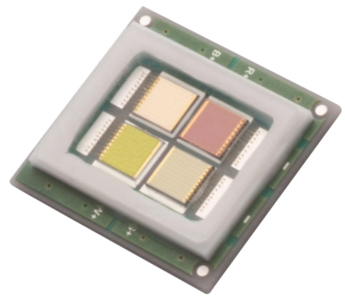
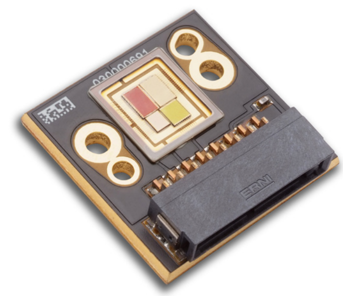
Thermal Cross-Talk in Multi-Chip LED Packages





Designers using LEDs have to balance, among other factors, the lumen output of the LED and its lifetime. The two factors usually counteract each other—increased lumen output, achieved by increasing drive current, results in increased junction temperature (T_j), which reduces lifetime. The median lifetime of an LED is dependent on T_j—typically, for a 10,000 hour median lifetime, the T_j of Blue, Green and White LEDs have to be 150 °C or lower, while the T_j of Red LEDs, because of their increased temperature sensitivity, should be maintained at 110 °C or lower. Additionally, flux, dominant wavelength and forward voltage are all parameters that vary with T_j. The significant impact of T_j on an LED's lifetime and reliable operation thus necessitates its accurate determination.

In an individually addressable multi-chip module, the T_j of any chip is affected by both the power dissipated by the chip and the power dissipated by adjacent chips—both contributions have to be accounted for to accurately determine T_j. Multi-chip modules such as the SBM-160 and the CBM-380 possess individually addressable red, green, blue and white chips and allow the option of driving the chips individually, in combinations of 2 or 3, or all four simultaneously. When multiple chips are driven simultaneously, the rise in T_j of any individual chip is the sum of two components: the rise in T_j of the chip due to its drive current, and the rise in T_j due to the power dissipated by adjacent chips—a phenomenon known as thermal cross-talk. In such cases, a thermal cross-talk matrix is used to determine T_j. This application note illustrates the determination of T_j of any chip in the SBM-160 and the CBM-380 using the thermal cross-talk matrix; familiarity with the contents of "Thermal Management of Big Chip LEDs", a Luminus Devices application note that describes the relationship between electrical power in, optical power out and the temperature at various points in the LED package is assumed.

Figure 1 depicts the cross-section of a multi-chip module mounted on an aluminum coreboard. Also shown are the temperatures of the junction (T_j), case or substrate (T_c), coreboard (T_b), heat-sink (T_{hs}) and thermistor (T_{ref}). The junction temperature of any individual chip is calculated as follows:

1. The reference temperature (T_{ref}) of the aluminum coreboard is first determined by the thermistor read-out.
2. The temperature rise from the thermistor to the ceramic 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.

$$\text{Temperature rise} = \{\sum P_a\,(1-\eta_{rad,a})\} \times R_{\theta c\text{-}ref} \quad (1)$$

where a is R, G, B or W; P_a is the input power to an individual chip and η_a is the radiometric efficiency of the chip and takes into account the fraction of the input power that is converted to light.

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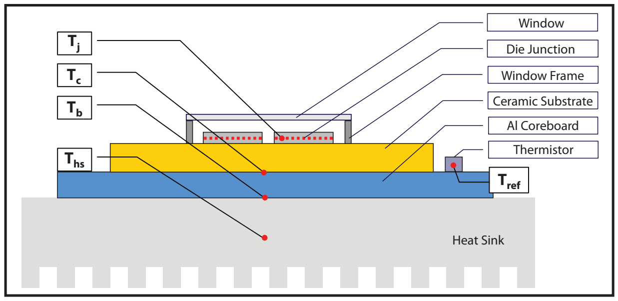

Figure 1: Cross-Section of a Multi-Chip Module

Note that, while Figure 1 shows a typical arrangement, the choice of coreboard, the location of the thermistor, and the solder used to mount the SBM-160 to the coreboard 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-160 data-sheet.

3. The temperature rise from the substrate to the junction of a chip is given by the product of two matrices as shown below—the thermal cross-talk matrix and the power dissipated by the chip. T_j rise for the SBM-160 is given by:

$$\begin{bmatrix} \Delta T_{jR} \\ \Delta T_{jG} \\ \Delta T_{jB} \\ \Delta T_{jW} \end{bmatrix} = \begin{bmatrix} 1.486 & 0.019 & 0.003 & 0.019 \\ 0.018 & 1.462 & 0.018 & 0.003 \\ 0.003 & 0.018 & 1.462 & 0.018 \\ 0.018 & 0.003 & 0.019 & 1.486 \end{bmatrix} \begin{bmatrix} P_R \times 1\text{-}\eta_{rad,\,R} \\ P_R \times 1\text{-}\eta_{rad,\,G} \\ P_R \times 1\text{-}\eta_{rad,\,B} \\ P_R \times 1\text{-}\eta_{rad,\,W} \end{bmatrix}$$

Actual junction temperature (T_{ja}) of any chip in the SBM-160 is the sum of reference temperature (T_{ref}), temperature gradient from reference to case $\{\Sigma P_a(1\text{-}\eta_{rad,a})\} \times R_{\theta c\text{-}ref}$ and temperature rise from case to junction (ΔT_{ja}).

$$T_{ja} = T_{ref} + \{\Sigma P_a(1\text{-}\eta_{rad,a})\} \times R_{\theta c\text{-}ref} + \Delta T_{ja} \quad (2)$$

where a is R, G, B or W; P_a is the input power to an individual chip and η_a is the radiometric efficiency of the chip.

A similar approach can be followed to determine the T_j of any chip in the CBM-380. One of the principal differences between the SBM-160 and CBM-380 lies in packaging: the SBM-160 is a surface mount LED and the CBM-380 is a chip-on board LED. While the SBM-160 must be mounted to the user's Printed Circuit Board and requires that the thermistor-case thermal resistance be subsequently characterized; the CBM-380 includes an on-board thermistor with the junction-thermistor thermal resistance of each die already characterized. The thermal cross-talk matrix, then, is constructed to give the T_j rise from the thermistor, as opposed to the T_j rise from the case for the SBM-160. T_j rise for the CBM-380 is given by:

$$\begin{bmatrix} \Delta T_{jR} \\ \Delta T_{jG} \\ \Delta T_{jB} \\ \Delta T_{jW} \end{bmatrix} = \begin{bmatrix} 0.635 & 0.156 & 0.158 & 0.091 \\ 0.169 & 0.595 & 0.103 & 0.126 \\ 0.158 & 0.094 & 1.113 & 0.158 \\ 0.116 & 0.130 & 0.183 & 0.742 \end{bmatrix} \begin{bmatrix} P_R \times 1\text{-}\eta_{rad,\,R} \\ P_R \times 1\text{-}\eta_{rad,\,G} \\ P_R \times 1\text{-}\eta_{rad,\,B} \\ P_R \times 1\text{-}\eta_{rad,\,W} \end{bmatrix}$$

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Actual junction temperature (T_{ja}) of any chip in the CBM-380 is the sum of reference temperature (T_{ref}) and temperature rise from reference to junction (ΔT_{ja}).

$$T_{ja} = \{\Sigma P_a (1-\eta_{rad,a})\} \times R_{\theta c\text{-}ref} + \Delta T_{ja} \quad (3)$$

where a is R, G, B or W; P_a is the input power to chip and η_a is the radiometric efficiency of the chip.

This product is protected by U.S. Patents 6,831,302; 7,074,631; 7,083,993; 7,084,434; 7,098,589; 7,105,861; 7,138,666; 7,166,870; 7,166,871; 7,170,100; 7,196,354; 7,211,831; 7,262,550; 7,274,043; 7,301,271; 7,341,880; 7,344,903; 7,345,416; 7,348,603; 7,388,233; 7,391,059 Patents Pending in the U.S. and other countries.

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