Bergquist

The World Leader In Thermal Management Technology

Materials Valley – Workshop
Hanau, 18.03.2010

IMS Substrates Thermal Management for Power and LED applications

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LED Light for you
powered by OSRAM

THE BERGQUIST COMPANY
Thermal Products Division

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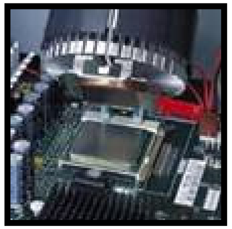
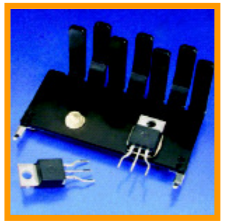
Agenda

- Thermal Management key in your design
- IMS technology
- Dielectric Characteristic
    - Thermal Resistance vs
    - Thermal Conductivity
- Next Generation Dielectric
- Thermal Model and Example
- Summary

Bergquist Product families - The best-known and most trusted names in the industry

- Gap Pad® - Thermally Conductive Material for Filling Air Gaps
- Sil-Pad® - Thermally Conductive Insulator
- Hi-Flow® - Phase Change Material
- Gap Filler – Liquid Gap Filling Material
- Thermal Clad® - Insulated Metal Substrate
- Liqui-Bond® - Thermally Conductive Liquid Adhesive
- Bond-Ply® - Thermally Conductive Adhesive Tape





Where does the heat come from?

Power Conversion for “White” Light Sources

	Incandescent† (60W)	Fluorescent† (Typical linear CW)	Metal Halide‡	LED*
Visible Light	8%	21%	27%	15-25%
IR	73%	37%	17%	~0%
UV	0%	0%	19%	0%
Total Radiant Energy	81%	58%	63%	15-25%
Heat (Conduction + Convection)	19%	42%	37%	75-85%
Total	**100%**	**100%**	**100%**	**100%**

Some claims of LEDs over 30% visible light

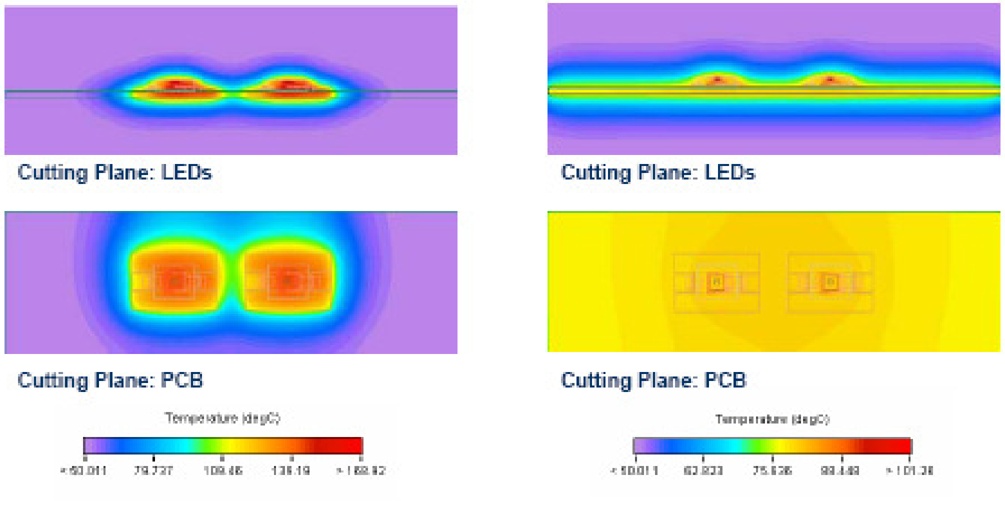
This is the source of the problem

† IESNA Handbook ‡ Osram Sylvania

* Varies depending on LED efficacy. This range represents best currently available technology in color temperatures from warm to cool. DOE’s SSL Multi-Year Program Plan (March 2006) calls for increasing extraction efficiency to more than 50% by 2012.

Source: PNNL-SA-51901, February 2007

Why is Thermal Management important



FR4 PCB

Cutting Plane: LEDs

Cutting Plane: PCB

Insulated Metal Substrate

Cutting Plane: LEDs

Cutting Plane: PCB

$T_{Junc} = 168.9\ °C$

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

-55% →

$T_{Junc} = 101.3\ °C$

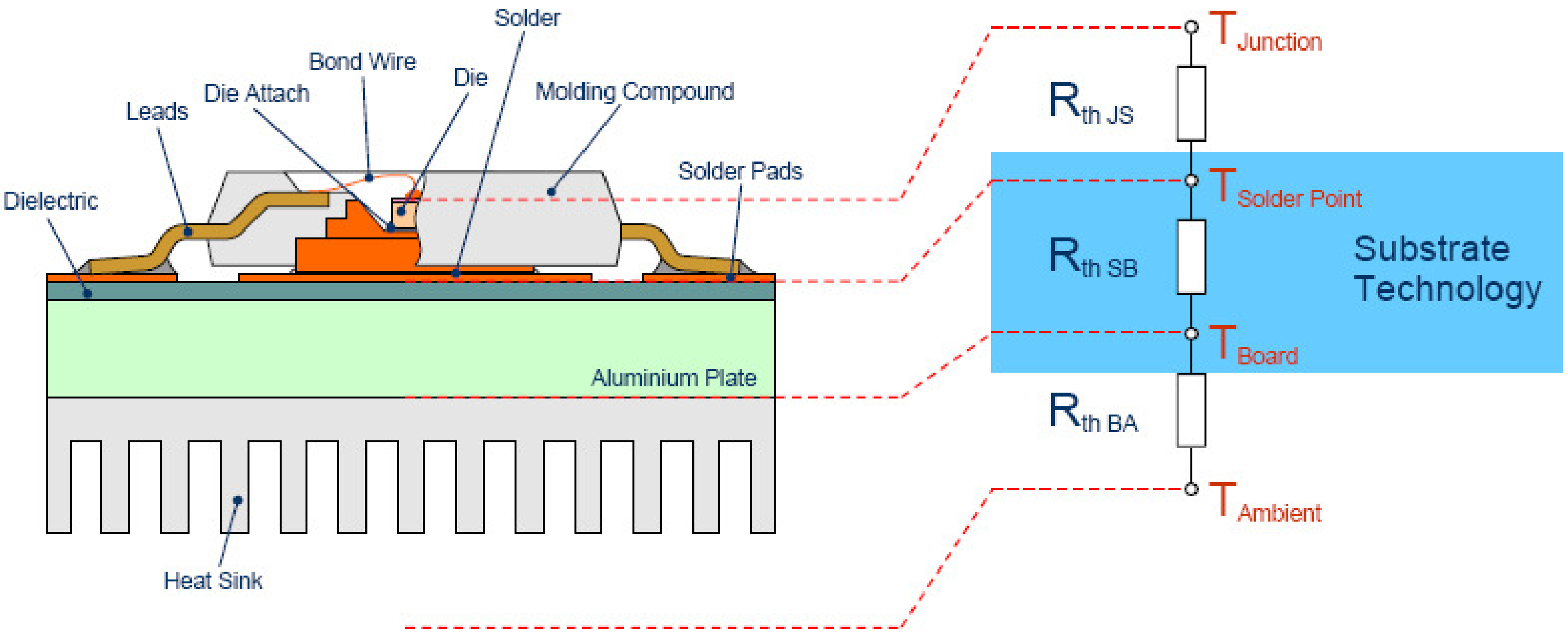
$\Delta T = T_{Junc} - T_{amb} = 51.3\ °C$

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

Opto Semiconductors OSRAM

Thermal Substrate Technologies



Thermal System Configuration **Thermal Resistor Network**

Opto Semiconductors OSRAM

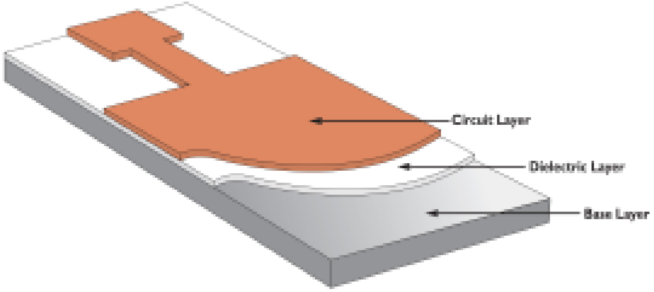
Thermal Substrate Technologies

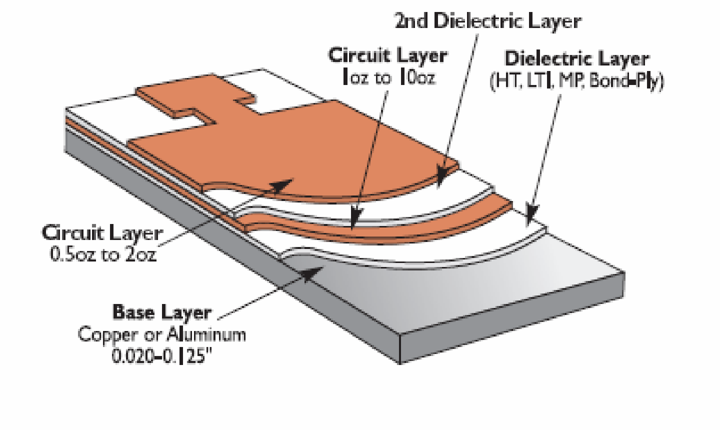
Copper	90..400 W/mK
Gold	290 W/mK
Aluminium	50 .. 235 W/mK
Steel (low carbon)	66 W/mK
Boron Nitride	39 W/mK
Solder	20..50 W/mK
Stainless Steel	20 W/mK
Alumina	27 W/mK
Mica	0.7 W/mK
Water	0.5 W/mK
FR4	0.3 W/mK
Epoxy	0.2 .. 0.3 W/mK
Mylar	0.2 W/mK
Air	0.027 W/mK

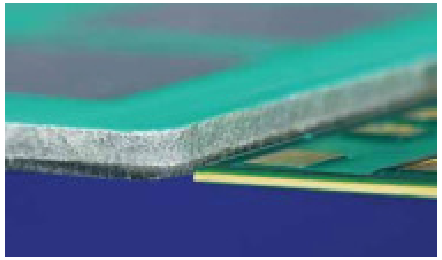
IMS Substrate Technology

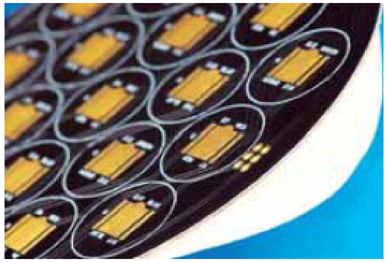
- Available IMS Systems

Single Layer – majority
Double Layer
Ultra Thin Substrate

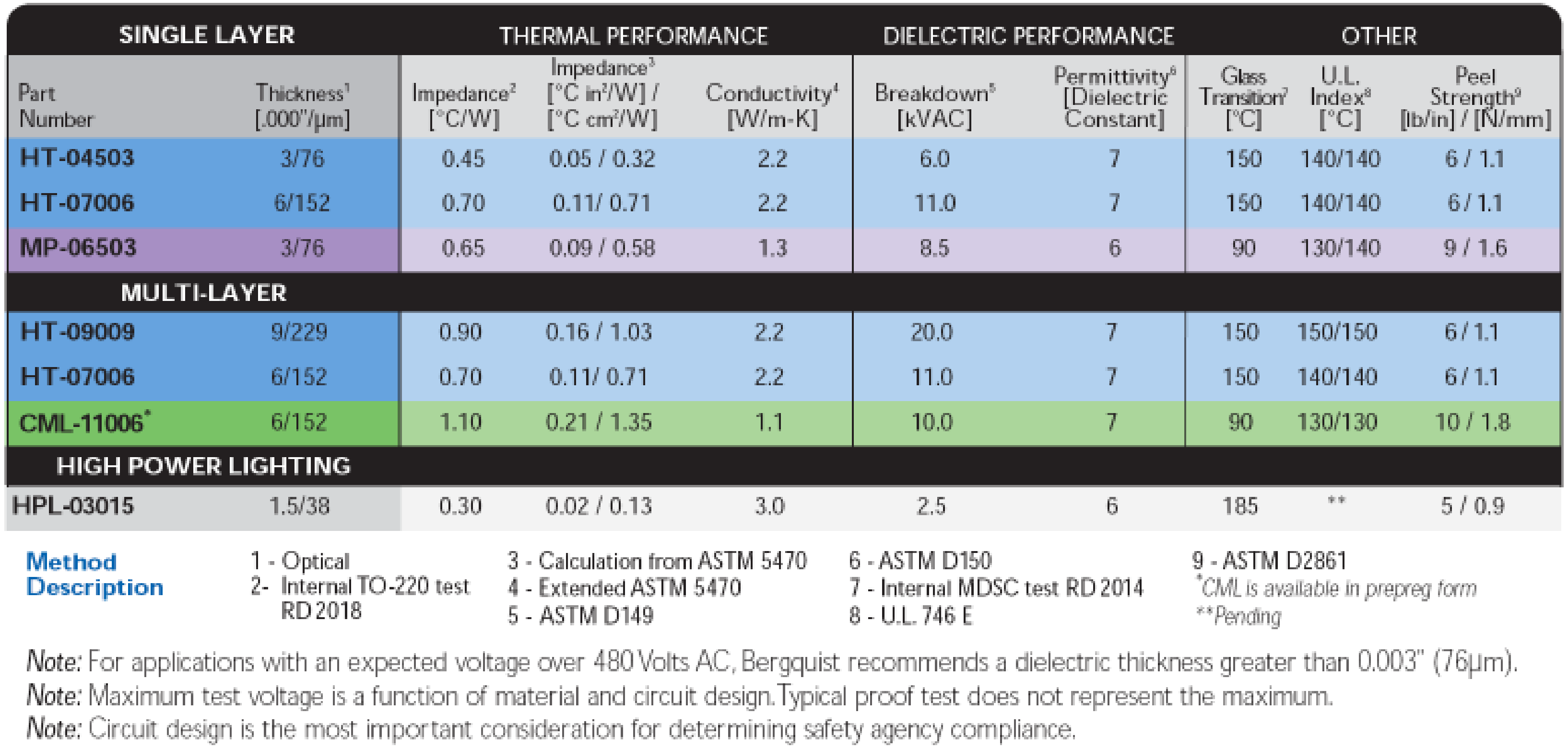








IMS – Dielectric Characteristic



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.

Thermal Measurement Variations

Part Number	Non-Standard Thermal Conductivity Test Methods and Model (W/m-K)				
	Model[1]	Guarded Hot Plate Laminate[2]	Guarded Hot Plate Laminate[3]	Laser Flash Laminate[2]	Laser Flash Laminate[3]
HT-04503	9.0	32.2	36.4	67.6	115
HT-07006	9.0	21.5	23.3	46.0	86.5
MP-06503	4.5	14.0	24.0	34.9	102

Method Description

1 - Bruggeman Model

2 - Tested with 0.062" (1.57mm) 5052 aluminum substrate and 2 oz. (70μm) copper foil

3 - Tested with 0.062"(1.57mm) 1100 copper substrate and 2 oz. (70μm) foil

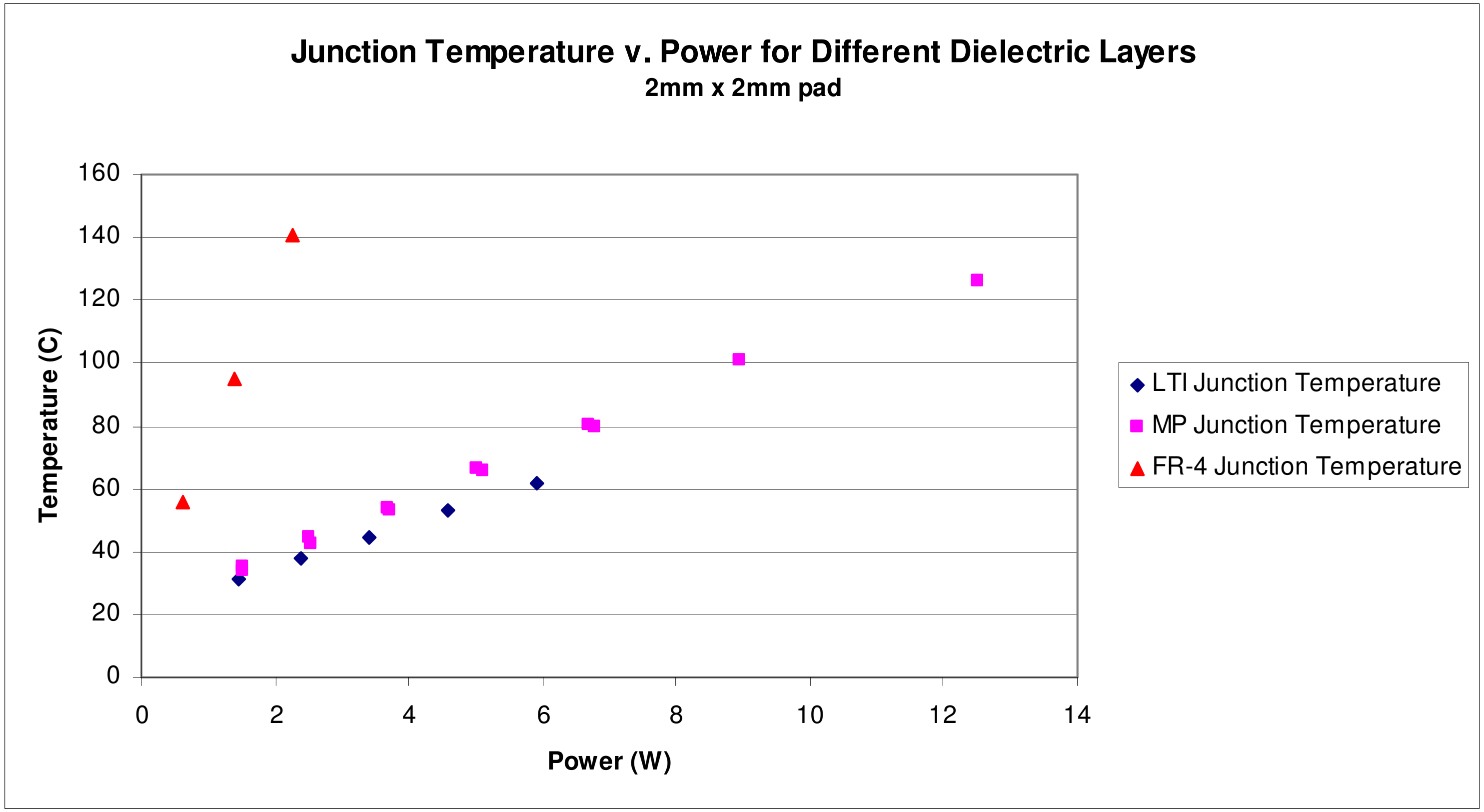
Part Number	Standardized Test Methods (W/m-K)	
	ASTM D5470[1]	ASTM E1461[2]
HT-04503	2.2	1.97
HT-07006	2.2	1.97
MP-06503	1.3	1.17

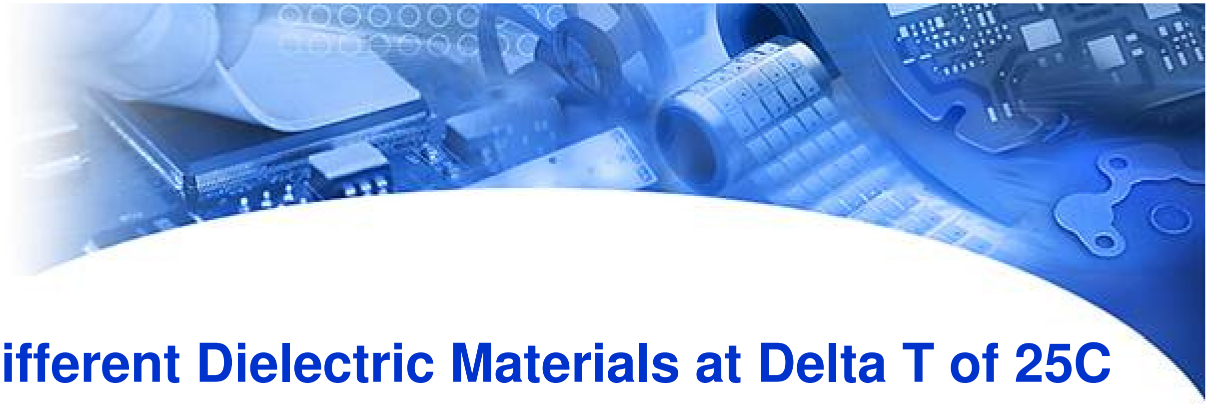
Method Description

1 - ASTM D5470
Guarded Hot Plate

2 - ASTM E1461
Laser Flash Diffusivity

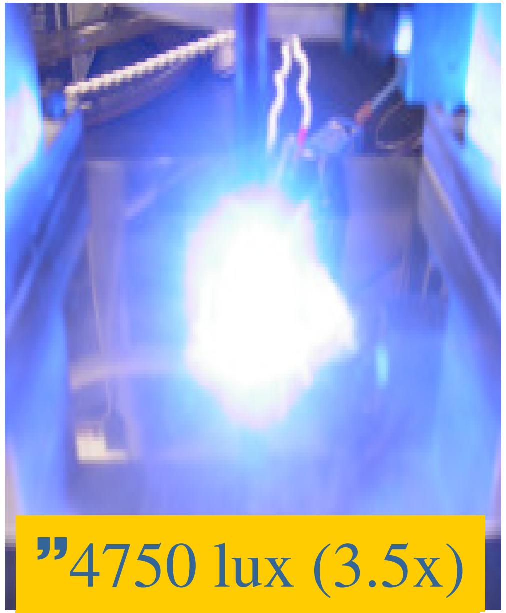
Junction Temperature v. Power



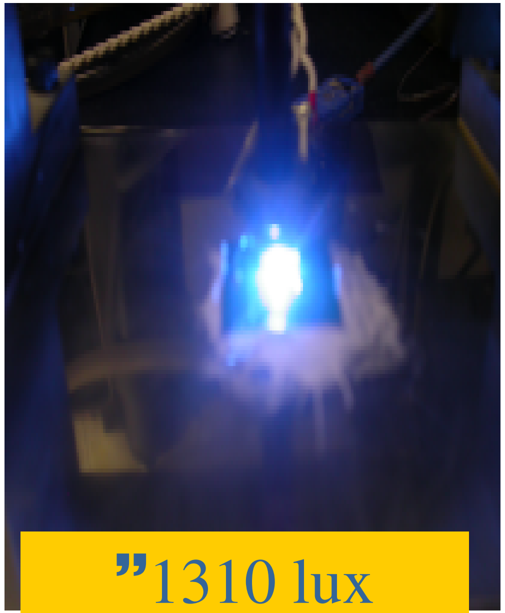


Light Output of Die on Different Dielectric Materials at Delta T of 25C

”5270 lux (4x)
2.2 W/mK
Bergquist HT



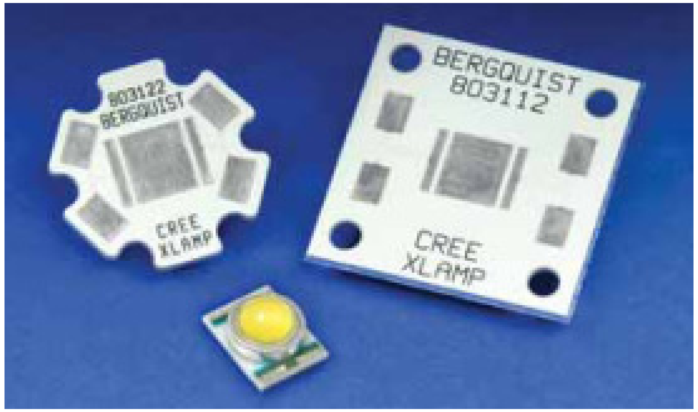
”4750 lux (3.5x)
1.3 W/mK
Bergquist MP

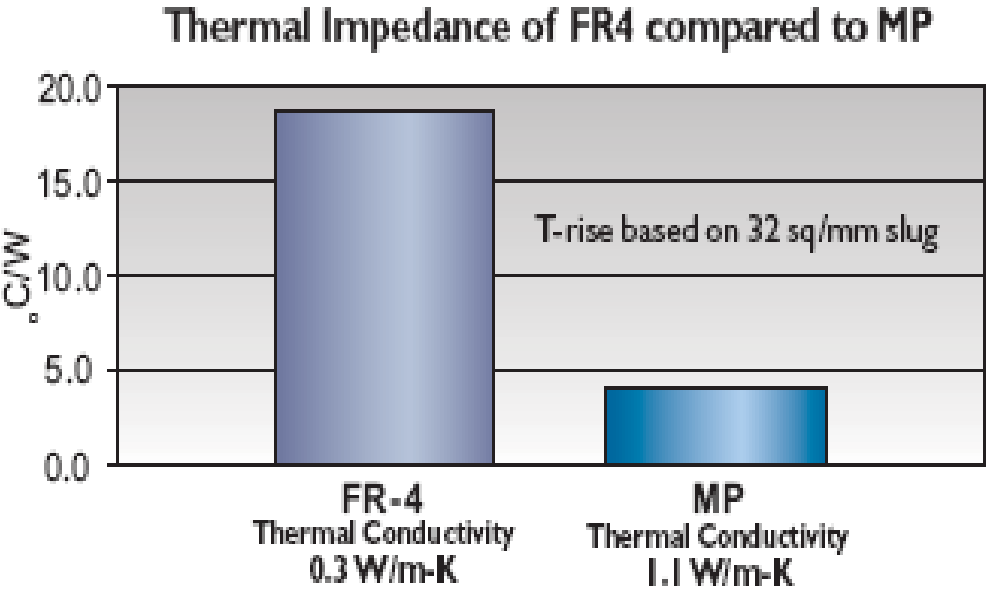


”1310 lux
0.30 W/mK
FR-4/Alu

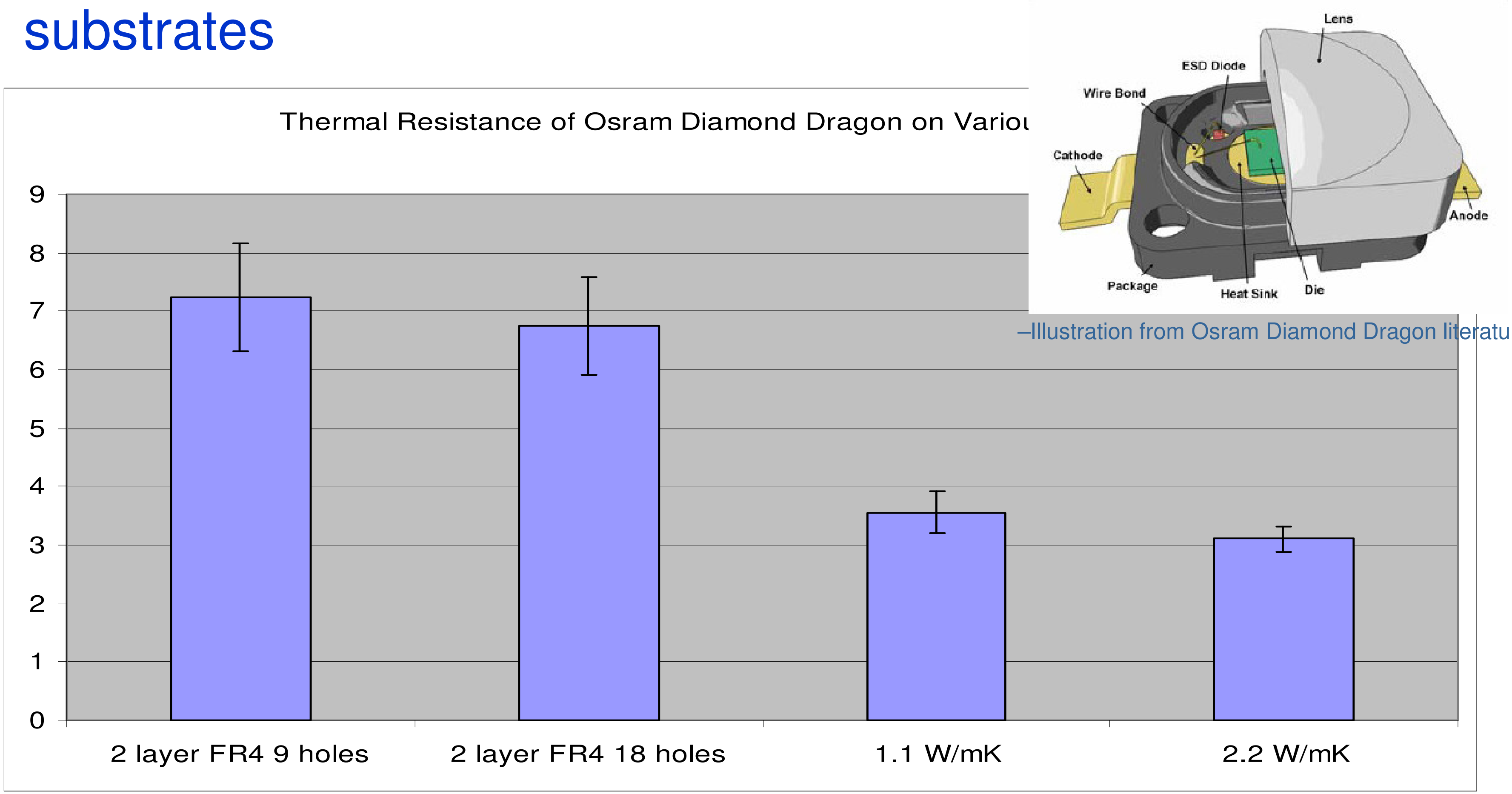
Thermal Substrate Technology Example

Comparing MCPCB Substrate – STAR Design

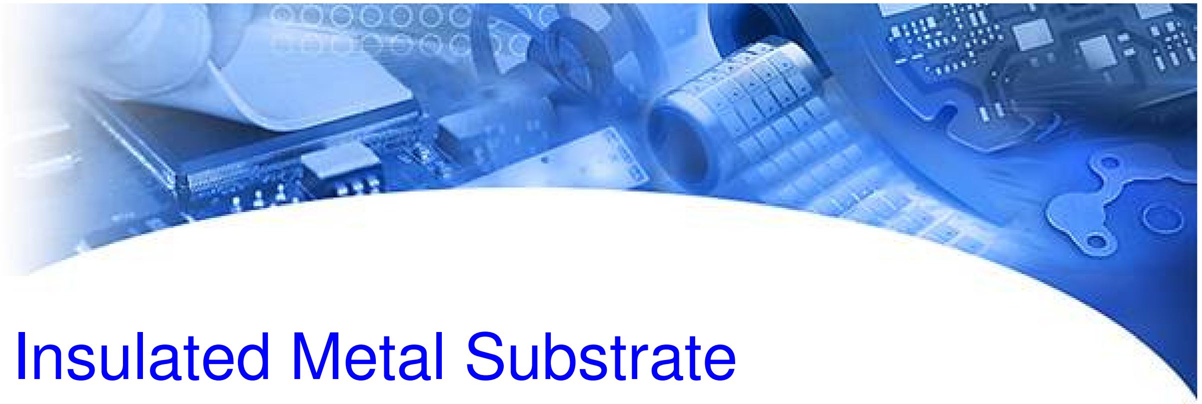




Thermal Impedance of Osram Diamond Dragon on different substrates



–Illustration from Osram Diamond Dragon literature

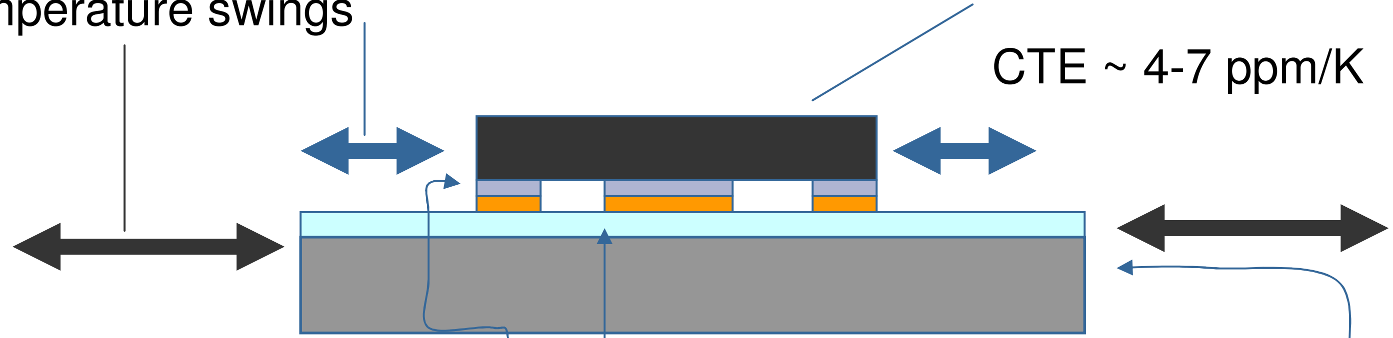


Thermal Clad® - IMS Insulated Metal Substrate

KEY TAKE-AWAY POINTS

1. **Dielectric thermal impedance dominates** the conductive portion on thermal impedance and use of insulated metal substrate (IMS) boards is critical to thermal management
2. TIM2 – the thermal interface between PCB and heat sink can be similar in magnitude to the board resistance – making **TIM2 selection important**.
3. **Reducing the conductive portion** of the thermal budget, by using IMS, provide **more options for heat sink selection**.

New Dielectric Generation
Low Modulus - for extreme Thermal Cycle Applications



Different expansion/contraction with temperature swings

Ceramic submount

CTE ~ 4-7 ppm/K

Stress Relief via Strain in:

Solder Joint

Dielectric

PCB CTE (ppm/K)

Stainless Steel ~ 12

Copper ~ 16

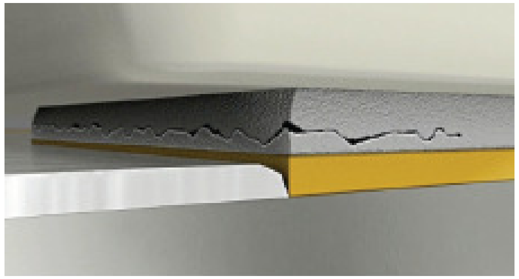
Aluminum ~ 25

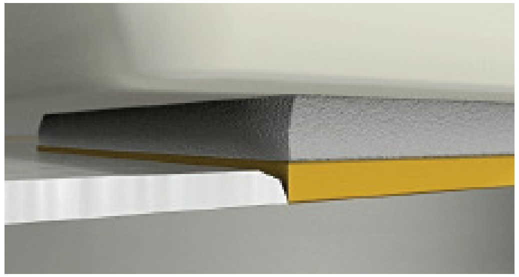
New Dielectric Generation

Thermo Mechanical Fatigue of Solder Joints

Driving Variables

- –CTE mismatch between package and circuit board
- –Geometry of the package
- –Solder joint material and thickness
- –Temperature swings and dwell time
- –Modulus and thickness of circuit dielectric
- –Thermal resistance of dielectric





Effects

- –Cycling of thermal stresses with each temperature cycle
- –Progressive mechanical fatigue/degradation of solder joint
- –Loss of function through loss of mechanical/electrical/thermal contact

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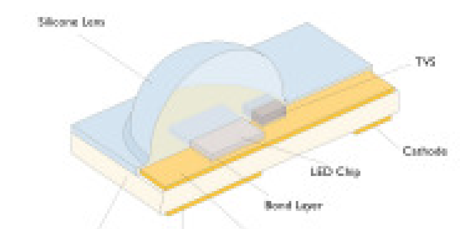
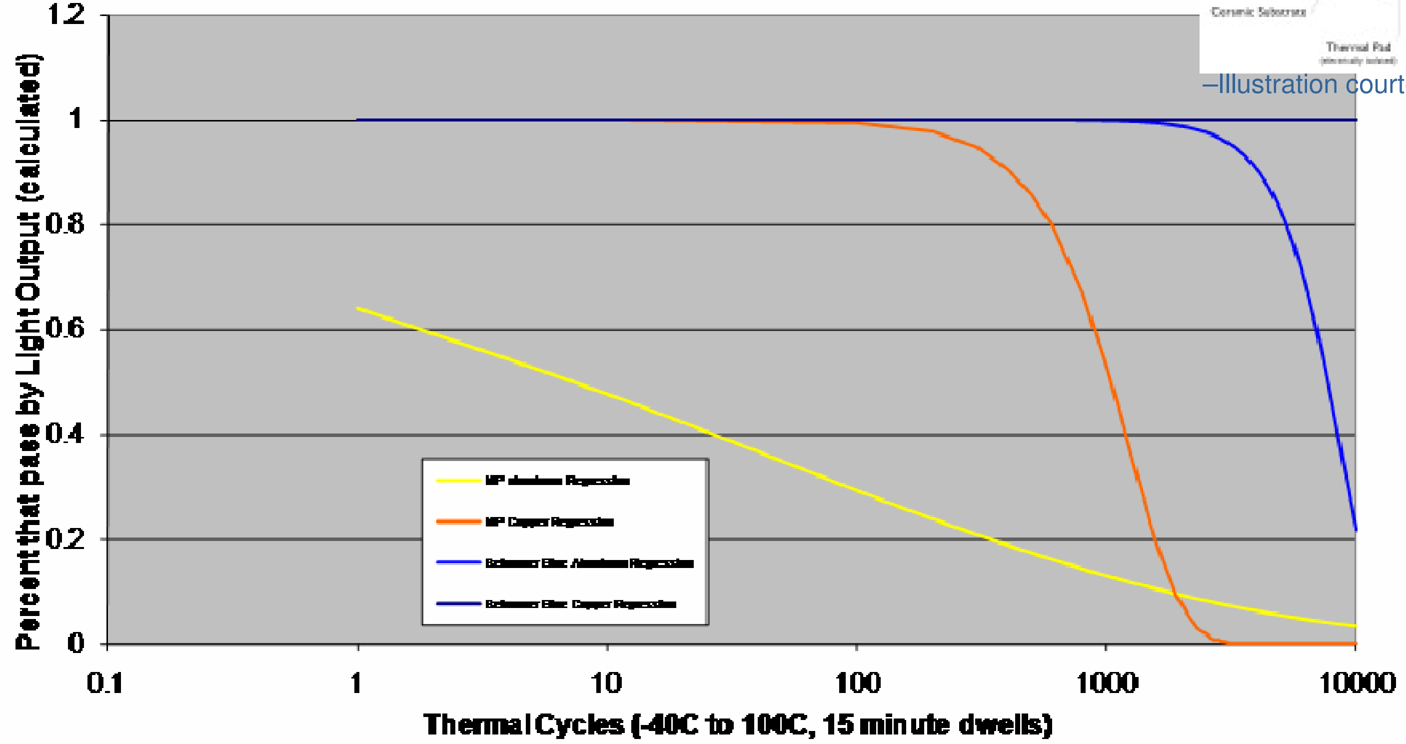
New Dielectric Generation
Solder Joint Reliability and Model Results



–Illustration courtesy of Phillips Lumileds



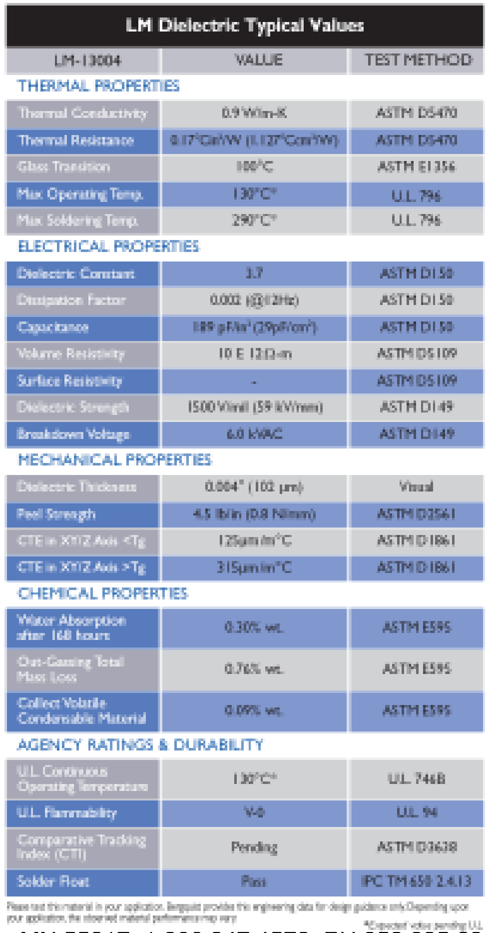
New Dielectric Generation
Thermo Mechanical Fatigue of Solder Joints

Benefits

- Low modulus to absorb CTE stresses
- Thermal conductivity of 0.9 W/m-k
- Improved solder joint reliability

Applications

- Ceramic LED packages
- Applications with significant CTE mismatches
- Direct die applications



LM Dielectric Typical Values

LM-13004	VALUE	TEST METHOD
THERMAL PROPERTIES		
Thermal Conductivity	0.9 W/m-K	ASTM D5470
Thermal Resistance	0.17°Cin²/W (1.127°Ccm²/W)	ASTM D5470
Glass Transition	100°C	ASTM E1356
Max Operating Temp.	130°C*	U.L. 796
Max Soldering Temp.	290°C*	U.L. 796
ELECTRICAL PROPERTIES		
Dielectric Constant	3.7	ASTM D150
Dissipation Factor	0.002 (@1 2Hz)	ASTM D150
Capacitance	189 pF/in² (29pF/cm²)	ASTM D150
Volume Resistivity	10 E 12Ω-m	ASTM D5109
Surface Resistivity	-	ASTM D5109
Dielectric Strength	1500 V/mil (59 kV/mm)	ASTM D149
Breakdown Voltage	6.0 kVAC	ASTM D149
MECHANICAL PROPERTIES		
Dielectric Thickness	0.004" (102 μm)	Visual
Peel Strength	4.5 lb/in (0.8 N/mm)	ASTM D2561
CTE in X/Y/Z Axis <Tg	125μm/m°C	ASTM D1861
CTE in X/Y/Z Axis >Tg	315μm/m°C	ASTM D1861
CHEMICAL PROPERTIES		
Water Absorption after 168 hours	0.30% wt.	ASTM E595
Out-Gassing Total Mass Loss	0.76% wt.	ASTM E595
Collect Volatile Condensable Material	0.09% wt.	ASTM E595
AGENCY RATINGS & DURABILITY		
U.L. Continuous Operating Temperature	130°C*	U.L. 746B
U.L. Flammability	V-0	U.L. 94
Comparative Tracking Index (CTI)	Pending	ASTM D3638
Solder Float	Pass	IPC TM 650 2.4.13

Please test this material in your application. Bergquist provides this engineering data for design guidance only. Depending upon your application, the observed material performance may vary

*Expected value pending U.L.

Thermal Interface Solutions for LED Designs

- **Case Study**
- **Thermal Measurements comparisons**
- **Summary**

Case Study: 1000 Lumen output Lamp (1st order approximation)

- This is approximately what is put out by a 75W incandescent lamp
- LED has electrically active heat spreader
- Assume the heat sink is the same for all substrate materials (0.5 C/W)
- Assume LEDs are thermally independent of one another until they reach the heat sink

http://www.nofs.navy.mil/about_NOFS/staff/cbl/lumentab.html

Case study: 1000 Lumen Output Lamp

- **Rule of thumb; 15 – 40% of LED output loss in the lamp optics (assume 20% for this study)**
  - **Our 1000 lumen lamp becomes 1250 lumens required**
- **Driver not included in assumptions**
  - **Adding the driver will increase wattage by 15%**

How Long Must the Lamp Last?

ENERGY STAR

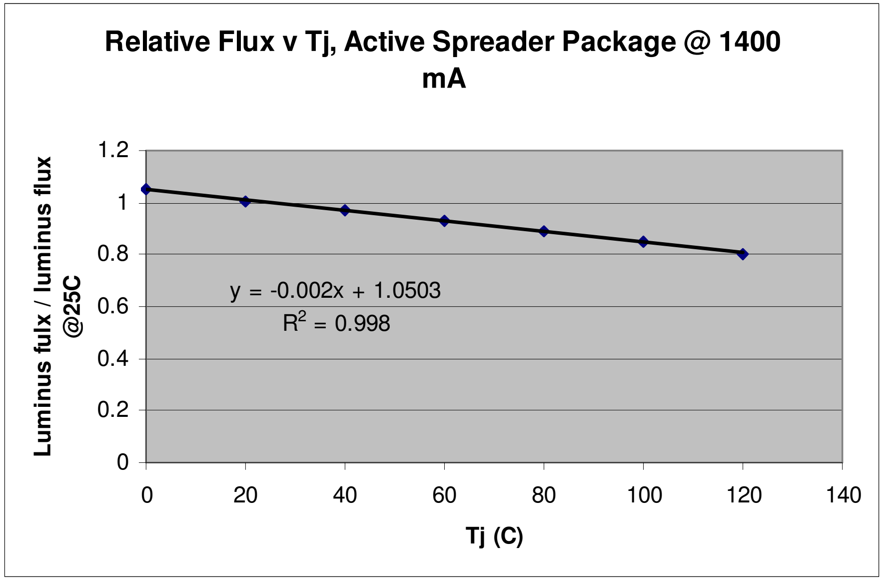
- For Commercial and Outdoor residential applications we need B50, L70 of 35,000 hours, and a 3 year warranty to meet EnergyStar Category A requirements

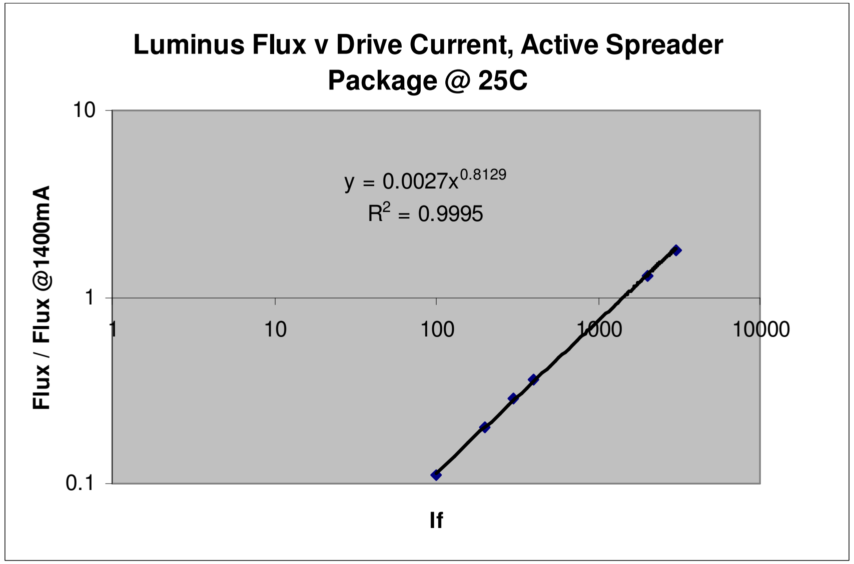
Thermal Resistance of LED devices from test

- LED with electrically active Heat Spreader
  - FR4 9 holes – 7.24 C/W
  - FR4 18 holes – 6.74 C/W
  - Thermal Clad MP – 3.56 C/W
  - Thermal Clad HT – 3.1 C/W

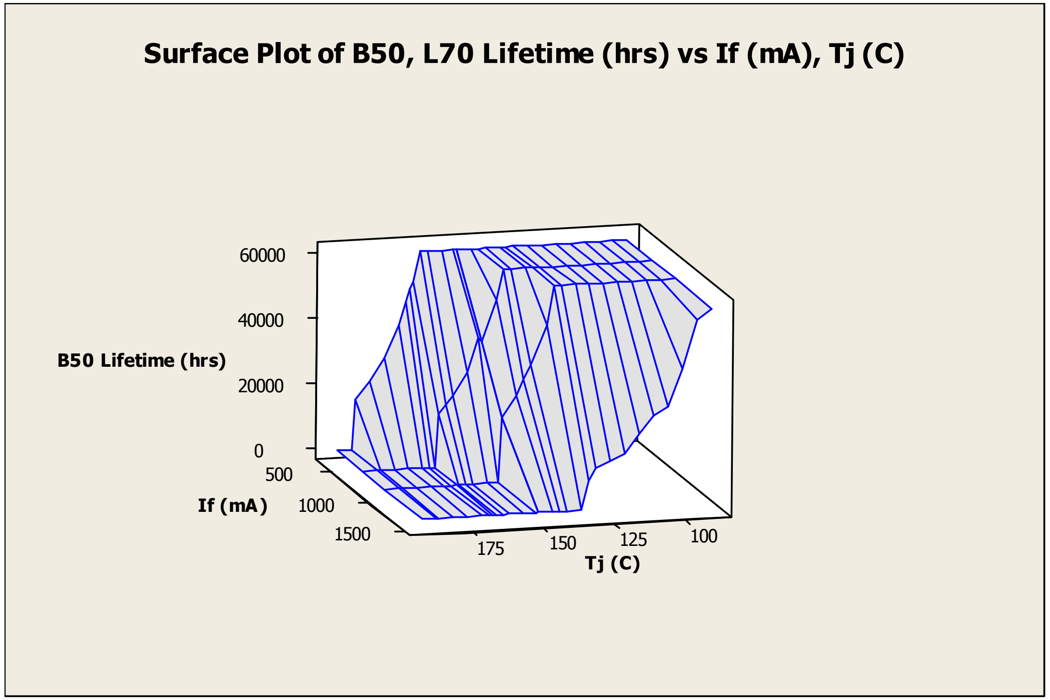
Note: FR4 with thermal vias requires electrical isolation, so we will add another 0.2 C/W for a good TIM.

Adjust Lumen Output for Temperature and Drive Current


Relative Flux v Tj, Active Spreader Package @ 1400 mA


Luminus Flux v Drive Current, Active Spreader Package @ 25C

Understand Effect of Drive Current & Tj on Lifetime



$$\text{B50 Lifetime (hrs)} = 156523 - 33.4\ \text{If (mA)} - 665\ \text{Tj (C)}$$

Iteratively Solve for Drive Current and Tj for A Lifetime that Meets Energy Star Criteria (35,000 hrs)

- **Tj is a function of Power which is a function of Vf and If.**
- **If is a function of Vf**
- **Life is a function of If and Tj, or ultimately Vf**

Results

All forward current set to 1500 mA

Material	Thermal Resistance / device	Tj	Vf	If	Power	% Light output	Lifetime (hrs)
2 layer FR4 9 + Sil Pad	7.44	118.9	3.55	1500	5.33	84	27288
2 layer FR4 18 + Sil Pad	6.94	115.4	3.55	1500	5.33	84	29658
MP + grease	3.56	99.0	3.55	1500	5.33	88	40528
HT + grease	3.1	96.7	3.55	1500	5.33	88	42058

FR4 system does not meet Energy Star lifetime requirements

Results

All lifetimes set to 35,000 hours

Material	Thermal Resistance / device	Tj	T amb	Vf	If	Power	% Light output
2 layer FR4 9 + Sil Pad	7.44	114.6	79.3	3.51	1355	4.75	78
2 layer FR4 18 + Sil Pad	6.94	112.6	79.5	3.52	1396	4.91	80
MP + grease	3.56	100.9	80.1	3.59	1629	5.85	94
HT + grease	3.1	98.8	80.2	3.60	1669	6.01	96

Continued

- **If the minimum flux (100%) from the lamp is 130 lumens and we want 1250 (1000/.8), then**

$$\#\ of\ \ LEDs = 1250 \div \left(\%\ light\ output \times 130\right)$$

Of course we need to round up on number of devices

What does this mean?

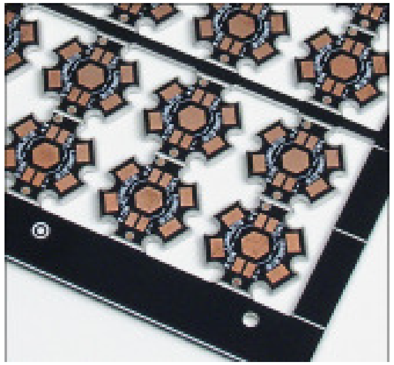
- **Assuming the heat sink costs ”$5**
- **The LEDs cost ~ $3/piece**
- **Then the results are**

Material	LEDs Needed	Lamp Cost
2 layer FR4 9 + Sil Pad	13	$46.28
2 layer FR4 18 + Sil Pad	12	$43.22
MP + grease	11	$40.10
HT + grease	11	$40.27

Summary Case Study

- IMS, like Bergquist T-Clad, offers thermal, structural, and cost effective solution to mounting packages. Approximately 1-5% of the system BOM cost, and can reduce the number of LEDs required.
- Conductive thermal management is becoming critical to finding thermal solutions with package power dissipation approaching
  1-2 W/mm^2

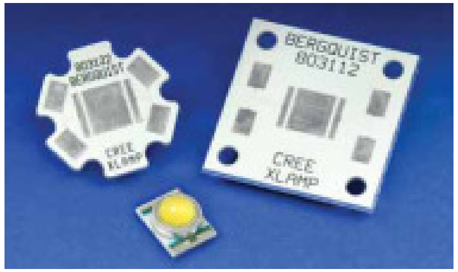
Key Advantages of the IMS Technology

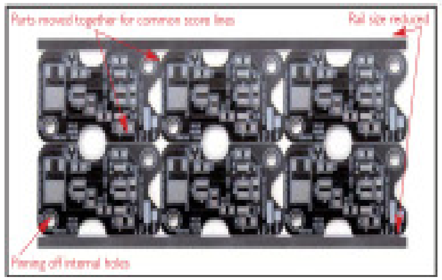


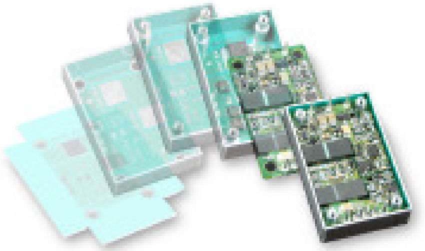
- Measurable improvement in Watt-Density
- Simplified thermal design – due to IMS
- Reliability – dielectric and base plate integrity
- Array panelization available
- Structural rigidity which allows for features like threaded holes
- Variety of configurations are available (shape, dielectric/base plate, option for direct die bond to base plate)

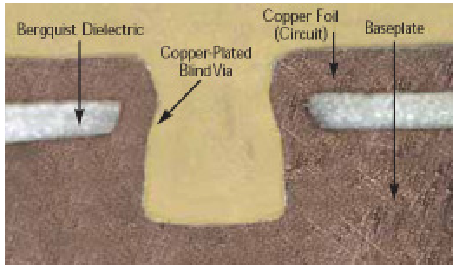
Bergquist known for

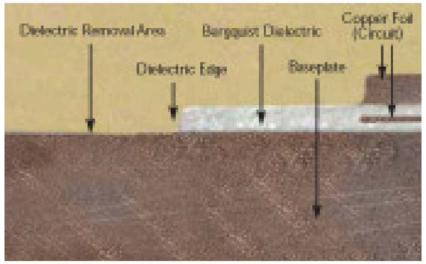
- **Materials Manufacturer**
  - ✓ **Thermal Interface Materials**
  - ✓ **IMS Materials**
- **Circuit Provider for IMS**
  - ✓ **IMS circuits supplier**
    - **Component and COB level**
    - **Piece Part and Array´s**
  - ✓ **Active Base Plate Solutions**
    - **Electric Vias to Metal Base**
   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

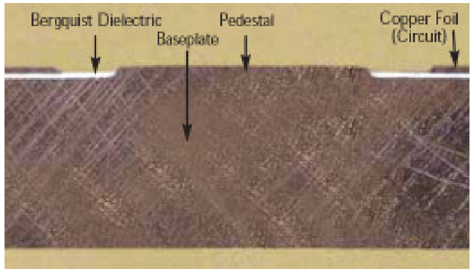




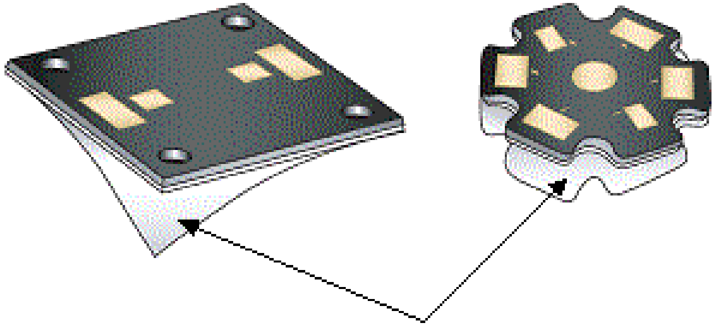








Combining IMS and Thermal Interface Materials



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

Thank you!

For more information contact

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