ZKZ 64717
12-05

Power Systems Design EUROPE

Power Control Intelligent Motion
December 2005

Thermal Management Made Simple

PSDE PowerLine
PSDE PowerPlayer
Marketwatch

ISSN: 1613-6365

COVER STORY

HIGH BRIGHTNESS LED THERMAL MANAGEMENT MADE SIMPLE

Bergquist's Thermal Clad® insulated Metal Substrate (IMS™) offers many of the same cooling benefits for LED lighting applications as it does for power electronics. **By Rick Samuelson, Market Development Manager and Justin Kolbe, Sr. R&D Engineer, The Bergquist Company.**

Like surface mounted power transistors, High-Brightness Light Emitting Diodes (HB-LEDs) require cost effective thermal management for long-term reliability. Consistent color and power magnitude are directly affected by the thermal management solution as well. Generally, as the light output of HB-LEDs increases, so does power dissipation or watts per HB-LED.

Currently, three and five-watt LEDs are commonplace, and industry experts are predicting 10-watt LED availability in the next few years. Packaging and thermal management solutions for HB-LEDs are paralleling surface mounted power devices.

HB-LEDs of greater than one-watt are almost always surface mounted devices. This is because the axial leads to the die in a leaded package do not conduct enough heat away from the LED. Chip-on-board (COB), flip chips and thermally efficient packages are emerging as the standard thermal management packaging solution for HB-LEDs.

THE EFFECT OF TEMPERATURE

HB-LED die have several temperature-dependent properties. The color, or wavelength, will change with temperature. As the die temperature increases, the wavelength of the color increases.

$$\frac{\Delta\lambda}{\Delta T} = K$$

$\Delta\lambda$ = Dominant wavelength change (nm)
ΔT = Die junction temperature change (°C)

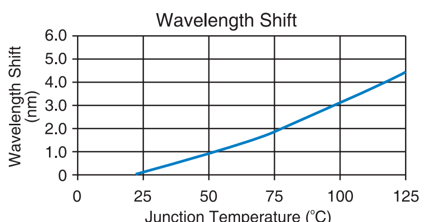


FIGURE 1

Figure 1 shows the temperature effect on wavelength.

An area in which this is of particular importance is with white light. The human eye can differentiate small color changes in white light. When HB-LEDs are populated in an array, consistent thermal resistance from one die to the next assures consistent color. Because of the comparatively low thermal resistance Thermal Clad offers versus FR-4, die temperature is less affected by slight variances in the junction-to-case thermal resistance that occurs with tin eutectic or epoxy-die mounting techniques.

Power magnitude, or watt density, is directly related to light output. The more power applied to the HB-LED while maintaining the desired die temperature, the higher the light output. It may also be possible to pack the die more closely in an assembly that utilizes good thermal management techniques, thereby reducing the effects of temperature.

Figure 2 shows the dramatic change in relative light intensity based on the forward current applied to the LED.

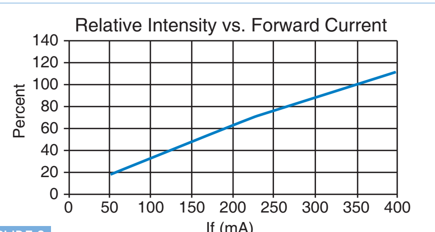


FIGURE 2

Finally, the junction temperature determines HB-LED lifetime. The heat rise in LEDs is due to the energy that is not turned into light energy.

$$P = I^2 R$$

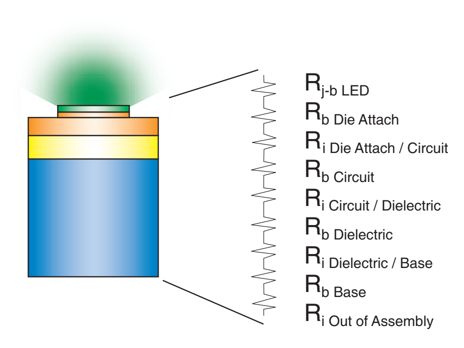


FIGURE 3

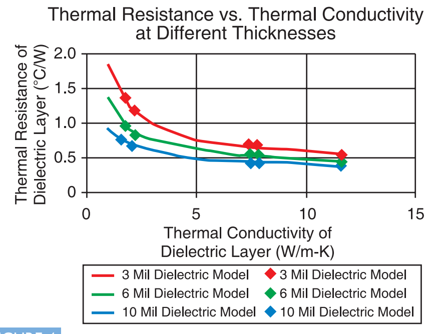


FIGURE 4

Generally, a 50 percent drop in light output for a constant-forward current indicates end-of-life for HB-LEDs. With proper thermal management, HB-LED lifetimes can exceed 100,000 hours. In addition to long life, other factors that make LEDs viable as compared to incandescent or fluorescent lighting are: versatility, safety factors (low voltage) and total cost of ownership.

Although the initial cost of HB-LEDs is higher, many applications such as traffic signals, architectural and display lighting have demonstrated HB-LED lighting is the most cost effective solution.

COST OF HEAT SUMMARY

Better thermal management allows for more forward current applied to the LED, which means more light and possibly reducing the number of LEDs required for the desired light output. Maintaining a cooler assembly at an equivalent power equates to more light per die. Ninety percent of the electrical energy in a red AlInGaP LED will be converted into visible light. Only part of this light energy can be ejected from the chip. The remaining energy, which cannot leave the chip, will be converted into heat.

HEAT TRANSPORT METHODS

Determining the exit path for thermal energy is important. Conduction, convection and radiation are the primary paths for the removal of heat from the HB-LED die. Conduction, or heat transfer through a solid body, is the most efficient thermal path, followed by convection, which is usually the final thermal path to ambient. Radiation is generally negligible in managing the temperature of HB-LEDs.

The following calculation is used for the stack's conductive heat transfer from the heat source to the air

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

Power that can be dissipated under a given temperature constraint is then influenced by:

A = area of the layer
K = thermal conductivity
dx = layer thickness
q = power

In the case of a typical HB-LED application, several thermal resistance interfaces are present. See **Figure 3**. Moving through the stack, thermal impedance depends on thermal conductivity and thickness. **Figure 4** depicts thermal impedance versus thermal conductivity at different thicknesses for the dielectric layer.

Note that as the dielectric thickness gets thinner, thermal conductivity has less effect on thermal resistance. As this relates to heat removal from the assembly, the total thermal resistance of each component in the stack in considered and then assembly-to-ambient. Thermal Clad has a 75 micron dielectric with relatively high thermal conductivity. This insulation layer is critical in the thermal management of HB-LEDs because the isolation layer is potentially one of the highest thermal resistance interfaces in the stack.

For the assembly-to-ambient interface, different options include an infinite heat sink (such as the chassis of an automobile or metal enclosure), forced air, or a dynamically cooled assembly (such as a fan or thermal electric cooler), often modeled as an infinite heat sink.

Removing the heat from the die is only effective if it can also be removed from the assembly. An infinite heat sink is the most effective solution thermally, but often impractical or too expensive.

Therefore, when using an infinite heat sink approximation, the problem becomes one of conduction only. This assumption is generally valid if the removal of heat from assembly is greater than the generation of heat, assembly is mounted to a large heat sink and assembly is being cooled dynamically.

q = dissipated power (W)
A = area (m^2)
ΔT = temp. plate - temp. ambient (K)
L = length plate (m)
h = convective heat transfer coefficient (W/m^2-K)
a = coefficient 1.32 for top of plate, 0.59 for bottom, dependent on shape and orientation

$$q = hA\Delta T$$

$$h = a\left(\frac{\Delta T}{L}\right)^{1/4}$$

EQUATION 1: FIGURING HEAT DISSIPATION IN STILL AIR

Ri is bulk or interfacial resistance
- Conduction R_b = L/k A

$$R_{Total} = \sum_i R_i$$

Interfacial resistance must be determined empirically (generally small, but not always)
- Convection R = 1/h A

EQUATION 3: FIGURING OVERALL THERMAL RESISTANCE

V = velocity of fluid (m/s)
p = density of air (kg/m^3)
u = viscosity of air (Poise)
q = dissipated power (W)
A = area (m^2)
T = temp. plate - temp. ambient (K)
L = length plate (m)
h = convective heat transfer coefficient (W/m^2-K)
a = coefficient 0.0366 for turbulant flow, 0.5 for laminar flow
B = 0.8 for turbulent flow, 0.5 for laminar flow
N_{Pr} = Prandtl Number = Cp m/k
C_p = heat capacity of air (J/kg k)
k = thermal conductivity of air (W/m-k)

$$q = hA\Delta T$$

$$h = a\left(\frac{Lv\rho}{\mu}\right)^{b} N_{Pr}^{1/3}\,\frac{k}{L}$$

EQUATION 2: FIGURING HEAT DISSIPATION IN MOVING AIR

Still air (natural convection) is probably the most common method of cooling but still requires air flow (e.g. holes in a cover or enclosure). Otherwise, air is just a good thermal insulator. Use equations 1, 2 and 3 for figuring heat dissipation in still or moving air and overall thermal resistance of a build.

Overall power dissipation in a given temperature rise:

$$q = \frac{T_2 - T_1}{R_{Total}}$$

Overall temperature rise for a given power dissipation:

$$T_2 = T_1 + qR_{Total}$$

These simple equations are good for first approximations of temperature rise in HB-LED designs. However, bench top testing and data confirmation are advisable to verify the design.

CIRCUIT BOARD COMPARISON MODELS

Insulated Metal Substrates (IMS) and standard FR-4 are commonly used circuit board materials in conjunction with HB-LEDs. Bergquist's Thermal Clad IMS is a thin, thermally conductive layer bonded to an aluminum or copper substrate for heat dissipation. See **Figure 5**.

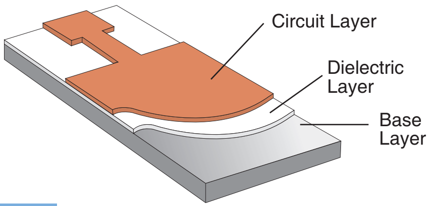


FIGURE 5

Thermal Clad circuit board materials are available from The Bergquist Company in two different thermal conductivities. Multi-Purpose (MP) and Low Thermal Impedance (LTI). **Figure 6** illustrates the modeling results of a Cree XB900 die mounted on each of these circuit board materials, along side an FR-4 board. This thermal model shows the temperature of the die when a constant current is applied to the die on different circuit board materials. The Cree die is modeled on 2 oz circuit foil, 0.020 in^2. Tin gold eutectic die was utilized with gold wire bonds to complete the circuit. Power dissipation was set at one watt. The resulting die temperature for the FR-4 is 63.7°C, MP is 36.9°C and LTI is 34.2°C.

BENCH TEST RESULTS

A bench test setup is used to verify the thermal model. The test is adapted from Voltage from Base to Emitter (VBE) testing used in power electronics. The die is calibrated by measuring voltage at different temperatures using a sense current small enough as to cause negligible heat rise. In this case, one milliamp was used. Following are all of the test parameters common in power electronics to determine junction temperatures.

- Sense Current - 1 mA
- Heating current and heating voltage from power supply
- Electrical resistance dependent on temperature
- Know V and I, can get T as a function of R
- Thermal resistance of the system is Tj-Ts/(V*I)

Once the LED die was calibrated using the described setup, the forward current to the die was adjusted in order to regulate the die temperature. **Figure 7** illustrates the light output of the same LED die on different circuit board materials at a maintained die temperature of 50°C. This bench test shows the higher light output of Thermal Clad versus FR-4.

Thermal resistance is both a function of thermal conductivity of the dielectric and pad size. As the conductor area that the LED is mounted on gets smaller, thermally conductive materials become more valuable. Building the mounting conductor larger, the LED improves thermal resistance as shown in **Figure 8**.

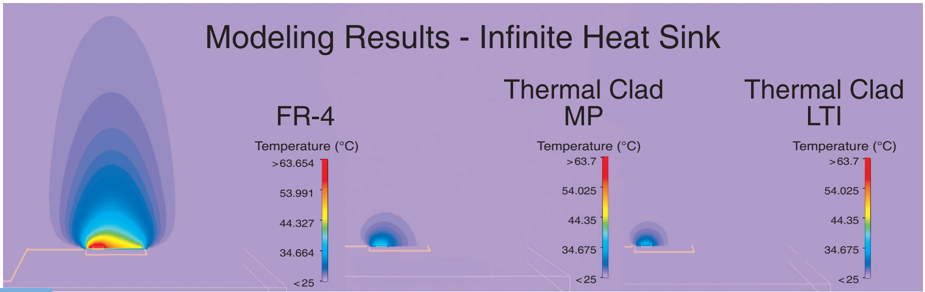
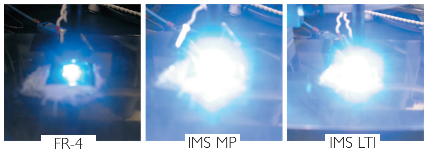


FIGURE 6

PACKAGING CONCLUSION

Several options are available for thermal management of HB-LEDs. Most common are packaged die from the manufacturer and direct-die-attach to the circuit board or substrate by the HB-LED integrator. The most critical thermal path in the stack is the one with the highest thermal resistance. Good practice suggests that you reduce the thermal resistance of that layer with Thermal Clad instead of FR-4. Typically, HB-LED packages from the manufacturer have a thermal resistance of > 15°C/W. When HB-LED packaging has thermal resistance this high, the circuit board choice has less impact on thermal management. When the opportunity exists to use tin eutectic gold die attach methods, as was the case in the model and bench test, the circuit board material greatly affects HB-LED thermal management. Bergquist's Thermal Clad material is a cost-effective option for HB-LEDs, improving heat transfer as compared to emitters. However, thermal management of HB-LED emitters is also improved on Thermal Clad as compared to FR-4, though the thermal impact is less than COB packaging.



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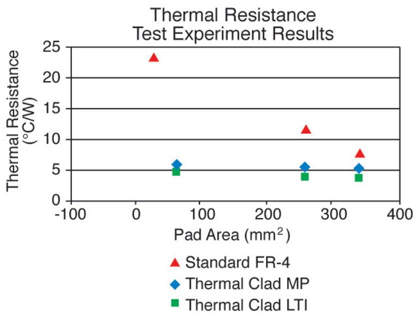

FIGURE 8

www.bergquistcompany.com

The Bergquist Company

Headquartered in Chanhassen, Minnesota, The Bergquist Company is a privately held, family owned business founded in 1964. The company started out as a modest midwest electronics distributor and is now a world leader in thermal management and consists of five main divisions.

Thermal Products
Membrane Switches
Touch Screens
Electronics
Labels & Graphic Overlays

Bergquist manufacturing facilities are located throughout the United States. Bergquist has additional facilities in The Netherlands, Germany, United Kingdom, Korea, Japan, Hong Kong, Taiwan, Singapore and China, and sales reps in 30 countries to support worldwide growth.

Bergquist's Thermal Products Group is the world's leading developer and manufacturer of thermal management materials and provides solutions to manage heat in electronic assemblies and printed circuit boards. These materials include an extensive line of standard Sil-Pads®; thermally conductive insulators, and many specialty materials which include Bond Ply®, Gap Pads®, Gap Fillers and a complete family of Hi-Flow® phase change grease replacement materials. The Thermal Division also manufactures Thermal Clad®, thermal management substrates (IMS™) for surface mount applications. Bergquist is the global source for the processing of Thermal Clad® IMS™ circuits and is ISO9001:2000 certified. Their products are used by many industries worldwide including automotive, computer, military, aerospace, telecommunications, power supply and motor control.

For more information on the Bergquist Company please visit:

www.bergquistcompany.com

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