

PCB Carolina 2011

Thermal Management Considerations for High Power LED Lighting Applications

Presented By: Garry Wexler

November 8, 2011



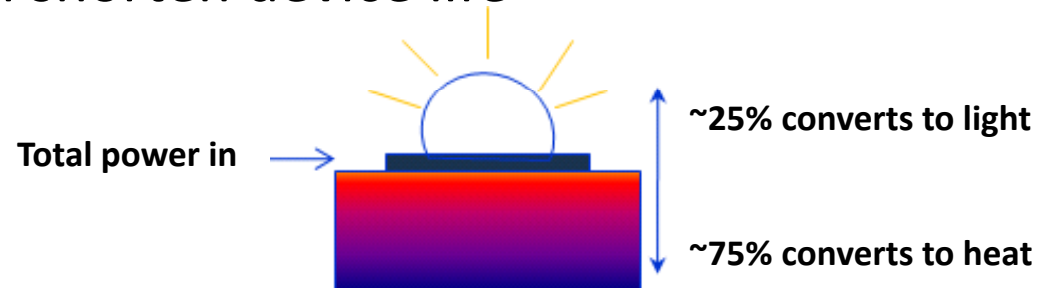
Thermal Management Considerations for High Power LED Applications

Outline

- Thermal management is key to your design
- Thermal performance of high power LED's
- PCB & MCPCB substrate options
- Thermal Interface Material (TIM) options
- Conclusions

Thermal Management is key to your design

- 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



Thermal Management is key to your design

R_T is the sum of all (5) components within the thermal path



R_T Total thermal impedance

R_{j-c} Junction-case (or package) impedance

R_{TIM2} Impedance of TIM 2 (solder or polymer TIM)

R_{board} Impedance of board (spreading and thru)

R_{TIM3} Impedance of TIM 3 (typically polymer TIM)

R_{s-a} Heat sink impedance, $\sim 1/h \cdot A$

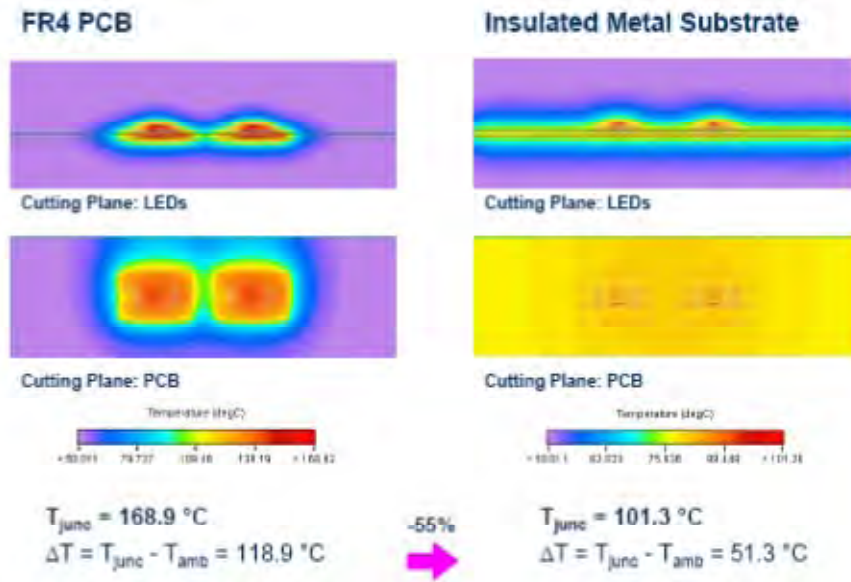
h is heat transfer coefficient, A is area

The primary heat flow path in an LED assembly is in the z axis

Thermal Management is key to your design

Model results

Comparison of FR-4 to IMS



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

Thermal Management is key to your design

Application Test comparing thermal impedance of an MCPCB with 1.1W/mK dielectric to 3W/mK

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

MCPCB: Al 1.57mm x Dielectric x 35 μ m cu

Result:

Thermal Impedance Zth

MP 1.8 – 2.0 K/W

HPL 0.8 – 1.0 K/W

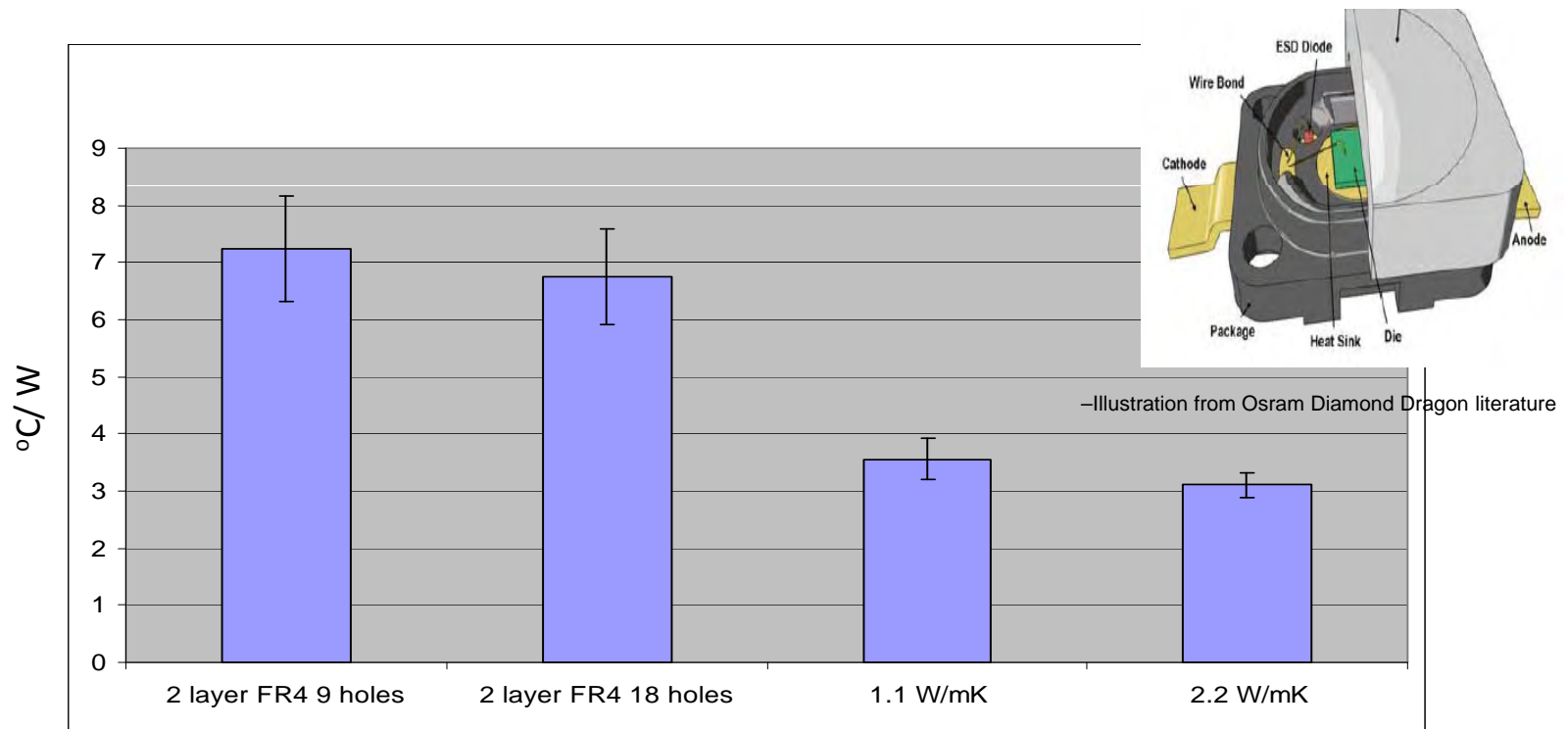


Increasing dielectric thermal conductivity from 1.1W/mK to 3W/mK
results in 2 x improvement in thermal impedance

Thermal Management is key to your design

Modeled study results

Thermal impedance of Osram Diamond Dragon on various substrates



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

Thermal Management is key to your design

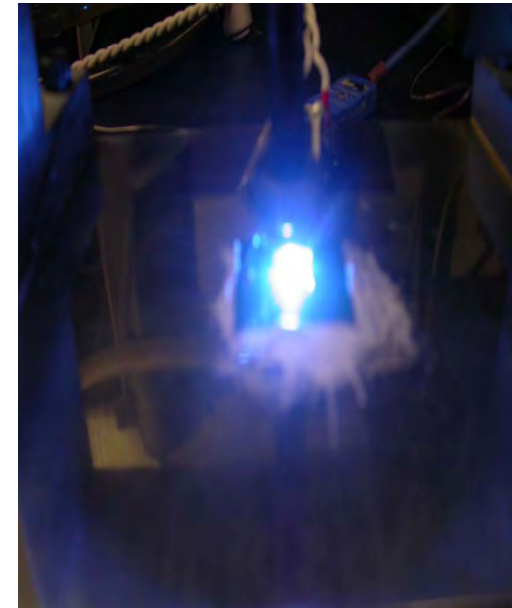
Light Output of Die on Different Dielectric Materials at ΔT of 25C



”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/Al

Thermal Management is key to your design

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, provides **more options for heat sink selection**
4. Electronic component suppliers estimate that **for every 10°C rise of the junction temperature, the device failure rate doubles**. If the waste heat generated inside a package or device is not removed, the reliability of the device is compromised

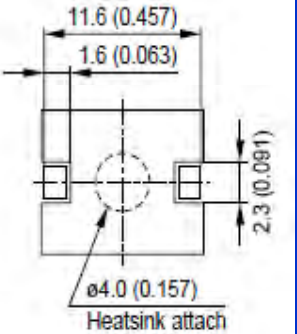
Thermal Management Considerations for High Power LED Applications

Outline

- Thermal management is key to your design
- **Thermal performance of high power LED's**
- PCB & MCPCB material options
- Thermal Interface Material (TIM) options
- Conclusions


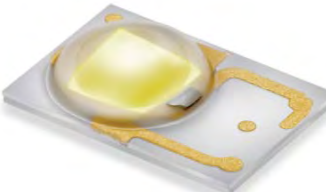
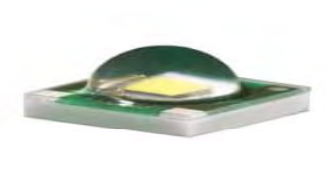

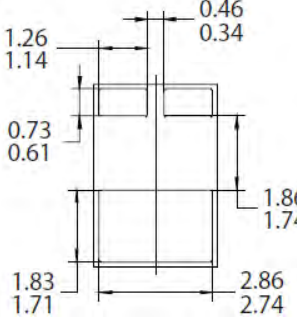
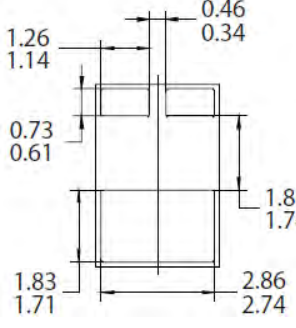
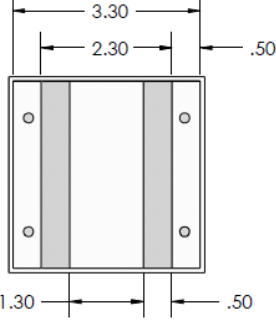
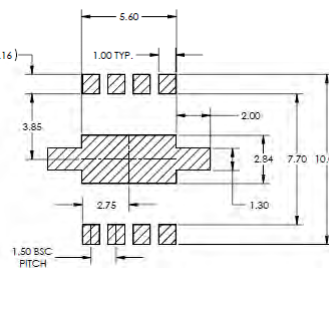
Common LED Surface Mount Components

LED's have different package styles & different $R_{th JS}$

Golden DRAGON®	Platinum DRAGON	Diamond DRAGON	OSTAR - SMT
			
ZW W5SG	LR W5SM	LUW W5AP	LE UW S2W Ultra White
			
Heat Slug area 12.6mm ² $R_{th JS}$ 15 K/W	Heat slug area 12.6mm ² $R_{th JS}$ 11 K/W	Heat slug area 12.6mm ² $R_{th JS}$ 5 K/W	Heat slug area 15.9mm ² $R_{th JS}$ 30K/W


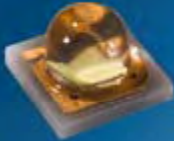


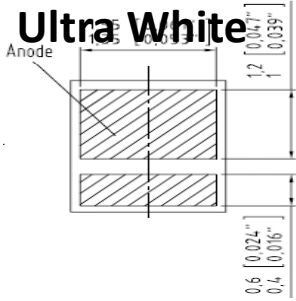
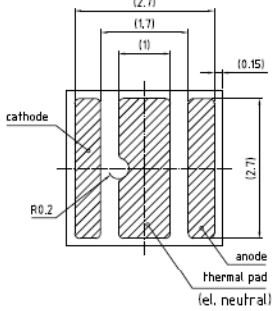
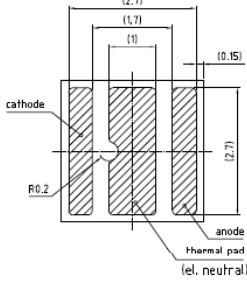
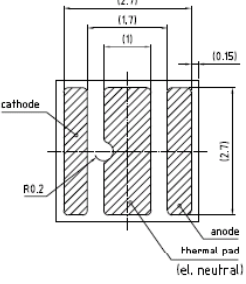
Common LED Surface Mount Components

LED's have different package styles & different $R_{th JS}$

<p>Rebel</p> 	<p>Rebel ES</p> 	<p>XLamp®</p> 	<p>XLamp®</p> 
<p>LXML-PW21</p>  <p>Heat slug area 1.86mm² $R_{th JS}$ 10 K/W</p>	<p>LXML-PWN2</p>  <p>Heat slug area 1.86mm² $R_{th JS}$ 6 K/W</p>	<p>XP-E</p>  <p>Heat Slug area 4.29mm² $R_{th JS}$ 6 K/W</p>	<p>MC-E</p>  <p>Heat slug area 21.1mm² $R_{th JS}$ 3 K/W</p>

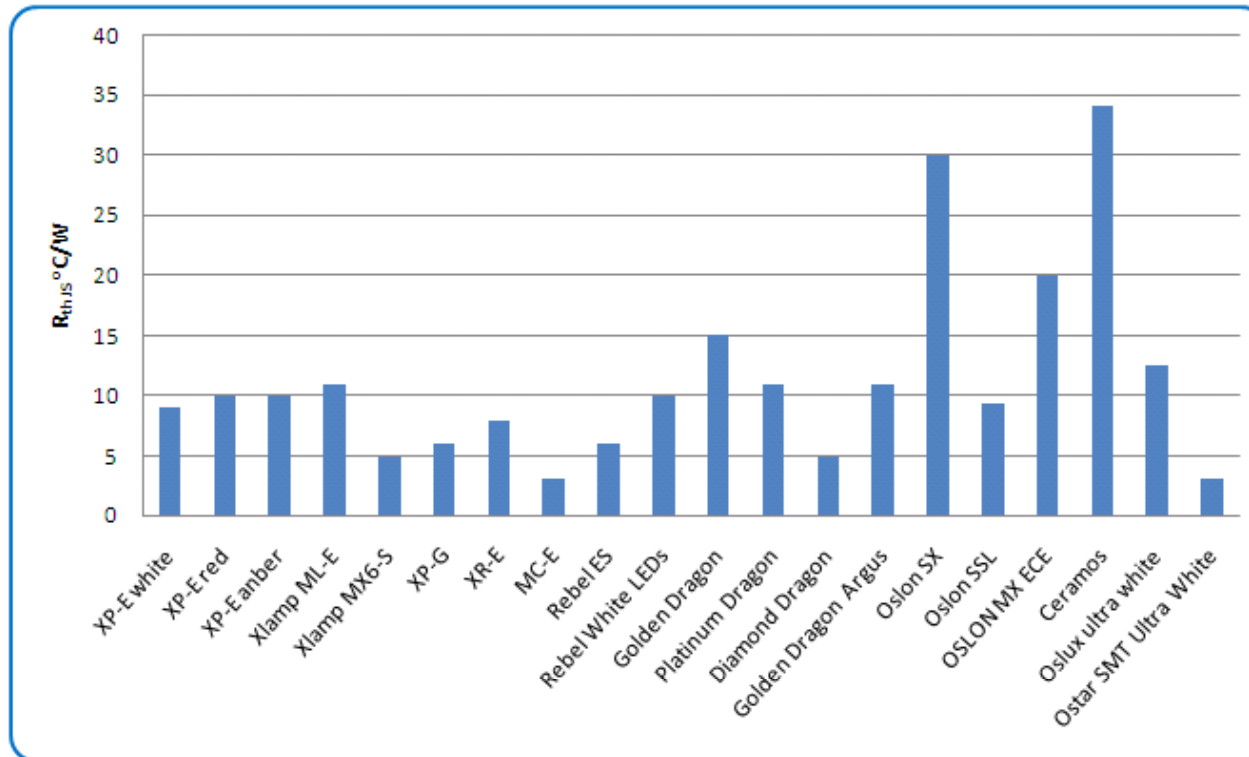
Common LED Surface Mount Components

LED's have different package styles & different $R_{th JS}$

CERAMOS™	OSLON SSL	OSLON SX	OSLON MX ECE
			
<p>LUW C9SP Ultra White</p>  <p>Anode</p> <p>Heat slug area 1.86mm² $R_{th JS}$ 34 K/W</p>	<p>LUW CP7P</p>  <p>cathode</p> <p>anode</p> <p>thermal pad (el. neutral)</p> <p>Heat slug area 2.7mm² $R_{th JS}$ 9.4 K/W</p>	<p>LUW CN5M</p>  <p>cathode</p> <p>anode</p> <p>thermal pad (el. neutral)</p> <p>Heat slug area 2.7mm² $R_{th JS}$ 30 K/W</p>	<p>LUW CN7N</p>  <p>cathode</p> <p>anode</p> <p>thermal pad (el. neutral)</p> <p>Heat slug area 2.7mm² $R_{th JS}$ 20K/W</p>

Common LED Surface Mount Components

LED's have different package styles & different $R_{th Jc}$



Smaller package footprints and lower thermal resistance LED's are driving the need for lower thermal resistance MCPCB materials

Common LED Surface Mount Components

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 resistances** from one part number to another
3. **Lowering the thermal resistance package can result in a greater benefit, such as a lower thermal impedance MCPCB**

Thermal Management Considerations for High Power LED Applications

Outline

- Thermal management is key to your design
- Thermal performance of high power LED's
- **PCB & MCPCB material options**
- Thermal Interface Material (TIM) options
- Conclusions
- Understanding thermal performance (reference data)

PCB & MCPCB Options

Common Substrate Technologies

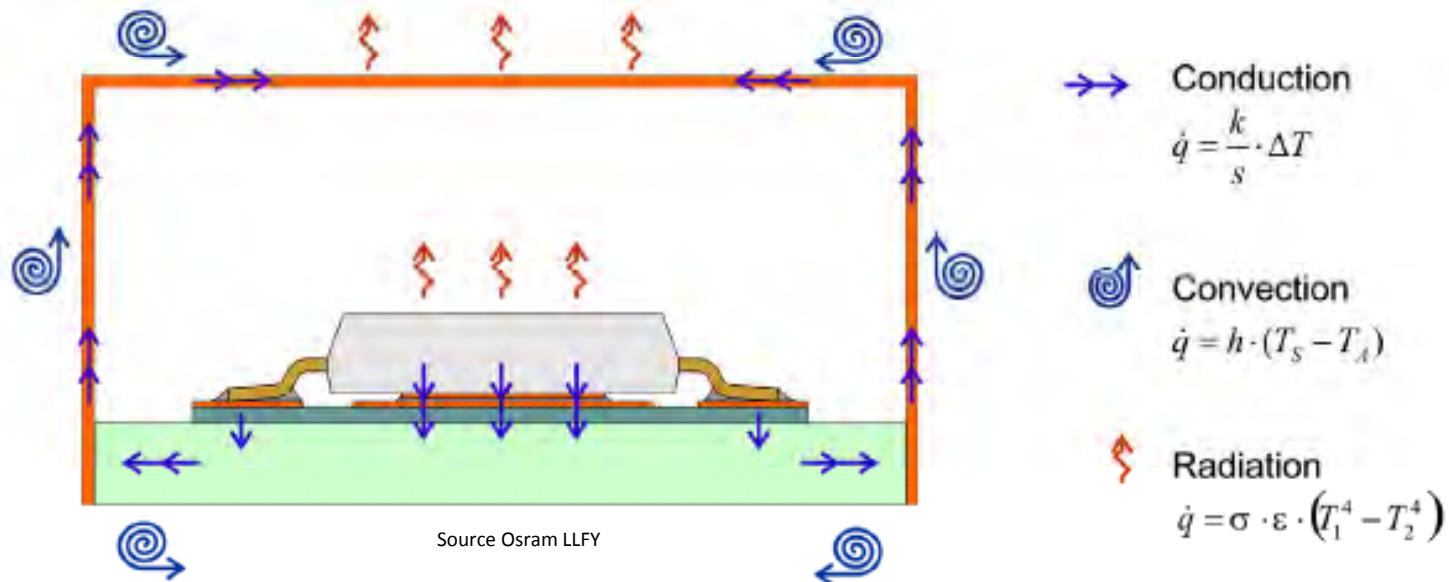
FR-4 PCB

- 2-layer with thermal via's
- 1-layer FR-4 on aluminum – 0.3W/mK

MCPCB

- 1 or 2 layer on aluminum or copper base
- Thermally conductive dielectric options ranging from 0.8W/mK – 3W/mK

LED assembly heat transport methods



Determining the exit path for thermal energy is important
concentrate on conduction and convection

MCPCB substrates

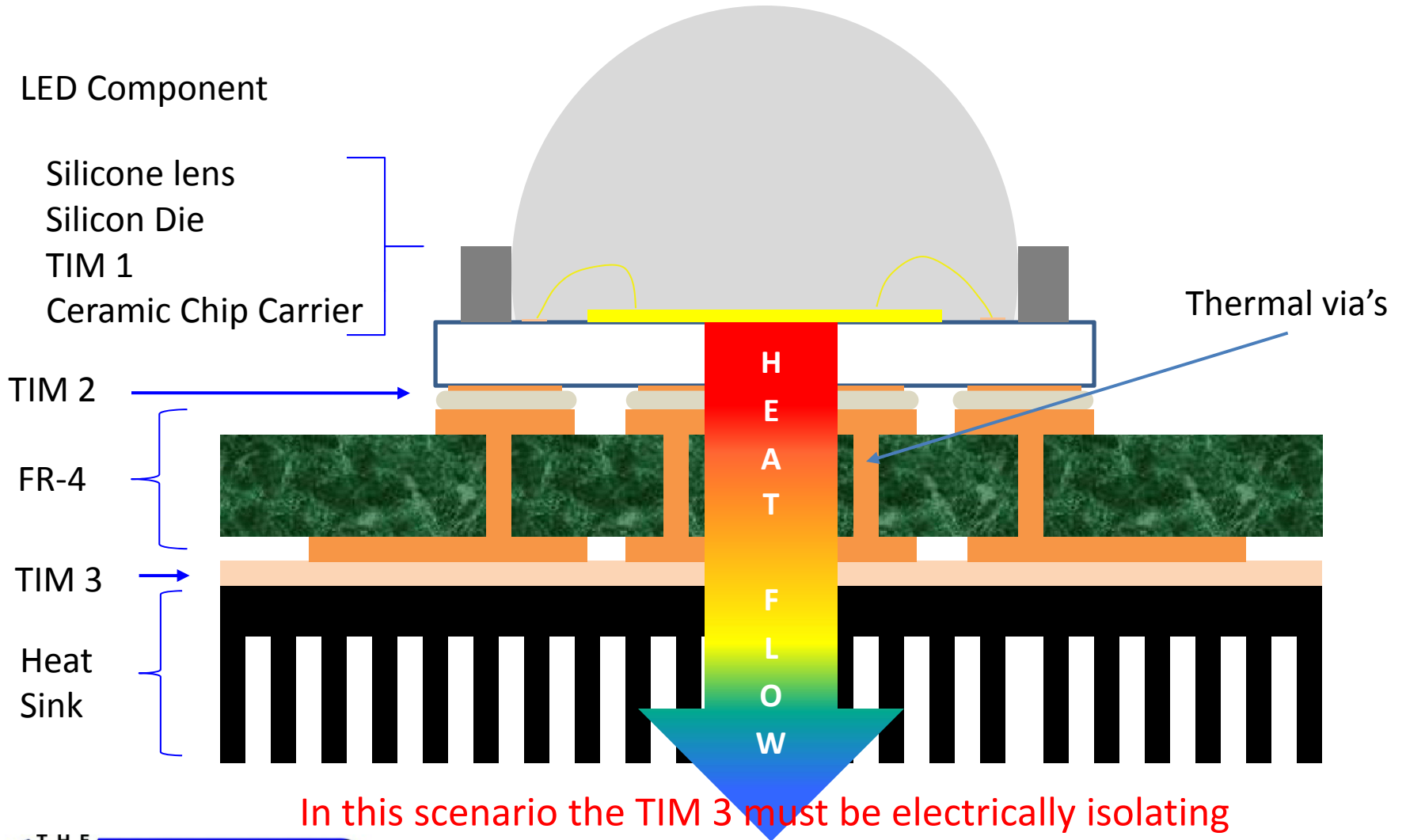
Basic Rule of Thumb for one dimensional heat flow

Under the assumption of a one-dimensional heat flow, the thermal resistance (R_{th}) of a piece of material is generally given by
$$R_{th} = \frac{d}{\lambda A}$$

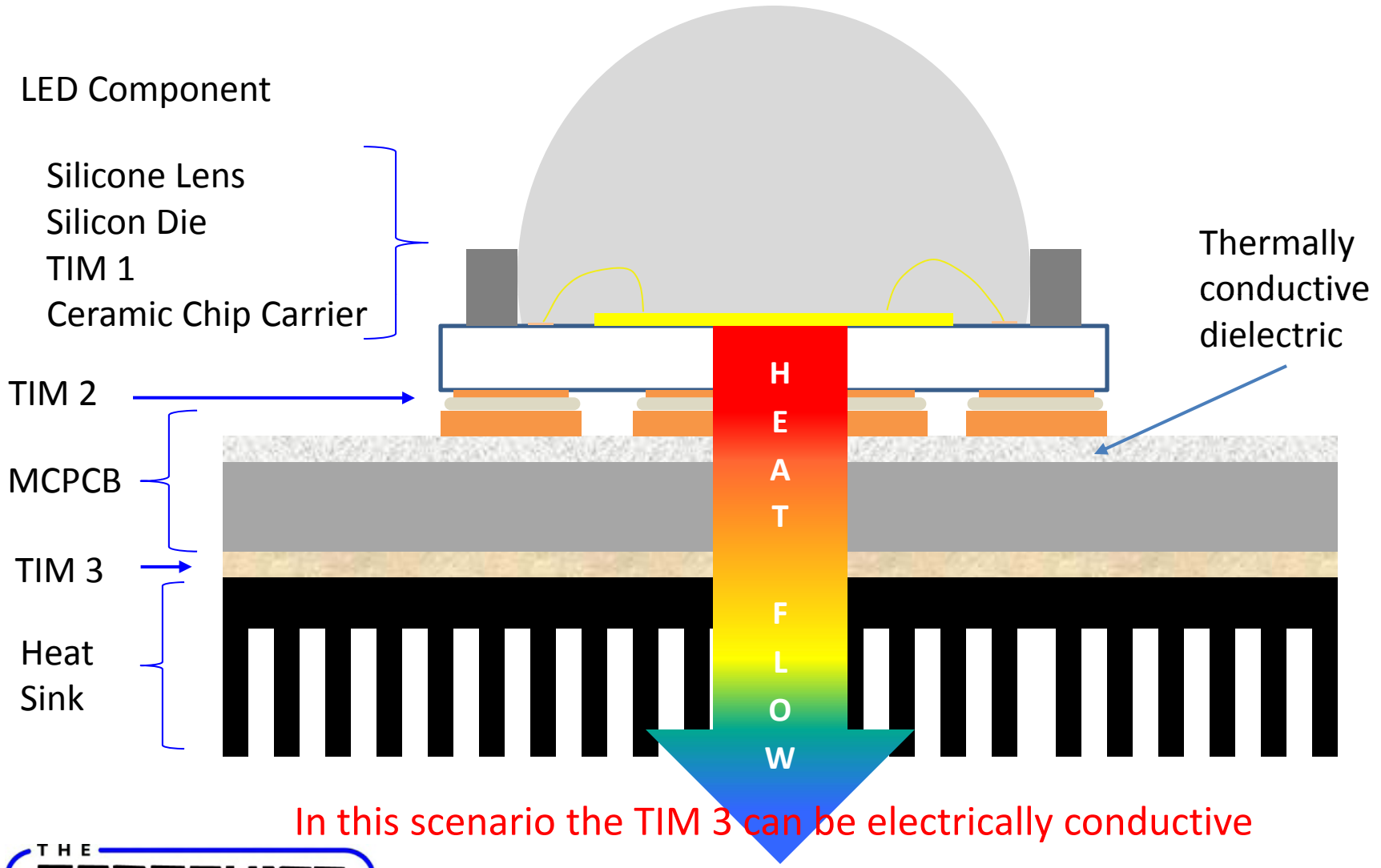
where d is the length of the heat path (the board dielectric thickness),
 A the heat conducting area and λ the thermal conductivity of the material.

This simple equation directly leads to a basic rule of thermal management:
- A low thermal resistance can be realized even through materials that have relatively bad thermal conductivity by increasing the heat-conducting area and/or reducing the heat path length

LED assembly cross section view using an FR-4 PCB



LED assembly cross section view using an MCPCB

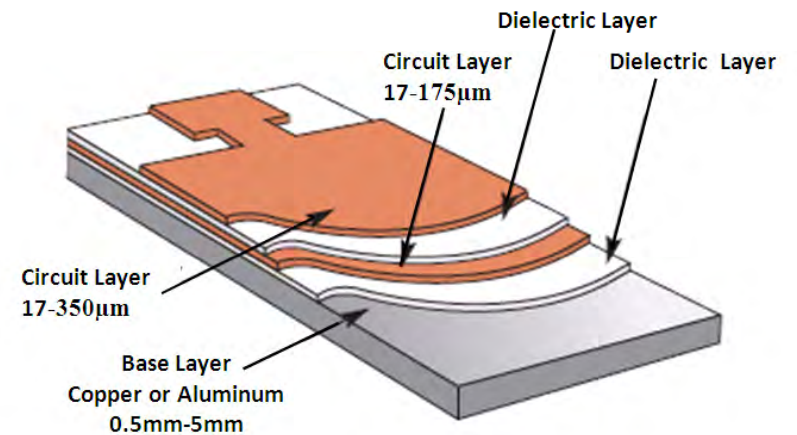
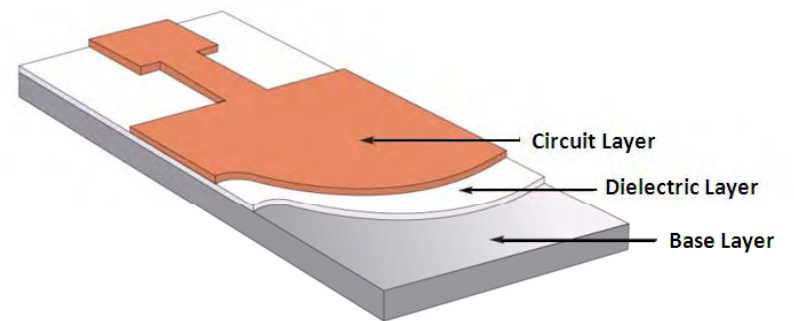
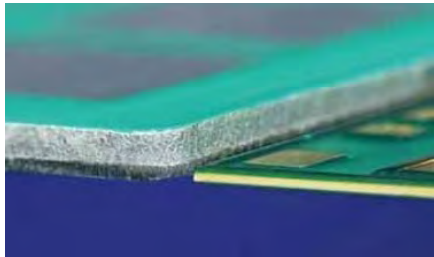


In this scenario the TIM 3 can be electrically conductive

MCPCB Substrate Technology

Available Systems

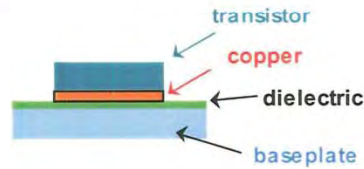
- Single Layer – most common
- Two Layer – increased routing area
- Ultra Thin Substrate – can be formed



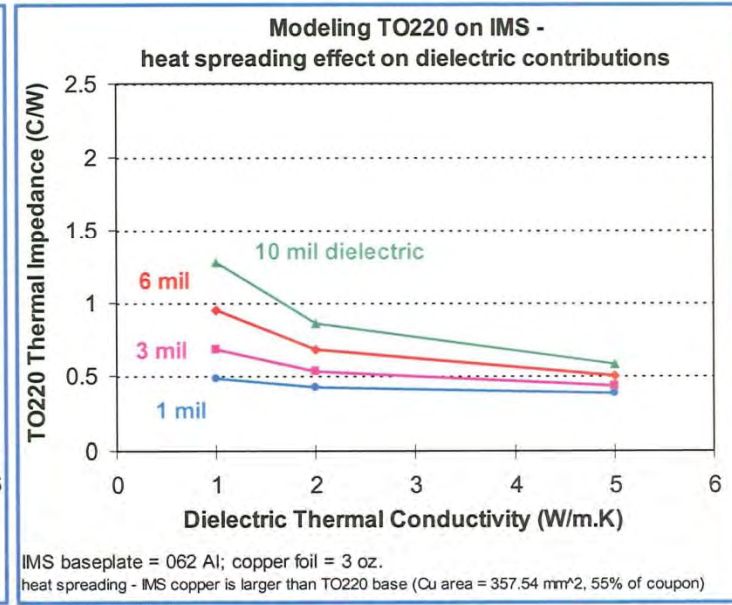
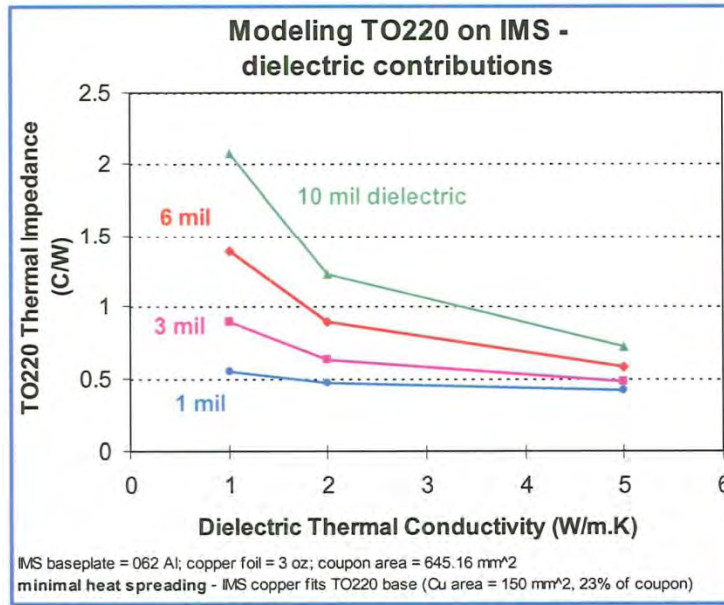
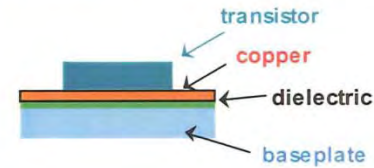
MCPCB substrates

Heat spreading in copper circuits

Minimum HEAT SPREAD



Maximum HEAT SPREAD



Increasing the solder pad size can reduce thermal resistance

MCPCB Substrate Technology

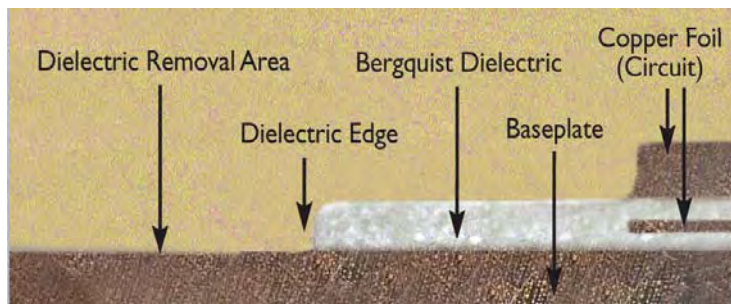
Choosing the appropriate MCPCB material stack up

Substrate material selection can vary with LED selection

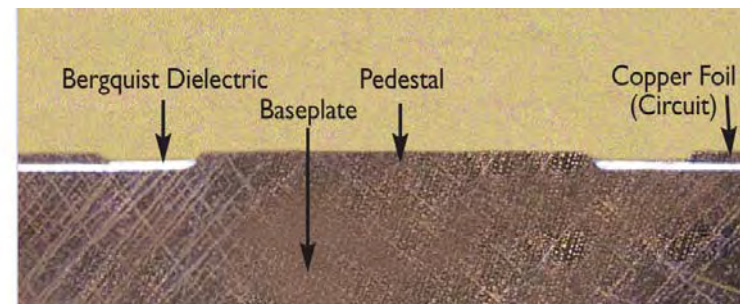
- The lower the thermal resistance of the LED package the greater the need for a higher performing substrate material
 - a) Copper circuit foil thickness is selected based on current carrying capacity needed
 - b) Dielectric thermal performance is selected based on LED's thermal resistance & power density
 - c) Base metal is selected based on thermal performance and mechanical, structural and environmental requirements

Advanced MCPCB Substrate Technology

Selective Dielectric Removal



Formed Pedestal



Exposing the base metal allows for mounting the LED directly on the base metal - shortening the thermal path

Advanced MCPCB Substrate Technology

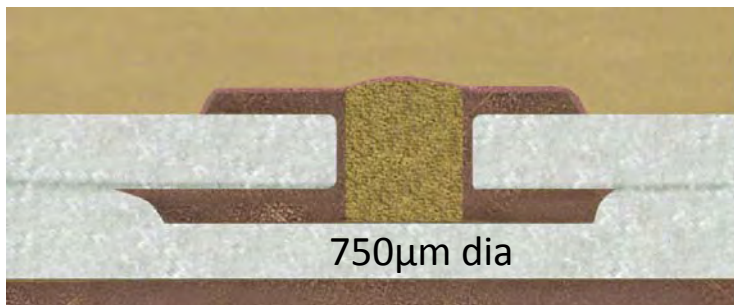
Blind Plated Via to Base



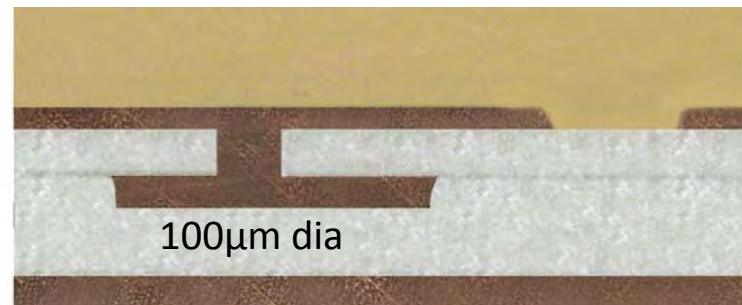
2-layer with plated via's



2-layer – via in pad



2-layer – laser via in pad



via technology can improve thermal performance

MCPCB substrates

KEY TAKE-AWAY POINTS

1. Decide FR-4 or MCPCB
2. If **FR-4**, should via in pad be used
3. If **MCPCB**, what dielectric
 - a) FR-4
 - b) thermally enhanced ceramic filled polymer
4. **Dielectric performance**, i.e. thermal conductivity and thickness
5. Copper **circuit foil** thickness
6. Circuit pad geometry, if possible make larger than the component footprint
7. **Base Plate Metal** – type and thickness

Thermal Management Considerations for High Power LED Applications

Outline

- Thermal management is key to your design
- Thermal performance of high power LED's
- PCB & MCPCB material options
- **Thermal Interface Material (TIM) options**
- Conclusions

Thermal Interface Materials (TIM)

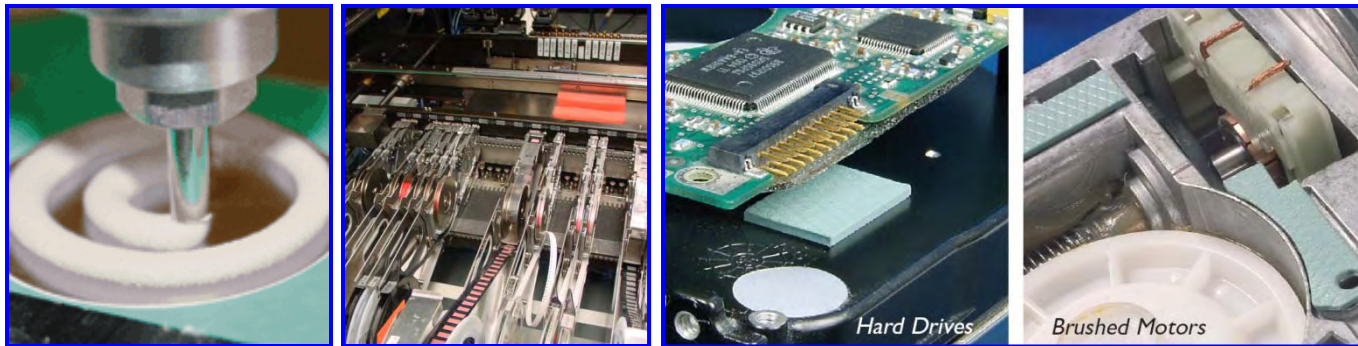
What is Thermal Interface Material?

- Used to optimize & achieve *consistent* thermal performance at component assembly interfaces
- Assembled interface surfaces do not align well due to planar miss-alignment (Micro & Macro)
- The consistent lowest cost solution

Thermal Interface Materials (TIM)

TIM construction and forms:

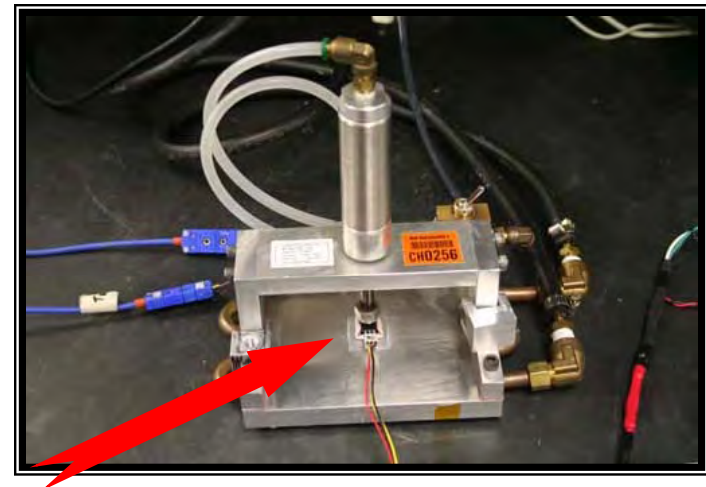
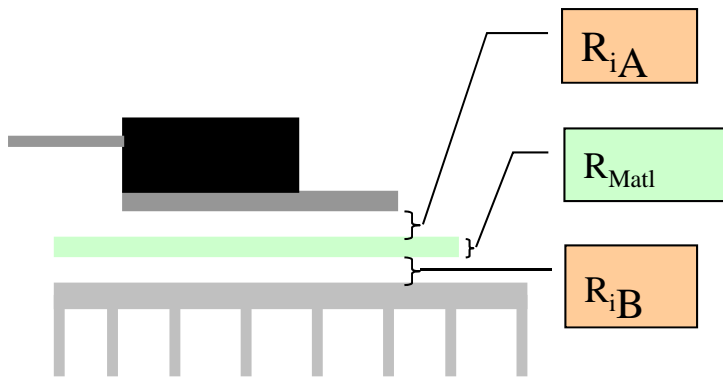
- Silicone & Sil-Free resin systems (Liquid or Pad Form)
- Thermally enhanced fillers (Al, BN, Al₂O₃, Al N...
- Carriers – pad form (Films, F/Glass, SP, Unsupported)
- Protective release Liners – Pad Form (PET, HDPE, LDPE...)
- Syringes, Tubes, Pails – Liquids (5 cc to 19k cc)



Thermal Interface Materials (TIM)

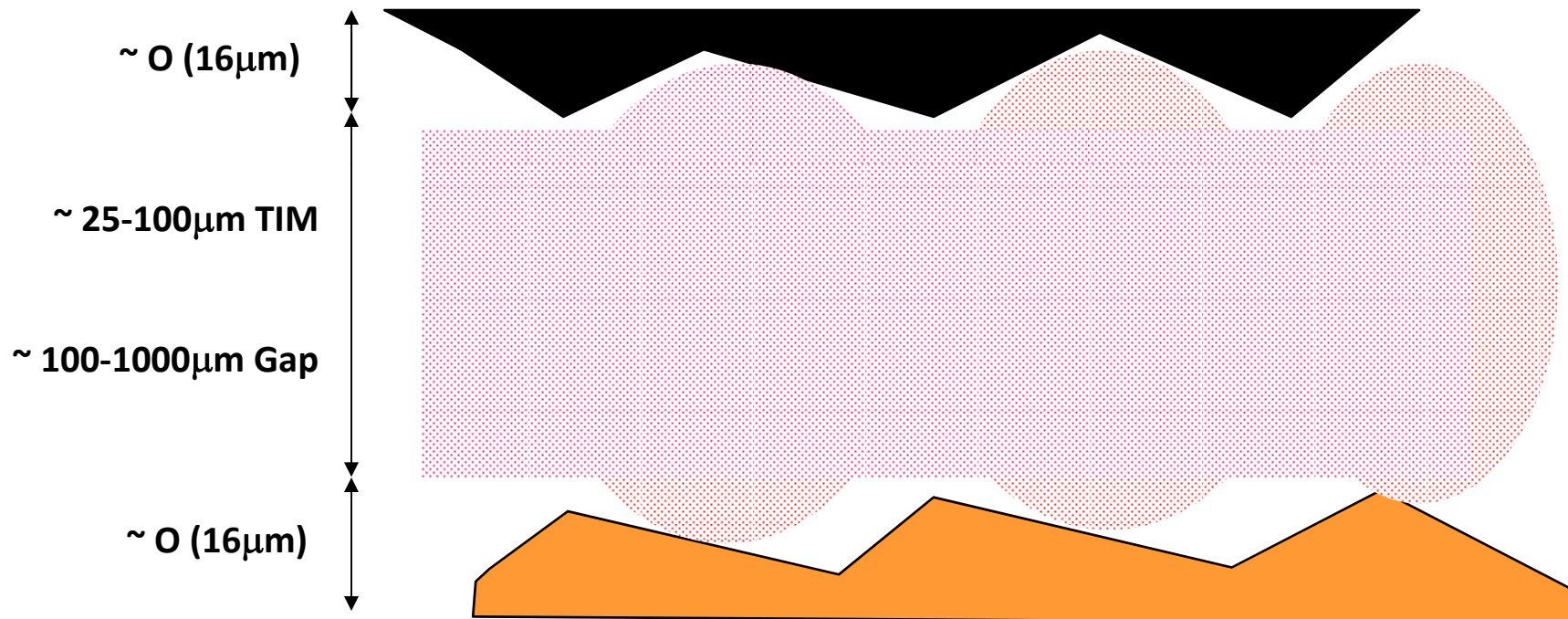
TIM performance is typically optimized by:

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



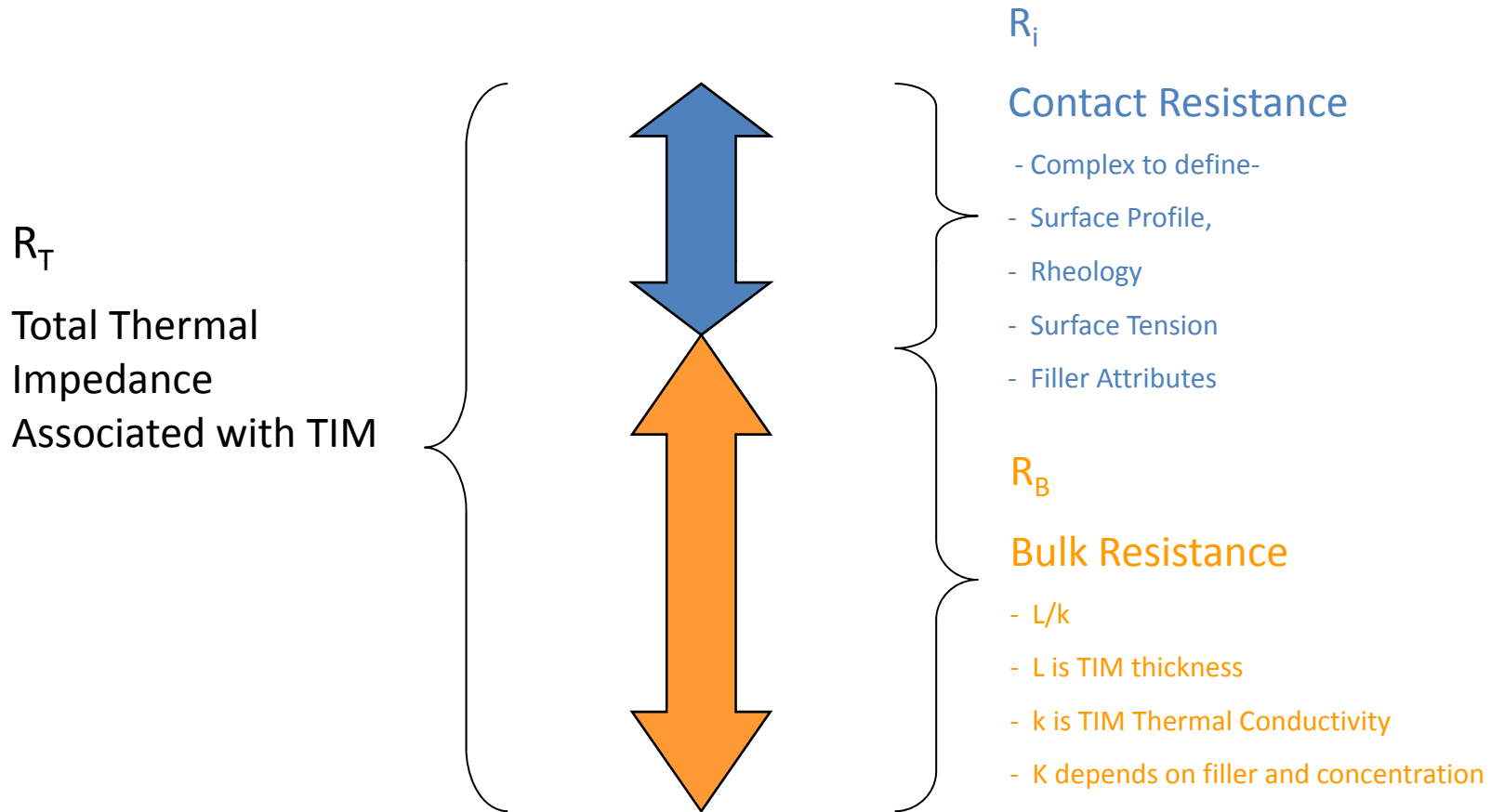
Thermal Interface Materials (TIM)

Typical Interface



Thermal Interface Materials (TIM)

Variables affecting Thermal Performance



Thermal Interface Materials (TIM)

Overview of TIM technologies today:

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

Thermal Interface Materials (TIM)

Sil-Pad®

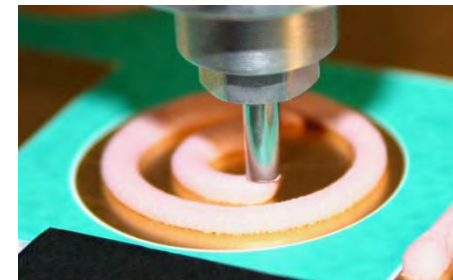
- The Sil-Pad brand name is recognized around the world. (*Sil-Pad is to thermal, what Kleenex® is to tissue*)
 - Sil-Pad was the first thermally conductive insulator to replace mica and grease
 - Sil-Pads reduce the overall manufacturing costs of OEMs by reducing labor costs
 - Sil-Pad improves the overall quality and performance of electronic assemblies



Thermal Interface Materials (TIM)

Gap Pad[®] and Gap Filler

- Gap Pads and Gap Fillers are popular alternatives to Sil-Pad
 - Gap Pad and Gap Filler cool components and can eliminate costly “active” cooling solutions and reduce the overall cost to the OEM
 - Often times, the gap between the component and the heat sink is large as compared to Sil-Pad applications



Thermal Interface Materials (TIM)

Hi-Flow[®]

- Hi-Flow is an automated alternative to thermal grease
 - Hi-Flow materials are used when the very best thermal performance is required
 - Hi-Flow materials change from a solid at specific temperatures and flow to assure total wet-out of each interface without overflowing beyond the part edge



Thermal Interface Materials (TIM)

Bond-Ply and Luqui-Bond® Adhesives

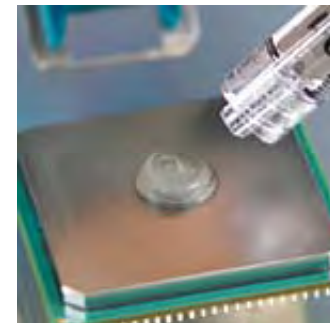
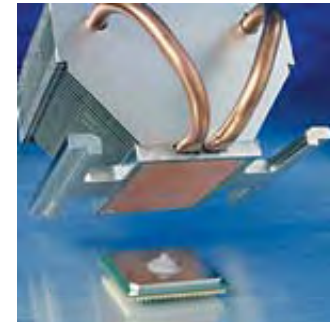
- Bond-Ply and Luqui-Bond are used where structural adhesion and thermal/electrical performance is required
 - Bond-Ply adheres materials with mismatched thermal coefficients of expansion. Strong enough to bond, yet soft enough to let materials expand contract at their own rate
 - Liqui-Bond liquid adhesives are high performance, thermally conductive, bonding materials



Thermal Interface Materials (TIM)

TIC™ - Thermal Interface Compound

- TIC material is a high performance grease
 - TIC products are designed for use between a high-end computer processor and a heat sink or in other high power density applications



Thermal Interface Materials (TIM)

KEY TAKE-AWAY POINTS

1. TIM materials can be **electrically conductive or electrically isolating**
2. TIM materials can be **non-adhesive, tacky or structurally adhesive**
3. TIM materials can **fill narrow or wide gaps**
4. TIM material **can improve thermal performance**

Thermal Management Considerations for High Power LED Applications

Outline

- Thermal management is key to your design
- Thermal performance of high power LED's
- PCB & MCPCB material options
- TIM selection considerations, options that are available
- **Conclusions**

Thermal Management Considerations for High Power LED Applications

Conclusions

1. Understand the LED that you want to use in your system
 - What is the thermal resistance
 - What size is the footprint
 - What is the maximum operating temperature
2. Calculate the thermal stack-up
 - Considering all materials and interfaces
 - Model if can, try substituting various materials to determine best performance vs cost
3. Choose the appropriate circuit technology PCB / MCPCB
 - Lower thermal resistance does not always mean lower T_{rise}
 - The lower the thermal resistance of the LED the more beneficial a low thermal resistance dielectric will be
4. Choose the appropriate TIM material
 - Consider electrical and mechanical requirements
 - Minimize thermal resistance
 - Insure good wet out
5. Make sure you have an exit path for waste heat i.e. what heat sink technology should be used, passive or active

Thank you!

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

www.bergquistcompany.com



PCB Carolina 2011