Thermal Management of SMT LED

Application Note

Introduction

To achieve reliability and optimal performance of LED Light sources a proper thermal management design is necessary.
Like all electronic components, LED's have thermal limitations. The allowed operation temperature for the specific lifetime is limited by the glass-point of the LED resin.
Usually the maximum permissible junction temperature of common SMT LED's is in the range of 95 – 125 °C. This means that the temperature of the die inside does not have to exceed this value when exposed to the expected operation temperature.
This brief will give the design engineer an introduction in the thermal basic of SMT LED's. Furthermore, some concepts are shown in order to improve the thermal design.

Explanation of Basic Relationships

The following explanations are given for OSRAM LED packages with leadframe, e.g. Power TOPLED, TOPLED.
The power dissipation P_D on the junction of a chip is distributed in the package and in the circuit board by means of heat conduction and is transferred from the free surfaces to the environment by means of radiation and convection.
"Junction" refers to the p-n junction within the semiconductor die. This is the region of the chip where the photons are generated.
Figure 1 shows the basic internal structure of a SMT LED Package, in this case a TOPLED, and it's method of mounting on a printed circuit board with the major routes of heat flow.
The LED consists of a chip mounted on a leadframe by solder or bonding adhesive.

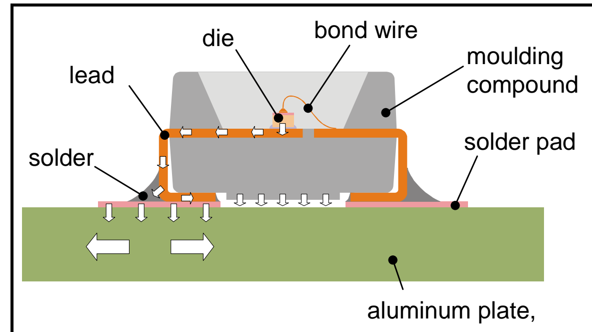

Figure 1: Internal Structure of SMT LED Package

The leads consist of a high-conductivity material such as copper.
The primary thermal path of the heat flow is from the junction through the leadframe to the end of the leads by heat conduction. Another partial path travels from the surface of the chip to the package surface.
From the end of the leads simultaneous processes of heat spreading by conduction and heat extraction over the surface of the board by convection and radiation takes place. The efficiency of heat transfer from the PCB to air has a significant effect on the temperature difference between chip and air.
The associated static equivalent circuit diagram is shown in figure 2. The following analogies with electrical quantities have been used:

- The power dissipation P_D occurring close to the chip surface is symbolised by a current source.
- The "resistance network" is essentially a serial connection to the ambient temperature.
- The ambient temperature T_A is represented by a voltage source.

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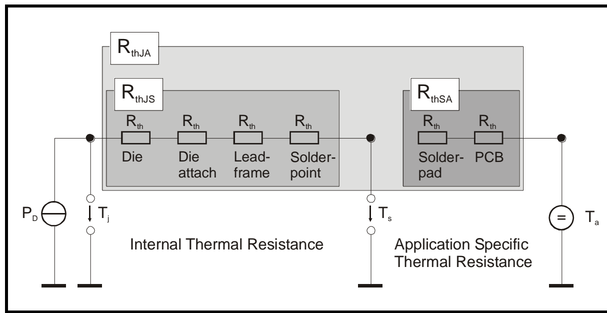

Figure 2: Static Equivalent Circuit

In accordance with the analogy, the thermal current P_D = Q/t can now be calculated from the “thermic Ohm´s law”.

$$U = I \cdot R \text{ as } T_j - T_a = P_D \cdot R_{thJA,real}$$

Equation 1

For the purpose in application, the junction temperature Tj is of practical interest.

$$T_j = R_{thJA,real} \cdot P_D + T_a$$

Equation 2

The total thermal resistance R_{thJA} of this package can be further broken down into two contribution levels of the heat transfer path from a component’s junction to its ultimate environment.
At the component level the internal thermal resistance is defined between the junction and an outside surface of the component case. This resistor value is given by the package construction e.g. geometry, used material and chip size.
In the case of OSRAM SMT LED this resistor value refers to the thermal resistance junction to solder point. R_{thJS} is specified for each LED in the datasheet.
The solder point temperature is defined as the temperature of the solder joint on one of the cathode[1] leads.

[1] For thin film LED, the anode lead has to be used.

The external level resistance is the application specific resistance to the heat that flows from the surface of the leads to a surrounding environment. This resistance is a consequence of in-plane heat flow in the solder pads, the through-plane flow in dielectrics and the mode of heat transfer through convection and radiation. This resistor value R_{thSA} is defined between the solder point temperature and ambient temperature.
The thermal resistance solder point to ambient is strongly influenced by various factors e.g. solder pad design, component placement or printed circuit structure. This value is application specific.

These two components of thermal resistance are in a series configuration.

$$R_{thJA,real} = R_{thJS,real} + R_{thSA,real}$$

Equation 3

There is a great variety of system applications in which OSRAM LED packages are used. These applications vary from a few components on a small, natural-convection-cooled printed circuit board, to many LED arranged in an array for backlighting. As a consequence, it is impossible to anticipate all of the possible applications, or to provide thermal data relevant to each application. As mentioned the maximum permissible junction temperature isn’t allowed to exceed during operation.

Factors Impacting External Resistance

A Printed Circuit Board can act as a heat fin, resulting in a lower solder point-to-ambient thermal resistance due to the increased heat transfer area.
In order to show the impacts of different factors the method of numerical analysis is

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used. All following results are based on a CFD[2]-Analysis with the following conditions.

- A geometry model of the entire configuration is created from the design drawings for the Power TOPLED package and the geometry data of the test board and its metallization. The geometric and material data as well as the standard boundary conditions are listed in the following table.

Component	PowerTOPLED
Outer PCB Dimensions L x W x H	76 x 76 x 1.5 mm^3
Board Material	FR4
Material for Solder Pads	35 µm Cu
Power Dissipation	0.1 W
Ambient temperature	25 °C
Orientation of PCB	Perpendicular to gravity

- In the analysis model no traces are considered, only the solder pads are modelled. This is done to reduce the additional heat transfer.

- Unless expressly stated, the steady state calculations always performed with a typical power dissipation of 0.1 W.

- The goal of the analysis is a comparison under the same environmental conditions. Therefore, a relative temperature scale is used in the illustrations. All plots show the temperature distribution within the solder pad plane.

The thermal model can be seen in the following figures.

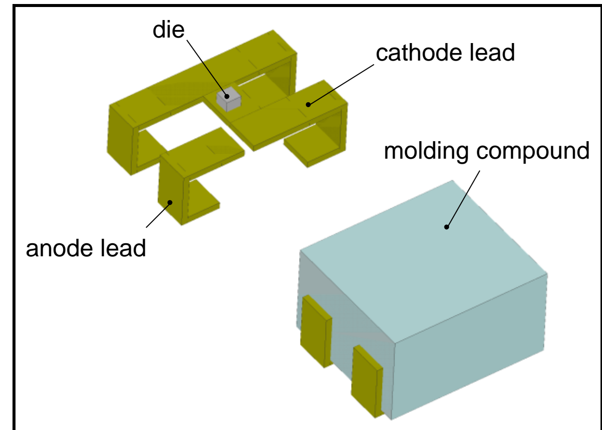

Figure 3: Thermal model of the Power TOPLED

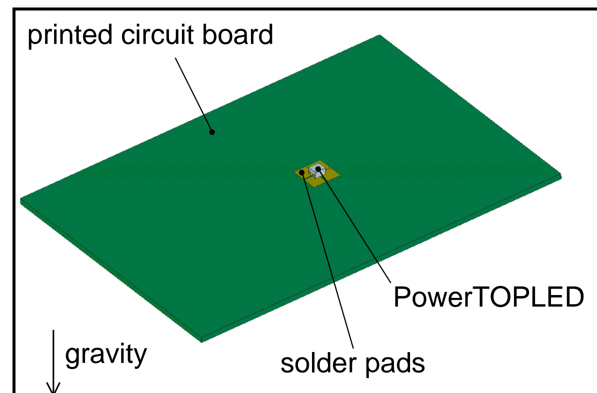

Figure 4: Thermal model of assembly

Solder Pad Area

The value of thermal resistance R_{thSA} can be lowered by enlarging the cathode lead solder pad areas. The heat flows in the solder pads and is spreaded in in-plane direction.
This effect can be seen in the temperature distribution below (Figure 5 & 6). The cathode solder pads distribute the heat over the PCB depending on the pad area.

[2] **C**omputational **F**luid **D**ynamics

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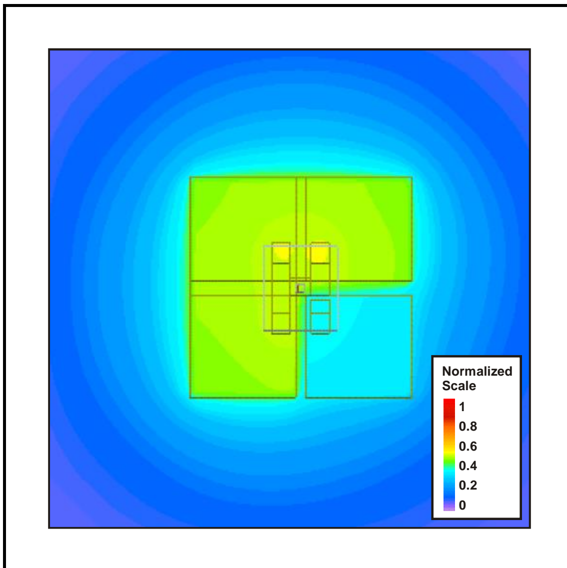

Figure 5: Pad area per cathode: 16 mm²

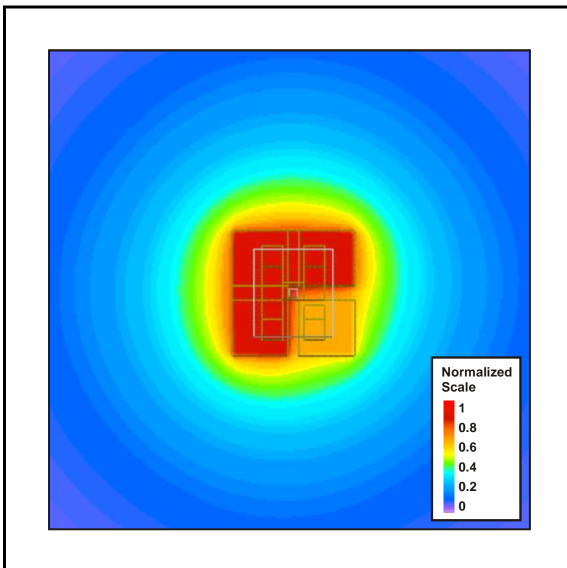

Figure 6: Pad area per cathode: 4 mm²

This example shows that optimised layout designs are able to improve the thermal resistance R_{thSA} significantly. Figure 7 shows R_{thSA} based on measurements in dependence on pad area per cathode.

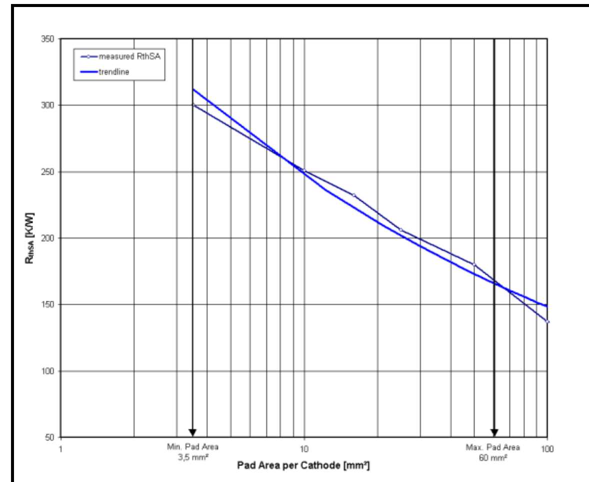

Figure 7: Influence of pad area per cathode to R_{thSA}

Printed Circuit Board

Another factor that impacts the thermal resistance from solder point to ambient is the board thermal conductivity. As board thermal conductivity increases, the spreading resistance through the board reduces, and a larger board area becomes available for heat transfer to the ambient.
Figure 8 shows the thermal resistance R_{thJA} for different kind of PCB materials with FR4 as reference. This correlation is valid only for a single LED mounted on solder pads with a pad area per cathode of 12 mm².

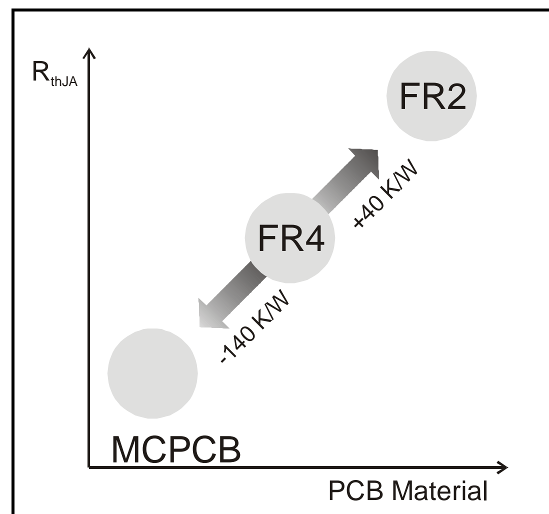

Figure 8: Influence of PCB material to R_{thJA}

The same effect can be seen in the following thermal temperature distributions (Figure 9 to 11). The solder pad size is 16 mm² for each cathode.

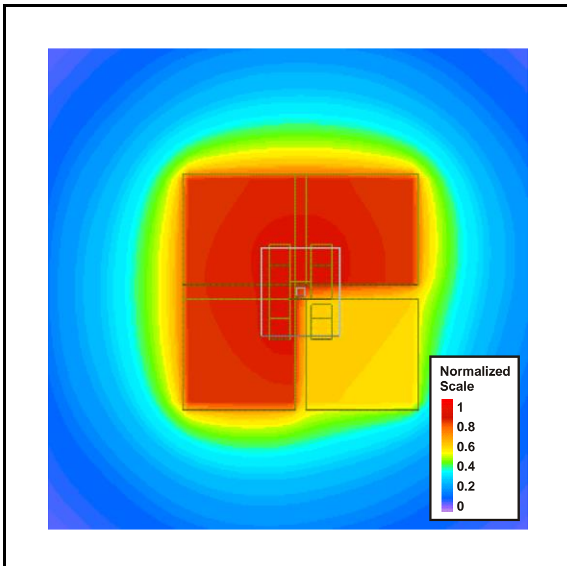

Figure 9: Substrate material with thermal conductivity of 0.2 W/(K m) (in the range of FR2)

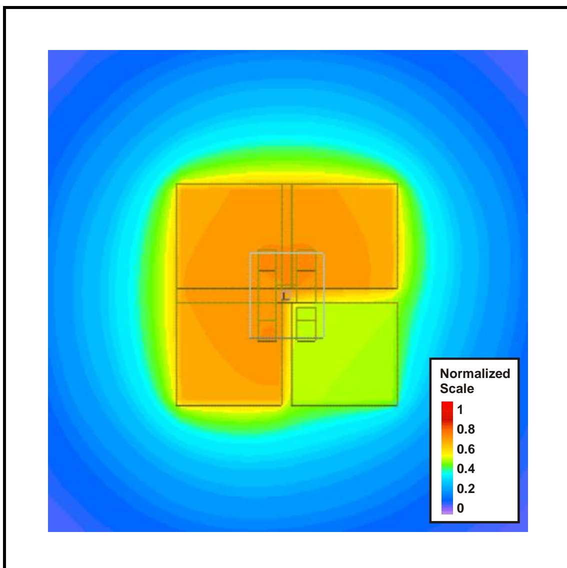

Figure 10: Substrate material with thermal conductivity of 0.35 W/(K m) (in the range of FR4)

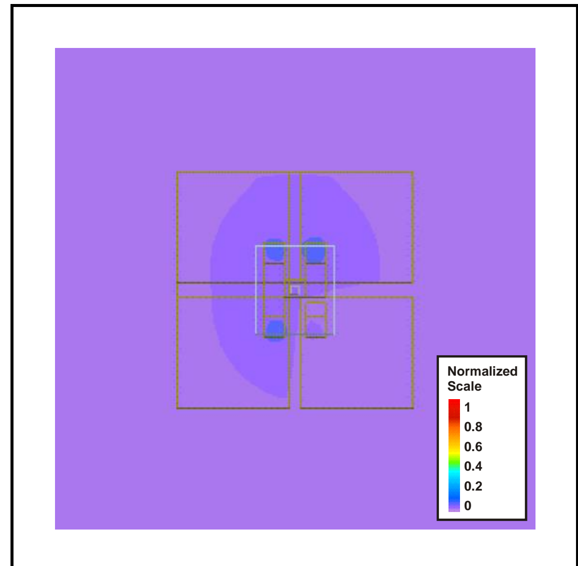

Figure 7: Substrate material with thermal conductivity of 1 W/(K m) laminated on 1.5 mm Aluminium (in the range of MCPCB)

The board thermal conductivity increases also with the use of multilayer printed circuit boards. For example, a FR4 PCB (total thickness of 1.6 mm) with 2 internal and 2 external copper layers, each 35 µm thickness (Figure 12 & 13).

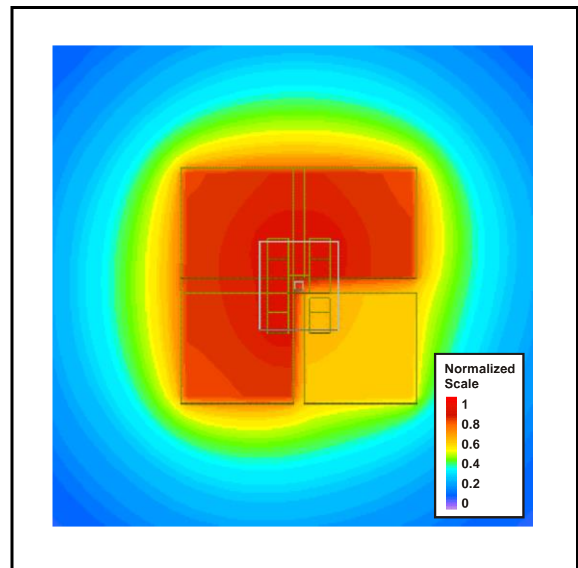

Figure 12: Single layer printed circuit board

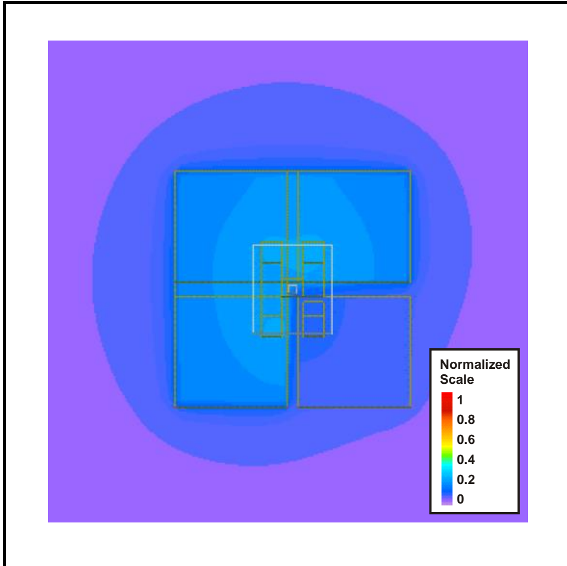

Figure 13: Multilayer printed circuit board (outer layer: 2 x 35 µm; inner layer: 2 x 35 µm)

Additional influences that affect the thermal performance of LED are:

- Placement of other components with higher power dissipation on the printed circuit board e.g. resistors, power semiconductors
- Clearance between closed by LED packages, in order to minimise the thermal interacting of the LEDs. For example, a minimum clearance of 5 mm (FR4) is required for the TOPLED.

Measurement techniques in real application

Due to difficulties in direct measurement of junction temperature T_j, it has to be evaluated indirectly by using the introduced thermal resistance model. For this procedure the thermal resistance, solder point to ambient $R_{thSA,real}$ of the device under test is measured. With this value a calculation of the junction temperature can be performed. Following the simplified procedure for measuring the $R_{thJA,real}$ and therefore T_j is described.

1. Take the $R_{thJS,real}$ of the LED from the respective data sheet
2. Choose the interested LED on the PCB to be used as the DUT.
3. Place a small thermocouple onto the cathode pin of the device under test. In case of the radial LEDs near the top surface of the PCB. The thermocouple should be < 0.25 mm in diameter. Larger thermocouples are considered to alter the thermal properties of the DUT. In this case, a correction factor should be added to the measured thermal resistance.
4. Turn on the LED assembly at the necessary forward current If. The LED assembly should stay energised for about 30 minutes to reach the thermal stabilisation of the assembly. This is reached when no temperature changes can be registered for a few minutes.
5. Note the pin temperature T_S, the ambient temperature T_{amb}, the current If and the corresponding forward voltage Uf.
6. Calculate the junction temperature T_J of the device under test by equation 4:

$$T_j = T_S + (I_F \cdot U_F - \Phi_e) \cdot R_{thJS,real}$$

Equation 4

The value of $R_{thJS,real}$ is listed in the datasheet of the LED

Based on the values all other thermal resistances of interest can be calculated. For worst-case considerations, variation of forward voltage U_f has to be taken into account.

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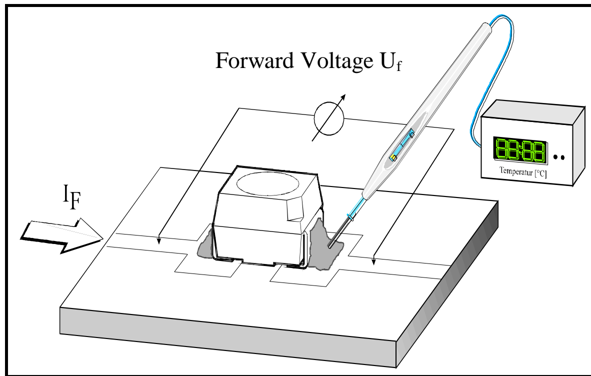

Figure 14: Test setup (schematically) to evaluate junction temperature T_j

Example

For a Power TOPLED LA E67B application, the developer has estimated an I_F of 50 mA. According to the datasheet of LA E67B it must be guaranteed not to exceed the permissible junction temperature of 125°C, so it is necessary to measure the ambient temperature, solder point temperature T_S and forward voltage U_F.

The test results are:

- T_S = 70 °C
- U_F = 2.1 V

In the data sheet of LA E67B a value of 130 K/W for the R_{thJS} is stated.

$$T_j = 130 \cdot \frac{°C}{W} \cdot 50 \cdot mA \cdot 2.1 \cdot V + 70°C$$

$$T_j = 83.7°C$$

$$T_j < \max .T_j < 125°C$$

For worst-case considerations (current source operation: I_{Fmax} and U_{Fmax}) however it must be calculated with U_F of 2.4 V what will boost the actual junction temperature to 85.6°C.

The measurement of the solder point temperature could be done by IR Imaging or thermocouples. More information on using thermocouples can be found in the article “Notes on using thermocouple”.

(http://www.electronics-cooling.com/Resources/EC_Articles/JAN97/jan97_01.htm).

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