SEC
SATURN ELECTRONICS
CORPORATION

# MCPCBs for LED Applications

## Thermal Management Material Specifications

# Purpose of the Webinar

## Defining your needs

To break down your needs for thermal management materials, specifically metal core printed circuit board (MCPCB), in LED Applications by *technical requirements* in order to make more effective callouts.

**Controlling the process**

The end result should be shorter lead times, lower cost, and more reliable product.

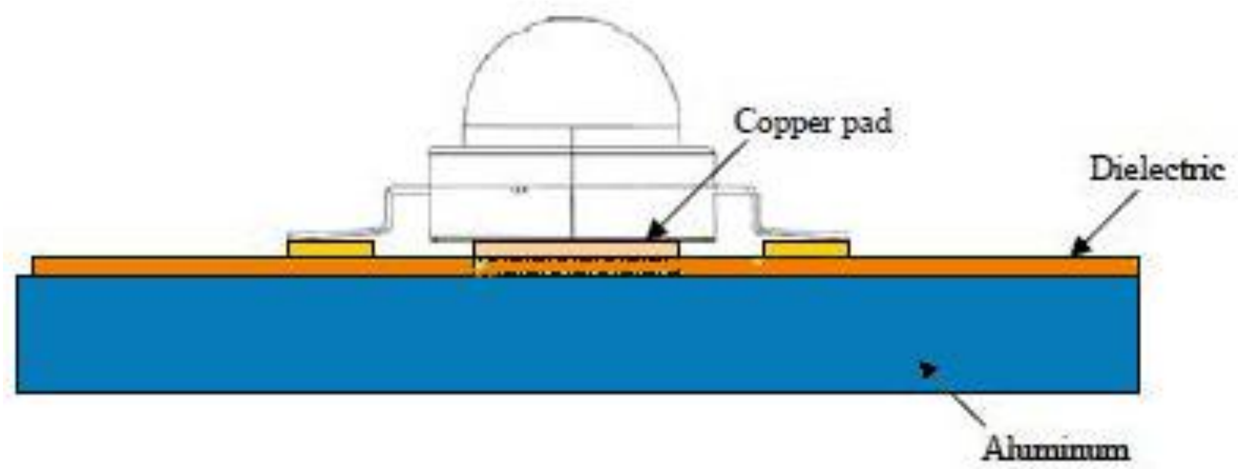
**Non-browning soldermasks**

Introduce new non-browning white LED soldermasks.

# Metal Core Boards

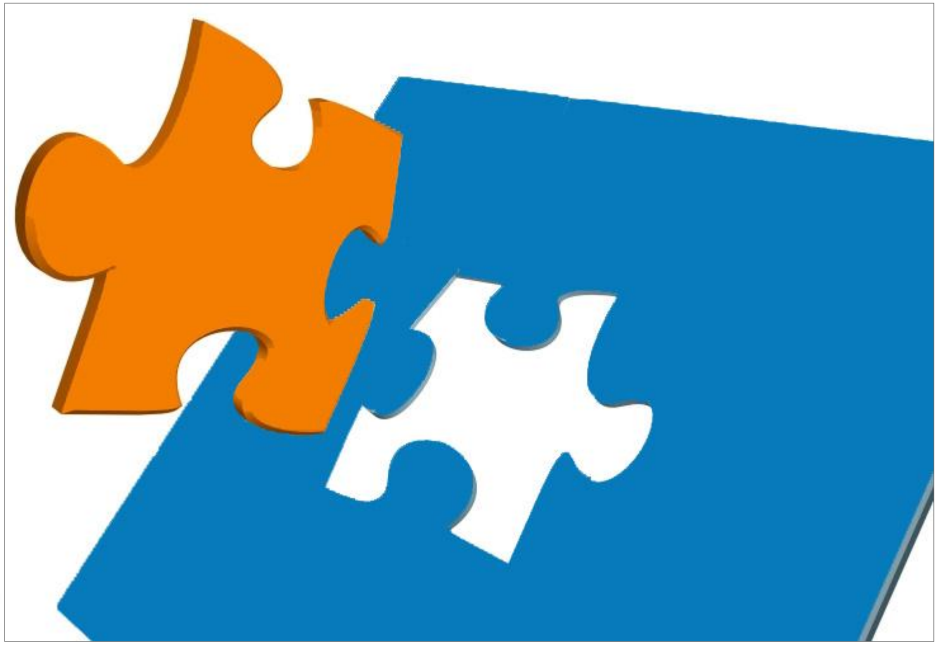
## Definition

The MCPCB commonly consists of a metal core layer (typically aluminum or copper), a continuous dielectric layer and a copper circuit layer.



# Part One

## Specifying Materials for LED Applications



## Survey Question

**How do you specify materials in MCPCB LED applications?**

a) Company Name and/or Part Number (e.g. Bergquist, Laird, DuPont, etc.)
b) Thickness of dielectric
c) $T_g$ or $T_d$
d) “Metal Core”
e) Insulation Resistance & Thermal Conductivity Values

# Survey Answer

**How do you specify materials in metal core LED applications?**

a) Company Name and/or Part Number (e.g. Bergquist, Laird, DuPont, etc.)

**Comment**

Specifying by brand name locks you into a particular product produced by a particular manufacturer.

**Risks Include:**

- Locked into pricing
- Subject to lead times
- Preventing new materials from being used on your product

# Survey Answer

**How do you specify materials in metal core LED applications?**

b) Thickness of dielectric,
c) Tg,
d) Td

**Specifying only these items may not fully address your needs.**

- Does not address thermal conductivity
- Does not address electrical insulation resistance
- Does not address type of dielectric

# Answer

**How do you specify materials in metal core LED applications?**

e) “Metal Core”

**Comment:**

Specifying “metal core” does address anything whatsoever.

# Answer

**How do you specify materials in metal core LED applications?**

f) Insulation Resistance & Thermal Conductivity Values

**Comment:**

**You are a rock star! This is the whole point of our webinar.**

# Consider ***your needs*** when bringing the bare board into the equation

# Survey Question

**What Are Your Needs When Selecting Materials? (Choose all that apply)**

a) Transfer heat (Thermal Conductivity)
b) Prevent short circuiting to base metal core (Electrical Insulation Resistance)
c) Thickness of dielectric
d) Brand name of the material?

# Cost Drivers For MCPCBs

## Dielectric Substrate

The # 1 cost component of the MCPCB is the dielectric substrate between the copper traces and the metal heatsink / core.

**Definition**

An insulating medium which occupies the region between two conductors. In this case, the copper circuits and the metal core heat sink.

# Cost Drivers For MCPCBs (cont.)

## Introducing competition

**The most effective way to reduce cost of dielectric is to introduce competition:**

- Laird
- Bergquist
- Dupont
- Uniplus
- Iteq
- Insulectro
- Plus future innovators

# Definition and Applications

Thermal Transfer

Product Application

Electrical Insulation

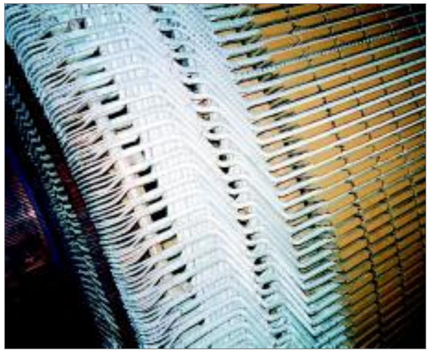
Product Reliability

# Purpose #1

## Transfer Heat

Common Callouts include Thermal Impedance / Resistance (°C in$^2$/W) and Thermal Conductivity / (°W/m-K).

# Why Kapton® / Polyimide?



Heat Resistance

Stability

Flexibility

Dielectric Properties

Density/Weight

**CooLam™ MCPCB (metal core PCB) Offers:**

- Very Low Thermal Impedance
- Excellent Reliability Performance
- Excellent Durability and Stability at High Temperature
- Uniform Thermal, Mechanical & Electrical Properties Under Environmental Stress
- Lead Free Solder and Wirebond Process Compatibility
- Halogen Free
- Meets UL 94 V-0
- Construction Variations to Meet Thermal Management Needs
- 3D Shapes

# Thermal Measurement

## Characterize the Thermal Performance of Materials

### Objective:

Measuring thermal performance per ASTM D5470.

### Equipment:

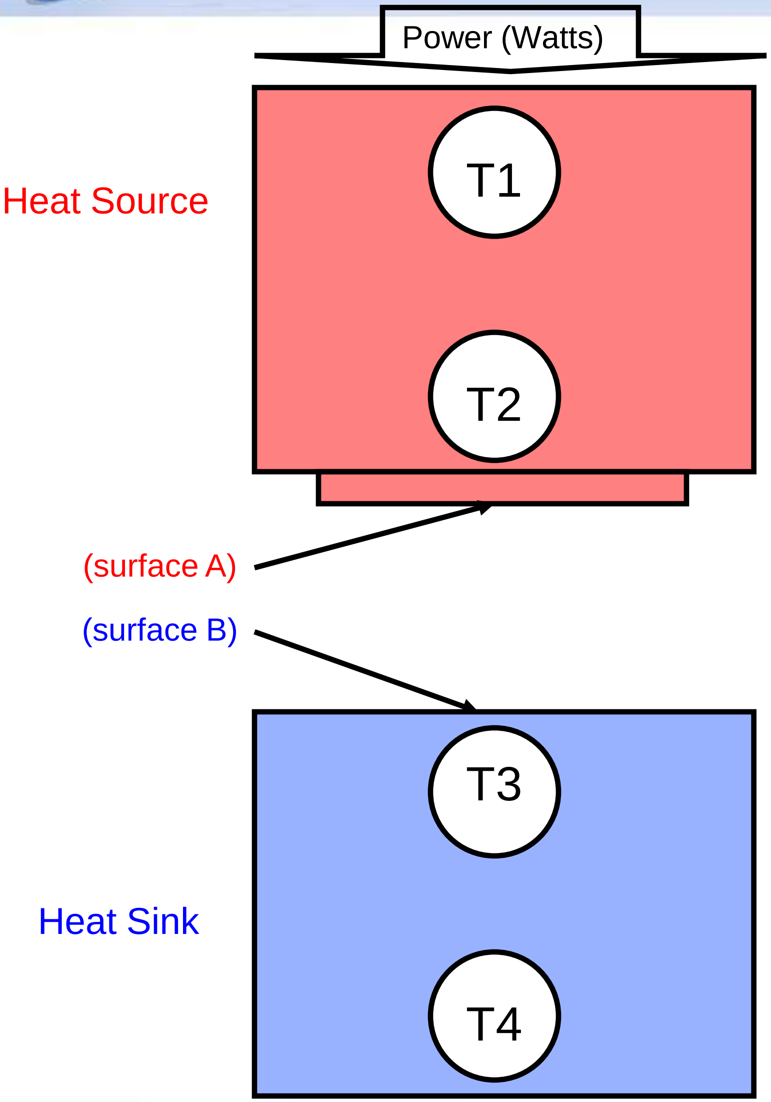
1) Steady State "Thermal Interface Material Tester" (TIM) (Analysis Tech. Inc.)

### Factors to Consider:

1) Reducing contact resistance between sample and test unit
2) Repeatability of measured values
3) Identify any equipment and/or material limitations

# Basic Principles of ASTM D5470

## What is Thermal Resistance ?

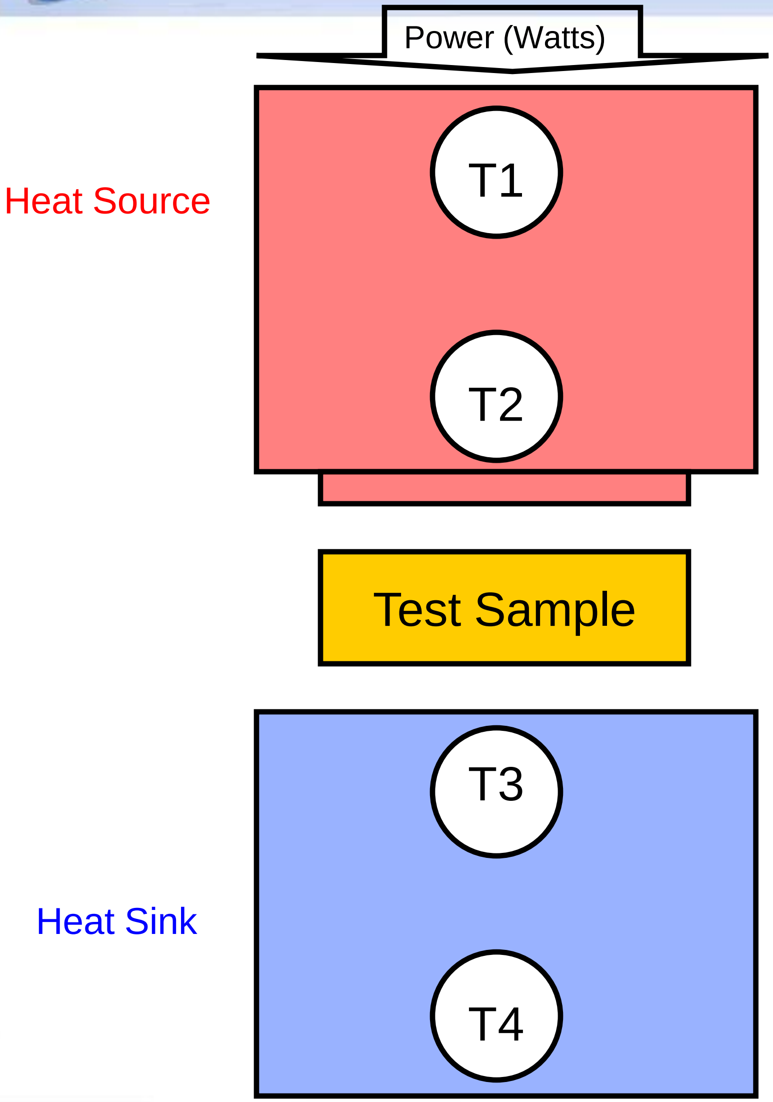


**Thermal Resistance ($R_{th}$)** is defined as the difference in temperature between two closed isothermal surfaces divided by the total heat flow between them.

$$R_{th} = (T_{(A)} - T_{(B)}) \div \text{Power}$$

$$\frac{\Delta °C}{\text{Watt } (V*I)}$$

* Present system does a good job of accounting for all heat and monitoring temperature but nothing is perfect.



## Output from TIM unit:

Thermal Resistance ($R_{th}$): $\frac{\Delta^{\circ}C}{\text{Watt}}$

= (Δ Temp. ÷ power)

Thermal Impedance ($R_{thI}$): $\frac{^{\circ}C\text{ - in2}}{\text{Watt}}$

= (Thermal Resistance) x area (of test sample)

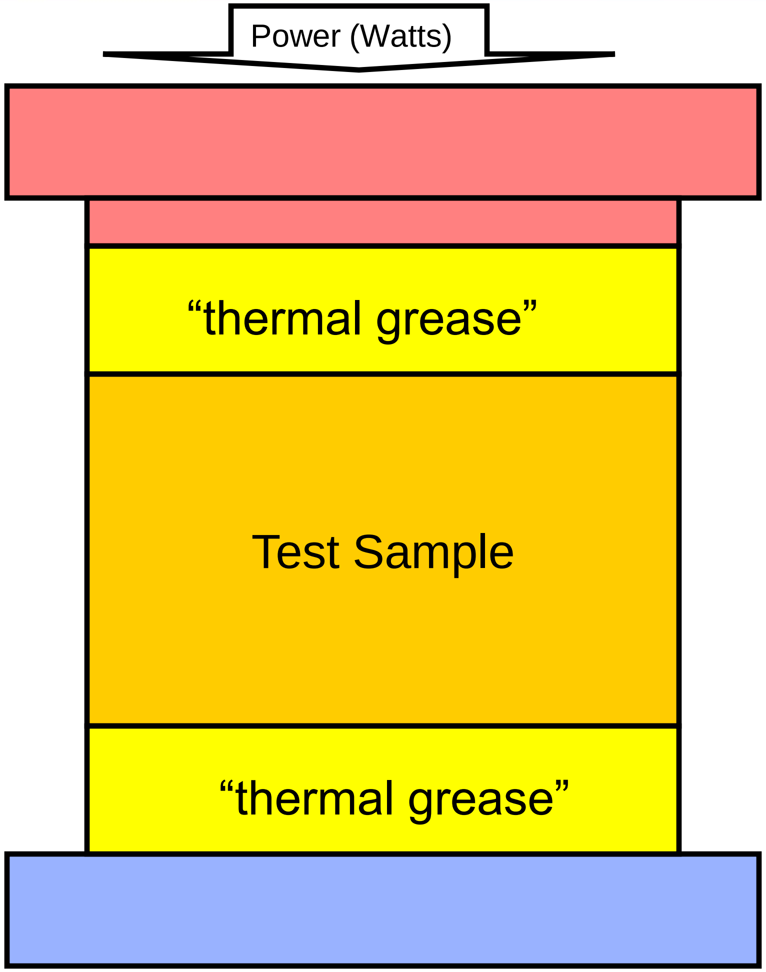
and

Thermal Conductivity: $\frac{\text{Watt}}{\text{m -}^{\circ}C}$

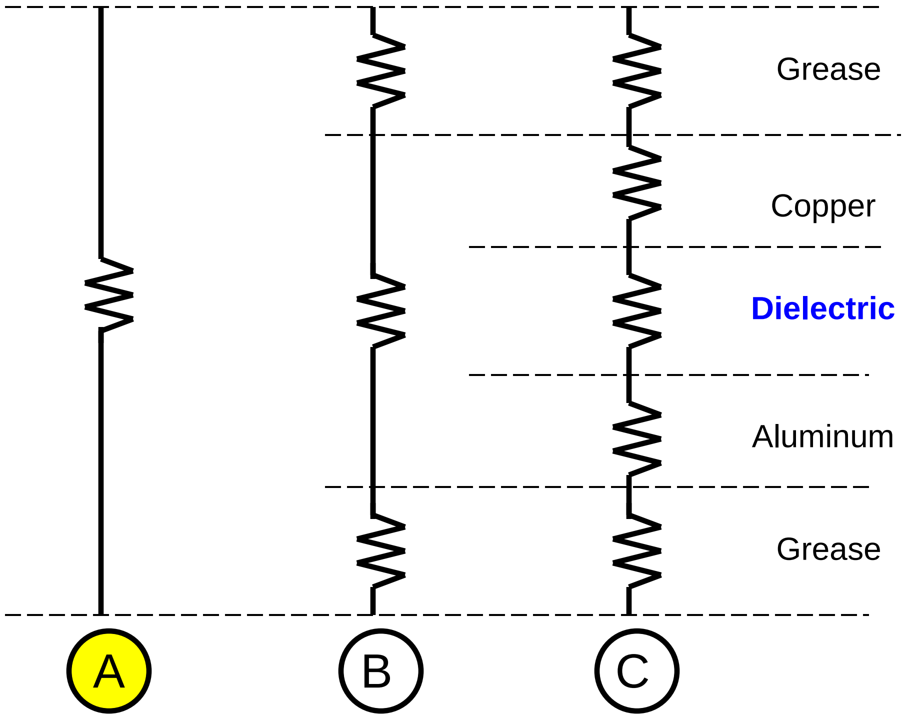
= thickness (material) ÷ thermal impedance

## Basic Principles of ASTM D5470 (cont.)

# ASTM D5470 Thermal Measurement Technique



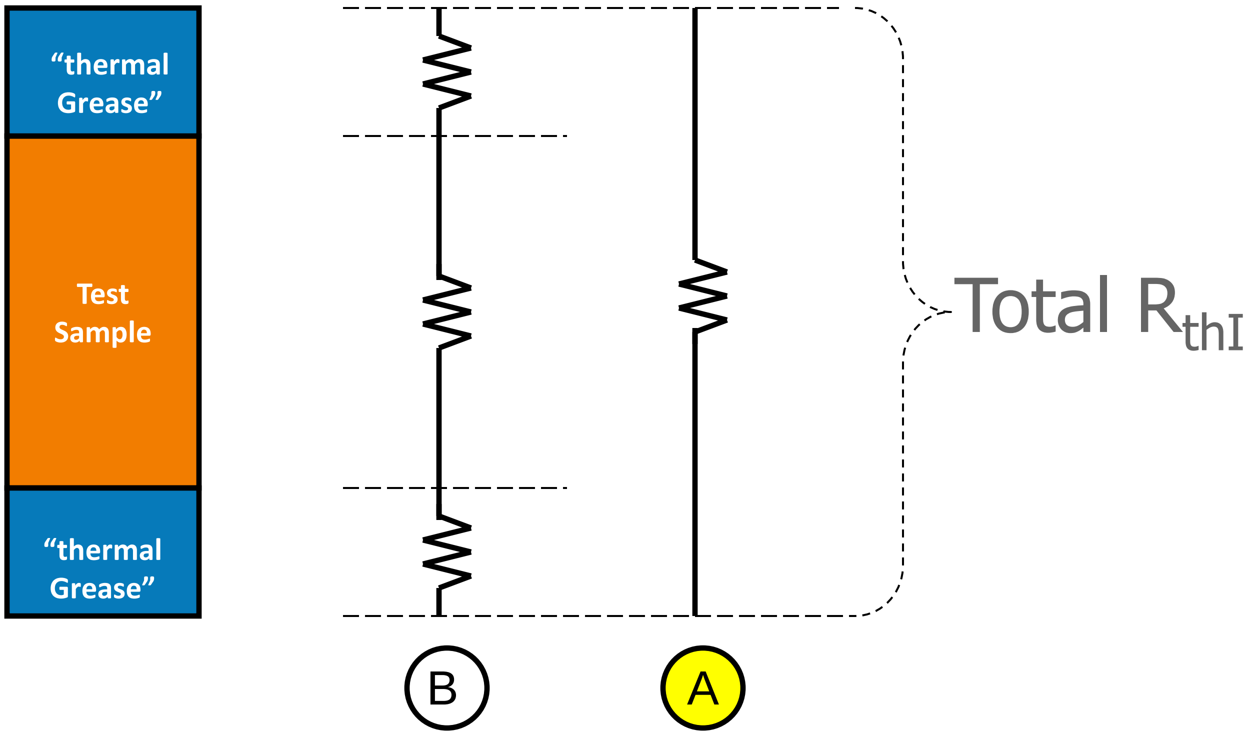
- Total Thermal Resistance ($R_{th\ total}$) is the sum of components and its thermal resistance value.



# ASTM D5470 Thermal Measurement Technique

## Measured Thermal Impedance (C-in²/Watt):

$$
\begin{array}{l}
R_{thI\ (grease\_top)} \\
+ \\
R_{thI\ (sample)} \\
+ \\
R_{thI\ (grease\_bottom)} \\
\hline
\text{Total } R_{thI}
\end{array}
$$



$$R_{thI\ (sample)} = \text{Total } R_{thI} - (R_{thI\ (grease\_top)} + R_{thI\ (grease\text{-}bottom)})$$

# Thermal Impedance

Electronics industry defines thermal impedance as the following:

$$impedance_{thermal} = \frac{thickness}{k}$$

This does **not** include an area through which the heat flows!

**Thermal Impedance**

$$I = \frac{t_{Diel}}{k_{Diel}}$$

Units:

$$I \rightarrow \frac{m}{W/mK} = \frac{m^2 K}{W}$$

**Thermal Resistance**

$$R = \frac{t_{Diel}}{k_{Diel} A}$$

Units:

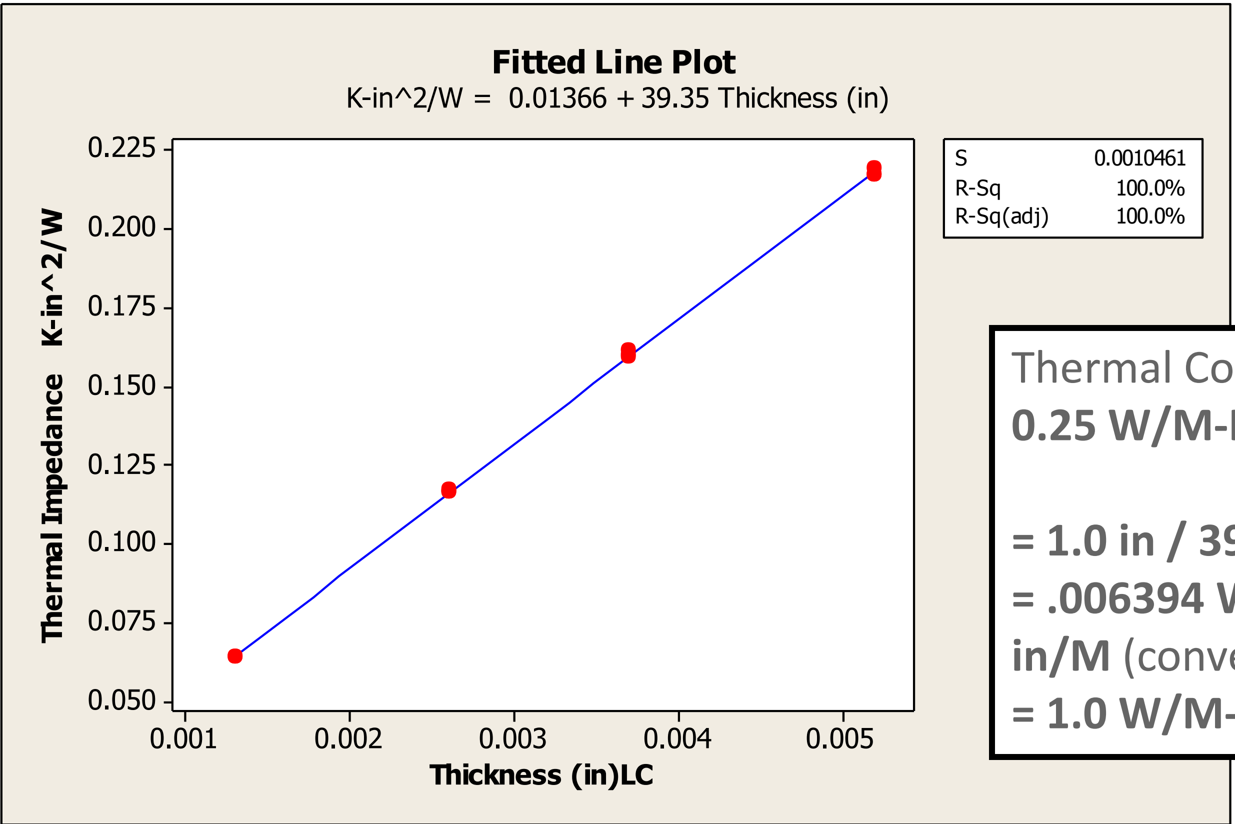
$$R \rightarrow \frac{m}{W/mK \, m^2} = \frac{K}{W}$$

# Thermal Impedance

## Calculating the thermal conductivity of a material

Plot Ra vs. thickness from TIM tester

1/k =thermal conductivity   k = is the slope of the line



Thermal Conductivity LG:
**0.25 W/M-K**

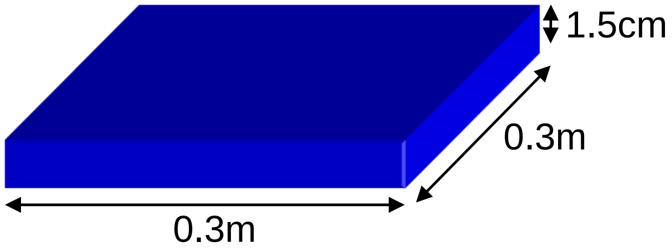
**= 1.0 in / 39.35 K-in2/W**
**= .006394 W/in-K x 39.4 in/M** (convert to metric)
**= 1.0 W/M-K**

Data Plotted from multiple readings

# Example problems

What is the thermal resistance through the thickness of a 0.3 meter by 0.3 meter piece of stainless steel that is 1.5 cm thick?  Assume the thermal conductivity of stainless steel is 15 W/mK.

k=15 W/mK



$$R = \frac{t}{kA}$$

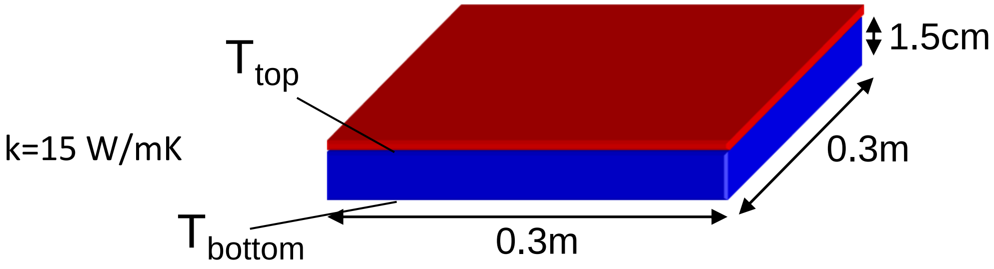
$$R = \frac{t}{kA} = \frac{0.015m}{(15W/mK)(0.3m)(0.3m)}$$

$$R = 0.011K/W$$

# Example Problems

This same piece of stainless steel now has a heater attached to one side that generates 100 Watts of heat into the plate.

If the bottom of the plate measures 45°C (318K), what is the temperature of the top side of the plate?



$$q = \frac{(T_{top} - T_{bottom})}{R_{thermal}} \Longrightarrow (T_{top} - T_{bottom}) = q \cdot R_{thermal}$$

$$T_{top} = q \cdot R_{thermal} + T_{bottom}$$

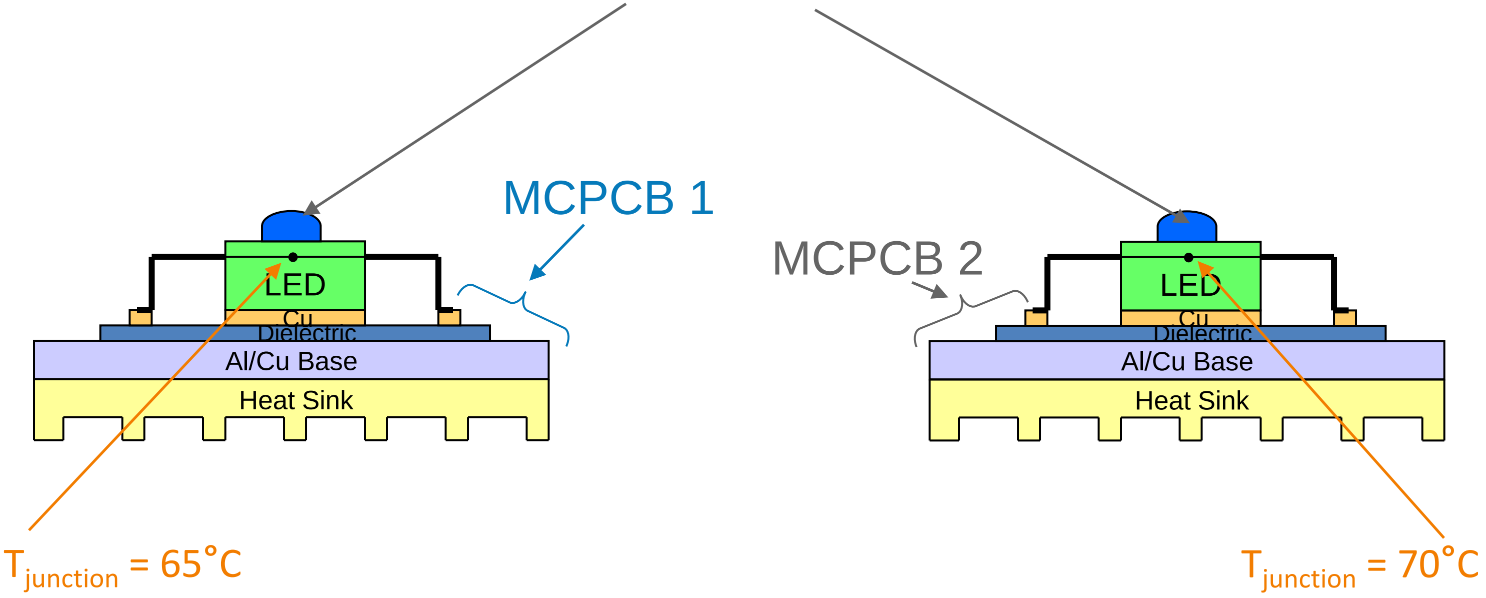
$$T_{top} = 100W \cdot 0.011K/W + 318K$$

$$T_{top} = 319.1K = 46.1°C$$

# Basic Question

Room Temp = 30°C

Same LED and power input



$T_{junction}$ = 65°C

$T_{junction}$ = 70°C

**WHY???**

*Heat Transfer*

# Thermal Management for LED Applications

## What is the role of the PCB?

**Presented by Clemens Lasance**

Clemens is a former Principal Scientist Emeritus with Philips Research, the Netherlands, with a 30 year + focus on thermal management of electronic systems.

He is now a consultant for *Somelikeit Cool*, contact info: lasance@onsnet.nu

# Motivation

## Providing the right information the first time

The goal is to provide the LED application engineer with the right information to select the most optimal MCPCB from a thermal point of view.  Thus, ensuring the best decision is made for a specific application in regards to thermal performance and cost.

# Main Goal of Thermal Management

## The Calculation of application-specific junction temperatures

Reasons / Key Issues

- Lifetime
- Color point
- Efficiency

All these key issues are significantly dependent on the junction temperature.

# Basics of Heat Transfer

## Fundamentals of Critical Temperature Calculation

Determining critical temperatures is contingent upon a critical understanding of:

- The electrothermal analogue
- Thermal conductivity *k*
- Heat transfer coefficient *h*
- Thermal resistance $R_{th}$

# Electro-Thermal Analogue

$\Delta T = q * R_{th} \rightarrow \Delta V = I * R$

Temperature drop (°C) → Voltage drop (V)

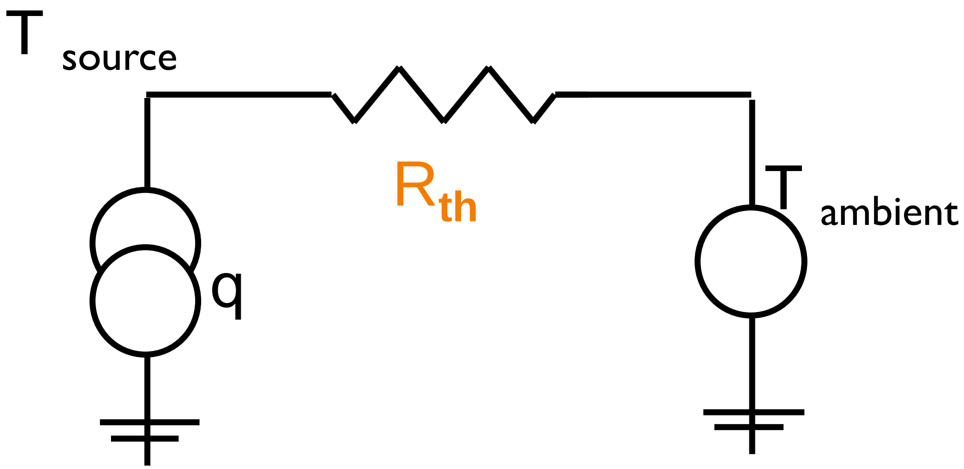
Power dissipation (W) → Current (A)

Heat flux (W/m$^2$) → Current density (A/m$^2$)

Thermal resistance (K/W) → Resistance (Ohm)

# Electro-Thermal Analogue

## A heat transfer path can be described by an electrical network

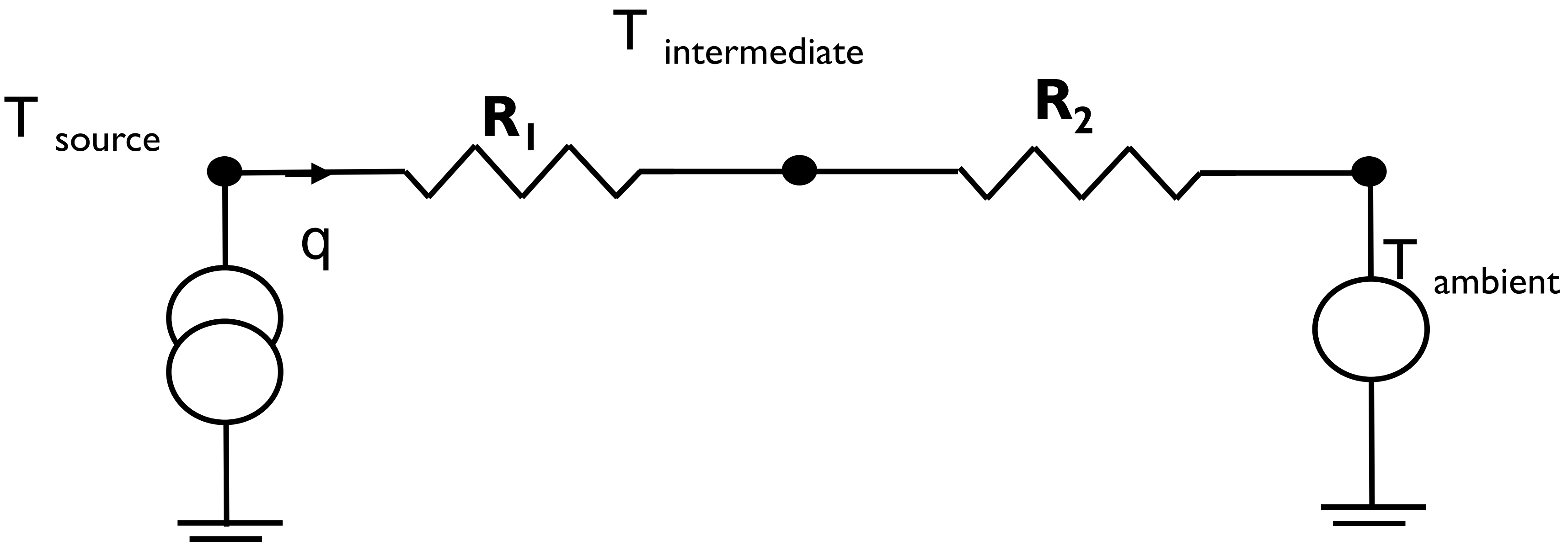


$\Delta T = T_{source} - T_{ambient}$

$R_{th}$ (K/W) = thermal resistance

# Series Circuit

## Example for two resistances in series

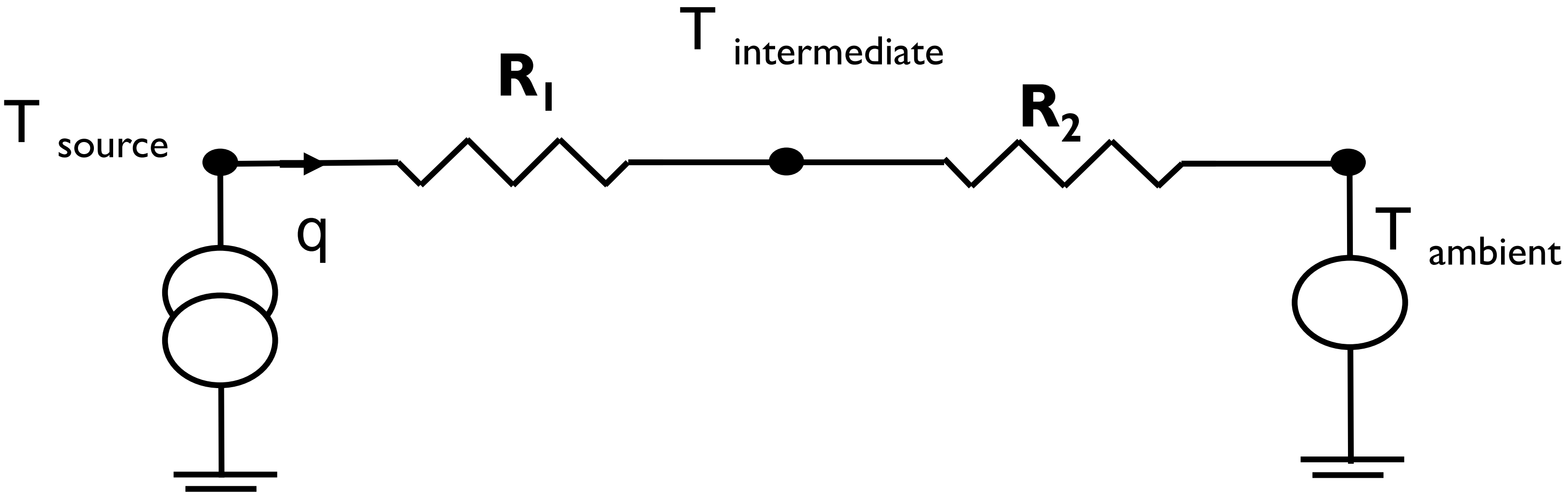


$\Delta T = T_{source} - T_{ambient} = q * R_{total}$

$R_{total} = R_1 + R_2$

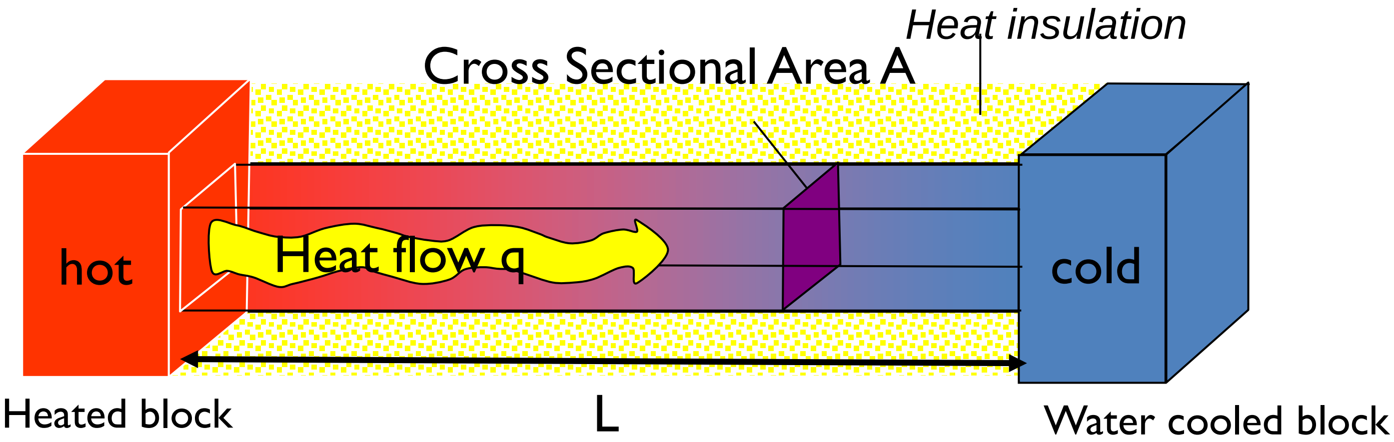
# Consequence of Series Circuit

## Often only the largest R is relevant!



Designer’s job: find the largest resistance!

# Thermal Conductivity: Fourier’s Experiment (1822)



Result of Fourier’s experiment:

$q \sim \Delta T = T_{hot} - T_{cold}$

$q \sim A$ = cross-sectional area

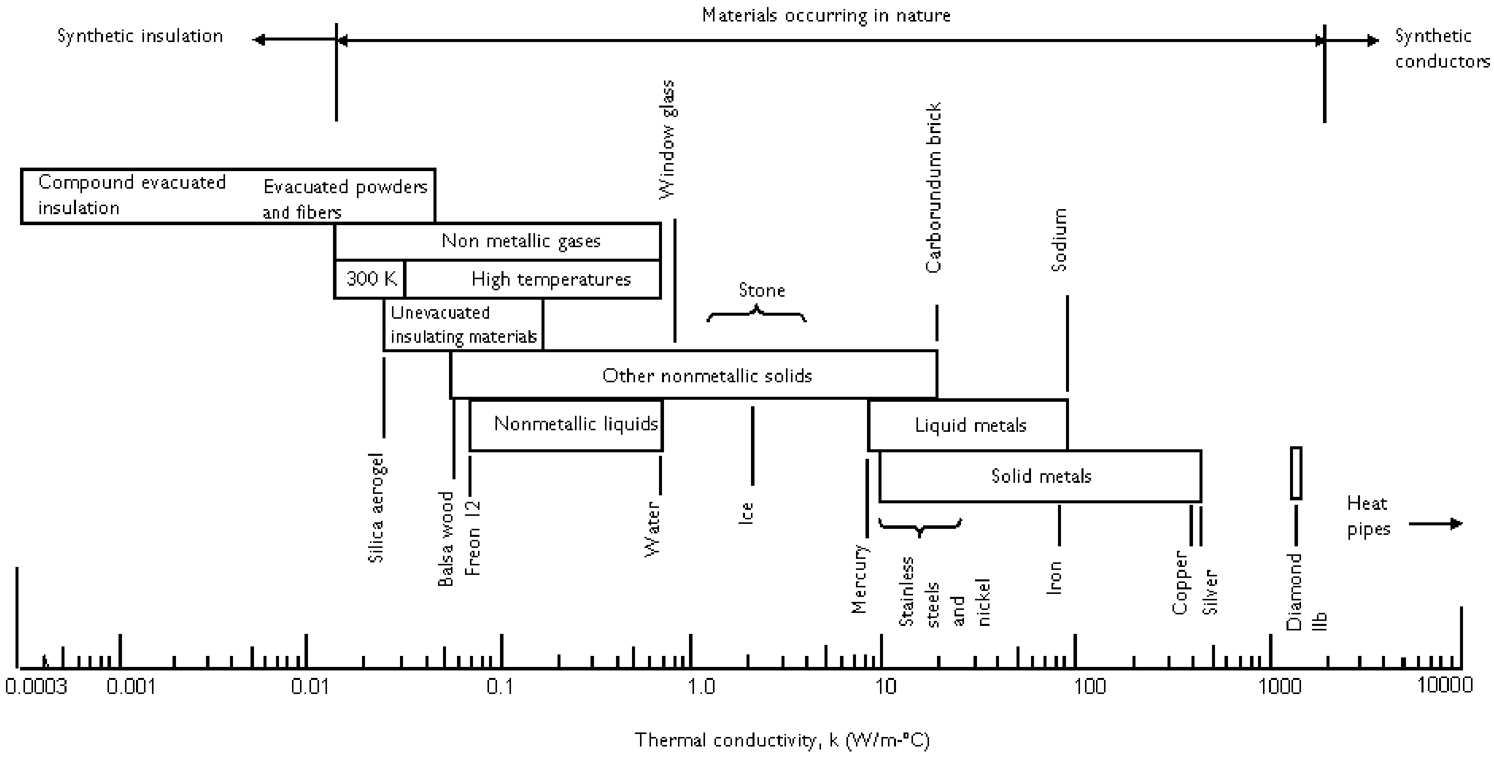
$q \sim L^{-1}$

→

$$q = k \cdot \frac{A}{L} \cdot \Delta T$$

The proportionality constant *k* is called the *‘thermal conductivity’*

# Typical Thermal Conductivity Values



Approximate ranges of thermal conductivity for various substances
(All values are in the neighborhood of room temperature unless noted)

# The Heat Transfer Coefficient *h*

The heat transfer from a solid wall into a fluid (air, water) is called convection, and to first order this heat transfer is proportional to the area and the temperature difference between the wall and the fluid:

$$q = h \cdot A \cdot \Delta T$$

The proportionality constant *h* is called the
*'heat transfer coefficient'*

Typical values:
Natural convection: 10 W/m$^2$K
Forced convection: 50 W/m$^2$K

# Practice

Suppose a Designer needs 5W to reach a required light output

What procedure is most optimal?

$$q = \frac{\Delta T}{R_{th-total}}$$

Information required for first order guess:

- Maximum junction temperature: e.g. 120 °C
- Maximum ambient temperature: e.g. 40 °C
- An estimation of all thermal resistances in the total heat transfer path

# Practice (2)

## Next steps

- Check if required power is manageable by suitable heat sinks & convection

- Check which thermal resistances are dominant
  - Then focus on them to reduce the total thermal resistance

- Final step should always be a detailed analysis
  - Recall that often we don’t talk one-dimensional heat transfer but heat spreading, which is a rather complicated issue
    - For more information please see *Heat Spreading, Not a Trivial Problem* in the May 2008 issue of **ElectronicsCooling**

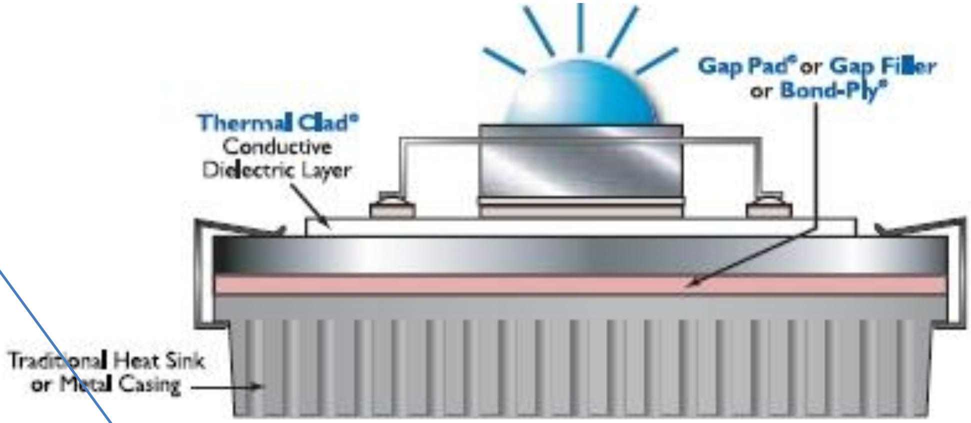
# Practical Example

$$q = k \cdot \frac{A}{L} \cdot \Delta T$$

$$R_{th} = \frac{L}{k \cdot A}$$

$$q = h \cdot A \cdot \Delta T$$

$$R_{th} = \frac{1}{h \cdot A}$$



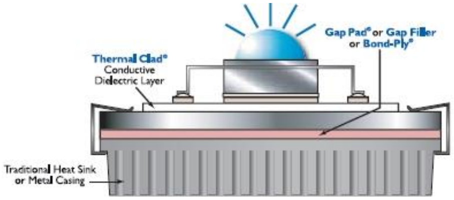
Relevant thermal resistances, assume 1 cm² PCB

| | K/W | |
|---|---|---|
| $R_{th}$-LED | 16 | Luxeon Rebel |
| $R_{th}$-MCPCB | 0.5 | t = 100 µm, k = 2 W/mK |
| $R_{th}$-TIM | 1 | t = 100 µm, k = 1 W/mK |
| | | |
| $R_{th}$-heatsink | 50 | A = 20 cm², h = 10 W/m²K |
| $R_{th}$-heatsink | 2 | A = 100 cm², h = 50 W/m²K |
| $R_{th}$-heatsink | 1 | A = 1 cm², h = 10000 W/m²K |

# Practical Example

## We need *5W* for our light output

Can we find a suitable heat sink?



### We have:

$T_{junction}$ = 120 °C

$T_{ambient}$ = 40 °C

$R_{th}$-LED + $R_{th}$-MCPCB + $R_{th}$-TIM = 17.5 K/W; $R_{th}$-heatsink = ?

### Can we dissipate 5W? No way:

q = 80 / (17.5 + $R_{th}$-heatsink)

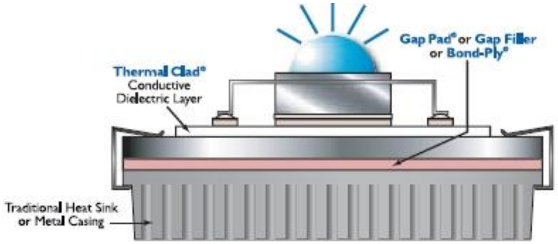
$$q = \frac{\Delta T}{R_{th-total}}$$

### Conclusion:

Even with an ideal heat sink ($R_{th}$-heatsink = 0) we cannot dissipate the required 5W. In this case we need an LED with less thermal resistance.

# Practical Example

## We need *1W* for our light output



We have again:

$T_{junction}$ = 120 °C

$T_{ambient}$ = 40 °C

$R_{th}$-LED + $R_{th}$-MCPCB + $R_{th}$-TIM = 17.5 K/W; $R_{th}$-heatsink = ?

$$q = \frac{\Delta T}{R_{th-total}}$$

Which heat sink is OK?

q = 80 / (17.5 + $R_{th}$-heatsink) ; $R_{th}$-heatsink = 62.5 K/W

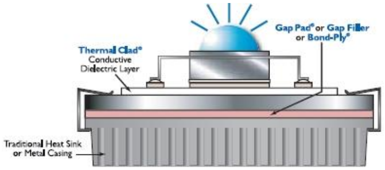
We found earlier:

A=20 $cm^2$, h=10 $W/m^2K$ → $R_{th}$-heatsink = 50 K/W

Conclusion:

We can use a simple heat sink with natural convection.

# Practical Example Conclusion



## Thermal resistance of the MCPCB does not play any role

- In our first case, the LED thermal resistance was dominant; while in the last case, the convective resistance was dominant.

- Hence, *from a thermal point only*, you can choose MCPCBs with a much lower thermal performance and, hence, lower cost.

- The thermal performance of the PCB is relevant only for very high heat flux cases (e.g. liquid cooling) and for top-of-the-bill LEDs.

# Nomenclature

## The confusing situation regarding *‘thermal impedance’*

### Fact:

*‘Electrical impedance’* is historically reserved to describe time-dependent electrical resistance. In the limit of steady state, thermal impedance equals thermal resistance → hence, units should be the same!

### Hence,

*‘Thermal impedance’* , as used by U.S. vendors, violates the electro-thermal analogy, because:

- Unit does not correspond (K/W vs. $m^2K/W$)
- Definition does not correspond (time-dependent vs. steady state)

### Is this a problem?

Yes, because time-dependent (dynamic) test methods will be increasingly used, one output of which is the ‘correct’ thermal impedance.

### Proposal:

Use thermal resistance per unit area, or unit $R_{th}$.

# Electrical Properties

Presented by Michael Gay (Isola) and Norm Berry (Insulectro)

# Common Tests

- Insulation Resistance (IR)
    - This test is used to provide a quantifiable resistance value for all of a product's insulation
- Dielectric Breakdown Strength Test
    - The test voltage is increased until the dielectric fails, or breaks down, allowing too much current to flow.
- Dielectric Withstand Voltage Test (DWS) or High Potential Test (HiPot)
    - A standard test voltage is applied (below the established Breakdown Voltage) and the resulting leakage current is monitored
- Conductive Anodic Filament Test (CAF)
    - This test is used to determine the capability of the material for various design feature spacing under high humidity conditions with applied voltage

# Typical Proof Test (VDC)

## Proof Test or High Potential Test (HiPot)

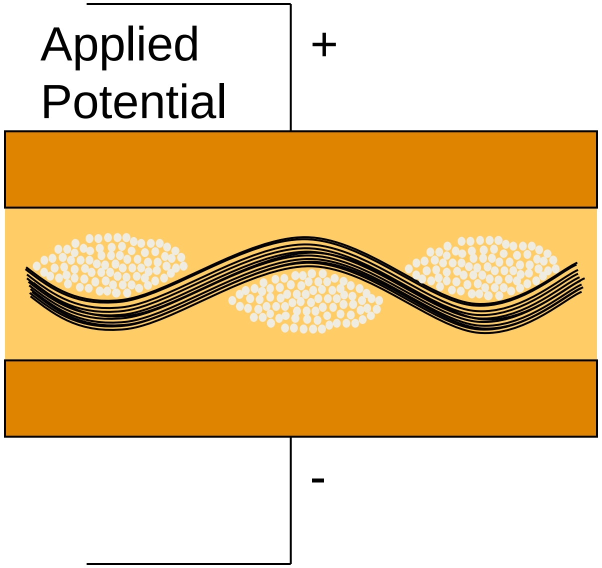
A standard non-destructive test voltage is applied (below the established Breakdown voltage) and the resulting leakage current is monitored.  The test is done to evaluate the integrity of the dielectric material.

# Typical Proof Test (VDC)

## High Potential Dielectric Testing (HiPot)

This non-destructive testing methodology is used to characterize the laminate material insulation capability under a specified potential. Leakage current is measured and compared to predetermined limits

**Typical Test Conditions:**
500-2500 Volts DC (VDC)
700-1200 Volts AC @50-60 Hz (VAC)
Up to 30 seconds
10 MΩ – 500 MΩ
10 µA – 100 µA



# Breakdown (kV AC)

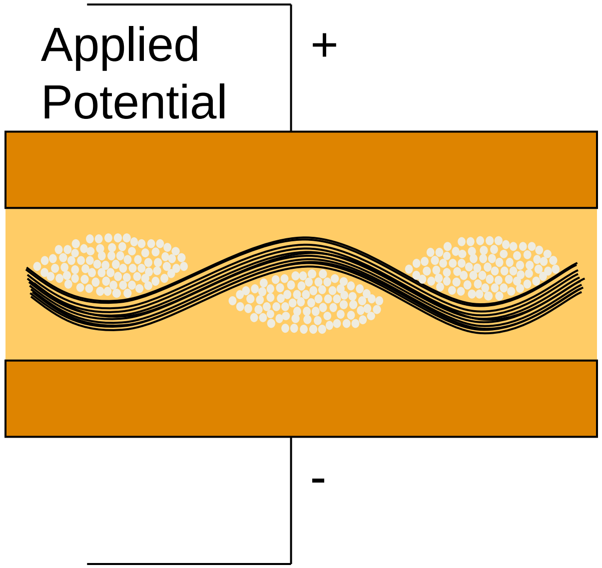
## Breakdown Voltage Test

Breakdown voltage is the stress at failure when AC at power frequency is applied using a rate of rise is 500 Volts/second. Breakdown voltage testing does not relate to proof stress “Proof Testing”. Breakdown voltage is the potential difference at  which **dielectric failure** occurs under prescribed conditions in an electrical insulating material located between two electrodes.

# Breakdown (kV AC)

## Dielectric Breakdown Voltage

This testing methodology is used to characterize the laminate material insulation capability to failure.



**Typical Test Conditions:**
Ramp Volts AC @50-60 Hz (VAC) until failure

**Example:**
Determine the electric strength in volts per mil for each specimen by dividing the breakdown voltage expressed in kilovolts by the thickness express in inches.

ES = (6.8 KV/.005 inch) X (1000 V/KV) X (1 inch/1000 mils) = 1360 v/mil

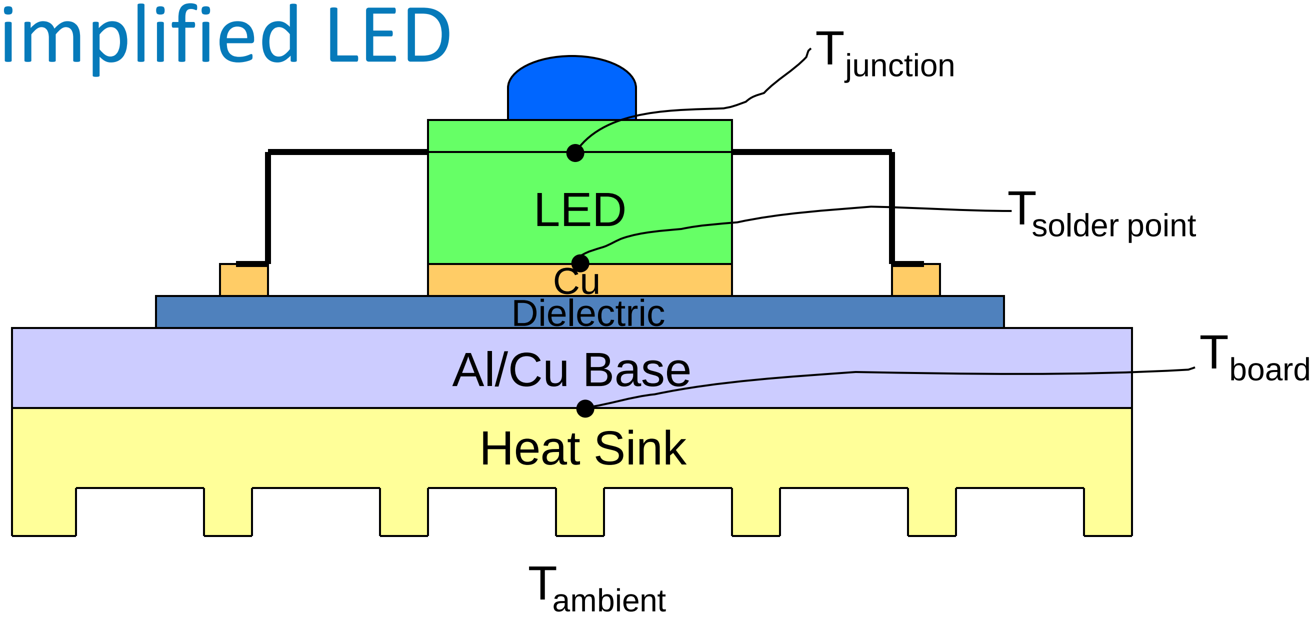
# Permittivity (Dk)

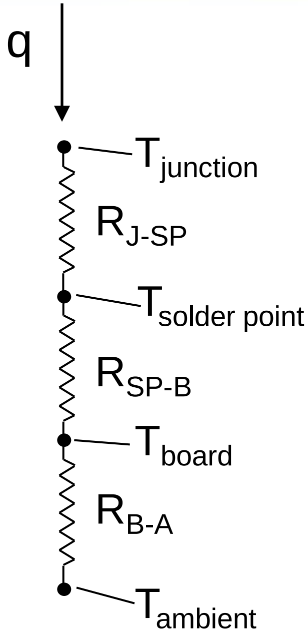
Typical thermal management materials are modified to have higher thermal conductivity. The modifications of the dielectric material raise the Dk of the material to the range of 6 or higher.

# Product Reliability

Presented by Richard A. Wessel of DuPont

# Simplified LED





Big concern: what is $T_{junction}$?

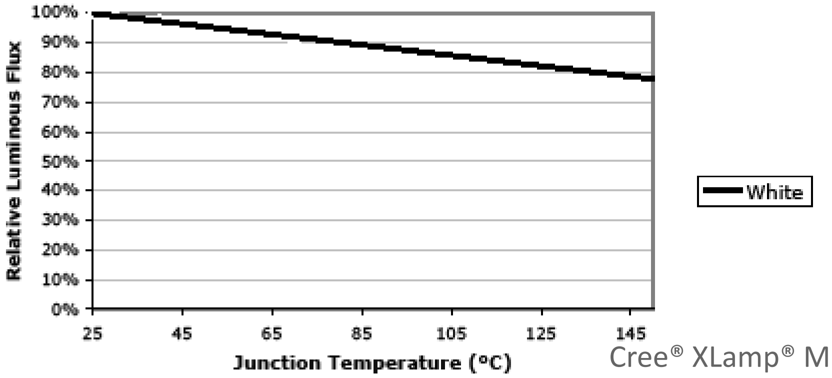
Why?

# Lower $T_{junction}$ Better

Increased relative luminous flux for lower junction or thermal pad temperature

**Relative Flux vs Junction Temperature ($I_F$ = 350 mA)**

The following graph represents typical performance of XLamp MC-E LEDs with all four LEDs driven in series at 350 mA.



Cree® XLamp® MC-E LED

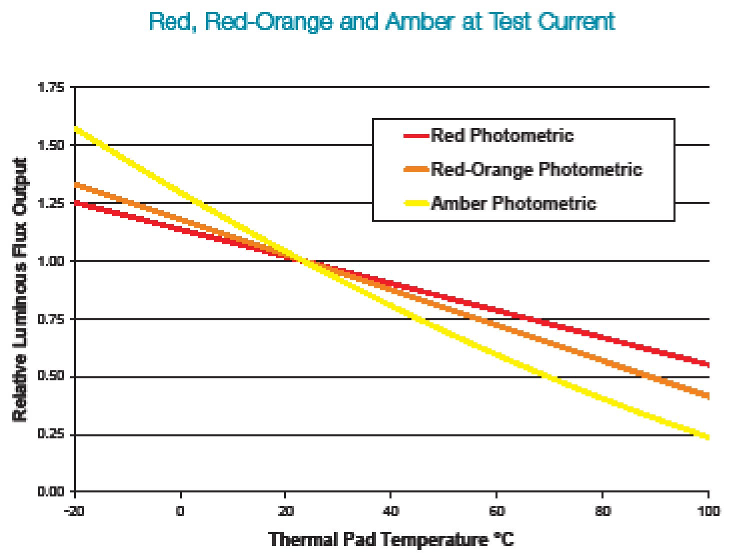


Figure 7. Relative light output vs. Thermal Pad temperature for Red, Red-Orange and Amber.

Luxeon®
Rebel

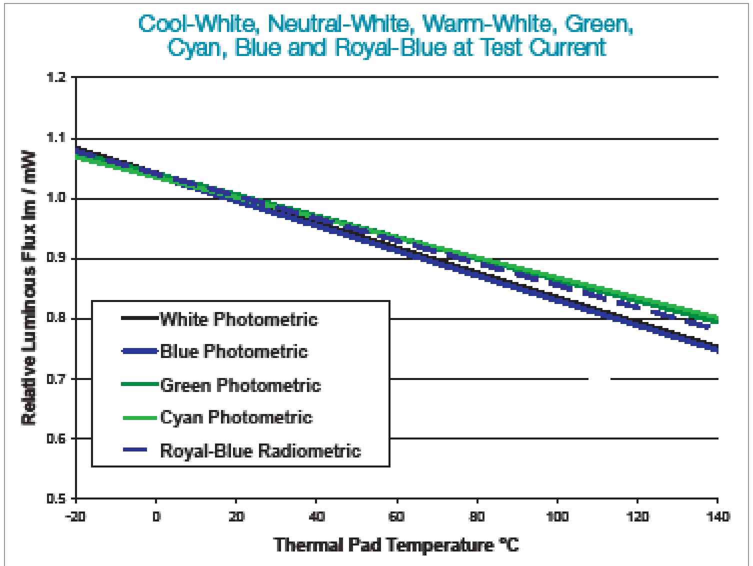


Figure 6. Relative light output vs. Thermal Pad temperature for White, Green, Cyan, Blue and Royal-Blue.

# Increased Lifetimes

## Lower Junction Temperature

Increased lifetimes for lower junction temperature

Luxeon®
Rebel

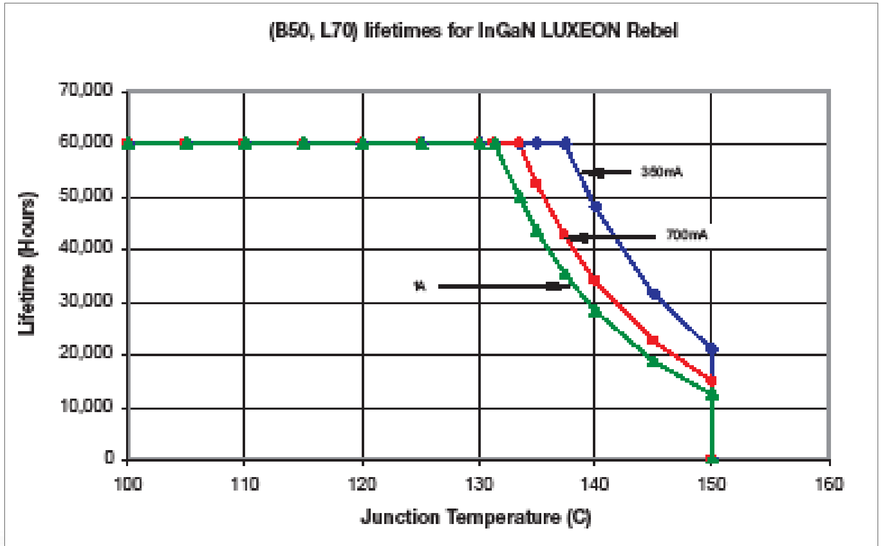


Figure 7. Expected (B50, L70) lifetimes for InGaN LUXEON Rebel.

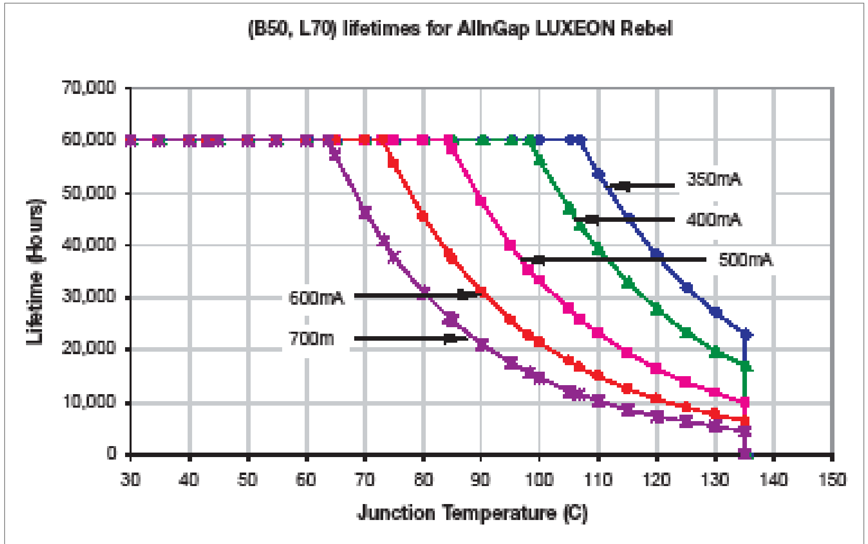


Figure 11. Expected (B50, L70) lifetimes for AlInGaP LUXEON Rebel.

# Suggested Fabrication Notes

Taking Control of Your Design!

# Suggested Fabrication Notes

## Purpose of Fab Notes

Take ***your*** requirements for each characteristic that ***you*** deem most important and specify (values for thermal conductivity and electrical insulation resistance).

We also suggest including a list of pre-approved materials.

# Suggested Fabrication Notes (cont.)

## Example of a Fab Note

**Copper Weight:** 2 oz.

**Metal Core:** 0.060” Al 5051

**Dielectric:**

**Thermal Conductivity:** Must meet or exceed 1.3 (°W/m-K)

**Thermal Resistance:** Maximum 0.9 (°C in$^2$/W)

**Electrical Insulation:** Must meet or exceed 2,000 VDC

***Any other characteristic you feel is important: XYZ***

**Currently Approved Materials:**

- ☐ Bergquist HT-07006
- ☐ Bergquist LTI-06005
- ☐ Laird T-lam SS 1KA06
- ☐ DuPont CooLam

# Suggested Fabrication Notes (cont.)

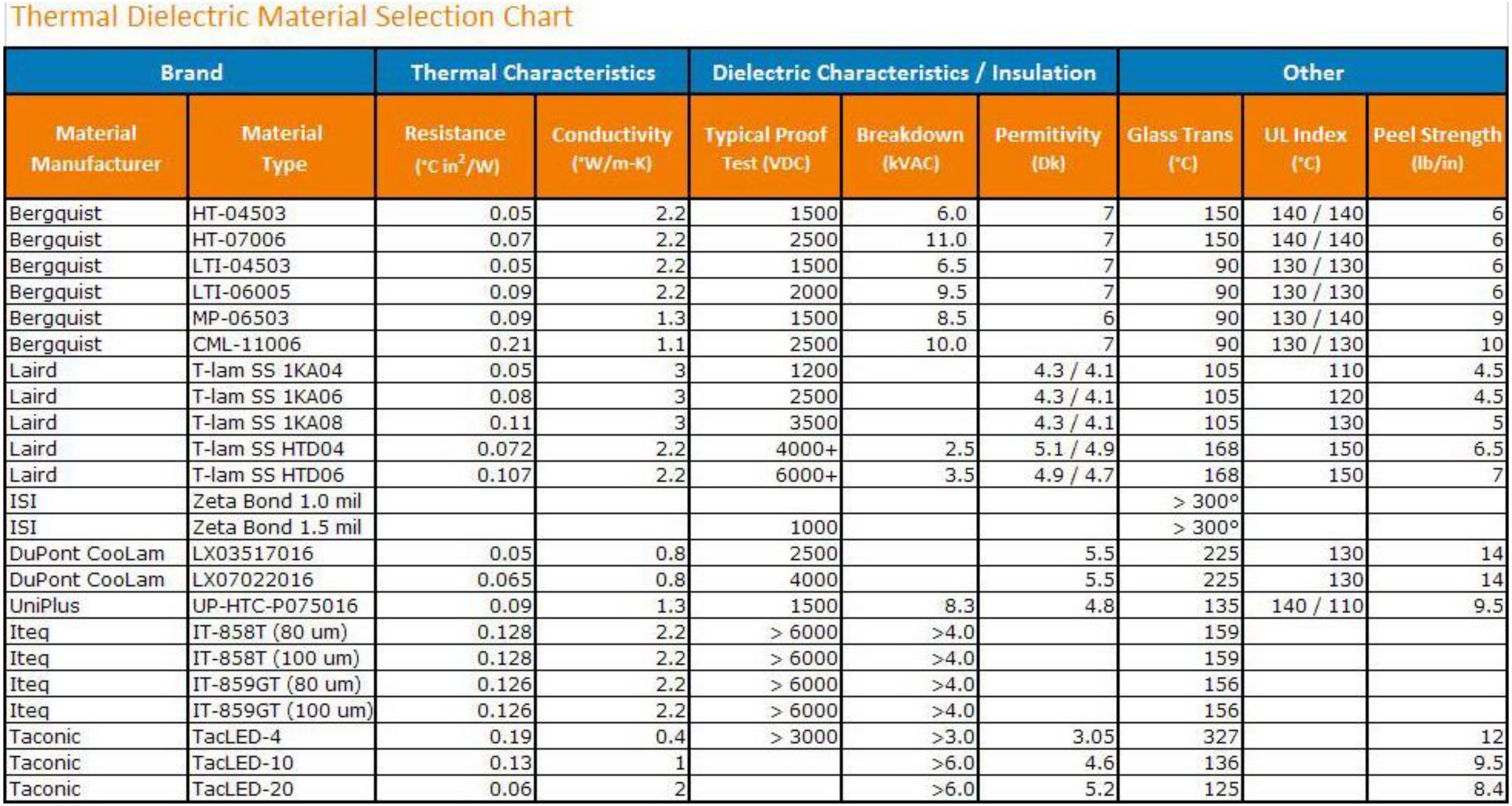
## Benefits of Fab Notes

Allows supplier to quote ***multiple vendors***.

**Subsequent Results**

- Lower Cost
- Quicker Lead Times
- Adaptability to take advantage of new technologies down the road
- Introduce competition from the raw materials and finished PCB suppliers

# Materials Chart



Thermal Dielectric Material Selection Chart

| Brand | | Thermal Characteristics | | Dielectric Characteristics / Insulation | | | Other | | |
|---|---|---|---|---|---|---|---|---|---|
| Material Manufacturer | Material Type | Resistance ($^\circ$C in$^2$/W) | Conductivity (°W/m-K) | Typical Proof Test (VDC) | Breakdown (kVAC) | Permitivity (Dk) | Glass Trans (°C) | UL Index (°C) | Peel Strength (lb/in) |
| Bergquist | HT-04503 | 0.05 | 2.2 | 1500 | 6.0 | 7 | 150 | 140 / 140 | 6 |
| Bergquist | HT-07006 | 0.07 | 2.2 | 2500 | 11.0 | 7 | 150 | 140 / 140 | 6 |
| Bergquist | LTI-04503 | 0.05 | 2.2 | 1500 | 6.5 | 7 | 90 | 130 / 130 | 6 |
| Bergquist | LTI-06005 | 0.09 | 2.2 | 2000 | 9.5 | 7 | 90 | 130 / 130 | 6 |
| Bergquist | MP-06503 | 0.09 | 1.3 | 1500 | 8.5 | 6 | 90 | 130 / 140 | 9 |
| Bergquist | CML-11006 | 0.21 | 1.1 | 2500 | 10.0 | 7 | 90 | 130 / 130 | 10 |
| Laird | T-lam SS 1KA04 | 0.05 | 3 | 1200 | | 4.3 / 4.1 | 105 | 110 | 4.5 |
| Laird | T-lam SS 1KA06 | 0.08 | 3 | 2500 | | 4.3 / 4.1 | 105 | 120 | 4.5 |
| Laird | T-lam SS 1KA08 | 0.11 | 3 | 3500 | | 4.3 / 4.1 | 105 | 130 | 5 |
| Laird | T-lam SS HTD04 | 0.072 | 2.2 | 4000+ | 2.5 | 5.1 / 4.9 | 168 | 150 | 6.5 |
| Laird | T-lam SS HTD06 | 0.107 | 2.2 | 6000+ | 3.5 | 4.9 / 4.7 | 168 | 150 | 7 |
| ISI | Zeta Bond 1.0 mil | | | | | | > 300° | | |
| ISI | Zeta Bond 1.5 mil | | | 1000 | | | > 300° | | |
| DuPont CooLam | LX03517016 | 0.05 | 0.8 | 2500 | | 5.5 | 225 | 130 | 14 |
| DuPont CooLam | LX07022016 | 0.065 | 0.8 | 4000 | | 5.5 | 225 | 130 | 14 |
| UniPlus | UP-HTC-P075016 | 0.09 | 1.3 | 1500 | 8.3 | 4.8 | 135 | 140 / 110 | 9.5 |
| Iteq | IT-858T (80 um) | 0.128 | 2.2 | > 6000 | >4.0 | | 159 | | |
| Iteq | IT-858T (100 um) | 0.128 | 2.2 | > 6000 | >4.0 | | 159 | | |
| Iteq | IT-859GT (80 um) | 0.126 | 2.2 | > 6000 | >4.0 | | 156 | | |
| Iteq | IT-859GT (100 um) | 0.126 | 2.2 | > 6000 | >4.0 | | 156 | | |
| Taconic | TacLED-4 | 0.19 | 0.4 | > 3000 | >3.0 | 3.05 | 327 | | 12 |
| Taconic | TacLED-10 | 0.13 | 1 | | >6.0 | 4.6 | 136 | | 9.5 |
| Taconic | TacLED-20 | 0.06 | 2 | | >6.0 | 5.2 | 125 | | 8.4 |

# Part Two

## Non-browning White Soldermask

# White Soldermask

## Current Resin Systems

- Focus on initial thermal shock, not constant heat
- Tend to Brown over time
- Not developed to be a Reflecting Surface for LEDs

# White Soldermask (cont.)

## Desired Resin Systems

- Remain white through Assembly and Lifespan of LED final product

- Have high reflectivity to enhance LED performance
    - Some believe high reflection soldermask results in lower power consumption for same light output

# What are the Solutions?

## New White High Temperature Liquid Photo-Imageable Soldermasks

- Past two years a number of "LED" white soldermasks have been introduced
  - Unfortunately we have not seen improvements in all of them

- Through numerous studies we have so far found two offerings that show significant improvement:
  - Peters ***(SD2491SM TSW)***
  - Sun Chemicals ***(CAWN 2589/2591)***

# What are the Solutions? (cont.)

## New White High Temperature Thermal Soldermasks

**If *Bright* white soldermask is the objective, these solutions may not suffice**

- Suggest base coat of LPI White then topcoat of High-Temp thermal white soldermask
- After numerous thermal whites, one does not brown after multiple cycles ***(Peters SD2496TSW)***
- This is the formula behind “proprietary” white soldermasks offered by other PCB vendors

# Cost Expanders

## New White High Temperature Liquid Photo-Imageable Soldermasks

- To date, we’ve seen cost increases over standard soldermask price of 30% - 100%
  - Approximately .20 to .30 cents per panel (18” x 24”)

## New White High Temperature Thermal Soldermasks

- To date, we’ve seen cost increases over standard soldermask price of > 100%
  - Approximately $1 per panel (18” x 24”)
  - Includes labor and set up for secondary application process

# Thermal Webinar Conclusion

**SPECIFY** your needs for thermal performance of the dielectric

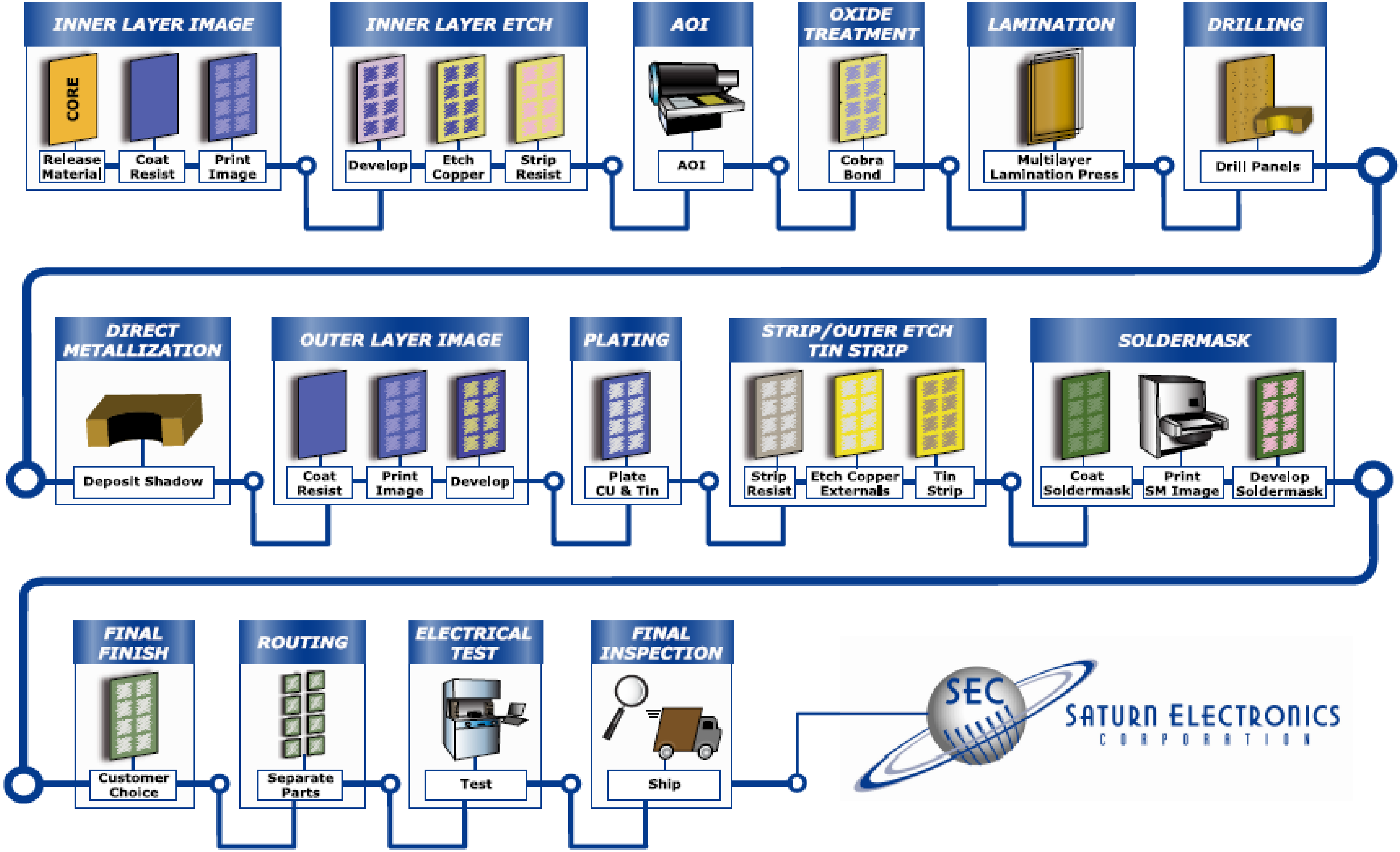
**SPECIFY** your needs for the electrical performance of the dielectric

**SPECIFY** your needs in context of entire product, not just PCB (when applicable)

**KNOW** that you have white soldermask choices

*but keep your fab notes open to take advantage of future developments*

# PCB Flow Chart



**INNER LAYER IMAGE**
- Release Material
- Coat Resist
- Print Image

**INNER LAYER ETCH**
- Develop
- Etch Copper
- Strip Resist

**AOI**
- AOI

**OXIDE TREATMENT**
- Cobra Bond

**LAMINATION**
- Multilayer Lamination Press

**DRILLING**
- Drill Panels

**DIRECT METALLIZATION**
- Deposit Shadow

**OUTER LAYER IMAGE**
- Coat Resist
- Print Image
- Develop

**PLATING**
- Plate CU & Tin

**STRIP/OUTER ETCH TIN STRIP**
- Strip Resist
- Etch Copper Externals
- Tin Strip

**SOLDERMASK**
- Coat Soldermask
- Print SM Image
- Develop Soldermask

**FINAL FINISH**
- Customer Choice

**ROUTING**
- Separate Parts

**ELECTRICAL TEST**
- Test

**FINAL INSPECTION**
- Ship

SEC
SATURN ELECTRONICS
CORPORATION