Heat Transfer Mechanism

in LED Packages

With the rapid replacement of incandescent light bulbs by Light-Emitting Diodes (LEDs), the thermal management of LEDs has become even a greater necessity. Prior to devising cooling schemes to keep the LEDs running cool, understanding the fundamental heat transfer mechanism in an LED package is a must. This article discusses a basic fundamental issue of the underlying heat transfer mechanism in LEDs.

LEDs are solid state devices that directly convert electricity to light. They are called solid state because the solid chip or die is the active component that produces light [1]. Just like a diode, an LED has Cathode (Negative) and Anode (Positive) poles and is activated by a forward voltage. This generates the forward current and the conversion is made at the junction, as shown in Figure 1. The goal in any LED design is to keep the junction temperature low. The Junction Point is at the interface of the p-n junction at the die, where photons are generated.

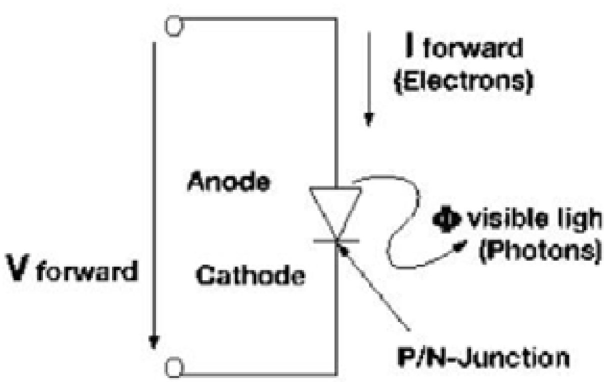


Figure 1. Forward Bias of an LED [1]

The basic schematic of an LED assembly is shown in figure 2.

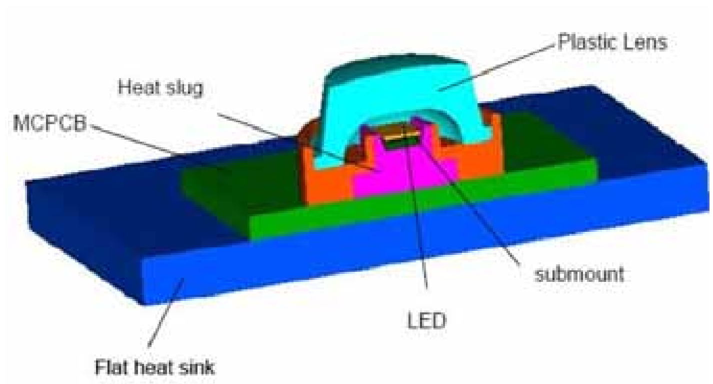


Figure 2. Basic Schematic of an LED Assembly [2]

In this diagram, the LED is placed on a silicon sub-mount and the sub-mount is directly mounted on a heat slug [2]. The LED assembly is mounted on a Metal Core Printed Circuit Board (MCPCB). MCPCBs have a higher conductivity than a regular PCB and are used to transfer the heat from the LED to the heat sink more efficiently. A plastic lens is attached on top of the LED and filled with a silicone encapsulant to enhance the light extraction efficiency. The low power LEDs dissipate their power through leads, but high power or high brightness LEDs, which use their package to dissipate heat, are mostly a Surface Mount Technology (SMT) type.

Figure 3 shows the different thermal resistances between the junction and the ambient air of a typical LED.

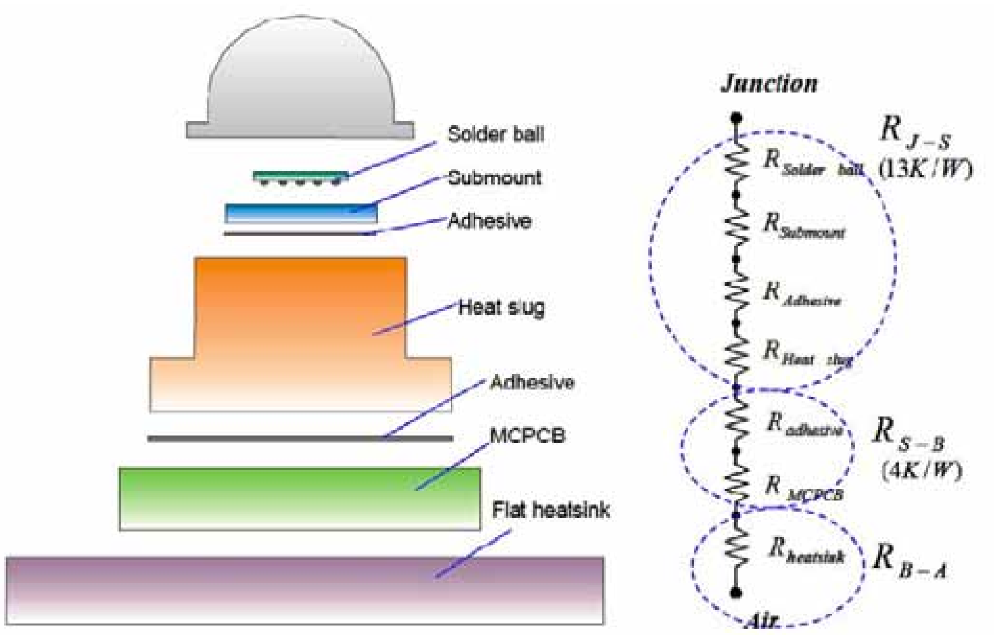


Figure 3. Resistance Path between LED Junction and Air [3]

The thermal resistance path is divided into three sections. $R_{J\text{-}S}$ the resistance between junction and the heat slug; $R_{S\text{-}B}$, the resistance between heat slug and the board and $R_{B\text{-}A}$ the resistance between board and ambient. The resistance between the LED and top of the lens is very high and can be neglected in comparison to the resistance path from junction to board. This means almost all the heat is transferred downward through the board and heat sink.

The thermal resistance of junction to heat slug is calculated as follows:

$$R_{J\text{-}S} = R_{die} + R_{solderball} + R_{submount} + R_{adhesive} + R_{heatslug}$$

The thermal resistance between heat slug and the board is calculated as:

$$R_{S\text{-}B} = R_{adhesive} + R_{MCPCB}$$

Where

$$R_{MCPCB} = R_{dielectric\ layer} + R_{Al\ layer}$$

And the thermal resistance between the board and air is:

$$R_{B\text{-}A} = R_{tape} + R_{convection}$$

Properties and dimensions of most common materials used in LED construction are shown in table 1.

	Thermal conductivity (W/m-k)	Thickness (mm)
Solder	50	0.1
Submount (Si)	150	0.5
Adhesive (Submount-heat slug)	1	0.035
Heatslug (Cu)	360	2.87
Adhesive (Heat slug-MCPCB)	1	0.07
MCPCB		
Dielectric Layer	1.8	0.1
Metal layer (Al)	237	1.5
Tape	0.067	0.130
Heat sink (Al)	237	1.6

Table 1 – Properties of Common Materials in an LED Package [2]

To reduce the junction temperature, each thermal resistance in the path from junction to air should be minimized. One of the parameters in keeping the junction temperature low is to keep the thermal resistance of the heat sink low. This can be achieved by using very high performance heat sinks or some type of liquid cooling. But even with low thermal resistance from a heat sink, there is a limit on how much the junction temperature can be cooled. Often, it depends on

Advanced Thermal Solutions, Inc.
89-27 Access Road | Norwood, MA 02062 | USA
www.qats.com | T: 781.769.2800 | F: 781.769.9979

ATS is here to help. Our Design Services provide custom solutions for the toughest thermal challenges.

the resistances of the different parts in the package. A high value in any of the resistances would be a major obstacle in cooling the LED.

If we calculate the thermal resistances of different materials in Table 1, assuming they all have the same area, it shows that the major resistances are due to tape, heat slug adhesive, dielectric layer and sub-mount adhesive (in that order). Minimizing each of these resistances can greatly reduce the overall thermal resistance of the package thermal resistance.

The principal mechanism for cooling LEDs is to transfer the heat from the junction to the board and from there the heat sink will carry the heat to the ambient. The state- of-the-art for board application is to use a MCPCB (Metal Core Printed Circuit Board). These are boards with a base metal material as a heat spreader. Figure 4 shows the schematic of a single layer MCPCB. This configuration consists of a copper layer on top, a high conductivity dielectric layer beneath, and a metal core at the base. The typical thicknesses of these layers are: copper at 35-200 um, dielectric layer at 75- 100 um and metal core at 1-3 mm. The metal core is usually made of aluminum.

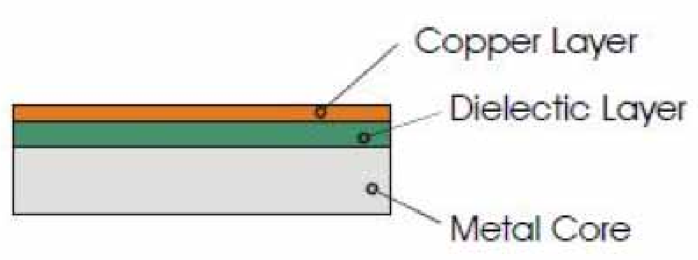
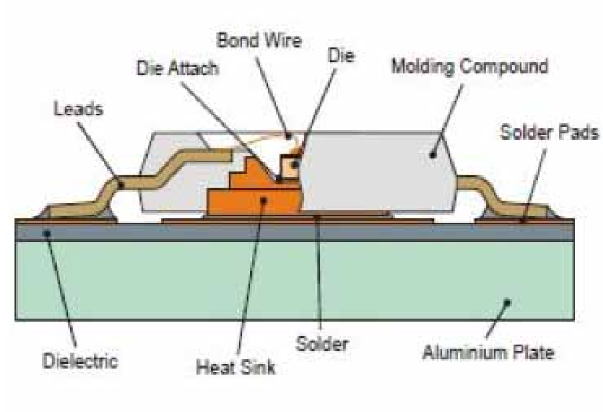


Figure 4. Schematic of a Single Layer MCPCB[4]

In [4], Osram conducted a simulation based on 100 um thickness for the dielectric, 1.5 mm for the aluminum and 35 um for the copper. The thermal conductivity of the dielectric was assumed at 1.3 W/m.K. The results of the analysis using CFD are displayed in Figure 5, which shows the temperature distribution normalized with respect to a reference at the solder pads plane.



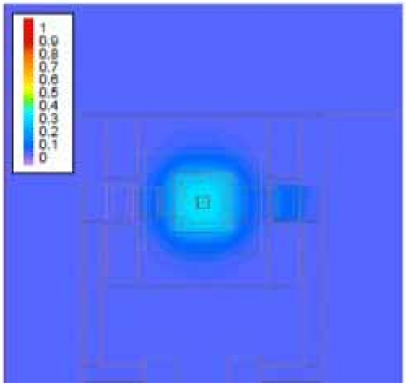


Figure 5. Temperature Distribution in an MCPCB at the Solder Pads Plane [4]

Figure 6 shows the temperature distribution of the same package, but using standard dielectric FR4 with a thermal conductivity of 0.3 W/m.K. Comparing Figures 5 and 6, the temperature gradient has almost doubled using standard FR4.

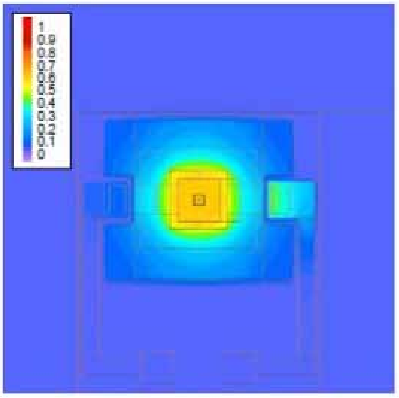


Figure 6. Temperature Distribution in an MCPCB at Solder Pads Plane Using FR4 for Dielectric [4]

A standard FR4 PCB, glued to an aluminum plate by itself, is not a good thermal solution. But the use of vias can enhance the combined thermal resistance. Figure 7 shows the implementation of thermal vias on a FR4 PCB glued to aluminum.

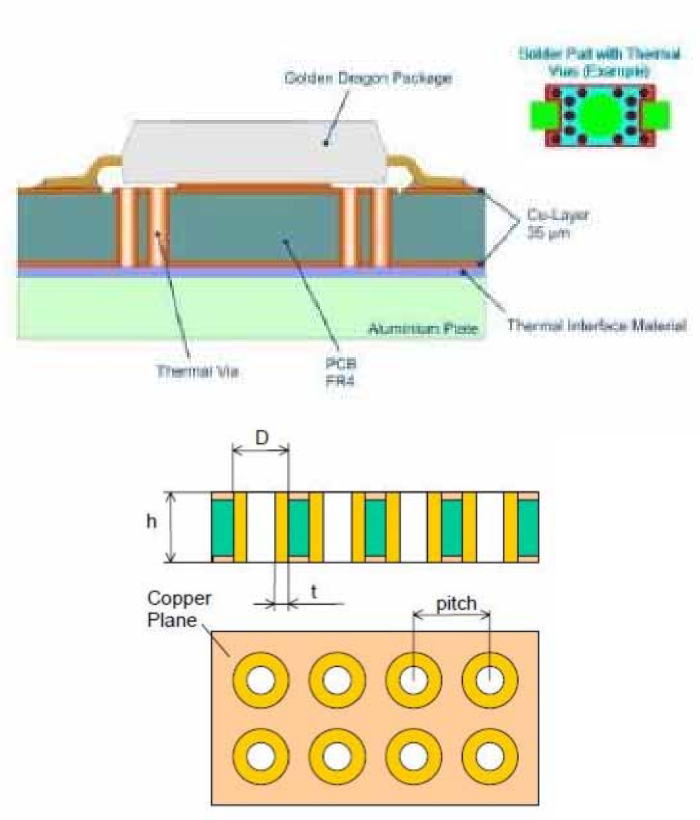


Figure 7. Thermal Vias on a FR4 PCB Attached to Aluminum [4]

Thermal vias are holes drilled in FR4 with height h, outside diameter D, and plated with copper which has a thickness of t. The thermal resistance of N vias can easily be obtained from 1-D analysis. The conduction thermal resistance can be calculated as R = h/KA, where A is the surface area of the concentric circle, with outside diameter D and inside diameter D-2t. It is equal to the following:

$$R=\frac{h}{n.\pi.K(D.t-t^2)}$$

where K is the thermal conductivity of copper.

Table 2 shows the thermal resistances of different combinations for the board. The table indicates that the MCPCB with enhanced dielectric has the best performance. The second rank is the MCPCB with FR4 dielectric. The enhanced FR4 PCB, glued on aluminum with vias, is ranked #3.

Substrate technology	Thermal Resistance (solder to board) °C/W
MCPCB with enhanced dielectric	3.4
MCPCB with FR4 dielectric	7.3
FR4-PCB glued on aluminum with thermal vias	9.7

Table 2 – Typical Thermal Resistances of PCB Technologies[4]

Understanding the heat transfer inside the LEDs is very important for the LED manufacturers. The heat generated inside an LED package has to be transferred to the outside world through an external heat sink. If the internal thermal resistance of the package is high, it makes it very difficult -- if not impossible -- for the heat sink to cool the junction to a level that not only preserves its reliability but also enhances its luminosity. Of course, this is directly impacted by the junction temperature. In closing, this article has reviewed some of the relevant variables that require attention during the design phase of an LED package. More studies on LED packages will follow in future issues.

References:

1. Hadco Information Brief "LED Thermal Management".

2. Kim, D., "Convection and Flow Boiling in Microgaps and Porous Foam Coolers" Ph.D. thesis, University of Maryland, 2007.

3. Lumileds Application Brief AB05, 2007.

4. Osram Semiconductors, "Thermal Management of Golden Dragon. LED", Application Note.