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OSRAM LLFY WORKSHOP
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MCPCB's and Thermal Interface Material Considerations for High Power LED Lighting Applications

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The Bergquist Company

Acknowledgements:

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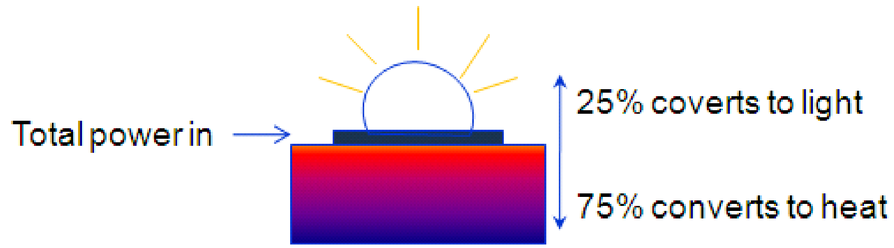
MCPCB's and TIM Considerations for High Power LED Lighting Applications

Outline

- **Thermal management is key to your design**
- **Thermal performance of high power LED's**
- **Understanding thermal performance (reference data)**
- **MCPCB material options and part geometry**
- **TIM selection considerations, options that are available**
- **Conclusions**

Importance of Thermal Management of High Power LED's

- Only ~15-30% of input power is converted to light
- The remaining 70-85% of input power is converted to heat
  - Excessive heat can cause a shift in color
  - Excessive heat can reduce light output
  - Excessive heat can shorten device life



IESNA Handbook   Osram Sylvania

Source: PNNL-SA-51901, February 2007

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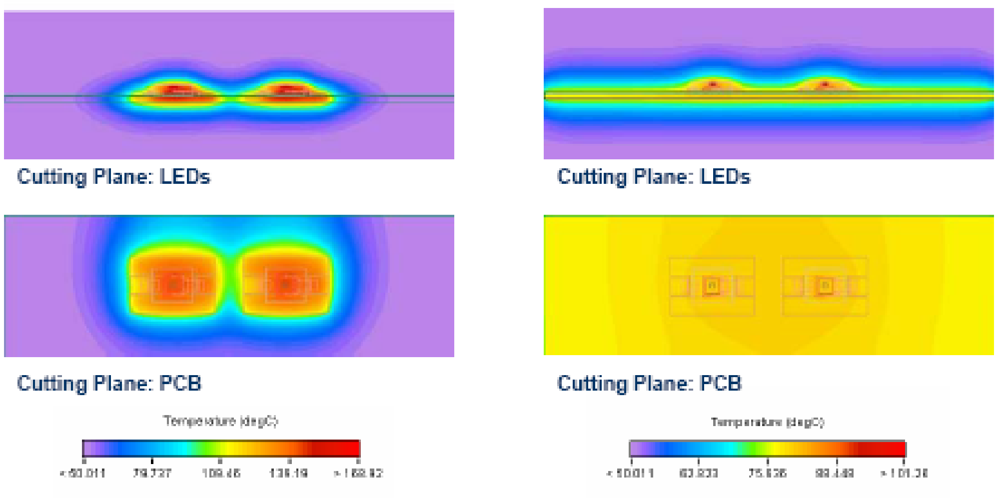
Model results

Comparison of FR-4 to IMS

FR4 PCB		Insulated Metal Substrate



$T_{junc} = 168.9$ °C

$\Delta T = T_{junc} - T_{amb} = 118.9$ °C

-55% →

$T_{junc} = 101.3$ °C

$\Delta T = T_{junc} - T_{amb} = 51.3$ °C

Influencing Factors

- Board material with higher thermal conductivity
- Attach to additional heat spreader (PCB on Aluminium)
- Solder pad layout and placement of other components
- Use of thermal vias

Good thermal management results in lower junction temperature

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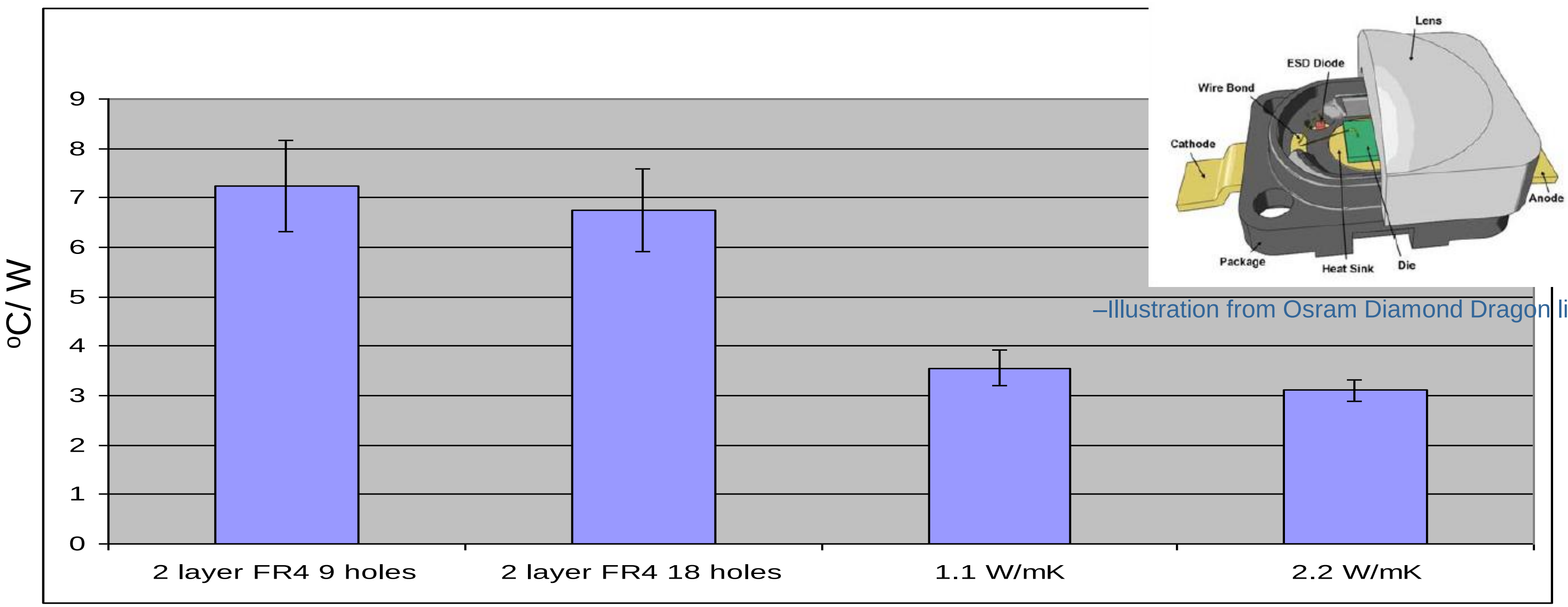
Case study results

Thermal impedance of Osram Diamond Dragon on various substrates



–Illustration from Osram Diamond Dragon literature

57% improvement from popular FR-4 configuration to 2.2 W/mK solution

Note: the two FR-4 samples needed an insulator pad between the board and heat sink adding 0.2ºC/W

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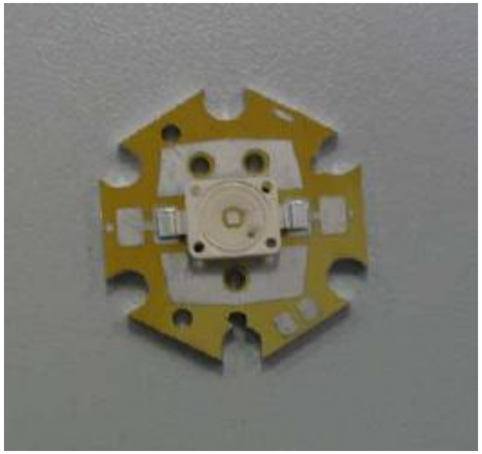
Comparison of thermal impedance of Bergquist MP and HPL dielectrics

Components: LED Golden Dragon (chip 1sqmm) (same wafer Lot)

MCPCB: Al 1,57mm x Dielectric x 35µm cu



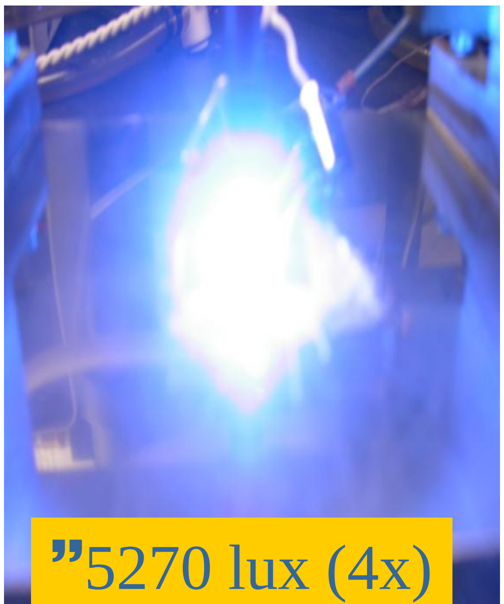
Result:

Thermal Impedance Zth

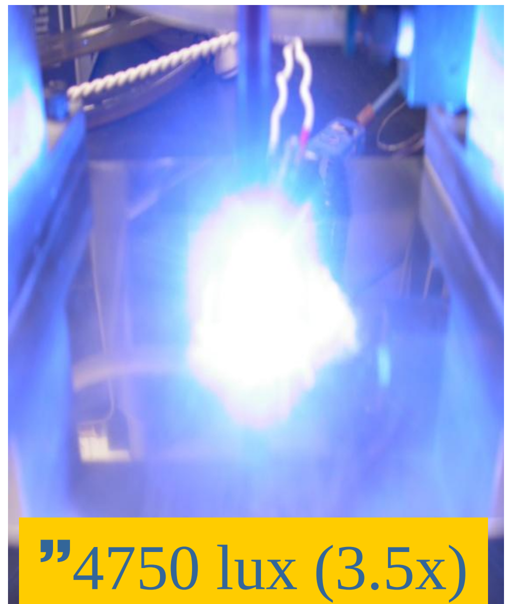
Bergquist MP	*1.8 – 2.0 K/W*
Bergquist HPL	*0.8 – 1.0 K/W*

2 x improvement by increasing to 3W/mK dielectric from 1.1W/mK

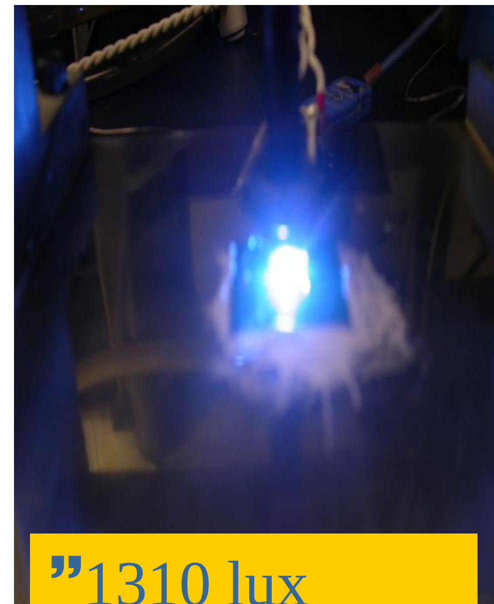
Light Output of Die on Different Dielectric Materials at ΔT of 25C



”5270 lux (4x)
2.2 W/mK
Bergquist HT



”4750 lux (3.5x)
1.3 W/mK
Bergquist MP



”1310 lux
0.30 W/mK
FR-4/Alu

Thermal Clad® - IMS Insulated Metal Substrate

KEY TAKE-AWAY POINTS

1. **Dielectric thermal impedance dominates** the conductive portion of the thermal path

2. Use of **MCPCB is critical to thermal management of high power LED's**

3. **Reducing the conductive portion** of the thermal budget, by using IMS, provide **more options for heat sink selection**.

MCPCB's and TIM Considerations for High Power LED Lighting Applications

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- Thermal management is key to your design
- **Thermal performance of high power LED's**
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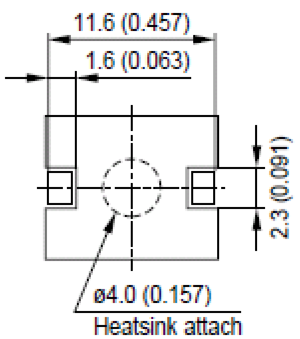
- Conclusions

LED’s have different package styles & different T_R

Golden DRAGON®

ZW W5SG

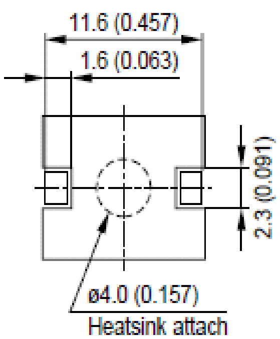


Heat Slug area 12.6mm²

$R_{th\ JS}$ 15 K/W

Platinum DRAGON

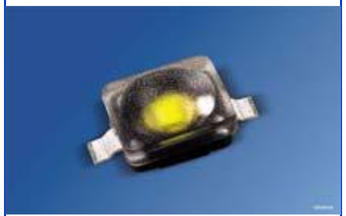
LR W5SM



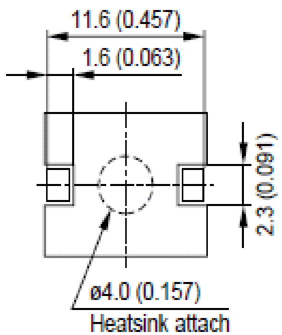
Heat slug area 12.6mm²

$R_{th\ JS}$ 11 K/W

Diamond DRAGON



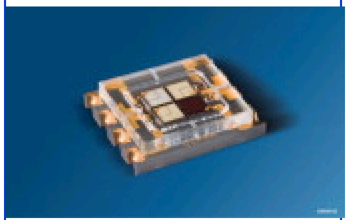
LUW W5AP

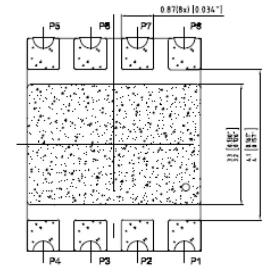


Heat slug area 12.6mm²

$R_{th\ JS}$ 5 K/W

OSTAR - SMT





Heat slug area 15.9mm²

$R_{th\ JS}$ 30K/W

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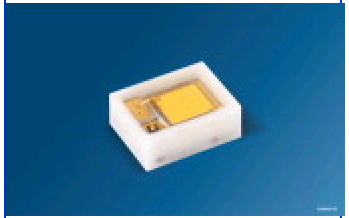
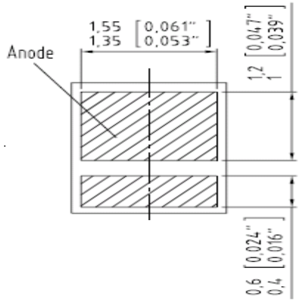
LED's have different package styles & different T_R

CERAMOS™



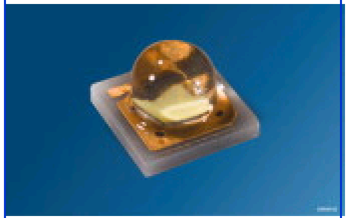
LUW C9SP
Ultra White



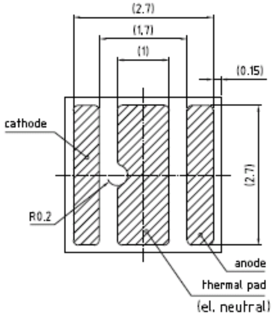
Thermal Pad 1.86mm²

$R_{th\ JS}$ 34 K/W

OSLON SSL



LUW CP7P

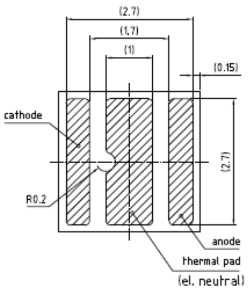


Heat slug area 2.7mm²

$R_{th\ JS}$ 9.4 K/W

OSLON SX

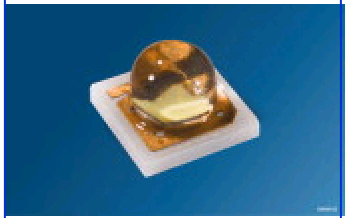
LUW CN5M
Ultra White



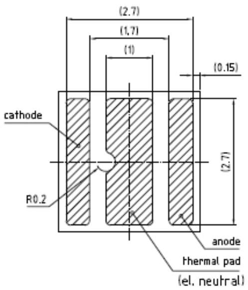
Heat slug area 2.7mm²

$R_{th\ JS}$ 30 K/W

OSLON MX ECE



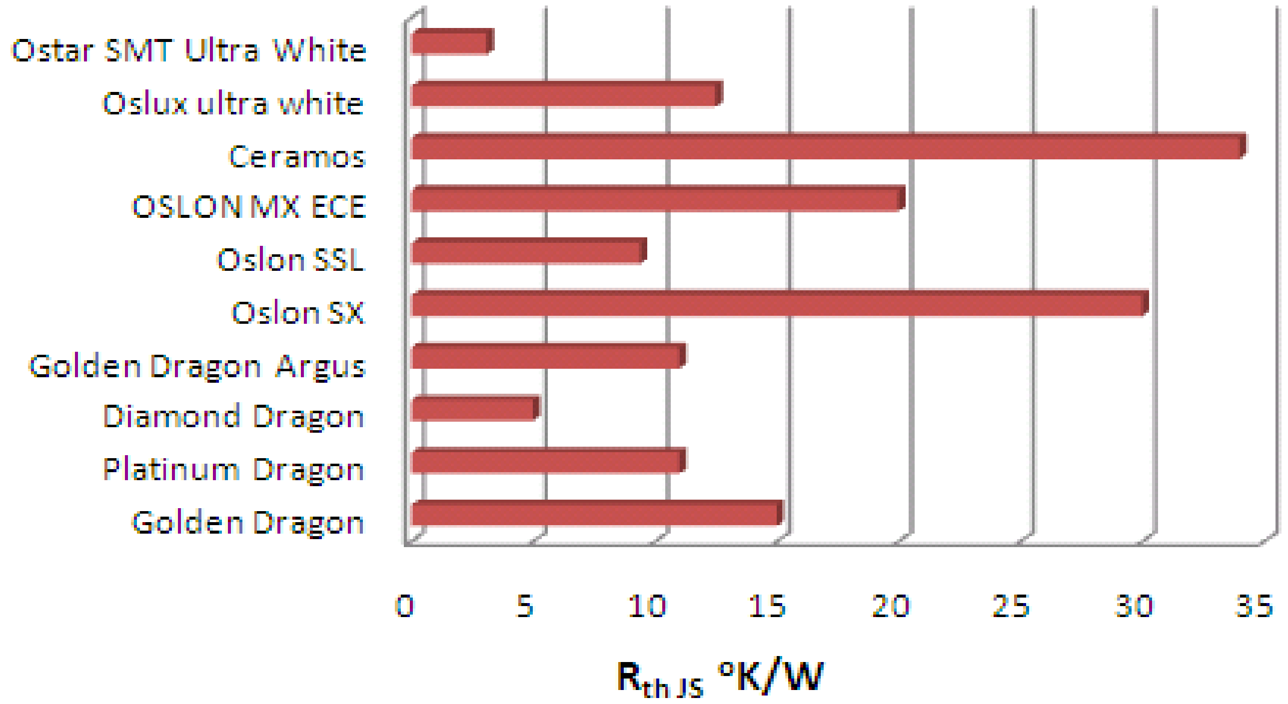
LUW CN7N
Ultra White



Heat slug area 2.7mm²

$R_{th\ JS}$ 20K/W

$R_{th\ JS}$ comparison of various LED's



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KEY TAKE-AWAY POINTS

1. There are many **different LED package styles**
2. Even LED's with the **same package style can have different thermal resistance** from one part to another
3. **Lower the thermal resistance package can see greater benefit from lower thermal impedance MCPCB**

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Thermal Performance

Understanding Thermal Conductivity

- Thermal Conductivity (*k*)
  - ✓ A material's ability to conduct heat
  - ✓ Inherent material property
  - ✓ Does not depend on thickness
  - ✓ T_C unit is:

$$\frac{Watt}{meter \bullet Kelvin}$$

For this purpose, the material is treated as isotropic.

Thermal Performance

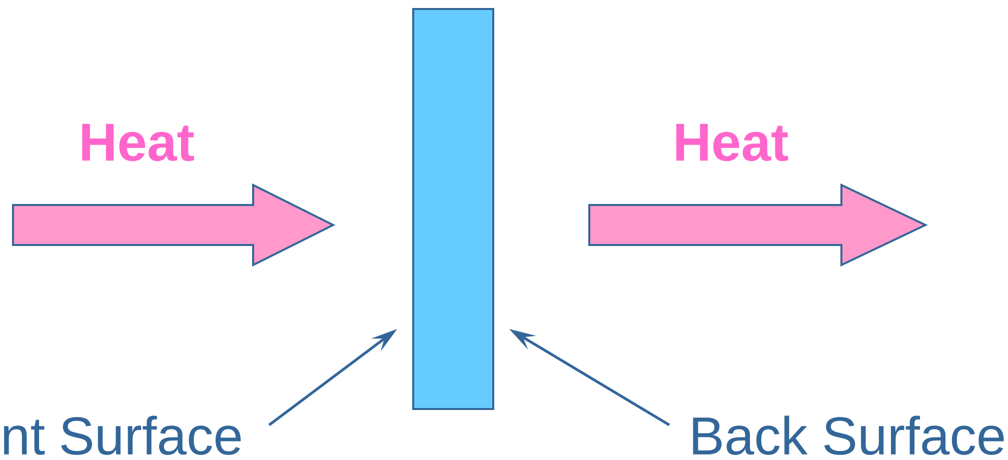
- Fourier's Law of Heat Conduction
  - ✓ Steady-state uniform heat conduction through a thin sample:

$$\frac{q}{A} = -k\frac{dT}{dx}$$

q = heat flow rate, Watt
A = area of sample, square meter
k = thermal conductivity, Watt/meter.Kelvin
x = thickness of specimen
dT/dx = temperature gradient through sample, Kelvin/meter

Thermal Performance

- Thermal Resistance, $R_{`e}$ (excludes interfacial resistance)



$$\text{Thermal Resistance} = \frac{\Delta T}{q/A} \qquad R_\theta = \frac{\Delta x}{k}$$

Thermal Performance

Understanding Thermal Resistance

- Thermal Resistance, R_0
  - ✓ A material's resistance to heat flow
  - ✓ Defined as temperature drop across a unit area material subjected to a steady state heat flow rate
  - ✓ Does not include interfacial resistance
  - ✓ Proportional to ratio of material thickness to material thermal conductivity
  - ✓ S_I unit is

$$\frac{meter^2 \bullet Kelvin}{Watt}$$

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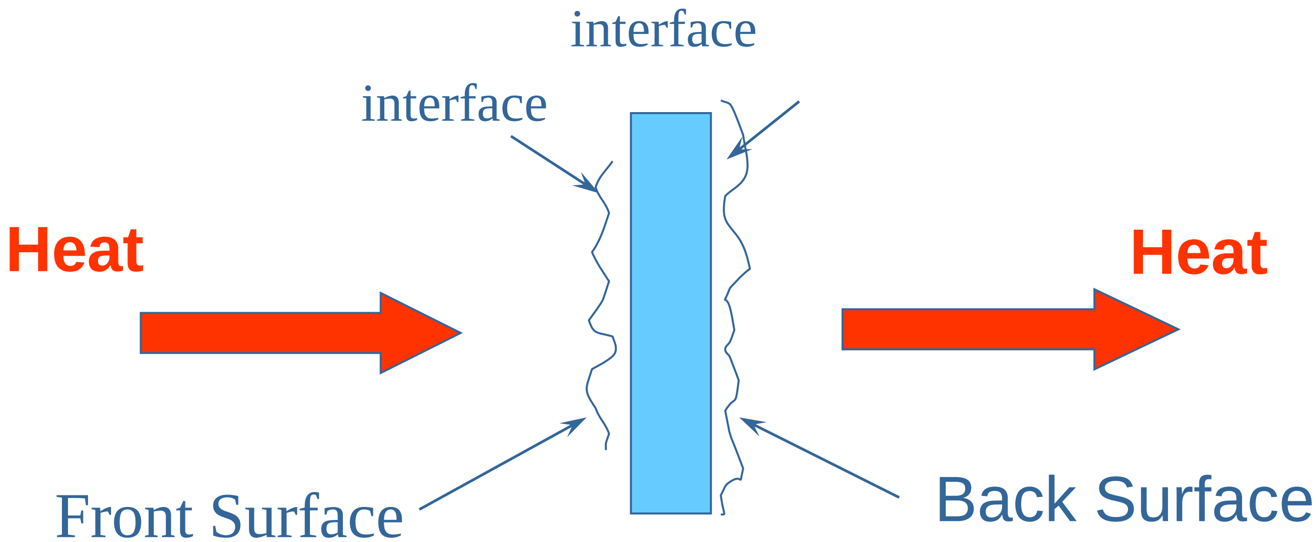
Thermal Performance

Understanding Thermal Impedance

- Thermal Impedance, Z_0 (includes interfacial resistance)



$$\text{Thermal Impedance} = \frac{\Delta T}{q}$$

Thermal Performance

Understanding Thermal Impedance

- Thermal Impedance, Z_0
  - ✓ The total opposition that an assembly (material and material interfaces) presents to the flow of heat.
  - ✓ Defined as temperature drop across one or more layers of materials subjected to a unit steady state heat flow rate
  - ✓ Interfacial thermal resistance (contact resistance) is highly variable and changes with pressure, texture, time and temperature
  - ✓ S_I unit is: $$\frac{Kelvin}{Watt}$$

Thermal Performance

Measurement Methods

- Thermal Conductivity (k) - ASTM D5470
- Thermal Resistance (Rq) - ASTM D5470
- Thermal Impedance (Z_0) - 1) ASTM D5470

  2) Bergquist Q1502

  3) Bergquist Application Test RD2018

Thermal Performance

KEY TAKE-AWAY POINTS

1. **Thermal conductivity** (k) is an **inherent property** of a material.
   – This property can be used for a sales agreement specification.

2. **Thermal resistance** (Rq) is an inherent property for each **thickness** of a material with a given thermal conductivity.
   – This property can be used for a sales agreement specification.

3. **Thermal impedance** (Zq) **varies** with thermal conductivity, thickness, area, interfacial thermal resistance, and test method used.

Thermal Performance

KEY TAKE-AWAY POINTS (cont)

4. **Interfacial thermal resistance** is **dependent** on heat source, time, texture, force and temperature

5. **Thermal impedance** (Zq) **cannot be used for a sales agreement specification due to interfacial resistance variables.** This variability has forced the thermal community to develop the methodology of D5470 measuring thermal resistance (Rq) and thermal conductivity (k).

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Thermal Substrates (MCPCB) Intro:

What is a Thermal Substrate?

- ✓ Metal clad printed circuit board used for surfacemount components and COB technologies
- ✓ Used to efficiently remove heat from the components, transfer and spread it in the metal substrate
- ✓ It gives a very good thermal / mechanical means of connecting to a heat sink
- ✓ It provides the best solution available to improve system performance and reliability by reducing component temperature

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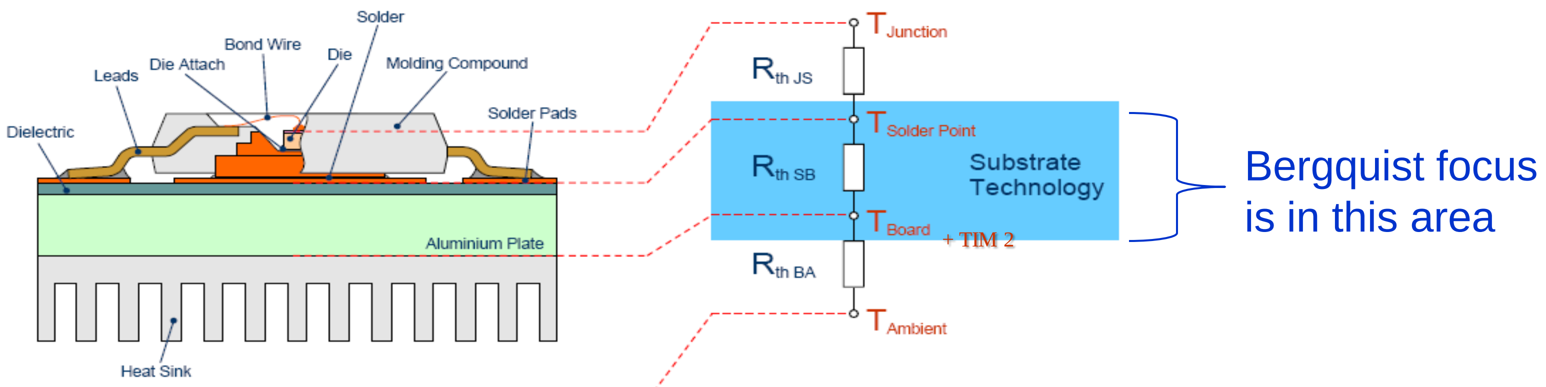
The role of a MCPCB in an LED lighting system

- R_T is the sum of all components within the thermal path
  - $R_T = R_{j\text{-}c} + R_{TIM1} + R_{MCPCB} + R_{TIM2} + R_{s\text{-}a}$



Thermal System Configuration

Thermal Resistor Network

Source: Osram Opto Semiconductor

Smaller package footprints and lower Thermal Resistance LED's is driving the need for lower thermal impedance MCPCB materials

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Choosing the appropriate MCPCB material stack up

Substrate material selection can vary with LED selection

- The lower the thermal resistance of the LED package the greater the need for a higher performing substrate material

a) Copper circuit foil thickness is selected based on current carrying capacity needed and surface heat spreading objectives

b) Dielectric thermal performance is selected based on LED's thermal resistance & power density

c) Base metal is selected based on thermal performance and mechanical/structural requirements

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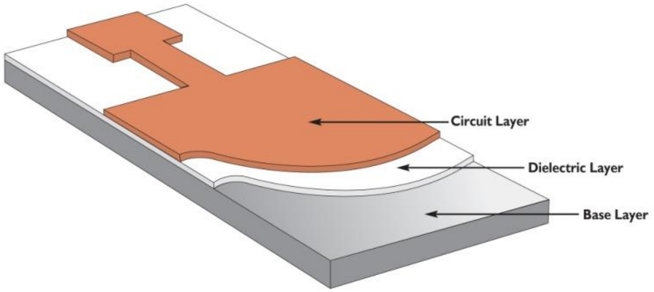
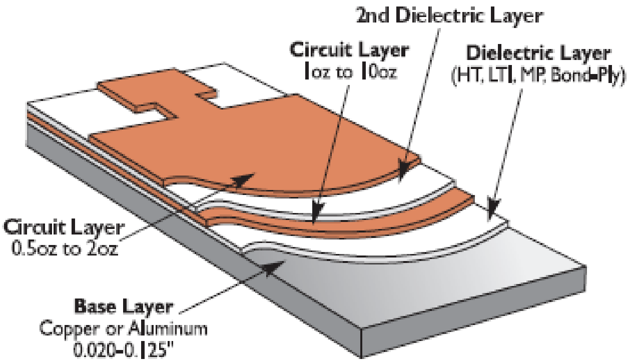
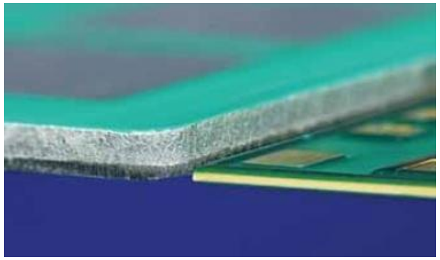
MCPCB Substrate Technology

Available Systems

- Single Layer – most common
- Double Layer – increased routing area
- Ultra Thin Substrate – can be formed







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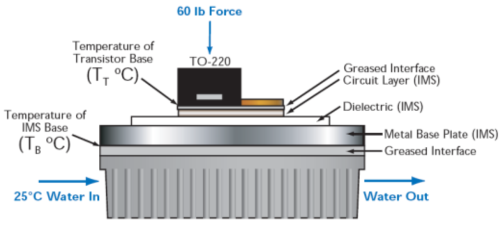
IMS – Dielectric Characteristics

Thermal Impedance

This drawing represents RD 2018 (at 40W) TO-220 thermal performance (25°C Cold Plate Testing).



Water-cooled Heatsink

$$\theta\left(\frac{^\circ C}{W}\right) = \frac{(T_T - T_B)}{40W}$$

SINGLE LAYER		THERMAL PERFORMANCE			DIELECTRIC PERFORMANCE		OTHER		
Part Number	Thickness[1] [.000"/µm]	Impedance[2] [°C/W]	Impedance[3] [°C in²/W] / [°C cm²/W]	Conductivity[4] [W/m-K]	Breakdown[5] [kVAC]	Permittivity[6] [Dielectric Constant]	Glass Transition[7] [°C]	U.L. Index[8] [°C]	Peel Strength[9] [lb/in] / [N/mm]
HT-04503	3/76	0.45	0.05 / 0.32	2.2	6.0	7	150	140/140	6 / 1.1
HT-07006	6/152	0.70	0.11/ 0.71	2.2	11.0	7	150	140/140	6 / 1.1
MP-06503	3/76	0.65	0.09 / 0.58	1.3	8.5	6	90	130/140	9 / 1.6
MULTI-LAYER									
HT-09009	9/229	0.90	0.16 / 1.03	2.2	20.0	7	150	150/150	6 / 1.1
HT-07006	6/152	0.70	0.11/ 0.71	2.2	11.0	7	150	140/140	6 / 1.1
CML-11006*	6/152	1.10	0.21 / 1.35	1.1	10.0	7	90	130/130	10 / 1.8
HIGH POWER LIGHTING									
HPL-03015	1.5/38	0.30	0.02 / 0.13	3.0	2.5	6	185	**	5 / 0.9

Method Description

1 - Optical
2- Internal TO-220 test RD 2018
3 - Calculation from ASTM 5470
4 - Extended ASTM 5470
5 - ASTM D149
6 - ASTM D150
7 - Internal MDSC test RD 2014
8 - U.L. 746 E
9 - ASTM D2861

**CML is available in prepreg form*
***Pending*

Note: For applications with an expected voltage over 480 Volts AC, Bergquist recommends a dielectric thickness greater than 0.003" (76µm).
Note: Maximum test voltage is a function of material and circuit design. Typical proof test does not represent the maximum.
Note: Circuit design is the most important consideration for determining safety agency compliance.

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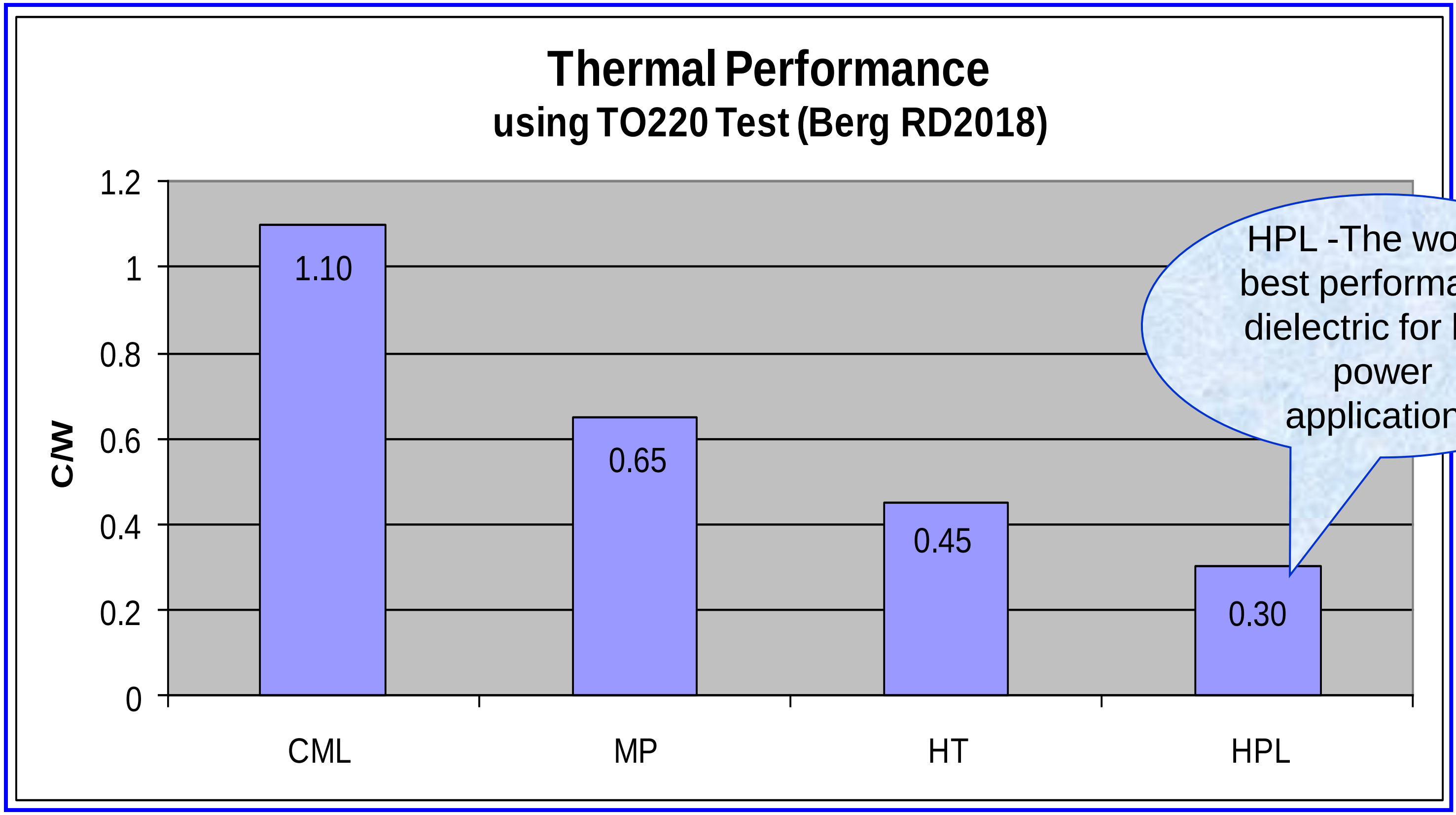
Dielectric Choices



Choose the dielectric which best suites your needs

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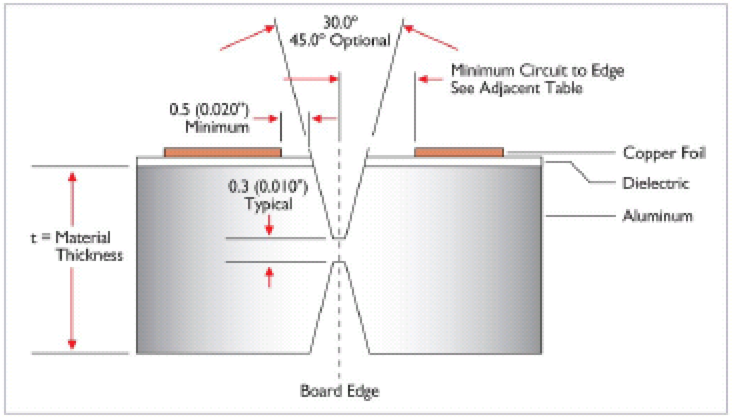
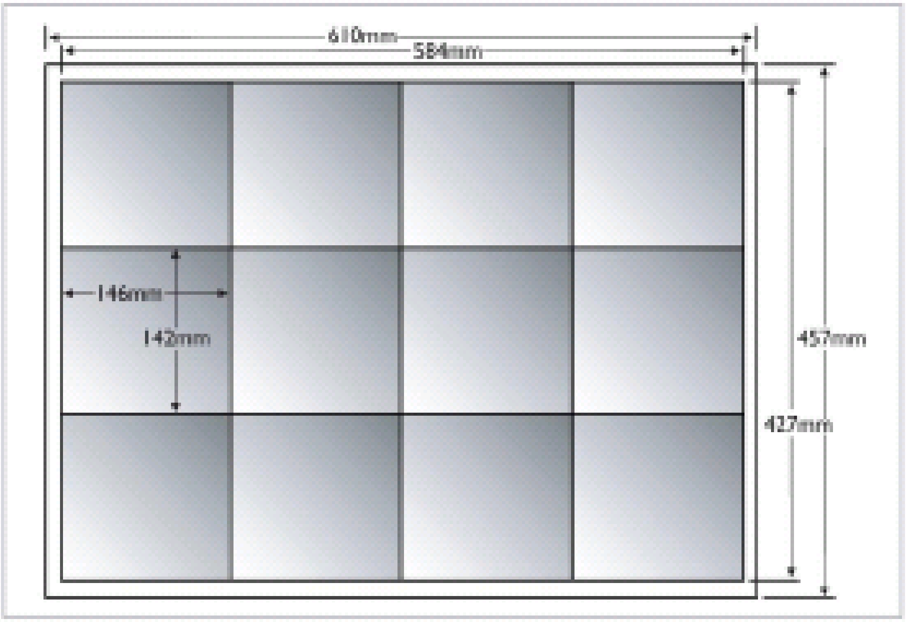
Thermal Clad Standard Material Configurations

- **Available Panel Sizes**
  - **Thickness** 0.5mm (0.020”) – 5mm (0.190”)
    - most popular thicknesses 1mm (0.040”) 1.57 (0.062”)
  - 18” x 24” (457mm x 610mm)
    - usable area 17” x 23” (432mm x 584mm)
  - 20” x 24” (508mm x 610mm)
    - usable area 19” x 23” (482.6mm x 584.2mm)
  - 18” x 25” (457mm x 635mm)
    - usable area 17” x 24” (432mm x 610mm)
- **Aluminum**
  - 6061 T6 (easy to machine)
  - 5052 H34 (lower cost & bendable)
- **Copper**
  - C1100 FH (full hard)

Thermal Clad standard v-score

- V-scored parts tend to utilize the material most efficiently
- Eliminates the need for hard tooling required with a punched part
- Easy to separate from panel





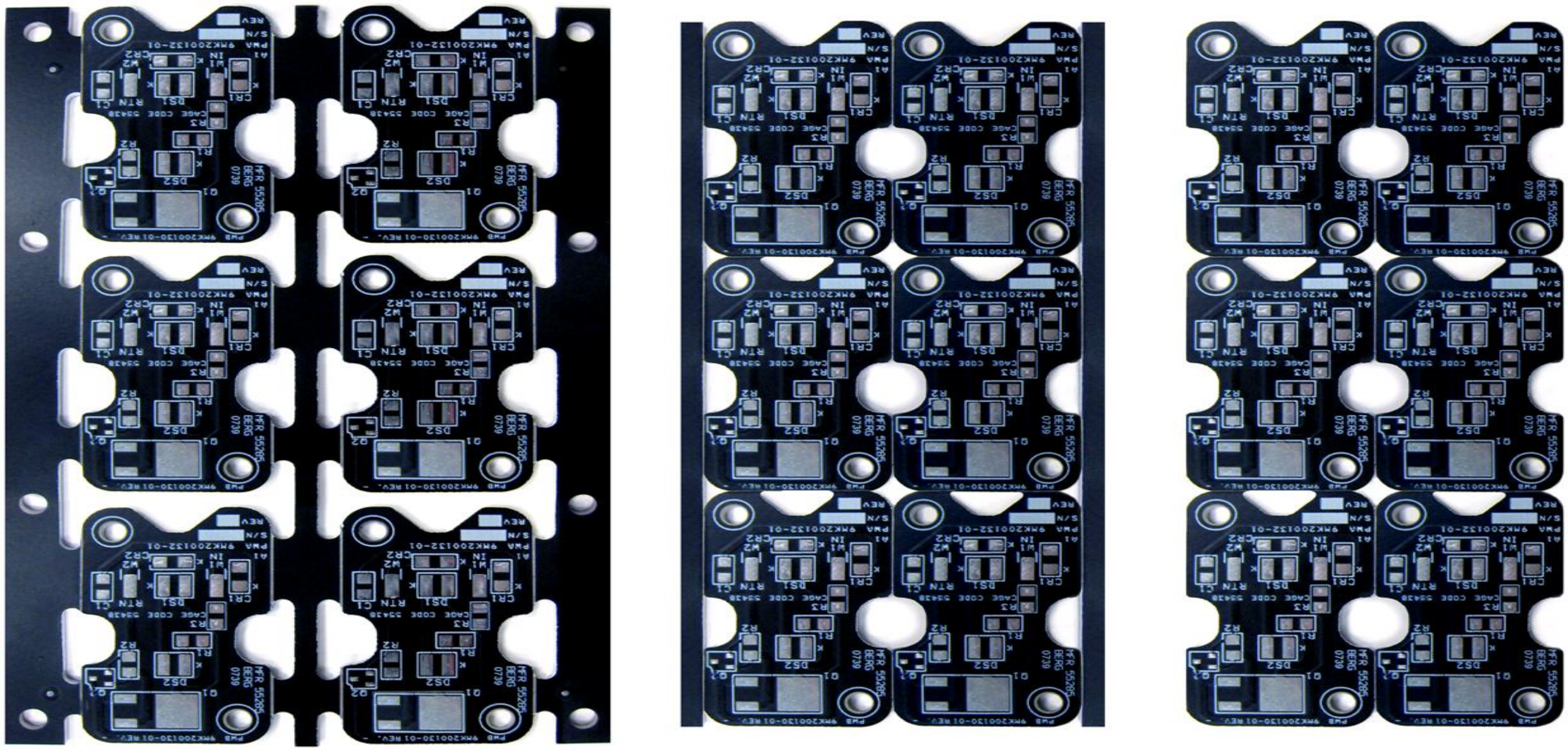
MCPCB surface finish options

- Soldermask
  - White
  - Black
  - Green
  - Red
  - Blue

  Typically LPI (liquid photo imagable)

- Pad finishes
  - HASL (with lead) - solder with lead
  - HASL (lead free) – solder without lead
  - OSP – organic surface preservative
  - ENIG – electroless nickel immersion gold
  - ENEPIG – electroless nickel electroless palladium immersion gold

Standard punch / v-score combinations

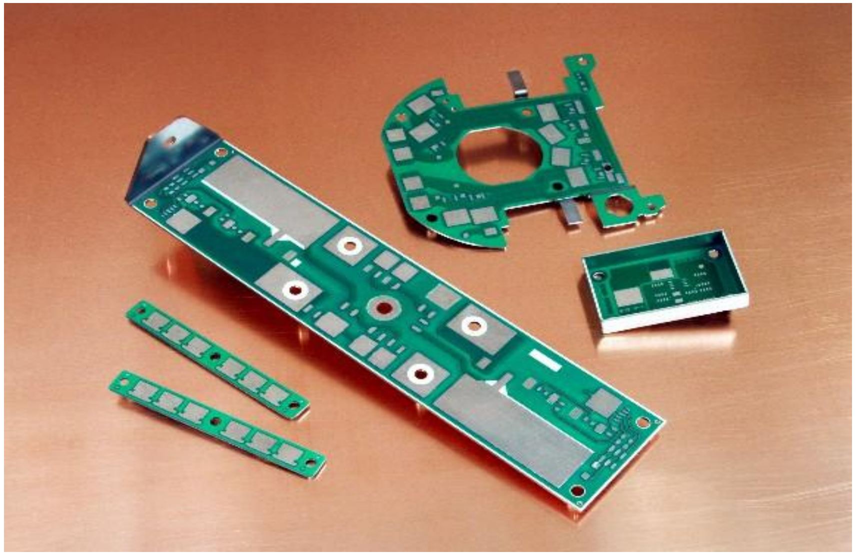


Material utilization is key in reducing cost

Advanced Substrate Technology

Formed MCPCB

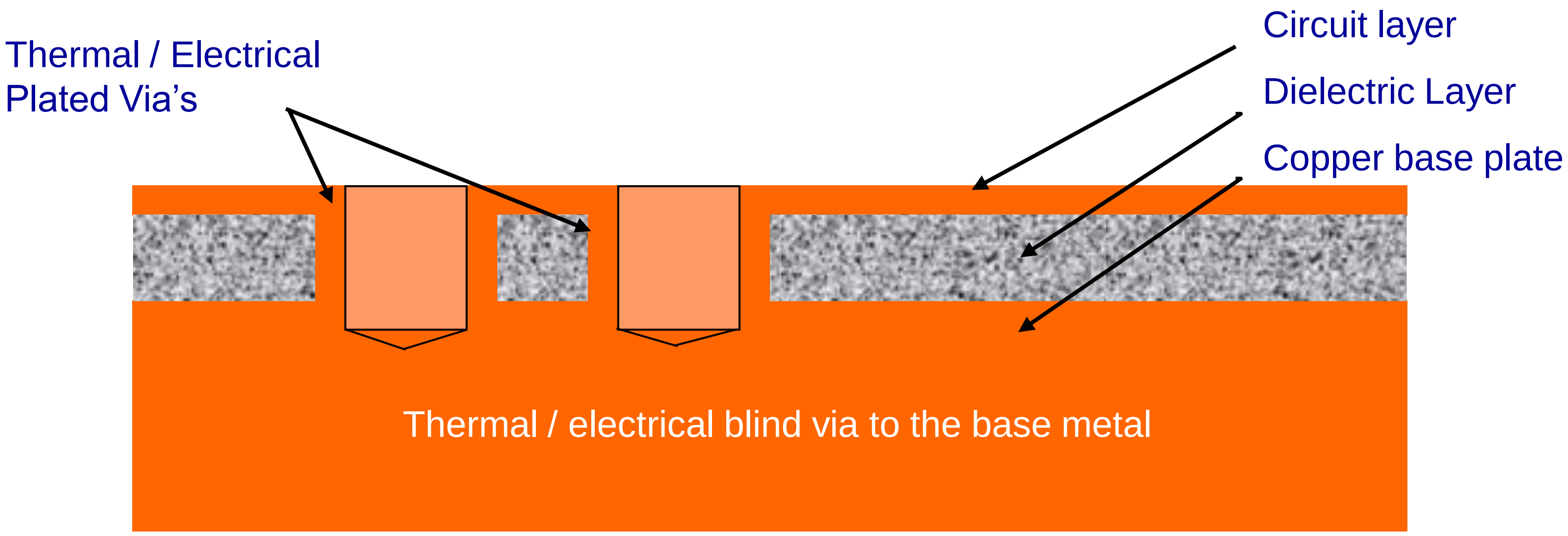
- Allows the substrate to be a part of the mechanical structure
- Can be single or two layer constructions
- Circuits cannot be routed around corners (yet)
- Base can be electrically active



Advanced Substrate Technology

Active Copper Base Plate

- ✓ Copper base with blind plated via's
- ✓ Can be a multilayer construction
- ✓ Laser drilling can enable the hole to stop at any copper layer



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Advanced Substrate Technology

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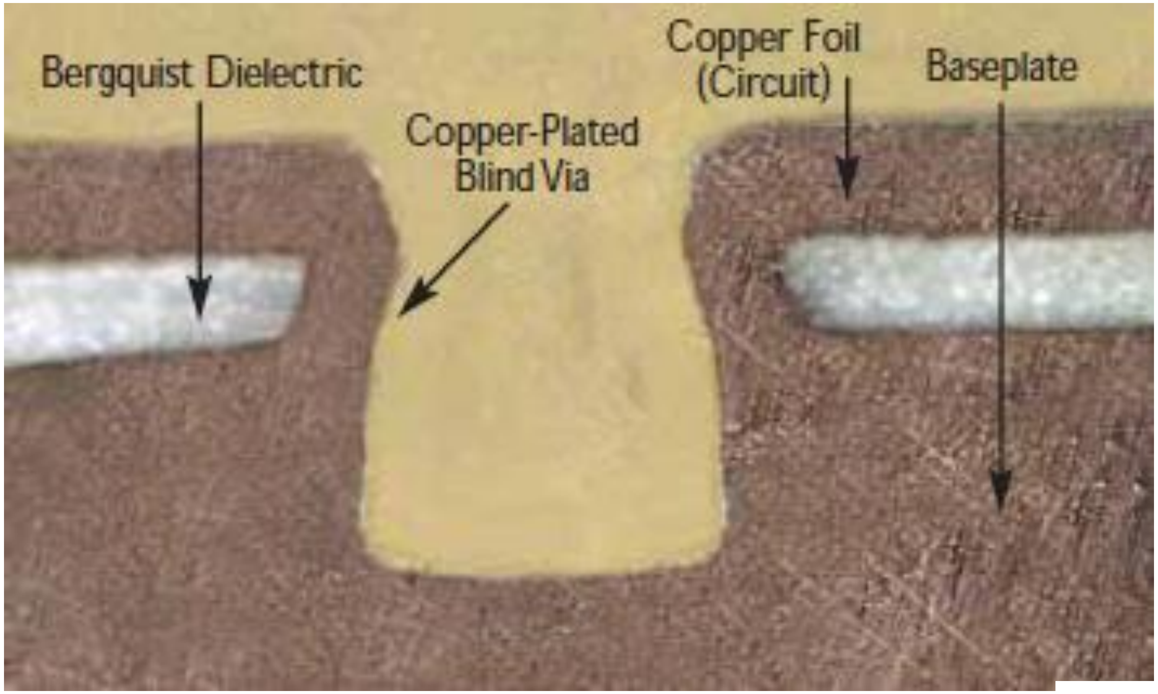
- ✓ Copper base with blind plated via's



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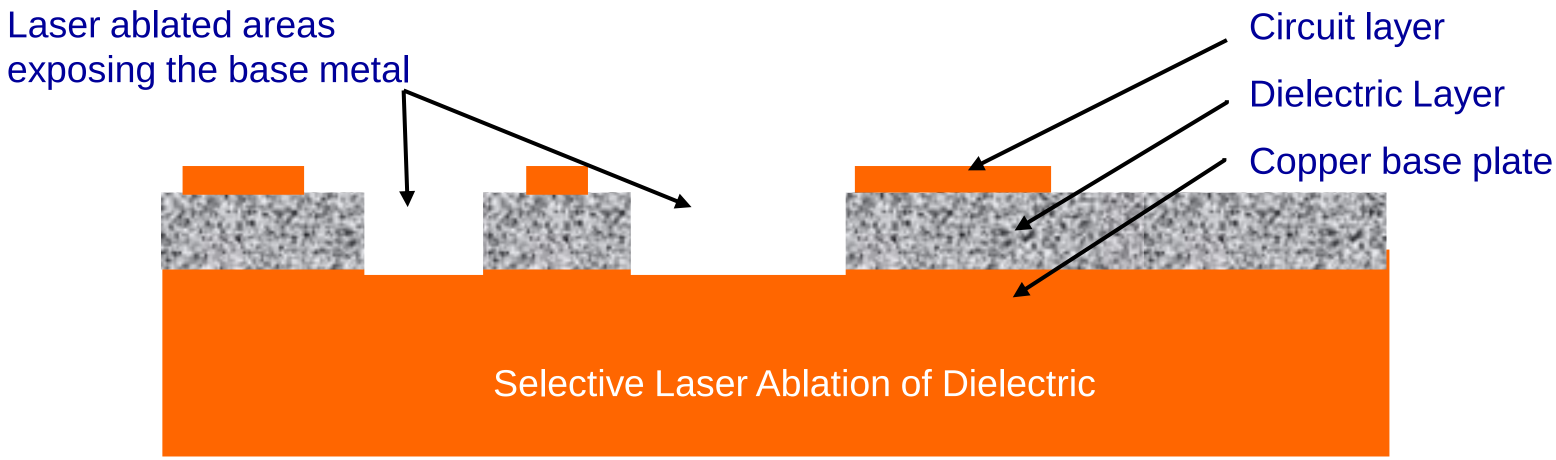
Advanced Substrate Technology

Selective Dielectric Removal

- Selective removal of dielectric - using a Co2 laser
- Tight tolerance capability - ± 0.05mm feature size and positional accuracy
- Reduce thermal resistance by mounting components directly to base metal



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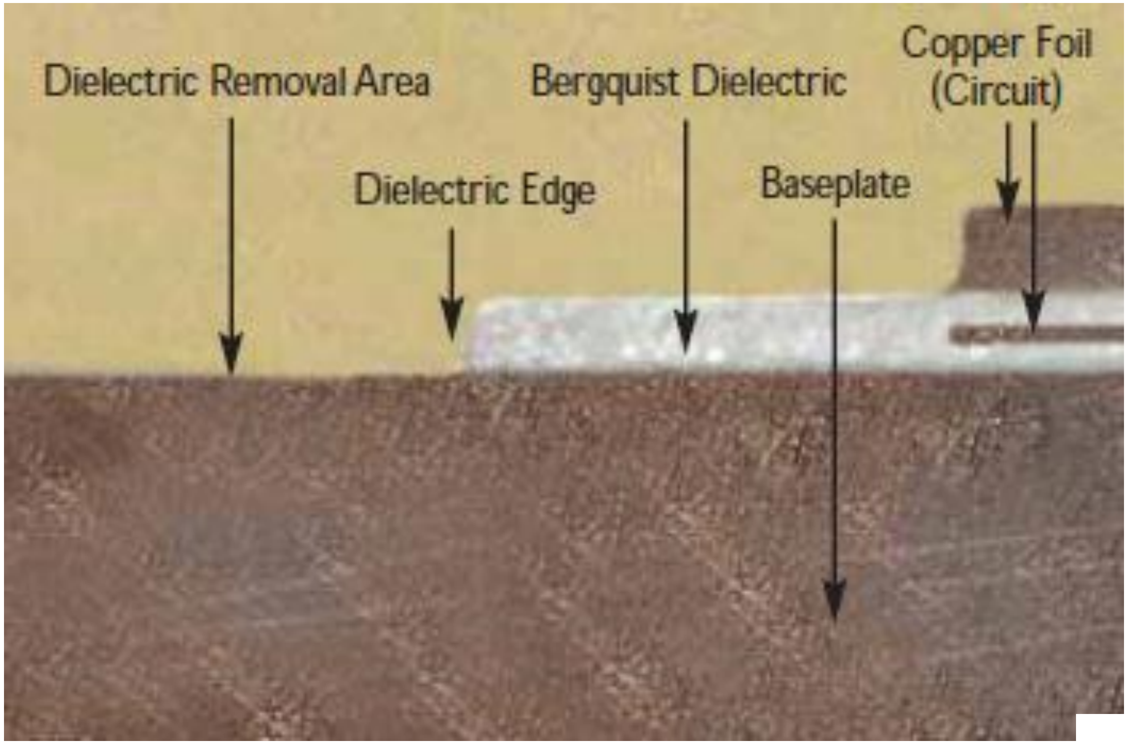
Advanced Substrate Technology

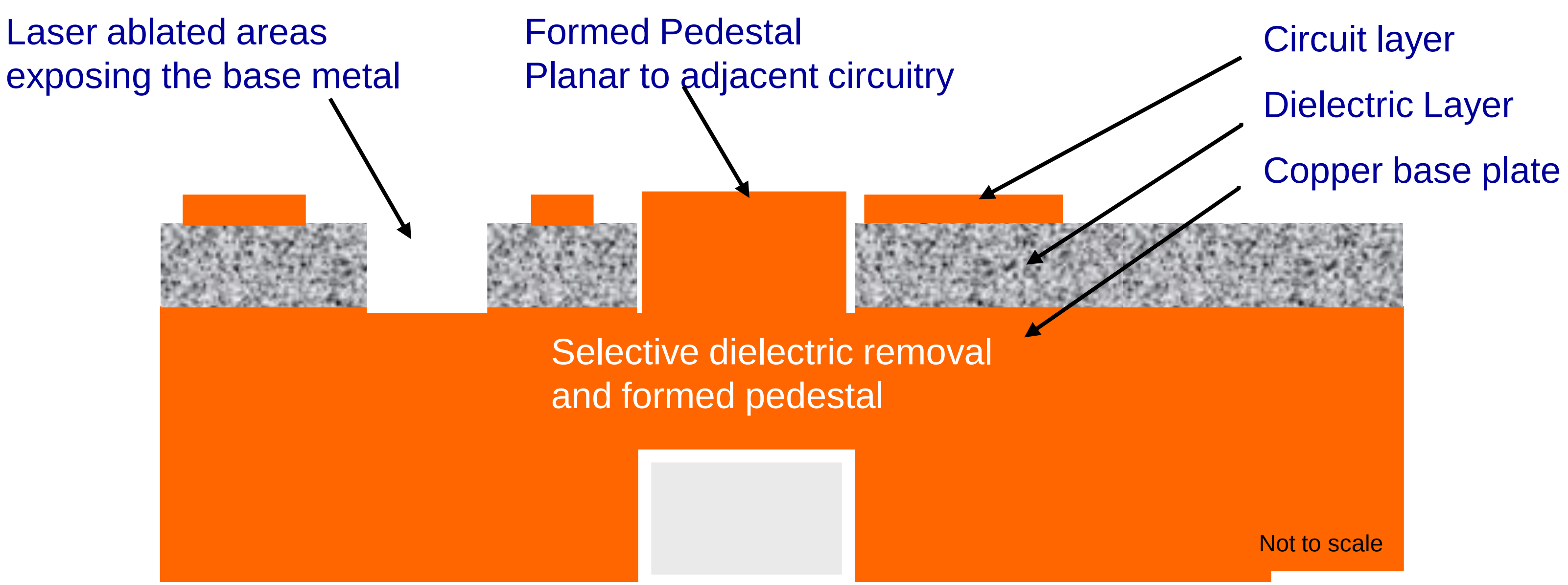
Selective Dielectric Removal



Advanced Substrate Technology

Formed Pedestal

- Form base metal to be planar with adjacent circuits
- Minimizes solder bond line when component or die attach to base metal



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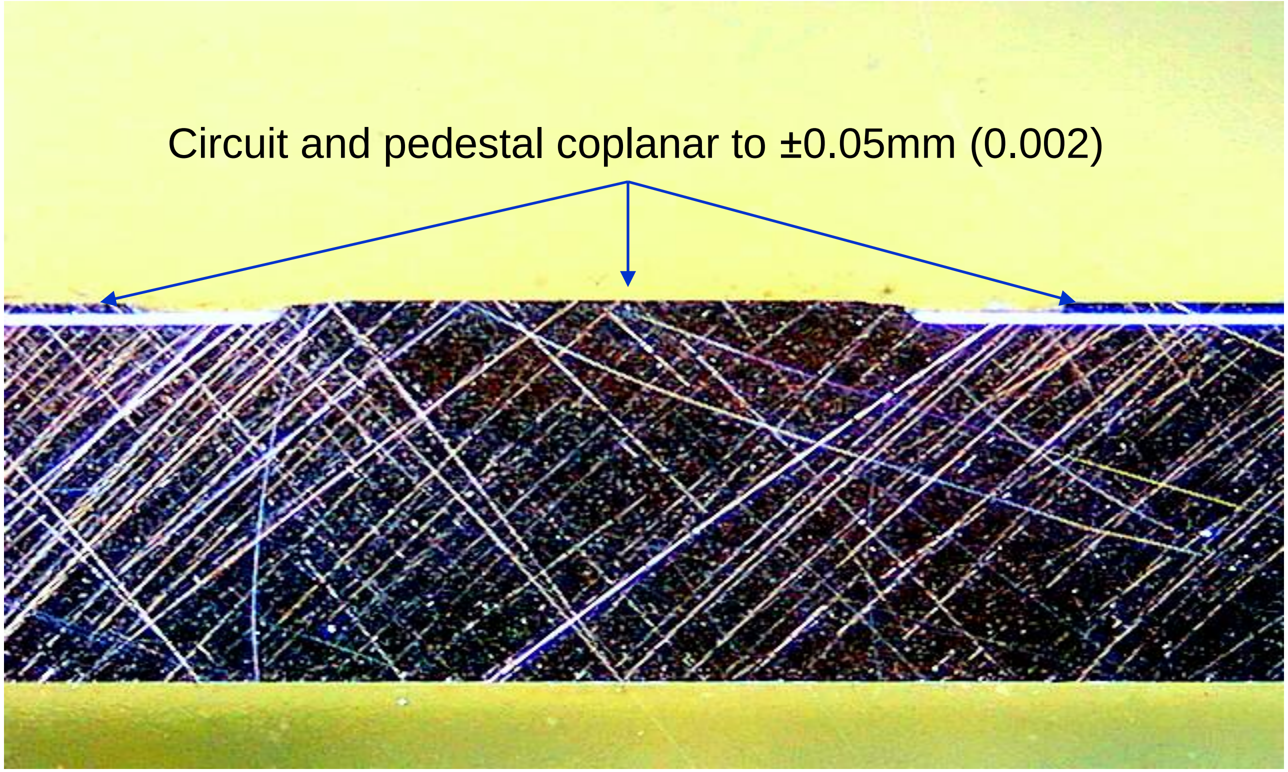
Cross Section of Pedestal Board



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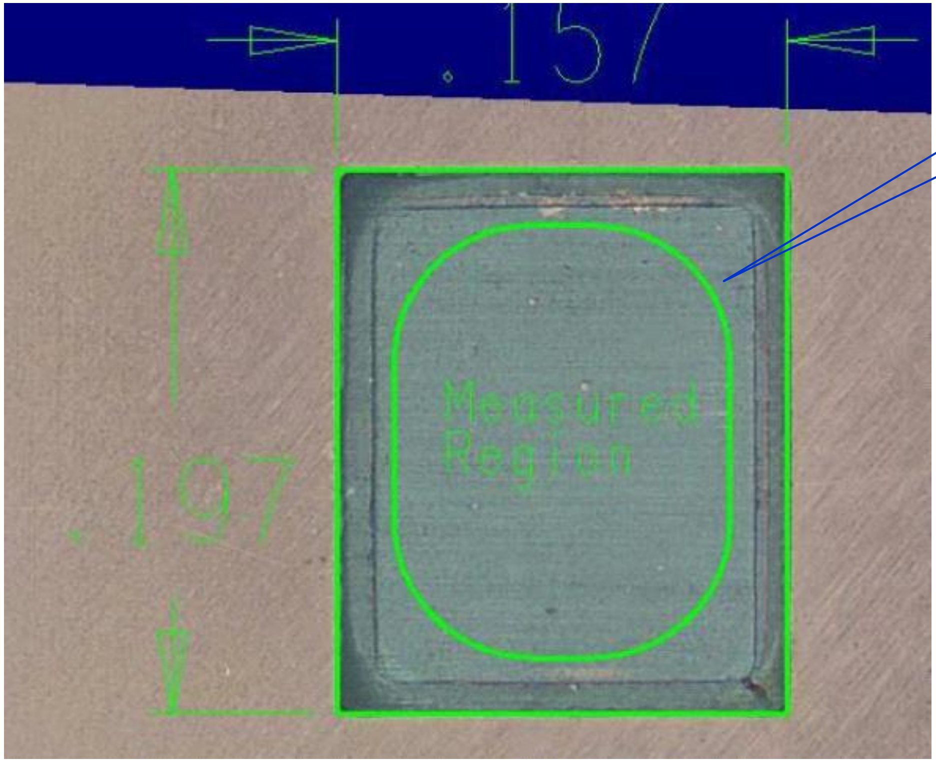
Planar Solder Area inside line

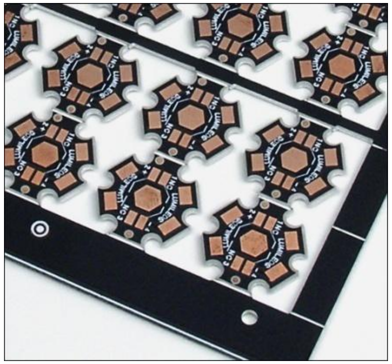


Radius begins

Cost Drivers

- BOM
  - AL vs CU , & thickness
  - Circuit foil weight 1oz vs 10oz
  - Dielectric type and thickness
- Form Factor
  - Number of layers
  - Shape – round vs square
- Panel Utilization
  - What percentage of the panel is utilized
- Non Standard holes
  - c-sinks
  - Threaded
- Surface finishes
- Single piece or panelized array

Key Advantages of the IMS Technology



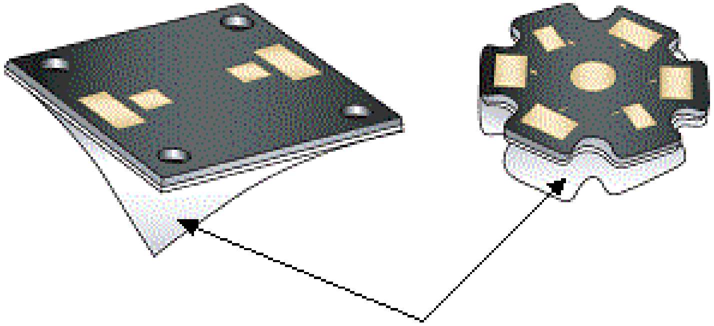
- Measurable improvement in Watt-Density
- Simplified thermal design – due to IMS
- Reliability – dielectric and base plate integrity
- Array panelization available
- Structural rigidity which allows for features like threaded holes
- Variety of configurations available

  - shape, dielectric & base plate

  - surface finishes for soldering and wire bonding

  - option for direct die bond to base plate

Combining IMS and Thermal Interface Materials



Bond Ply 450PA is pre-applied PSA thermally conductive tape
withstands Reflow temperatures
> easy peel and place <

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Thermal Clad® - IMS Insulated Metal Substrate

KEY TAKE-AWAY POINTS

1. Three basic performance related decisions
   - **base metal** – type and thickness, **dielectric performance** and thickness and copper **circuit foil** thickness

2. **Soldermask** color and solder pad **surface finish**

3. **Part geometry** (shape) and format, single up or array

4. You may want to **consider a pre applied TIM** to improve performance and reduce cost

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MCPCB's and TIM Considerations for High Power LED Lighting Applications

Outline

- Thermal management is key to your design
- Thermal performance of high power LED's
- Understanding thermal performance (reference data)
- MCPCB material options and part geometry
- Long term reliability concerns
- **TIM selection considerations, options that are available**
- Conclusions

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Thermal Interface Materials (TIM) Intro:

What is Thermal Interface Material?

- ✓ Used to optimize & achieve *consistent* thermal performance at component assembly interfaces

- ✓ Assembled interface surfaces do not align well due to planar mis-alignment (Micro & Macro)

- ✓ The consistent lowest cost solution

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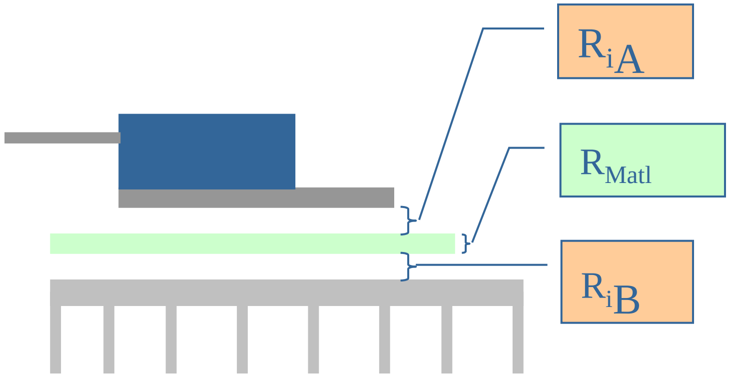
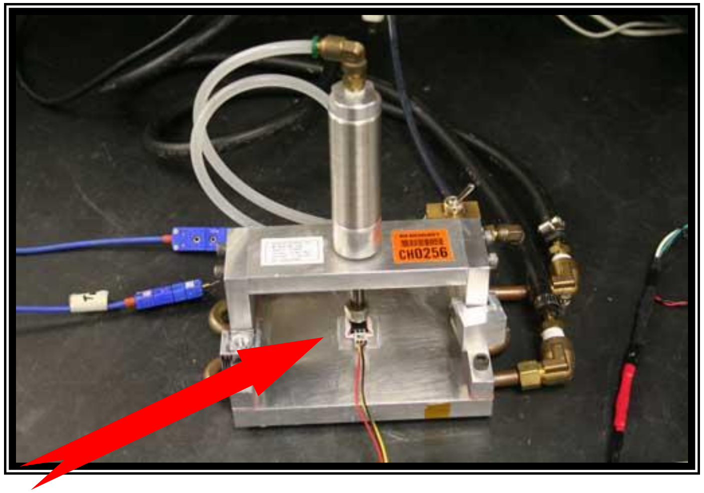
Thermal Interface Materials (TIM) Intro:

TIM performance is typically optimized by:

- Maximizing thermal conductivity
- Maximizing wet-out (maintaining contact to adjacent surfaces)
- Minimizing bond line thickness





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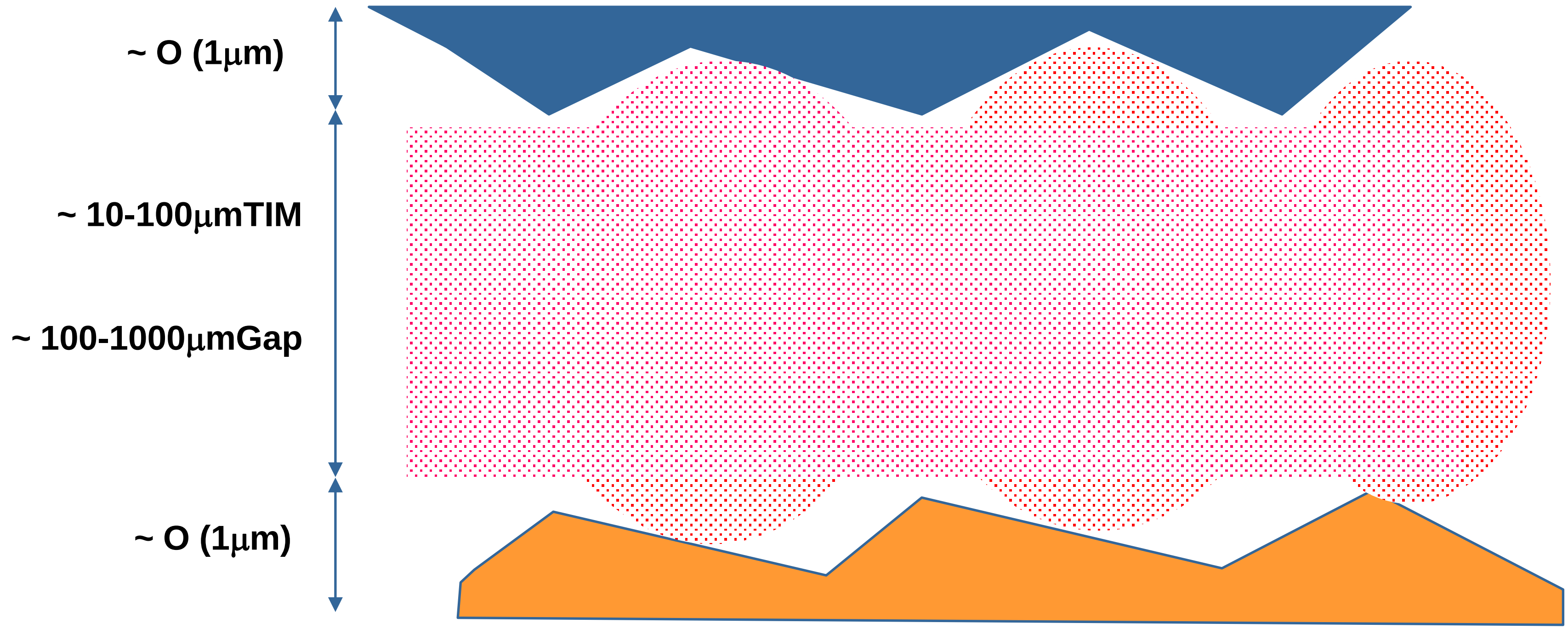
Thermal Interface Materials (TIM) Intro:

Typical Interface

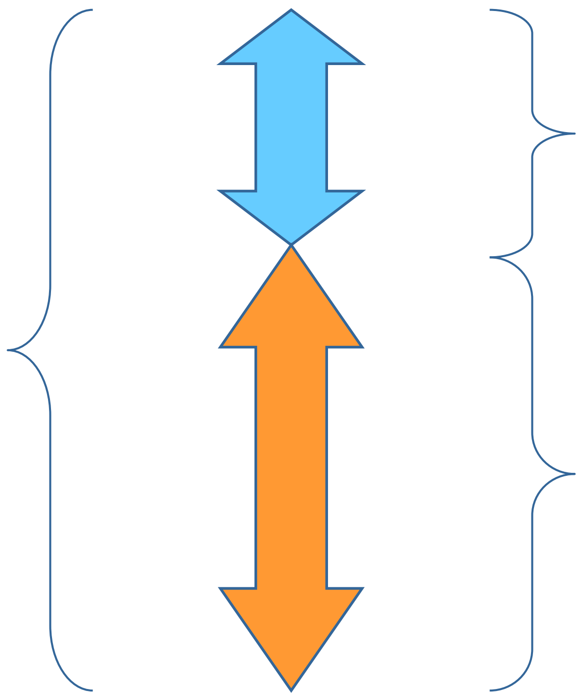


Thermal Interface Materials (TIM) Intro:

Variables affecting Thermal Performance

R_T

Total Thermal Impedance Associated with TIM



R_i

Contact Resistance

- Complex to define-
- Surface Profile,
- Rheology
- Surface Tension
- Filler Attributes

R_B

Bulk Resistance

- L/k
- L is TIM thickness
- k is TIM Thermal Conductivity
- K depends on filler and concentration

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Thermal Interface Materials (TIM) Intro:

Overview of TIM technologies today:

- Insulator Pads
- Gap Pads and Fillers
- Phase Change
- Adhesive Tapes
- Liquid Adhesives
- Compounds

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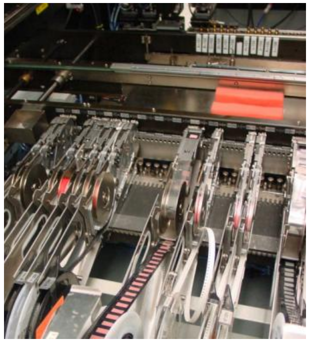
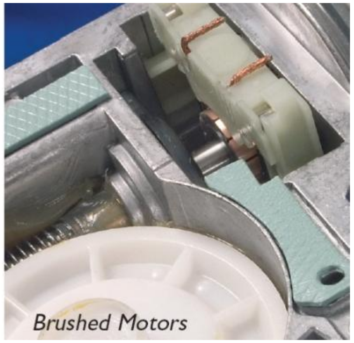
Thermal Interface Materials (TIM) Intro:

TIM construction and forms:

- ✓ Silicone & Sil-Free resin systems (Liquid or Pad Form)
- ✓ Thermally enhanced fillers (Al, BN, Al_2O_3, Al N…
- ✓ Carriers – pad form (Films, F/Glass, SP, Unsupported)
- ✓ Protective release Liners – Pad Form (PET, HDPE, LDPE…)
- ✓ Syringes, Tubes, Pails – Liquids (5 cc to 19k cc)





Thermal Interface Materials (TIM) Intro:

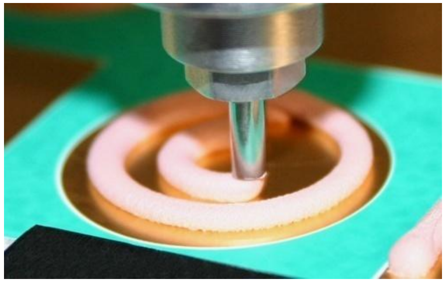
Insulator Pads

- Insulator pads were the first thermally conductive insulators to replace mica and grease
- Insulator pads reduce the overall manufacturing costs of OEMs by reducing labor costs
- Insulator pads improve the overall quality and performance of electronic assemblies

Thermal Interface Materials (TIM) Intro:

Gap Pad® and Gap Fillers

- Fill gaps created with different component topology and irregular heat sink surfaces
- Originally designed to cool digital components and eliminate costly “active” cooling solutions and reduce the overall cost of the OEM
- Now are commonly used in most all electronic applications
- Often times, the gap between the component and the heat sink is large as compared to that of a thermal pad application



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Thermal Interface Materials (TIM) Intro:

Phase Change

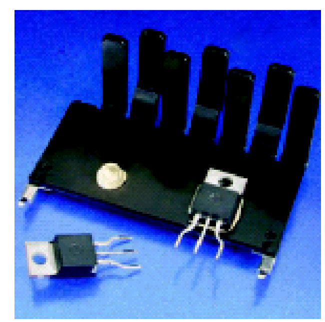
Alternative to thermal grease

- Phase change materials change from a solid at specific temperatures and flow to assure total wet-out of the interface without overflow. (phase change)
- Can easily be automated
- Offers the best thermal performance of a pad type product
- Was originally design for high end processor applications

Thermal Interface Materials (TIM) Intro:

PSA and Liquid Adhesives

- PSA can adheres materials with mismatched CTE strong enough to bond, yet soft enough to let materials expand and contract at their own rate.
- Liquid adhesives are high performance, thermally conductive, bonding materials. They tend to be less forgiving with CTE mismatch.

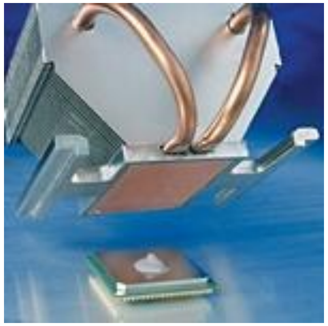


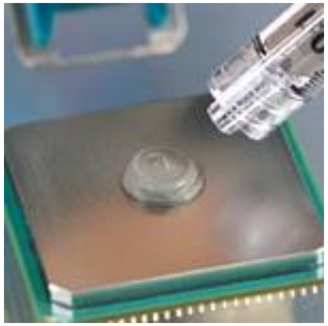
Thermal Interface Materials (TIM) Intro:

Thermal Interface Compounds

- High performance thermal greases are designed for use between a heat generating device or MCPCB and a heat sink

- Low performances greases can be used in place of high performance greases and thermal pads to reduce cost but be aware of potential long term performance issues





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- **Conclusions**

Conclusions

1. Understand the LED that you want to use
   - maximum operating temperature
   - Thermal resistance of the LED
2. Calculate the thermal stack-up
   - Considering all materials and interfaces
   - Model if can, try substituting various materials to determine best cost vs performance
3. Choose the appropriate dielectric material
   - Lower thermal resistance does not always mean lower $T\text{-}_{Rise}$
4. Choose the appropriate TIM material
   - Consider mechanical requirements
   - Try to minimize thermal resistance
5. Make sure you have an exit path for waste heat

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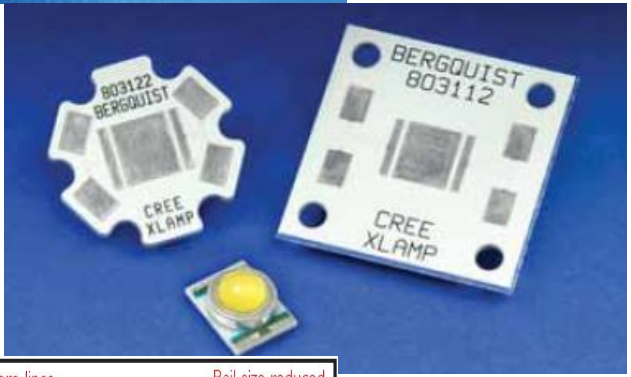
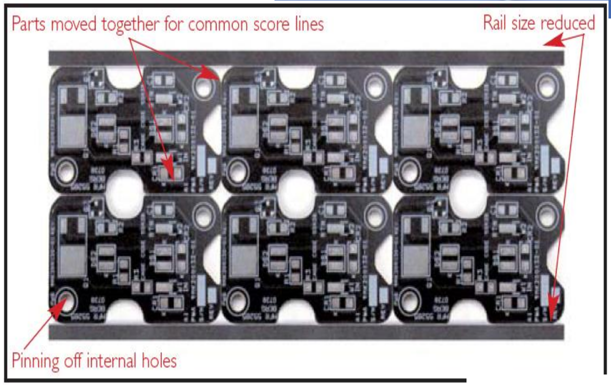
Bergquist known for

- Materials Manufacturer
  - ✓ Thermal Interface Materials
  - ✓ IMS Materials
- Circuit Provider for IMS
  - ✓ IMS circuits supplier
    - Component and COB level
    - Piece Part and Array´s
  - ✓ Active Base Plate Solutions
    - Electrical / Thermal Vias to Base
    - Selective Dielectric Removal
    - Pedestal Forming
  - ✓ Special Processes – 3D circuits





Thank you!

For more information on The Bergquist Company, please visit our website at:

www.bergquistcompany.com

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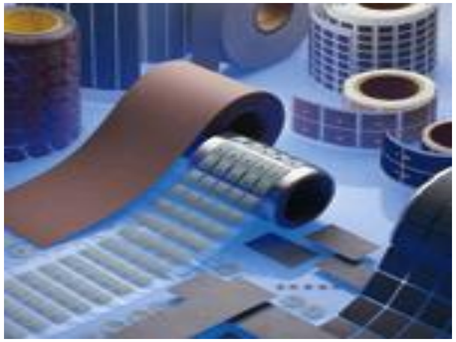
The Bergquist Company designs and manufactures high performance thermal management materials used to dissipate heat and keep electronic components cool. Our Thermal Clad® is a metal core printed circuit board (MCPCB) providing complete thermal management for COB, surface mount components, High Power LED's applications. Available in standard and custom configurations, Bergquist Thermal Clad® solutions provide better thermal management resulting in lower operating temperatures thus allowing extended LED life and increased light output. Bergquist Thermal Interface Materials are some of the best-known brands in the industry including: Sil-Pad®, Gap Pad®, Gap Fillers, Bond-Ply®, and Hi-Flow® phase change grease replacement materials

Bergquist is your total thermal management supplier

Please visit our web page at www.bergquistcompany.com



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