

APPLICATION NOTE:

Effective Thermal Management of Crystal IS SMD LEDs

July 24, 2015

THIS APPLICATION NOTE DESCRIBES THE THERMAL MANAGEMENT CONCEPTS AND GUIDELINES FOR THE PROPER USE OF CRYSTAL IS SURFACE MOUNT DEVICE (SMD) LEDs. INCLUDED IS A BASIC THERMAL MODEL, BASICS OF HEAT TRANSFER ENGINEERING, EXAMPLE CALCULATIONS FOR HEAT SINK SELECTION, AND LINKS TO MANUFACTURERS OF HEAT SINKS AND THERMAL INTERFACE MATERIALS.

Introduction

Crystal IS LEDs deliver the most efficient and reliable UVC LEDs in the wavelengths from 250 nm to 280 nm by using proprietary technology to manufacture low defect density aluminum nitride substrates. In addition, light emitting layers are grown in a way that preserves the low defect densities of these substrates. The resulting LED has higher efficiencies in converting the input electrical energy into UV radiation and longer lifetimes than other commercially available UVC LEDs.

Excess heat negatively impacts the light output and lifetime of an LED. Proper thermal management keeps the junction temperature as low as is required for the given application and maintains the performance of the LED. The word “junction” refers to the p-n junction within the LED die, where the photons are generated and emitted. Heat is transferred away from this junction to the ambient by attaching a heat sink.

Heat Generation

When forward voltage (V_f) is applied across the junction of an LED, forward current (I_f) flows through the LED and electrical power is dissipated as both light and heat. The amount of electrical power dissipated (P_D) can be expressed in Equation 1. UVC LEDs dissipate most of their power in the form of heat, therefore the heat generated is regarded as approximately equal to the power dissipation (P_D) for the purpose of this note.

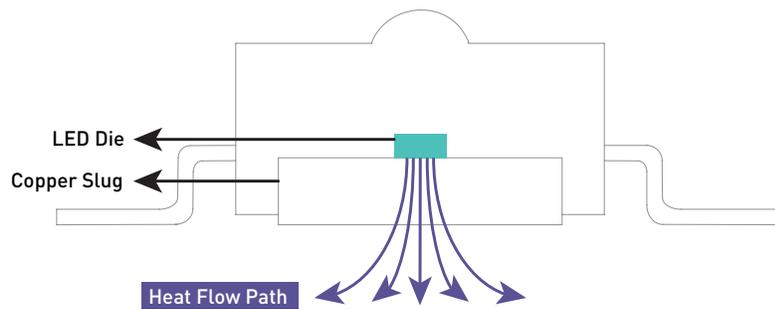
$$\text{Equation 1: } P_D = V_f * I_f$$

Impact on Junction Temperature

The junction temperature of an LED increases with the generation of heat, with the rate of increase dependent upon the amount of heat that is dissipated to the ambient. The heat is transferred from the junction to the ambient via all elements that make up the thermal management system.

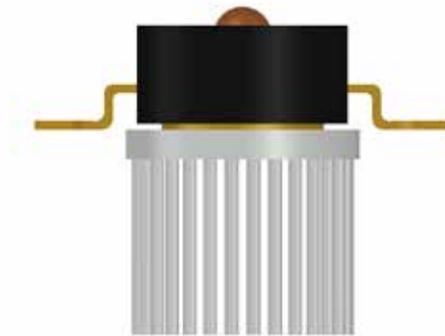
Crystal IS SMD LEDs generate less than 3.6 W of heat in addition to UV light, depending on the current within the suggested operating range. This heat is dissipated through the back end of the LED, unlike conventional UV light sources which emit heat forward. To increase the rate of heat dissipation from the backside of the LED, the SMD package includes a copper slug applied to the base of the package, which has direct contact with the LED die assembly. The low thermal resistance of the copper slug allows it to quickly transfer heat from the die. This heat flow path is illustrated in Figure 1. It is strongly recommended to attach a heat sink to the copper slug with thermal paste to facilitate further thermal transfer, as shown in Figure 2.

FIGURE 1



Schematic of Crystal IS SMD LED Heat Flow Path.

FIGURE 2



Schematic of Crystal IS SMD LED with Heat Sink.

This simple thermal management solution transfers heat to the ambient through the following thermal path:

- > Heat is conducted from the semiconductor chip to the submount and then to the copper slug at the bottom of the SMD LED.
- > Heat is then conducted from the copper slug through a thermal interface material, such as thermal paste, to the heat sink.
- > Finally, heat is conducted through the heat sink and transferred to the ambient via convection of the air around the heat sink.

The junction temperature (T_J) is related to the thermal resistance of the entire path ($R_{\theta_{JA}}$) by the following equation, where T_A is the ambient temperature.

$$\text{Equation 2: } T_J = T_A + R\theta_{JA} * P_D$$

The overall thermal resistance ($R\theta_{JA}$) can be expressed as the sum of the individual resistances of the thermal path from junction to ambient.

For Crystal IS SMD LEDs, the thermal resistance can be simply represented in the formula below, where $R\theta_{JC}$ is the thermal resistance from the junction of the LED die to the copper slug, $R\theta_{CS}$ is the thermal resistance from the copper slug to the heat sink, and $R\theta_{SA}$ is the thermal resistance from the heat sink to the ambient.

$$\text{Equation 3: } R\theta_{JA} = R\theta_{JC} + R\theta_{CS} + R\theta_{SA}$$

This model is analogous to an electrical circuit where heat flow is represented by current, voltages represent temperatures, and resistors represent thermal resistance (Figure 3).

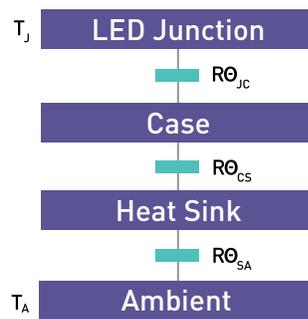
Basics of Heat Transfer Engineering

While the thermal resistance from the junction to the copper slug is fixed by the materials used in the package, application designers have flexibility in the selection of the heat sink and the thermal interface material between the package and the heat sink.

Some simple rules in heat sink design or selection:

- > Minimize the thickness of the interface materials between the package and the heat sink (i.e. the distance the heat must travel).
- > Use a heat sink with a large surface area.
- > Use materials that have a high thermal conductivity (k). Although copper is a better thermal conductor, aluminum is frequently the material of choice for heat sinks due to cost and weight considerations. Black anodized Al is used to combine good thermal conductivity and heat transfer to the ambient.

FIGURE 3



A simplified description of the thermal model for a Crystal IS LED package attached to a heat sink.

Heat Sink Configurations

The most common heat sinks, passive heat sinks, incorporate fins to increase the surface area and reduce the thermal resistance. Active heat sinks, on the other hand, use fans to improve the transfer of thermal energy by forcing convection and moving cooler air between the fins. Fluids can also be used to increase the transfer of heat to the ambient.

When mounting LED packages to heat sinks, it is ideal to use mechanical fasteners to minimize thermal resistance. If this is not possible, tapes and adhesives can aid in thermal contact. The addition of thermal grease can also minimize air gaps and improve thermal contact to uneven surfaces.

Heat Sink Selection

The minimum heat sink requirements can be determined by the following factors:

1. The amount of heat to be dissipated in watts (P_D): P_D is estimated using Equation 1 as described in the "Heat Generation" section of this document.
2. The ambient air temperature (T_A) in which the LED will be operated: For estimating the ambient temperature during device operation, please include other sources of heat, such as electronics, in the consideration. The maximum rated operating temperature can be found on the product data sheet. For Crystal IS SMD LEDs, this is typically noted as 55 °C.
3. The maximum allowable junction temperature, $T_{J(max)}$, of the LED during operation: This can be found on the product data sheet. For Crystal IS SMD LEDs this is typically noted as 100 °C, which has been used for example calculations in this document.

The total thermal resistance between the LED junction and ambient air is estimated using the result of Equation 3. Equation 4 illustrates how to calculate the maximum resistance from junction to ambient (RO_{JA}) using the maximum allowable junction temperature.

$$\text{Equation 4: } RO_{JA(max)} = (T_{J(max)} - T_A) / P_D$$

In order to keep the junction temperature below $T_{J(max)}$, a heat sink with a thermal resistance lower than $RO_{SA(max)}$ is required. The maximum thermal resistance of the heat sink can be calculated from the maximum overall thermal resistance ($RO_{JA(max)}$) by subtracting the other factors that contribute to overall thermal resistance:

$$\text{Equation 5: } RO_{SA(max)} = RO_{JA(max)} - (RO_{JC} + RO_{CS})$$

A heat sink with the required characteristics may be selected from one of the heat sink manufacturers listed in the "Thermal Management Resources" section of this document.

Design Validation

The calculations provide guidance on heat sink design; however successful thermal management depends on factors that cannot be predicted using theoretical methods. These parameters include the position of the LED on the heat sink, the extent to which airflow is hindered by the screening effect of nearby components, and heating from other components in the fixture. It is important to compare the results of the thermal model with the actual package temperature in prototypes.

The design validation should be performed at the expected ambient temperature range, ambient airflow, and with any additional heat loads. The temperature measurement should be done with the thermocouple in contact with the copper slug at the base of the package.

EXAMPLE CALCULATIONS:

Crystal IS SMD LEDs must be operated in conditions where junction temperature (T_J) is less than or equal to 100 °C (as stated in Crystal IS SMD product data sheets). The following examples are provided for Crystal IS Optan SMD product.

Example 1: Optan SMD operated at current of 100 mA

In this example calculation, a Crystal IS SMD LED is operated at 100 mA at an ambient temperature of 25 °C. The forward voltage of this particular LED is 8 V, therefore the power dissipation (P_D) is 0.8 W.

The SMD package is attached to a heat sink using thermal paste with a thermal resistance of 1 °C/W. Design requirements for an appropriate heat sink can be calculated as follows:

- $P_D = 0.8 \text{ W}$

- Therefore, from Equation 4, the maximum allowable thermal resistance from the junction to the ambient is:

$$R\theta_{JA(\max)} = (100 - 25)/0.8 = 93.75 \text{ °C/W}$$

- To estimate the maximum allowable thermal resistance from the heat sink to the ambient, we need to know the thermal resistance from the junction to the case ($R\theta_{JC}$) and from the case to the sink ($R\theta_{CS}$). The $R\theta_{JC}$ stated on the Optan SMD product data sheet is 12 °C/W. The $R\theta_{CS}$ is stated in this example as 1 °C/W. Thus maximum allowable thermal resistance from the heat sink to the ambient using Equation 5 is as follows.

$$R\theta_{SA(\max)} = 93.75 - (12+1) = 80.75 \text{ °C/W}$$

- To achieve the junction temperature target and ensure proper performance of the UVC LED, a heat sink with thermal resistance value, $R\theta_{SA}$, less than 80.75 °C/W has to be utilized. Heat sinks may be designed in different shapes depending on the space requirements of each application. For example, these parameters can be achieved with a flat, horizontal heat sink with only one free convection surface.

Example 2: Optan SMD operated at maximum current of 300 mA

In this example calculation, the UVC LED is operated at 300 mA at an ambient temperature of 25 °C. The forward voltage of this particular LED is 10 V, therefore the power dissipation (P_D) is 3 W.

The SMD package is attached to a heat sink using thermal paste with a thermal resistance of 1 °C/W. Design requirements for an appropriate heat sink can be calculated as follows:

1. $P_D = 3 \text{ W}$

2. Therefore, from Equation 4, the maximum allowable thermal resistance from the junction to the ambient is:

$$R\theta_{JA(\max)} = (100 - 25)/3 = 25 \text{ °C/W}$$

3. To estimate the maximum allowable thermal resistance from the heat sink to the ambient, we need to know the thermal resistance from the junction to the case ($R\theta_{JC}$) and from the case to the sink ($R\theta_{CS}$). The $R\theta_{JC}$ stated on the Optan SMD data sheet is 12 °C/W. The $R\theta_{CS}$ is stated in this example as 1 °C/W. Thus maximum allowable thermal resistance from the heat sink to the ambient using Equation 5 is as follows.

$$R\theta_{SA(\max)} = 25 - (12+1) = 12 \text{ °C/W}$$

4. To achieve the junction temperature target and ensure proper performance of the Crystal IS SMD LED, a heat sink with thermal resistance value, $R\theta_{SA}$, less than 12 °C/W has to be utilized. Heat sinks may be designed in different shapes depending on the space requirements of each application. For example, these parameters can be achieved with a finned heat sink with a reduced footprint.

THERMAL MANAGEMENT RESOURCES

The following list includes a few manufacturers that supply thermal management materials.

Heat Sink Manufacturers

Aavid Thermalloy www.aavidthermalloy.com

Mersen www.mersen.com

Wakefield www.wakefield.com

Thermal Interface Material Manufacturers

3M www.3m.com

Aavid Thermalloy www.aavidthermalloy.com

Bergquist www.bergquistcompany.com

Dow Corning www.dowcorning.com

Shin-Etsu www.sinetsu.co.jp

Indium Corp. of America www.indium.com

Omega www.omega.com

Additional Links

www.electronics-cooling.com

www.coolingzone.com

www.thermalwizard.com

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We invite you to learn more about our UVC LEDs.



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