 W/cm²

Case Study - Two Dimensional Laser Diode

RESULTS: 70 °C REDUCTION in $T_{junction}$

Laser Diode Application Experimental Results



Application:

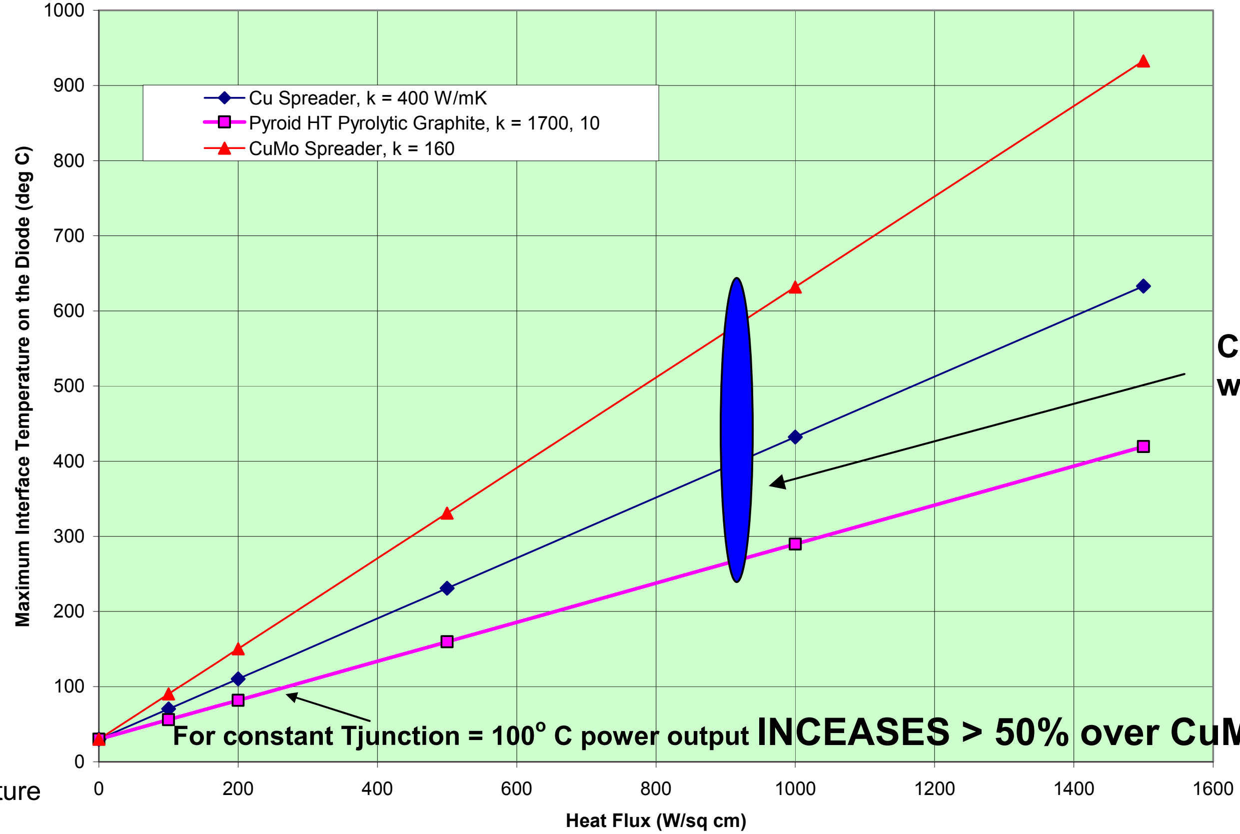
Laser Diode
Power Input
200 W/cm² flux

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

Case Study - Two Dimensional Laser Diode

RESULTS: > 50% INCREASE IN POWER OUTPUT

Interface temperature for three heat spreader configurations



Change in temperature with spreader type

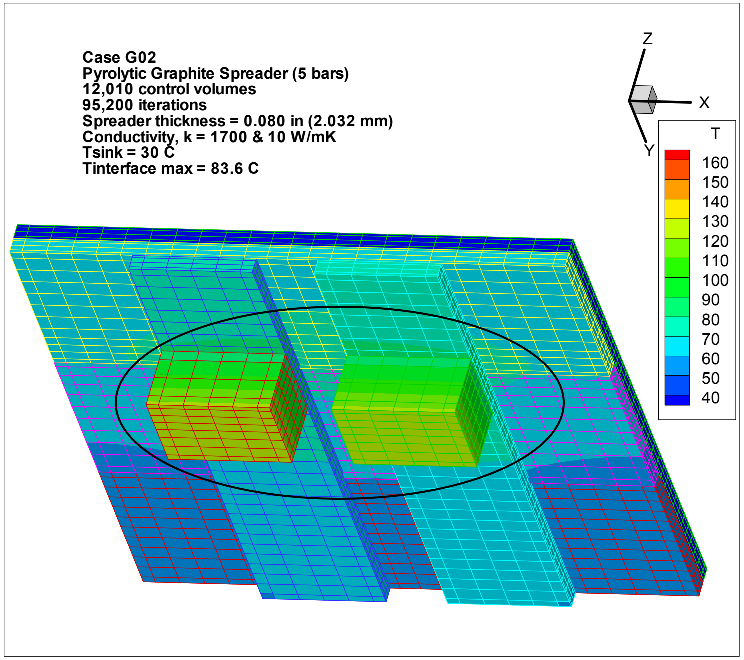
For constant Tjunction = 100° C power output **INCEASES > 50% over CuMo**

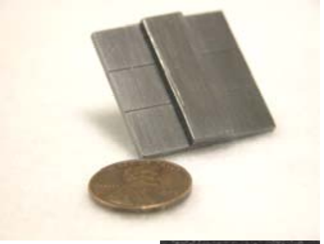
Heat sink Temperature 30 °C

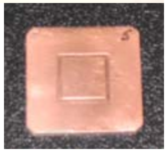
Case Study - Radar Transmit/Receive (T/R) Module

PYROID HT® Heat Spreaders

What is the optimum near isotropic 3D spreader?







Measure die/spreader interface temperature

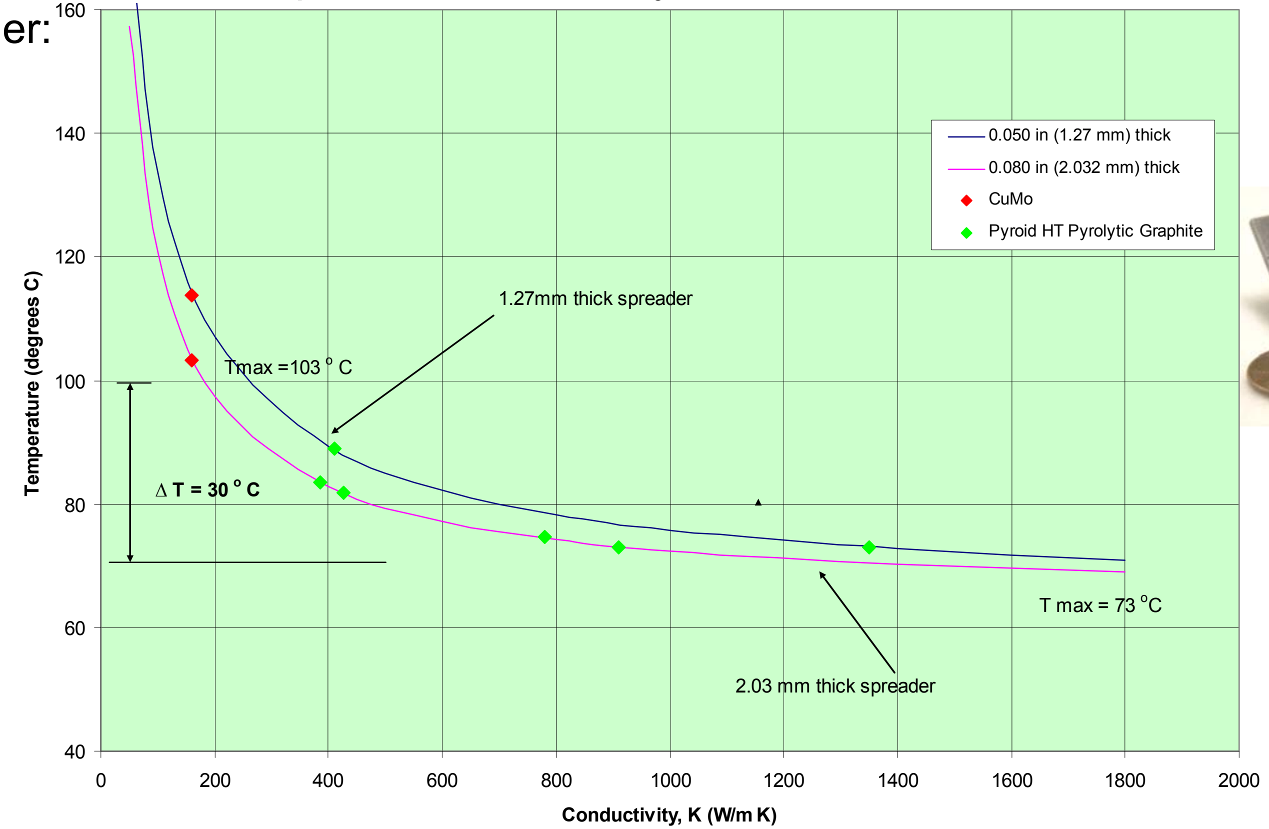
Grid & temperature contours
five bar Pyroid HT® T/R Module

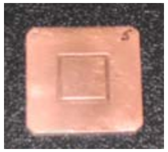
Case Study - Radar Transmit/Receive (T/R) Module

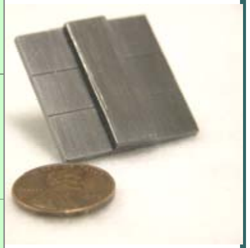
RESULTS: 30° C REDUCTION IN TEMPERATURE

3D PYROID HT® Heat Spreaders
Resultant K = 1350 W/mK isotropic bulk conductivity
Optimum spreader:

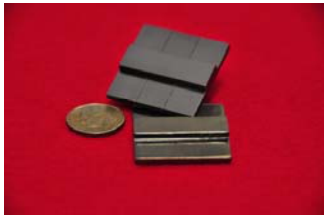
- 2.0 mm first layer
- 0.5 mm second layer
- 2.5 μ Au/Sn solder







Case Study - Three Dimensional CTE Stress Analysis

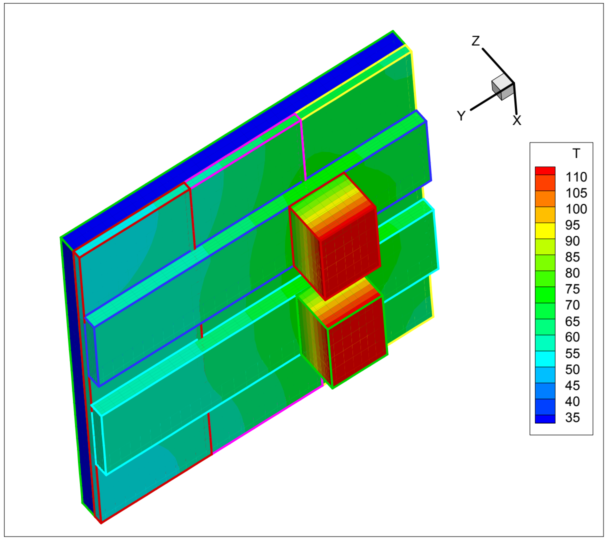


Consider two materials:

Low CTE material in restrained state creates:
- compression in high CTE material

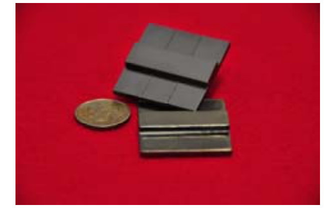
High CTE in restrained state creates:
- tension in low CTE material

Resultant Modulus of Elasticity of material is as important as is CTE

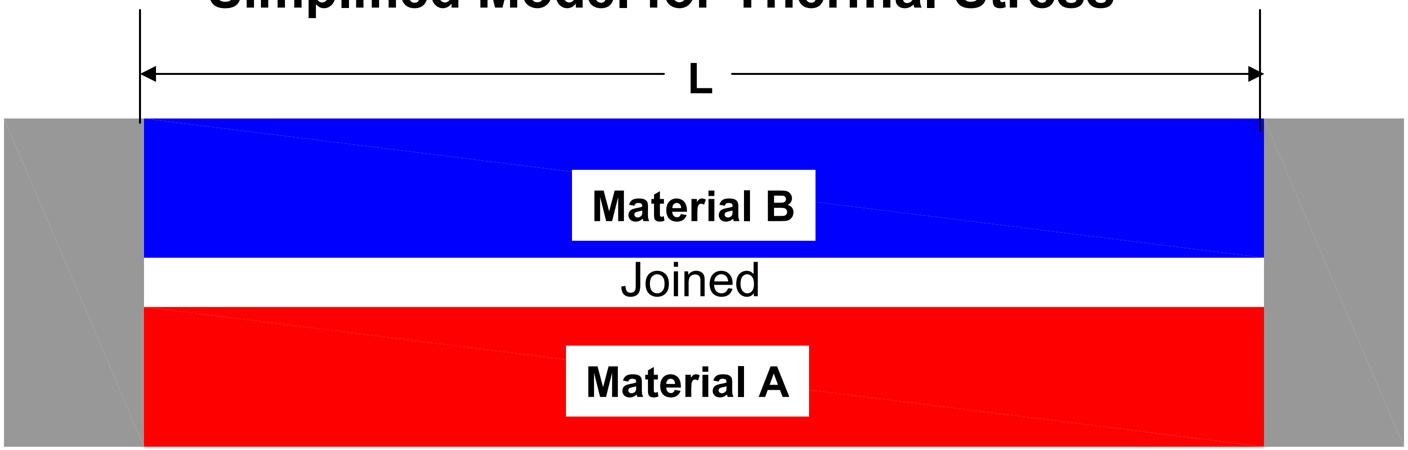


Resultant temperature contours five bar Pyroid HT Pyrolytic Graphite Heat Spreader 150 W/cm^2 heat flux

Case Study - Three Dimensional CTE Stress Analysis



Simplified Model for Thermal Stress



Schematic of thermal stress model for two dissimilar materials

High CTE material in restrained state creates:

- compression in High CTE material

Low CTE in restrained state creates:

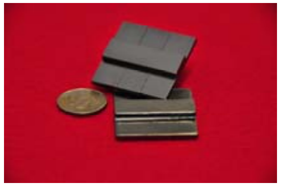
- tension in Low CTE material

Resultant governing system equation:

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

Assume materials are joined along surface with normal stresses transferred by shear (zero at joint center and along free surfaces)

Case Study - Three Dimensional CTE Stress Analysis



Properties of die and spreader materials

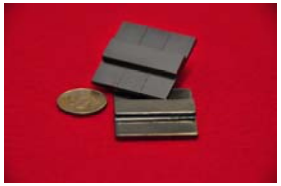
Material	CTE (1/°C)	E, modulus of elasticity, (GPa)
Silicon	4.68×10^{-6}	110.3
PYROID® HT Pyrolytic Graphite	0.5×10^{-6} ∥ 25×10^{-6} ⊥	< 50
Diamond	1.18×10^{-6}	700 - 1200
Copper	16.5×10^{-6}	110.3

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

Resultant governing system equation:

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

Case Study - Three Dimensional CTE Stress Analysis



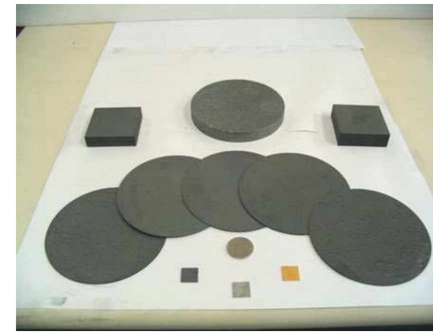
No damage after numerous thermal cycling RT to 150°C

For 200° 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

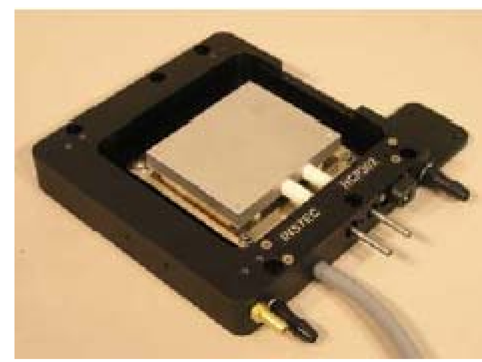
PYROID HT® Pyrolytic Graphite Options



- ✓ **Metallization or Non Metallized Graphite Base**
- ✓ **Metallization overlay on PYROID® HT Pyrolytic Graphite**

  Ti/NiCr/Au Ti/Ni/Au Ti/Pt/Au base other material

  - Forms a reliable and sealing overlay to allow solder process
  - Amenable solders Pb/Sn, SAC 305, In/Sn, Au/Sn, other



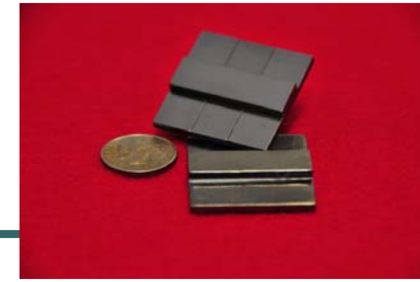
- ✓ **Mounting options**

  As is

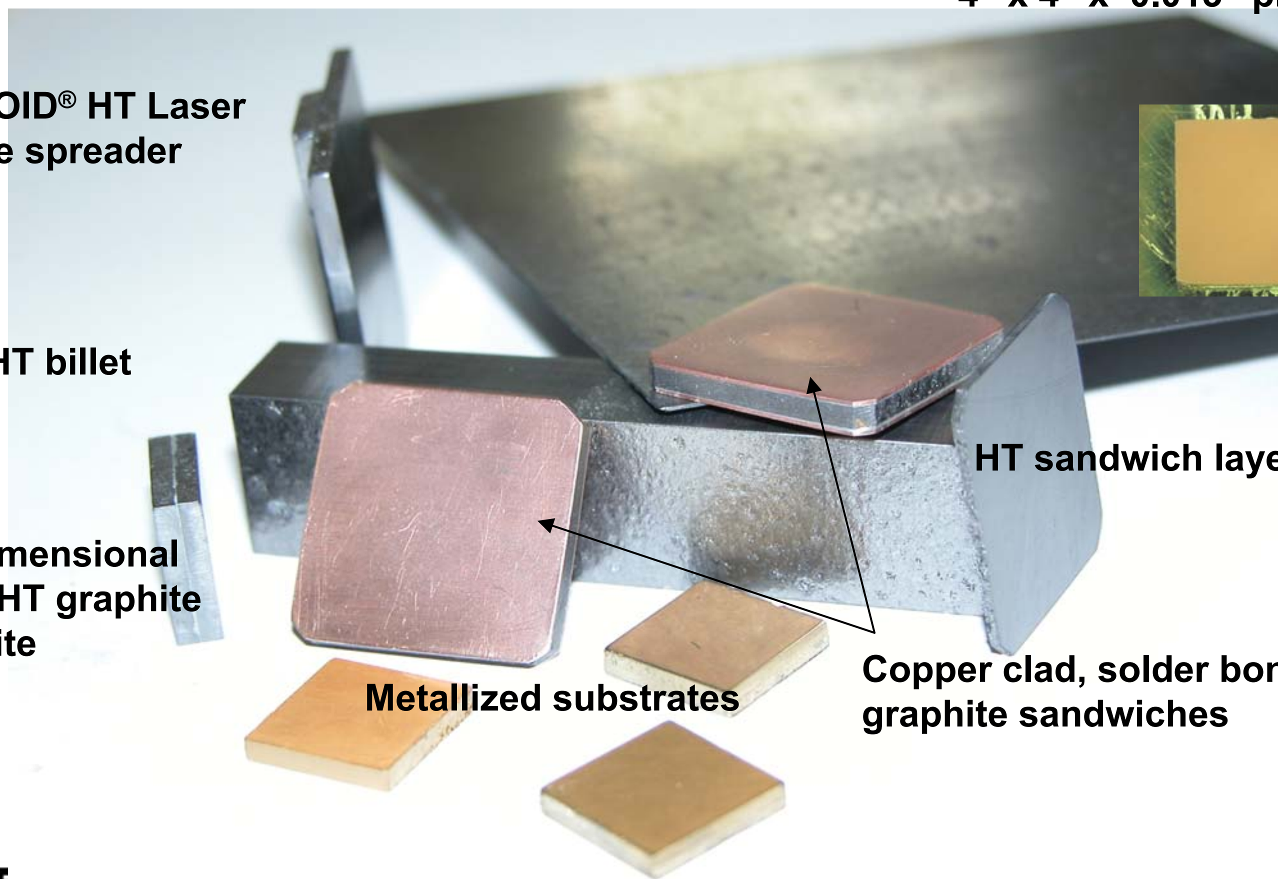
  Metal reinforcing backings

  Epoxy/fiberglass reinforcement
- ✓ **Amenable Pick/Place**

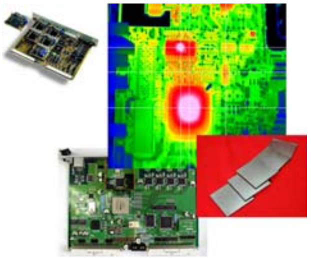
Portfolio Graphite Heat Spreader Architectures



4” x 4” x 0.013” plate radiator



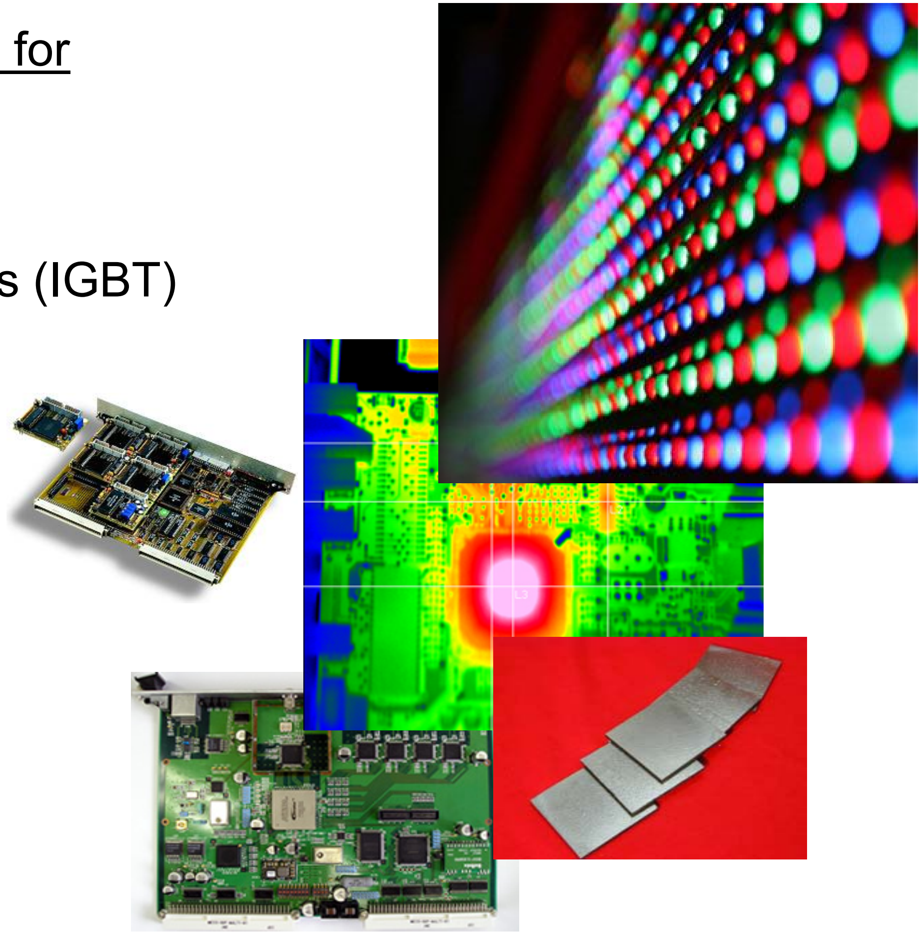
Conclusions



- Intrinsic anisotropy and strength limitations addressed through "**engineered" orientation** and **fabrication approaches**
- Optimization tools/models available for layered PYROID® HT Pyrolytic Graphite heat spreader designs and performance analysis
- Elastic Modulus is just as important as CTE to mechanical compatibility between spreader and die materials
- PYROID® HT Pyrolytic Graphite Heat Spreaders are cost effective alternatives to expensive diamond and heavier, low performing copper spreaders

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



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