High Performance Pyrolytic Graphite Heat Spreaders

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Agenda

Background

Metallization

Case Studies

- Two Dimensional Laser Diode Application
- Three Dimensional Heat Spreader Applications

CTE Analysis

Conclusions

Who Are We?

Pyrogenics Mission:

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

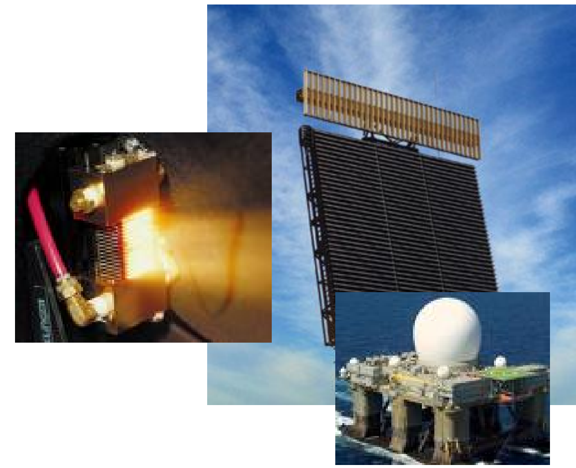
Largest single source producer of pyrolytic graphite, thin films, and specialty carbon composites
Markets – Aerospace, Semiconductor/ Electronics, Medical Imaging, Isothermal Forge, Glass

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

TREND: More Effective Thermal Management Solutions Required

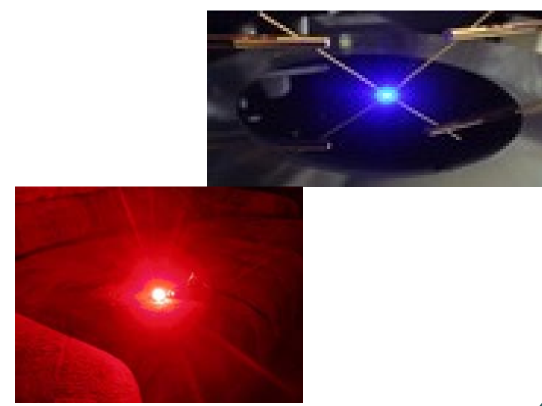
Widespread growth of increased power density for applications found in:

Defense/Military
Commercial Industry



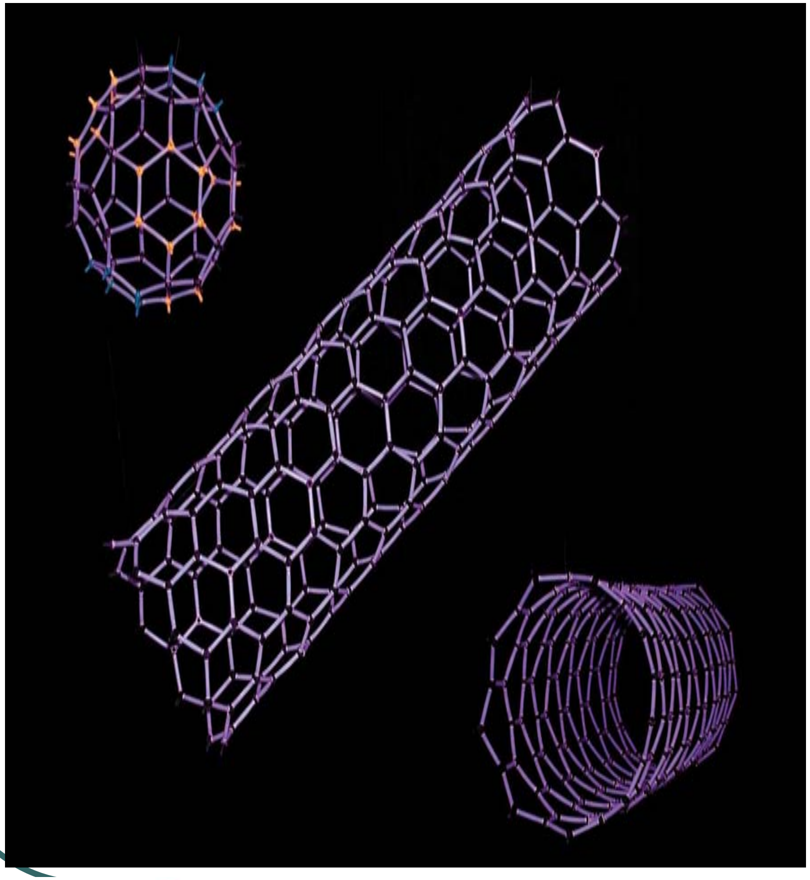
Need thermal management solutions for:

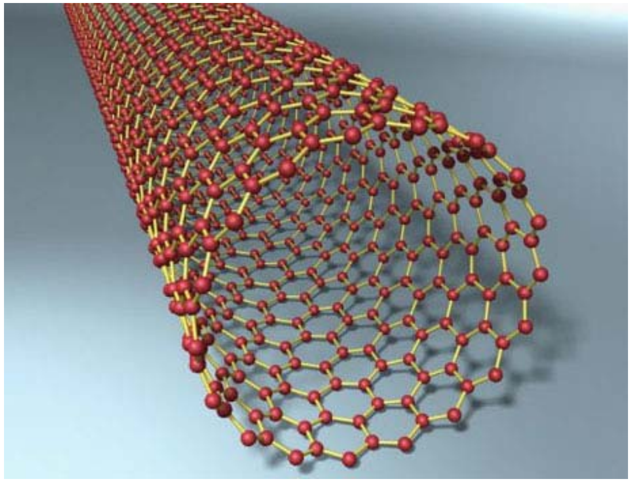
- Laser Diodes
- T/R Radar Modules
- Microwave Packaging
- LED Lighting
- OLED/COLED
- Electronics Packaging

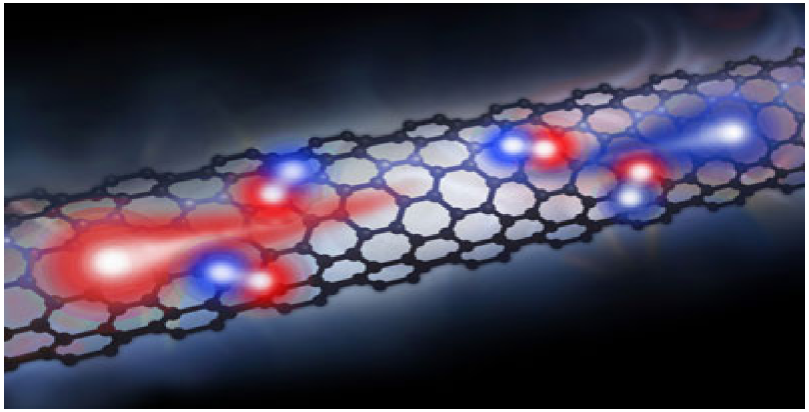


Carbon Nanotubes:

Thermal Management Material for the Next Century?



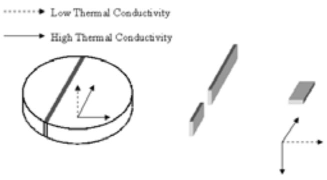


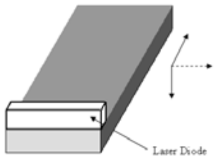


PYROID® HT Pyrolytic Graphite :

‘Thermal Management Material for the Next Decade’

MINTEQ Chemical Vapor Deposition Processing of Pyrolytic Graphite

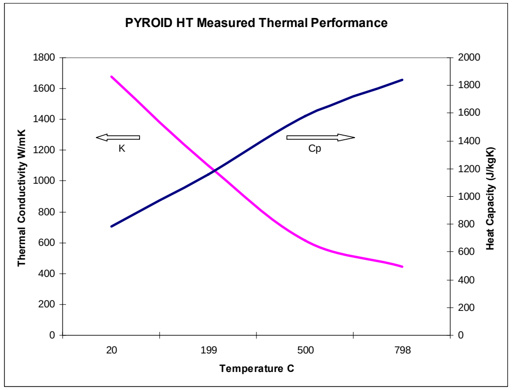




“Engineered” Z Orientation

- High purity > 99.999% , crystalline structure
- Thermal Conductivity
  - 1700 W/m-K X-Y
  - Anisotropic
- Engineered Material
- Density: 2.25 g/cc
- Custom production process
  - thickness 10 mils to 2.5 cm
  - machined and prepare to mirror finish
- Metallization Technology

Thermal Conductivity Measurements



PYROID® HT Thermal Conductivity (20° C)

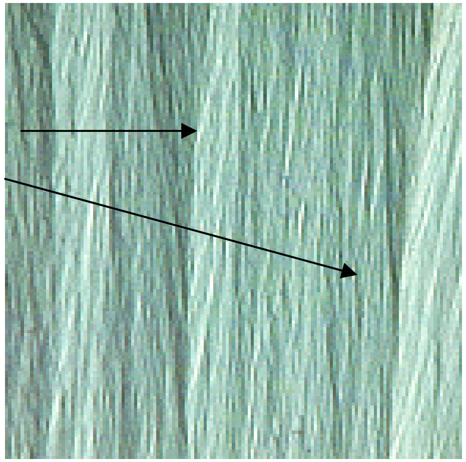
X-Y Plane	1,700 W/m-K
Z Plane	7 W/m-K

Standard Pyrolytic Graphite

X-Y Plane	440 W/m-K
Z Plane	1.7 W/m-K

- **Substrate-nucleated**
- **Columnar structure**
- **High purity**

PYROID® HT micrograph



100 µm

Metallization Development:

Insure Acceptable Bond Strength

Metallization of PYROID® HT Pyrolytic Graphite

Sebastian Pull Test

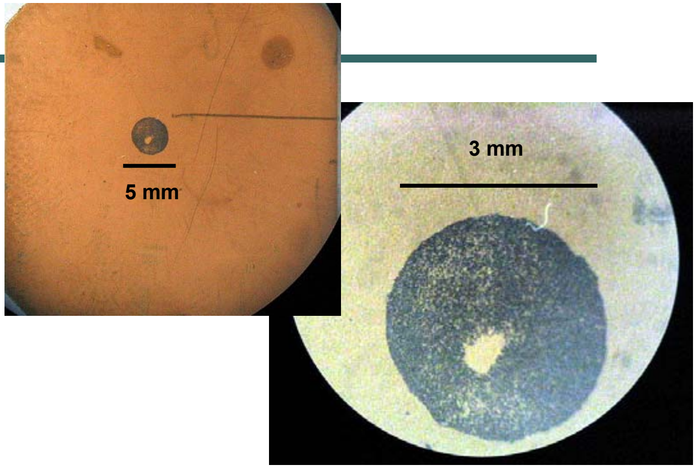
- ✓ **Epoxy coated 2.69 mm metal stud bonded to sample**
- ✓ **Constant strain rate "pull" perpendicular to bonding plane**
- ✓ **3 metallization compositions**
- ✓ **Tested with solder types (Pb-Sn, Au-Sn, Indium, etc.)**

Stud Pull Adherence Test

Shear test using MIL STD 883

Shear Test

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

Failures in the material
Not in the metallization interface

Compatibility of selected solder types with metallization

Sn (80Au/20 Sn)
Au Ag Sn
In Sn
SAC 305

Case Study - Two Dimensional Laser Diode

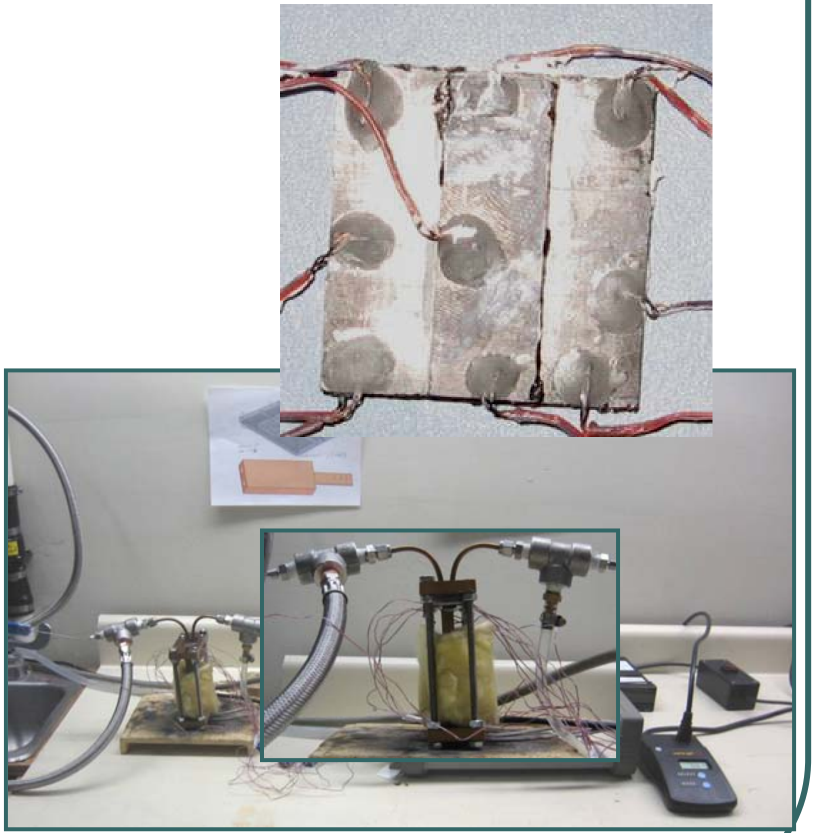
Two dimensional PYROID® HT Heat Spreaders vs. Copper

Experimental:

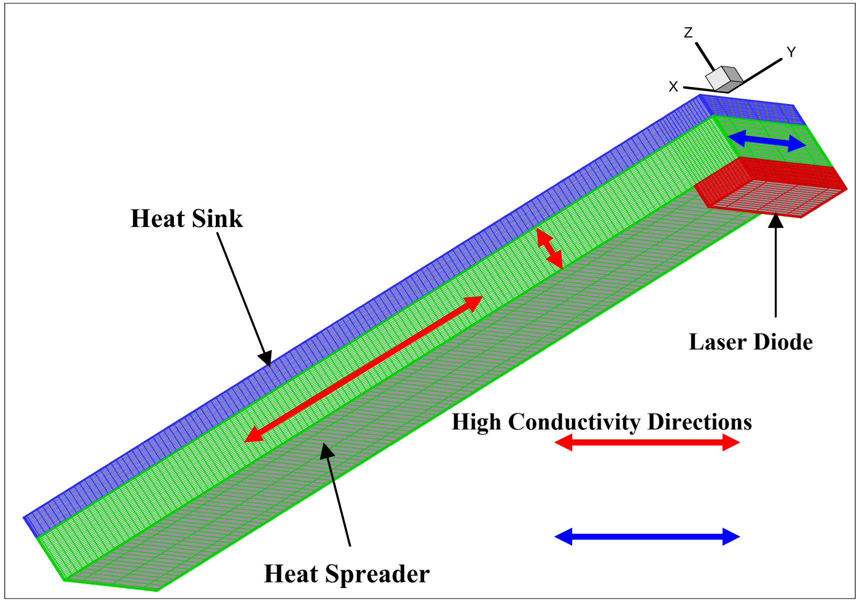
Measure laser diode temperature and match to 3D Omega Piezo Technologies' finite control volume thermal conduction program

Materials tested and modeled

1. Copper-Molybdenum
2. Copper
3. Pyroid® HT Pyrolytic Graphite



Case Study - Two Dimensional Laser Diode

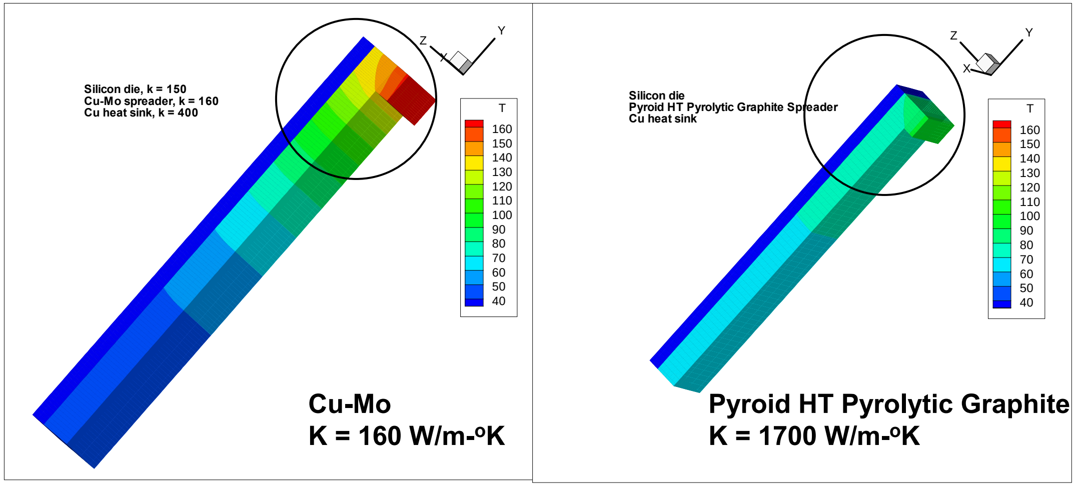


Finite control volume computational grid laser diode attached to the heat spreader

- **Two dimensional heat spreader configuration**
- **High conductivity plane**
- **Constant heat flux 200 W/cm^2**
- **Copper heat sink temperature 30 ^{o}C**

Case: Two Dimensional Heat Spreader

Resultant Temperature Contours for PYROID® HT Pyrolytic Graphite v. CuMo heat spreaders

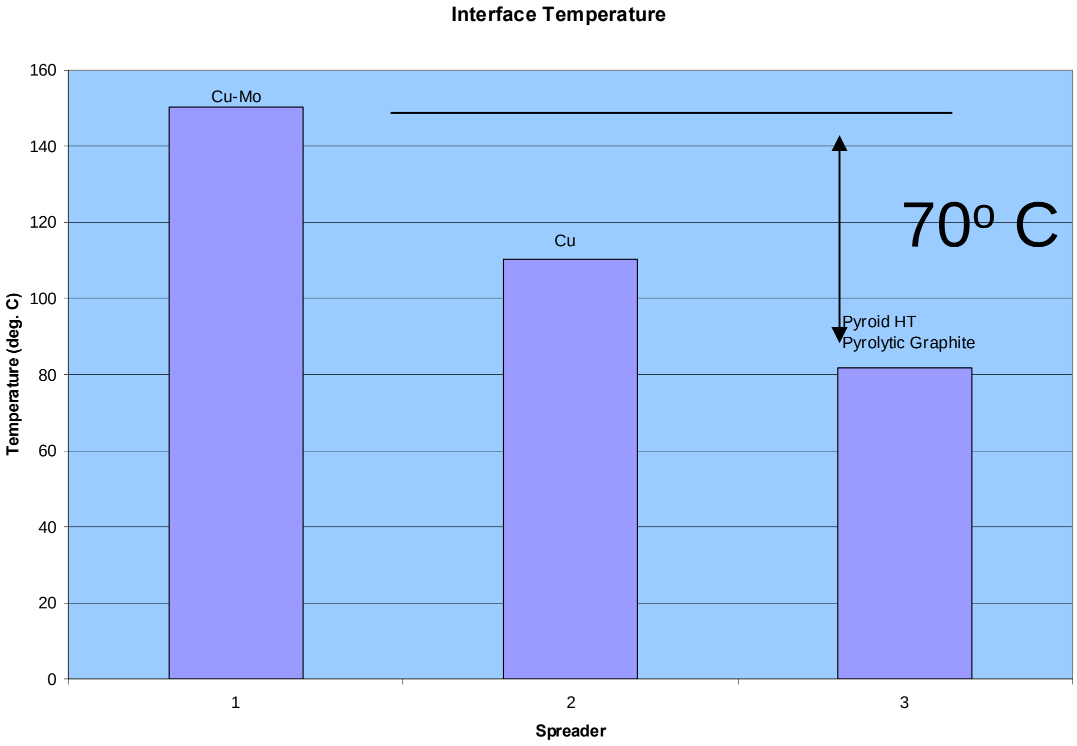


Resultant Temperature Contours for PYROID® HT Pyrolytic Graphite v. CuMo heat spreaders for a heat flux of 200 W/cm ^{2}

Case Study - Two Dimensional Heat Spreader

RESULTS: 70 ^{o}C <u>REDUCTION</u> in $T_{junction}$

Experimental Results



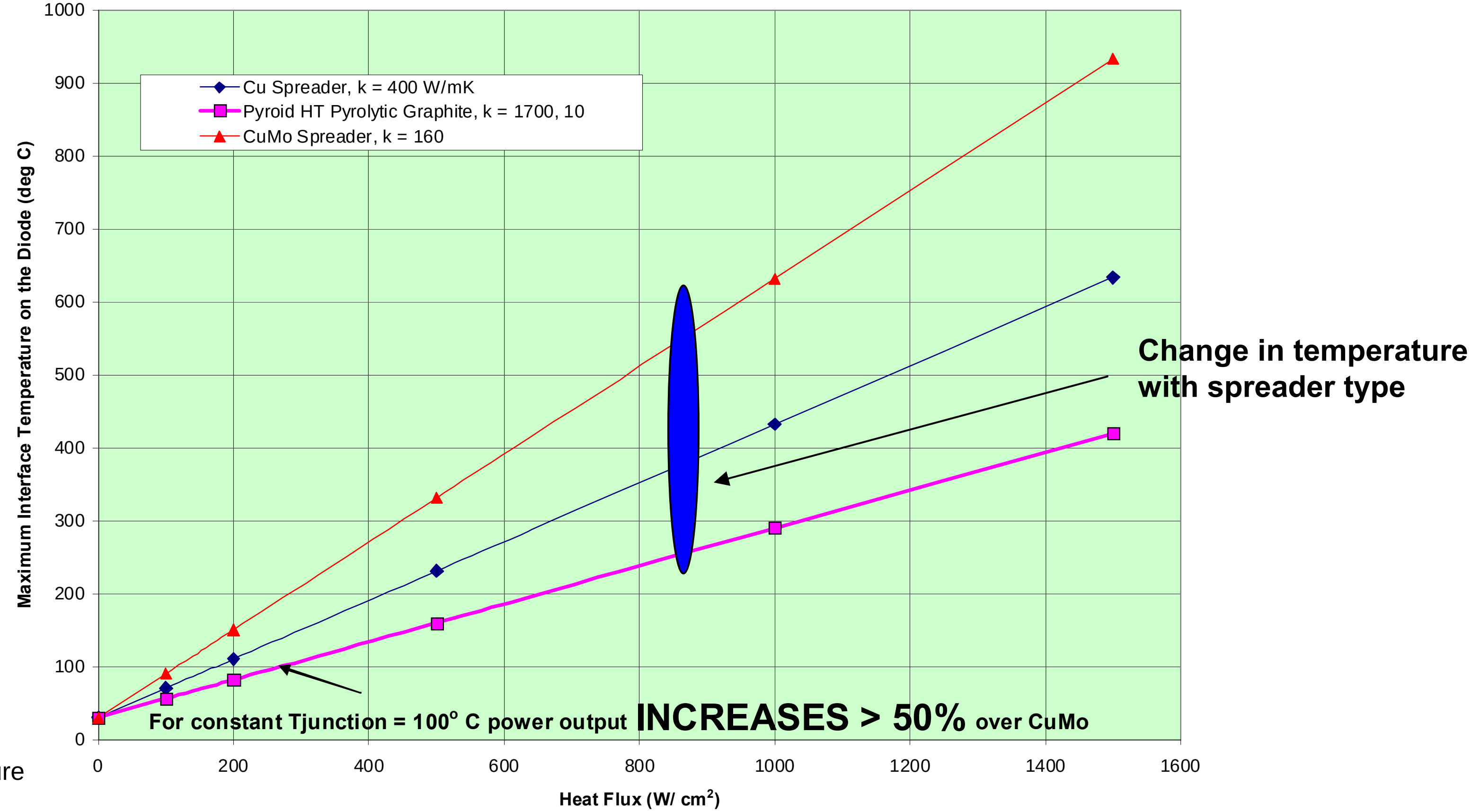
200 W/cm^2 flux

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

Case Study - Two Dimensional Heat Spreaders

RESULTS: INCREASE IN POWER OUTPUT

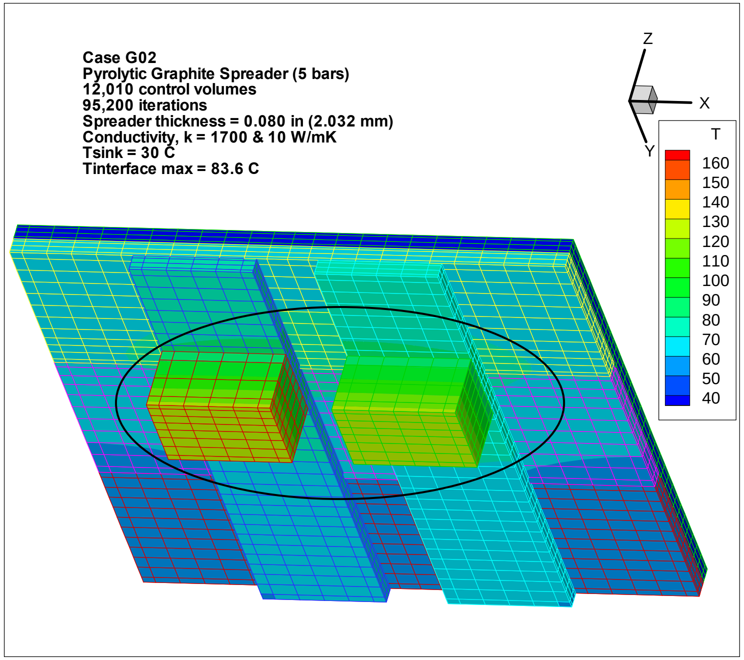
Interface temperature for Cu v. CuMo v. PG-HT heat spreaders

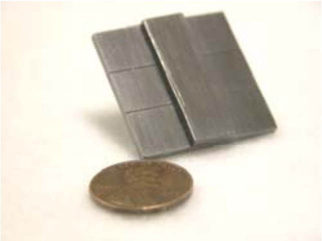


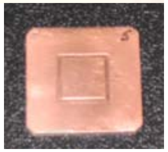
Heat sink Temperature 30 °C

Case Study - 3 Dimensional Heat Spreader
PYROID® HT PYROLYTIC GRAPHITE

What is the optimum near isotropic 3D spreader?







Measure die/spreader interface temperature

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

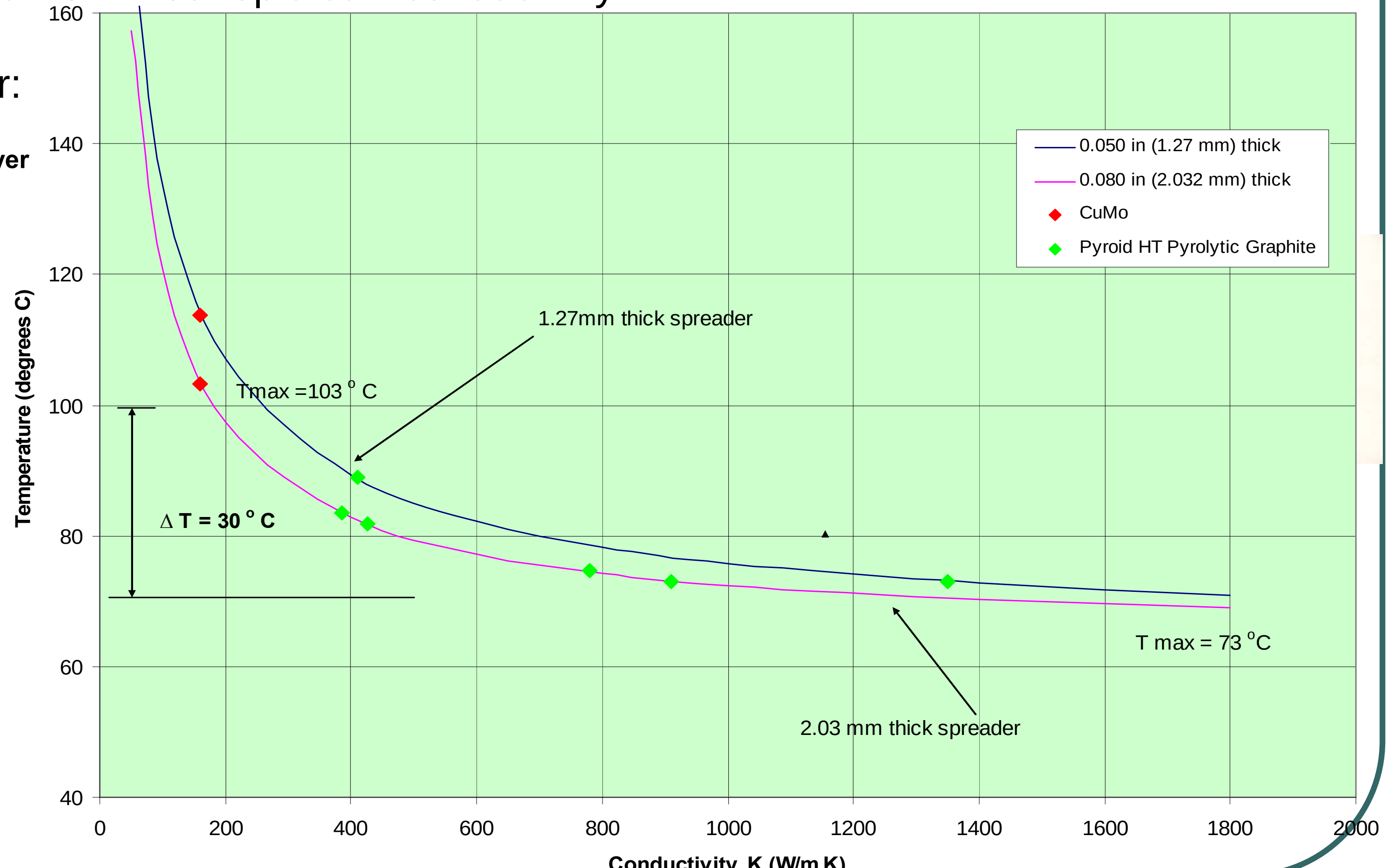
Case Study - 3-DIMENSIONAL HEAT SPREADER

RESULTS: 30° C REDUCTION IN TEMPERATURE

Resultant K = 1350 W/mK isotropic bulk conductivity

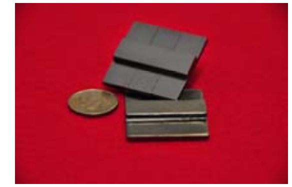
Optimum spreader:

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



Three Dimensional CTE Stress Analysis:

MODULUS OF ELASTICITY KEY PROPERTY



Properties of die and spreader materials

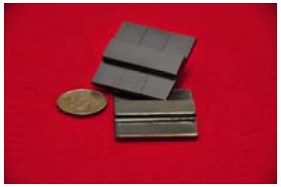
Material	CTE (1/ºC)	E, modulus of elasticity, (GPa)
Silicon	4.68×10^{-6}	110.3
PYROID® HT Pyrolytic Graphite	0.5×10^{-6} $\parallel$ 25×10^{-6} $\perp$	< 50
Diamond	1.18×10^{-6}	700 - 1200
Copper	16.5×10^{-6}	110.3

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

Resultant governing system equation:

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

Three Dimensional CTE Stress Analysis



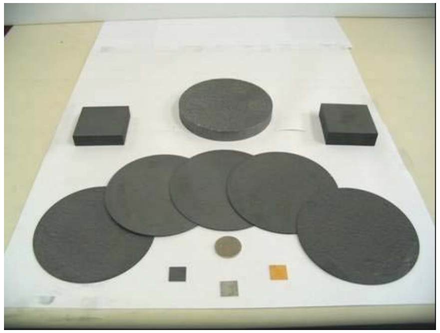
No damage after numerous thermal cycling RT to 150°C

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

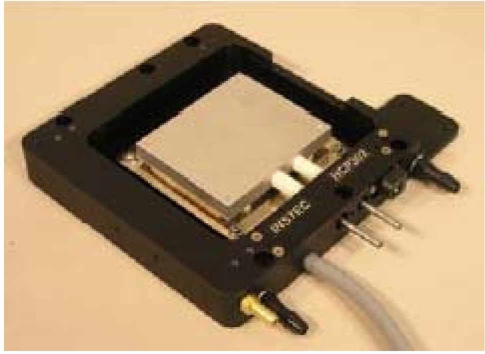
PYROID HT® Pyrolytic Graphite Options



- ✓ **Pyrolytic Graphite Base Material**
- ✓ **Metallization on PYROID® HT Pyrolytic Graphite**

  Ti/NiCr/Au Ti/Ni/Au Ti/Pt/Au

  - **Reliable overlay to allow solder process**
  - **Pb/Sn, SAC 305, In/Sn, Au/Sn**



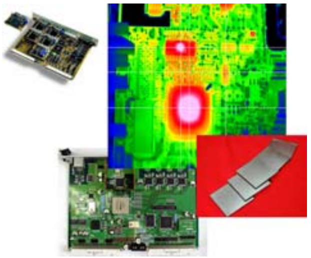
- ✓ **Mounting options**

  As is

  Metal reinforcing backings

  Epoxy/fiberglass reinforcement

Conclusions



- Intrinsic anisotropy and strength limitations addressed through "**engineered" orientation** and **fabrication approaches**
- **Optimization 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 diamond and copper spreaders

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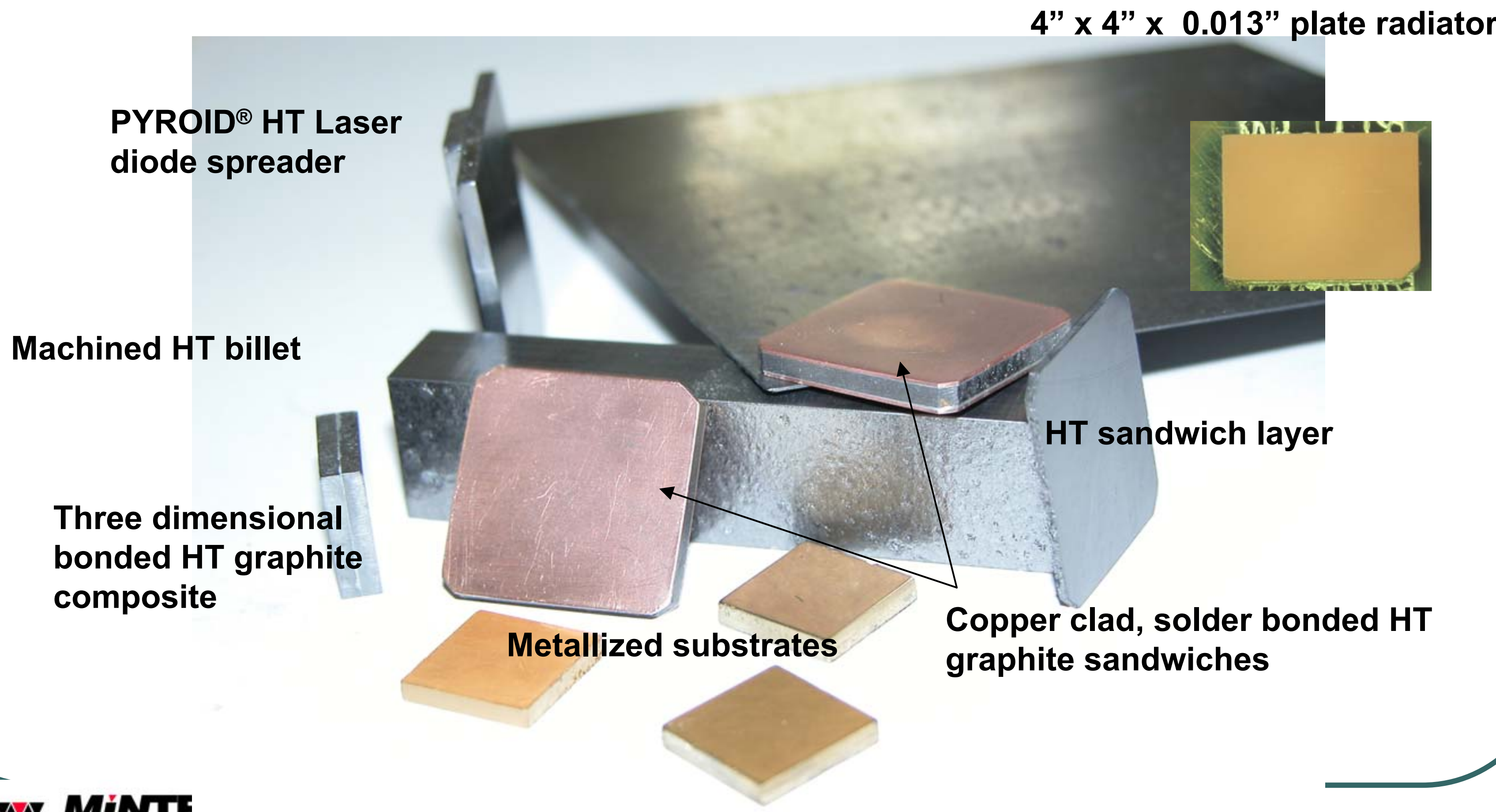
Pyrolytic Graphite Heat Spreader Architectures



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