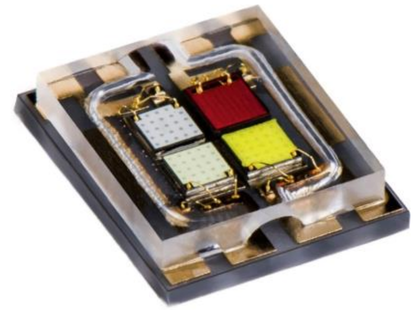
Application Note

Thermal Cross-Talk in Multi-Chip LED Packages



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Introduction

Temperature is one of the more important values to design around and balance in regards to LED's. With an increase in heat, light output typically decreases and lifetime shortens. Balancing the temperature, light output and current is a tricky subject for a multiple chip device.

In devices such as the SBM-40, the separate dies generate heat and light at different rates and the parameters of the Maximum Junction Temperature, Input current, Forward Voltage, Light Output, and Dominant wavelength will vary. With this type of individually addressable module, the Tj of any chip is affected by both the power dissipated by the chip as well as the power dissipated by the adjacent chips. This document will clearly describe the relationship between the chips to properly balance and design as per application.

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Scope

The design guidelines in this application note apply to all the SBM-40 packages and any devices that have multiple, individually addressable chips. Document is split into 2 main parts, calculation of the Case Temp from the Reference, and the calculation of Junction Temperature and the cross-talk between the Chips.

1. Evaluation of Case Temperature

Junction temperature is an important value to designers of products utilizing LED's. Figure 1 depicts the cross-section of a multi-chip module mounted on a copper metal core printed circuit board (MCPCB). Also shown are the temperatures of the Junction Temperature (T_j), Case Temperature (T_c), Board Temperature (T_b), Heat-sink Temperature (T_{hs}), and the Thermistor or Reference Temperature (T_{ref}). The Case Temperature of any individual chip can then be calculated as follows:

1. The reference temperature (T_{ref}) of the MCPCB is initially determined by the thermistor read-out to approximate Case Temperature (T_c).
   a. T_{ref} may also be obtained by using a point relative to the substrate of the device.
2. The temperature rise from the T_{ref} to the substrate (T_c) is the product of the thermistor-substrate thermal resistance ($R_{\theta c\text{-}ref}$) and the total power dissipated by all the chips in the package.

$$\Delta T_{C-Ref} = \left\{\sum P_a\left(1-\eta_{\mathrm{rad,a}}\right)\right\} \times R_{\theta\mathrm{c-ref}} \qquad \text{(eq.1)}$$

where ***a*** is a single R, G, B or W chip; ***P***$\boldsymbol{P_a}$ is the input power to an individual chip and $\boldsymbol{\eta_a}$ is the radiometric efficiency of the chip and takes into account the fraction of the input power that is converted to light.

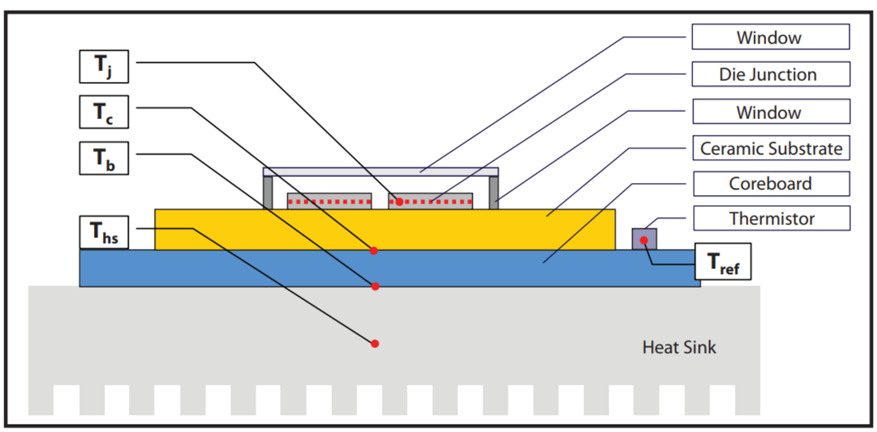

Figure 1: Cross-section of a multi-chip module mounted on an MCPCB on a Heat Sink. (Metal Core PCB, core-board, starboard)

Note that, while Figure 1 shows a typical arrangement, the choice of MCPCB, the location of the thermistor, and the solder used to mount the SBM-40 to the MCPCB lies with the user, thus $R_{\theta c\text{-}ref}$ is a reflection of those choices and can differ from the value listed in the SBM-40 data-sheet.
The MCPCB layout used for these tests, can be found in Appendix A

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2. Junction Temperature Calculation

Actual junction temperature (T_{ja}) of any chip in the SBM-40 is a sum of the temperature rise from junction to case (ΔT_{ja-C}), and the temperature gradient from the case to the reference from eq.1 (ΔT_{C-Ref}), and the reference temperature (T_{ref}).

$$T_{ja} = \Delta T_{ja-C} + \Delta T_{C-Ref} + T_{ref}$$

(eq.2)

where ***a*** is a single R, G, B or W chip; $\boldsymbol{P_a}$ is the input power to an individual chip and $\boldsymbol{\eta_a}$ is the radiometric efficiency of the chip

The temperature rise from the substrate to the junction of any chip is illustrated by the product the matrices below. To calculate the said rise, the cross-talk matrices combined with the power dissipated by the chips should output values corresponding to the eq.2 above.

In real case scenarios, the input power of a LED has a portion that is converted into optical power. Since the optical power does not contribute to thermals, this can be represented as the electrical power minus the optical output power. Alternatively this can be described as the power multiplied by 1, minus the efficiency of the chip.

$$\mathrm{P}_{\boldsymbol{a}} \times (1 - \eta_{\mathrm{rad},\boldsymbol{a}}) = \mathrm{P}_{\boldsymbol{a}\ \mathrm{Elec}} - \mathrm{P}_{\boldsymbol{a}\ \mathrm{Optical}} \quad \text{(eq.3)}$$

3. Temperature Matrices

Each version of the SBM-40 has different power outputs, thus yielding multiple matrices that correspond to the listed equations. The unit of each values in the matrices are °C/W.

3.1 SBM-40-SC (Real)

$$\begin{bmatrix} \Delta T_{jR-C} \\ \Delta T_{jG-C} \\ \Delta T_{jB-C} \\ \Delta T_{jW-C} \end{bmatrix} = \begin{bmatrix} 4.10 & 1.45 & 1.30 & 1.60 \\ 1.25 & 7.25 & 1.25 & 1.60 \\ 1.60 & 1.40 & 4.72 & 1.10 \\ 1.25 & 1.41 & 0.80 & 5.60 \end{bmatrix} \begin{bmatrix} P_R \times (1 - \eta_{rad,R}) \\ P_G \times (1 - \eta_{rad,G}) \\ P_B \times (1 - \eta_{rad,B}) \\ P_W \times (1 - \eta_{rad,W}) \end{bmatrix}$$

3.2 SBM-40-SC (Electrical)

$$\begin{bmatrix} \Delta T_{jR-C} \\ \Delta T_{jG-C} \\ \Delta T_{jB-C} \\ \Delta T_{jW-C} \end{bmatrix} = \begin{bmatrix} 3.16 & 1.16 & 0.92 & 1.20 \\ 1.00 & 6.02 & 0.92 & 1.25 \\ 1.13 & 1.03 & 3.02 & 0.75 \\ 0.94 & 1.10 & 0.55 & 4.09 \end{bmatrix} \begin{bmatrix} P_R \\ P_G \\ P_B \\ P_W \end{bmatrix}$$

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3.3 SBM-40-HC (Real)

$$\begin{bmatrix} \Delta T_{jR-C} \\ \Delta T_{jG-C} \\ \Delta T_{jB-C} \\ \Delta T_{jW-C} \end{bmatrix} = \begin{bmatrix} 4.08 & 0.36 & 0.58 & 0.55 \\ 0.34 & 3.47 & 0.51 & 0.54 \\ 0.59 & 0.56 & 3.70 & 0.38 \\ 0.58 & 0.61 & 0.38 & 3.88 \end{bmatrix} \begin{bmatrix} P_R \times (1 - \eta_{rad,R}) \\ P_G \times (1 - \eta_{rad,G}) \\ P_B \times (1 - \eta_{rad,B}) \\ P_W \times (1 - \eta_{rad,W}) \end{bmatrix}$$

3.4 SBM-40-HC (Electrical)

$$\begin{bmatrix} \Delta T_{jR-C} \\ \Delta T_{jG-C} \\ \Delta T_{jB-C} \\ \Delta T_{jW-C} \end{bmatrix} = \begin{bmatrix} 3.54 & 0.32 & 0.50 & 0.48 \\ 0.31 & 3.19 & 0.47 & 0.49 \\ 0.45 & 0.43 & 2.80 & 0.29 \\ 0.47 & 0.50 & 0.31 & 3.15 \end{bmatrix} \begin{bmatrix} P_R \\ P_G \\ P_B \\ P_W \end{bmatrix}$$

4. Design Example

Goal: To determine LED junction temperature in operation. Let us consider the case of a SBM-40-SC operating at a Red and Green current of 1A, and a Blue and White current of 0.5A. For this example, we will assume that the heat sink is infinite and the case is kept at a constant 40 ºC. We can therefore remove the thermal resistance from heat sink to ambient from the equation. While this assumption is not practical in many cases, it helps to explain the basic steps to calculate junction temperature.

From the SBM-40-SC datasheet, we can find the respective IV curves to give us the power in the matrix below.

$$\begin{bmatrix} P_R \\ P_G \\ P_B \\ P_W \end{bmatrix} = \begin{bmatrix} (1A * 2.7V) = 2.7W \\ (1A * 3.4V) = 3.4W \\ (0.5A * 3.1V) = 1.55W \\ (0.5A * 3.0V) = 1.5W \end{bmatrix}$$

By plugging in the values for the power matrix, we get the following

$$\begin{bmatrix} \Delta T_{jR-C} \\ \Delta T_{jG-C} \\ \Delta T_{jB-C} \\ \Delta T_{jW-C} \end{bmatrix} = \begin{bmatrix} 4.1 & 1.45 & 1.3 & 1.6 \\ 1.25 & 7.25 & 1.25 & 1.6 \\ 1.6 & 1.4 & 4.72 & 1.1 \\ 1.25 & 1.41 & 0.8 & 5.6 \end{bmatrix} \begin{bmatrix} 2.7W \\ 3.4W \\ 1.55W \\ 1.5W \end{bmatrix} = \begin{bmatrix} 20.3°C \\ 31.9°C \\ 17.9°C \\ 17.7°C \end{bmatrix}$$

Therefore, the junction temperature of each die should see a rise respectively within the matrix. In this example we have a case at 40 ºC so we should see a rise as in the calculation below.

$$\begin{bmatrix} T_{jR-C} \\ T_{jG-C} \\ T_{jB-C} \\ T_{jW-C} \end{bmatrix} = \begin{bmatrix} 20.3°C + 40°C = 60.3°C \\ 31.9°C + 40°C = 71.9°C \\ 17.9°C + 40°C = 57.9°C \\ 17.7°C + 40°C = 57.7°C \end{bmatrix}$$

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4.1 Consideration of Optical Power

In the previous example, for simplification purposes, it was assumed that all electrical power was converted to heat. Obviously, this is not the case and a portion of the input electrical power is converted to light. The amount that is converted into optical power depends on the color of the die and the drive conditions of each channel. Since different color LEDs have different efficiencies and the efficiency of LEDs degrades as a function of input power, each use case will be different. For the most up to date information on the optical power emittted from each channel of the SBM devices, please consult the latest product data sheets.

Goal: To determine LED junction temperature in operation. Let us consider the case of a SBM-40-SC operating at a Red and Green current of 1A, and a Blue and White current of 0.5A. For this example, we will assume the optical power of the chips will be 0.8W for Red, 0.7W for Green, 0.95W for Blue and 0.7W for White respectively. We will also assume that the heat sink is infinite and the case is kept at a constant 40 ºC.

$$\begin{bmatrix} P_R \times (1-\eta_{rad,R}) \\ P_G \times (1-\eta_{rad,G}) \\ P_B \times (1-\eta_{rad,B}) \\ P_W \times (1-\eta_{rad,W}) \end{bmatrix} = \begin{bmatrix} P_{R\ Elec} - P_{R\ Optical} \\ P_{G\ Elec} - P_{G\ Optical} \\ P_{B\ Elec} - P_{B\ Optical} \\ P_{W\ Elec} - P_{W\ Optical} \end{bmatrix} = \begin{bmatrix} (1A * 2.7V) - 0.8W = 1.9W \\ (1A * 3.4V) - 0.7W = 2.7W \\ (0.5A * 3.1V) - 0.95W = 0.6W \\ (0.5A * 3V) - 0.7W = 0.8W \end{bmatrix}$$

With the associated power values we can utilize the SBM-40-SC Real equations to calculate the rise in the junction temperature from the case.

$$\begin{bmatrix} \Delta T_{jR-C} \\ \Delta T_{jG-C} \\ \Delta T_{jB-C} \\ \Delta T_{jW-C} \end{bmatrix} = \begin{bmatrix} 4.10 & 1.45 & 1.30 & 1.60 \\ 1.25 & 7.25 & 1.25 & 1.60 \\ 1.60 & 1.40 & 4.72 & 1.10 \\ 1.25 & 1.41 & 0.80 & 5.60 \end{bmatrix} \begin{bmatrix} 1.9W \\ 2.7W \\ 0.6W \\ 0.8W \end{bmatrix} = \begin{bmatrix} 13.8°C \\ 24.0°C \\ 10.5°C \\ 11.1°C \end{bmatrix}$$

By finding the rise of each chip, we can find the junction temperature of each die compared to the case temperature.

$$\begin{bmatrix} T_{jR-C} \\ T_{jG-C} \\ T_{jB-C} \\ T_{jW-C} \end{bmatrix} = \begin{bmatrix} 13.8°C + 40°C = 53.8°C \\ 24.0°C + 40°C = 64.0°C \\ 10.5°C + 40°C = 50.5°C \\ 11.1°C + 40°C = 51.1°C \end{bmatrix}$$

5. Summary

The SBM-40 devices have been optimized to ease the design of thermal systems in LED applications. With industry leading thermal resistances and easy-to-mount packages, many of the challenges of proper thermal design have been considered.

Proper thermal design is very important to ensure a properly functioning and reliable system. Without it, LED junction temperatures could run higher than recommended, resulting in reduced light output, unanticipated changes in color, and reduced lifetime. Additionally, the surrounding materials can reach high temperatures, potentially causing burns or fires. Thus it is very important to ensure the thermal system surrounding multi-chip packages are designed properly.

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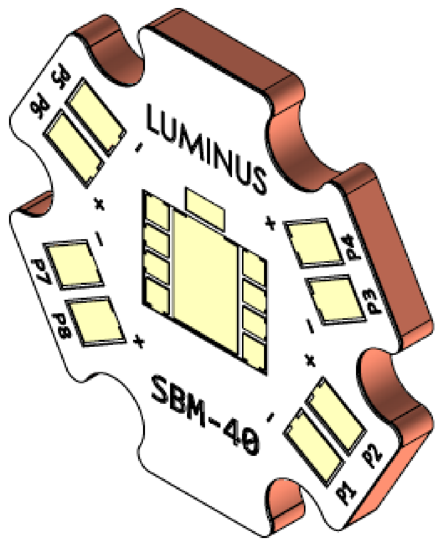
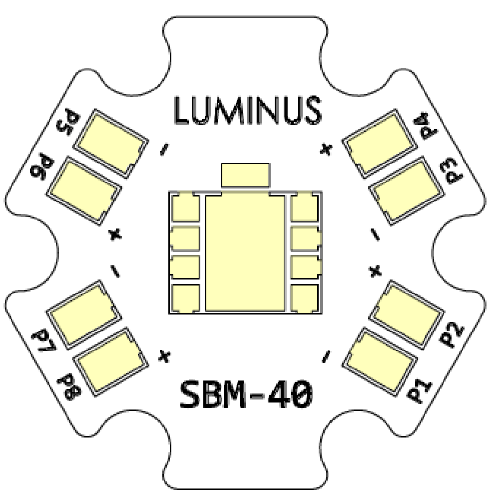
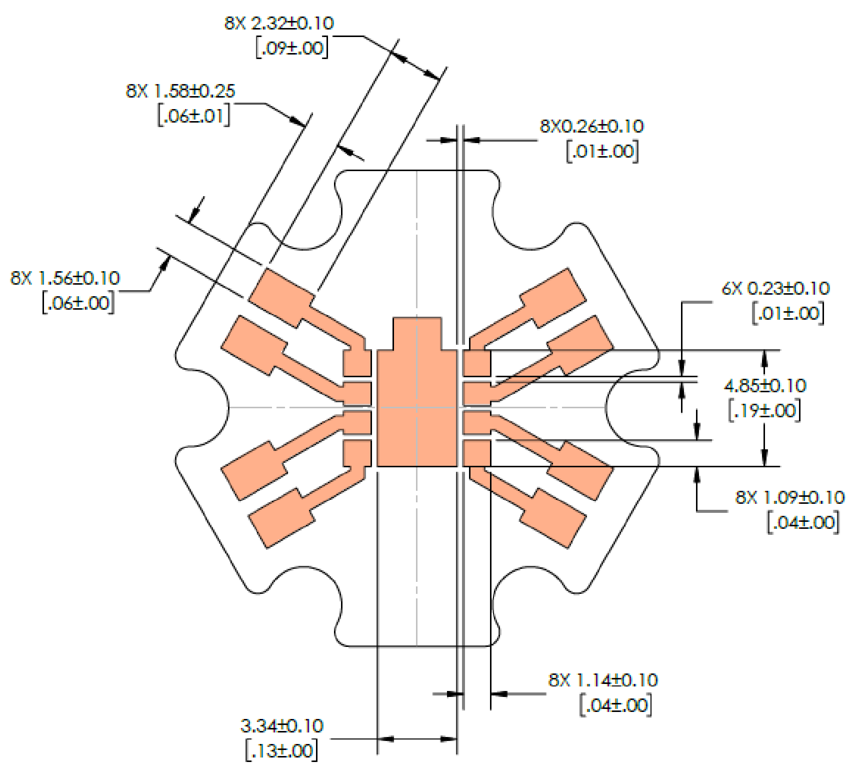
Appendix A

MCPCB design drawings







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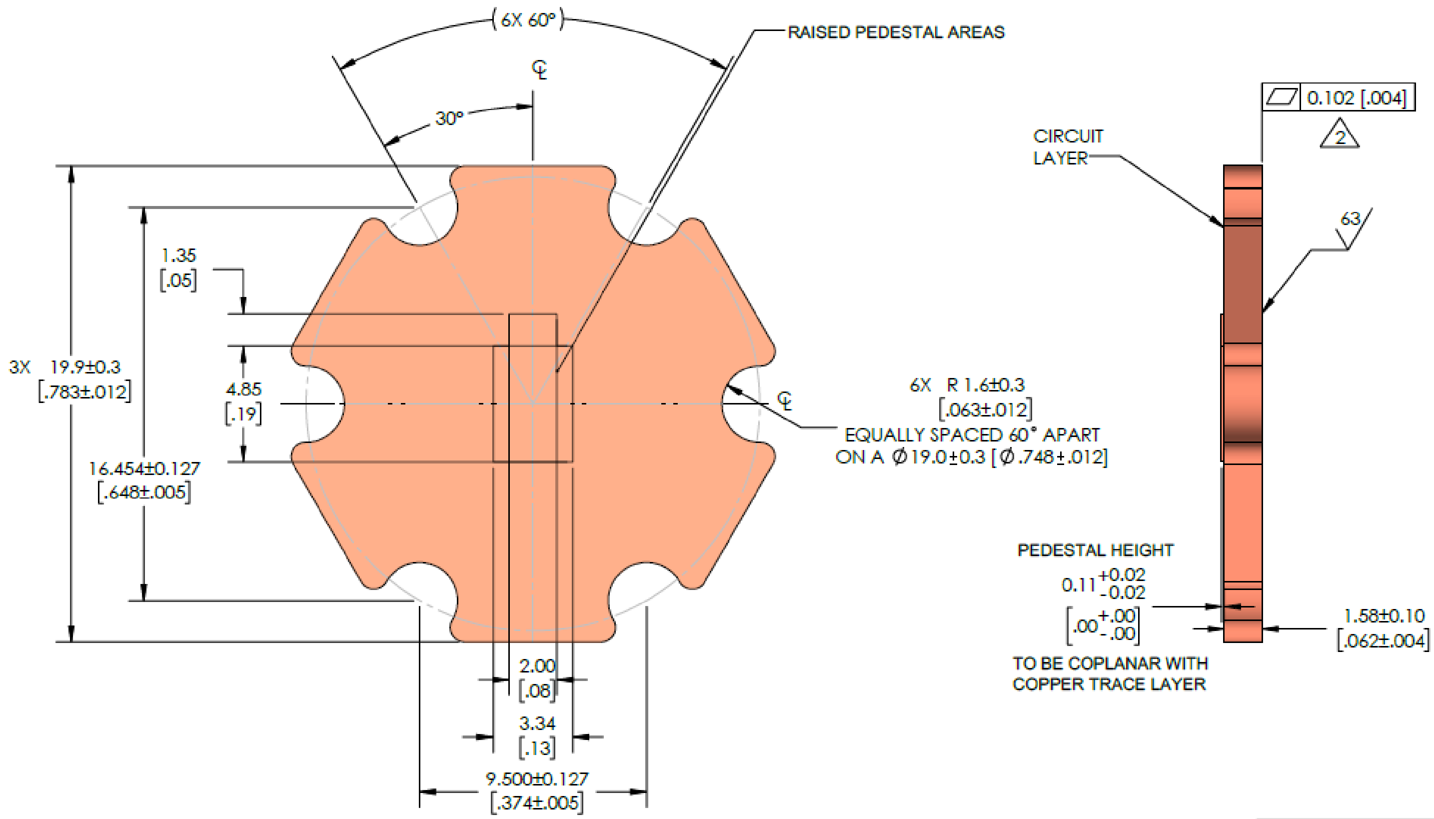
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RAISED PEDESTAL AREAS
30°
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[.05]
3X 19.9±0.3
[.783±.012]
4.85
[.19]
16.454±0.127
[.648±.005]
6X R 1.6±0.3
[.063±.012]
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ON A Ø19.0±0.3 [Ø.748±.012]
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[.08]
3.34
[.13]
9.500±0.127
[.374±.005]
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2
CIRCUIT
LAYER
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PEDESTAL HEIGHT
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[.00 +.00 -.00]
TO BE COPLANAR WITH
COPPER TRACE LAYER
1.58±0.10
[.062±.004]