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Effective Thermal Management of Crystal IS LEDs

This application note describes the thermal management concepts and guidelines for the proper use of Crystal IS UVC 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 delivers high performance 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.

However, excess heat negatively impacts the light output and lifetime of an LED. Proper thermal management keeps the junction temperature (T_J) 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 for the purposes of this note the heat generated is regarded as approximately equal to the power dissipation (P_D).

Equation 1: $P_D = V_F * I_F$

Impact on Junction Temperature

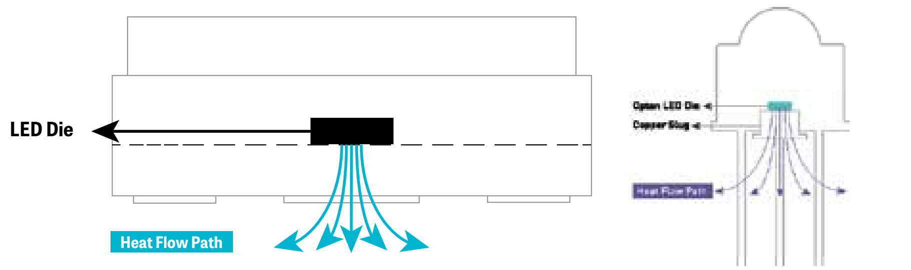
The junction temperature of an LED increases with the generation of heat, with the rate of increase dependent upon the amount of heat that is dissipated to the ambient. The heat is transferred from the junction to the ambient via all elements that make up the thermal management system.

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, special packages with high thermal conductivity are used for Crystal IS UVC LEDs. This heat flow path is illustrated in Figure 1. It is strongly recommended to attach a heat sink to facilitate further thermal transfer, as shown in Figure 2.

FIGURE 1

Figure A

Figure B

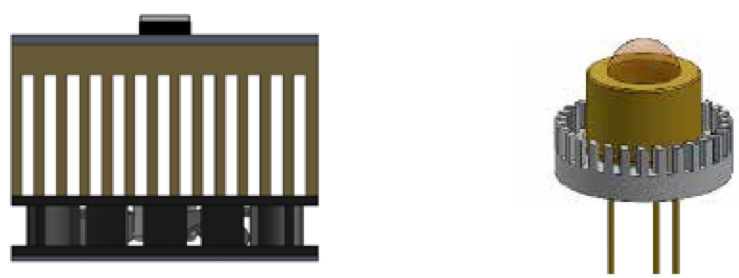


Schematic of heat flow path for Crystal IS surface mount (a) and through hole (b) packages.

FIGURE 2

Figure A

Figure B



Schematic of heat sink placement for Crystal IS surface mount (a) and through hole (b) packages.

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

> Heat is conducted from the semiconductor chip to the bottom of the package.

> Heat is then conducted from the thermal pad to the metal core PCB through the solder joint.

> Heat is conducted from the metal core PCB to the heat sink, through a thermal interface material, such as solder paste.

> Finally, heat is conducted through the heat sink and transferred to the ambient via convection of the air around the heat sink.

The case temperature is measured at the thermal pad under the device. As this pad should be soldered to a metal core PCB, it is recommended to characterize this temperature in operation by soldering a thermocouple* to the PCB solder pad near this point. This configuration can be accomplished by extending the PCB solder pad of the thermal pad slightly beyond the footprint of the device. T_J is then calculated using the following equation where T_S is the solder point temperature:

Equation 2: $T_j = T_S + R\theta_A * P_d$

*Crystal IS uses 40 AWG type T thermocouples when taking this measurement in our testing labs.

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

For Crystal IS LEDs, the thermal resistance can be simply represented in

Equation 3 where:

> $R\theta_{JC}$ is the thermal resistance from the junction of the LED die to the case

> $R\theta_{CP}$ is the thermal resistance from the case to the PCB

> $R\theta_{PS}$ is the thermal resistance from the PCB to the heat sink

> $R\theta_{SA}$ is the thermal resistance from the heat sink to the ambient

Equation 3: $R\theta_{JA} = R\theta_{JC} + R\theta_{CP} + R\theta_{PS} + R\theta_{SA}$

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 thermal pad of LED is fixed by the materials used in the package, application designers have flexibility in the selection of the PCB, the heat sink and the thermal interface material between the PCB and the heat sink.

Some simple rules in heat sink design or selection:

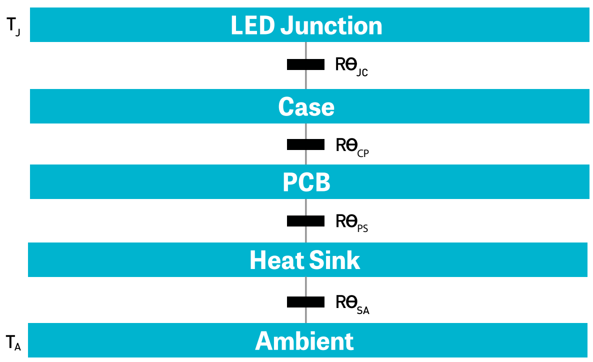
> When soldering the LED to the PCB, minimize the thickness of the interface materials between the PCB and the heat sink (i.e. the distance the heat must travel).

> Use a heat sink with a large surface area.

> Use metal core PCB for LEDs.

> 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 aluminum 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 attaching a PCB-mounted LED to a heat sink, 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: When estimating the ambient temperature during device operation, include other sources of heat, such as electronics. The maximum rated operating temperature can be found on the product data sheet.

3. The maximum allowable junction temperature, $T_{J(max)}$, of the LED during operation: This can be found on the product data sheet.

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 ($R\theta_{JA}$) using the maximum allowable junction temperature.

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

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

Equation 5: $R\theta_{SA(max)} = R\theta_{JA(max)} - (R\theta_{JC} + R\theta_{CP} + R\theta_{PS})$

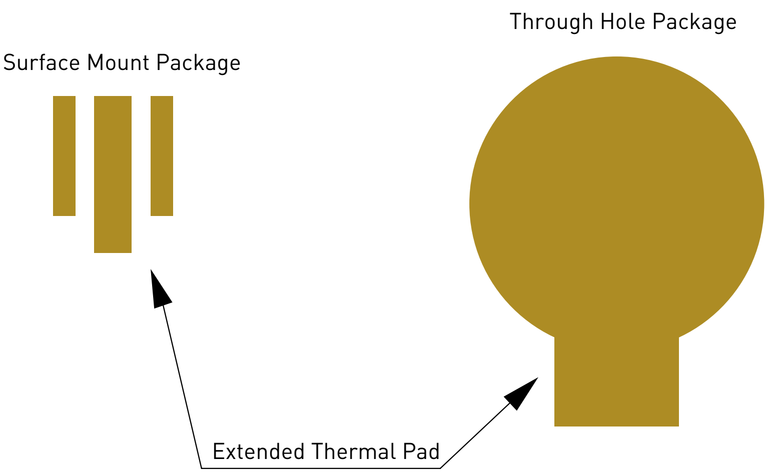
A heat sink with the required characteristics may be selected from one of the heat sink manufacturers listed in the "Thermal Management Resources" section of this document.

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 can be measured in different methods, such as the thermocouple in contact with the thermal pad at the base of the package (see sidebar on page 4). Figure 5 shows the suggested solder pattern for design validation with the extended thermal pad.

FIGURE 5



Suggested solder pattern showing extended thermal pad for measuring the solder point temperature.

Example Calculations

Crystal IS LEDs must be operated in conditions where the junction temperature (T_J) is less than or equal to the maximum junction temperature listed on the product data sheet. The following examples are provided for reference when designing systems with these UVC LEDs.

Example 1: Optan TO-39 Ball Lens operated at current of 100 mA

In this example calculation, a Crystal IS Optan TO-39 Ball Lens LED is operated at current of 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 Optan TO-39 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. $P_D = 0.8$ W

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

$R\theta_{JA(max)} = (85 - 25)/0.8 = 75$ °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 ($R\theta_{JC}$), the case to the PCB ($R\theta_{CP}$), and PCB to heat sink ($R\theta_{ps}$). Here $R\theta_{ps}$ includes thermal resistance of the PCB and the thermal resistance of the thermal paste, hence:

$R\theta_{PS} = 3 + 1 = 4$°C/W

The $R\theta_{JC}$ stated on the Klaran product data sheet is 37 °C/W. Thus maximum allowable thermal resistance from the heat sink to the ambient using Equation 5 is as follows.

$R\theta_{SA(max)} = 75 - (37 + 1) = 37$ °C/W

4. 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 37 °C/W should be used. 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 or with a finned heat sink with a reduced footprint.

Example 2: Klaran General Disinfection LED

In this example calculation, a Crystal IS Klaran LED is operated at 300 mA at an ambient temperature of 25 °C. The forward voltage of this particular LED is 7.45 V, therefore the power dissipation (P_D) is 2.235 W.

The Klaran package is soldered to an aluminum core PCB; the solder joint has a thermal resistance of 1 °C/W, and the PCB has a thermal resistance value of 3 °C/W. A heat sink, attached to the PCB with thermal paste, is required for adequate heat transfer for the LED. Design requirements for an appropriate heat sink can be calculated as follows:

1. P_D = 2.235 W

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

$R\theta_{JA(max)}$ = (85 - 25)/2.235 = 26.85 °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 ($R\theta_{JC}$), the case to the PCB ($R\theta_{CP}$), and PCB to heat sink ($R\theta_{ps}$). Here $R\theta_{ps}$ includes thermal resistance of the PCB and the thermal resistance of the thermal paste, hence:

$R\theta_{ps}$= 3 + 1 = 4°C/W.

The $R\theta_{JC}$ stated on the Klaran product data sheet is 10 °C/W and as stated in the Example 1 set up. Thus maximum allowable thermal resistance from the heat sink to the ambient using Equation 5 is as follows.

$R\theta_{SA(max)}$ = 26.85 - (10 + 1 + 4) = 11.85 °C/W

4. 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 11.85 °C/W should be used. 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 or a fan can be integrated into heat sink design.

Example 3: Assembly using materials with improved thermal properties

This example calculates the maximum allowed ambient temperature for the application when using materials with improved thermal properties. The Crystal IS Klaran LED is operated at 400 mA with a forward voltage of 8.45 V, with a power dissipation of 3.4 W.

The Klaran package is soldered to a copper core PCB; the solder joint has a thermal resistance of 0.1 °C/W, and the PCB has a thermal resistance value of 2 °C/W. A water cooled heat sink, attached to the PCB with thermal paste, has a thermal resistance of 0.06 °C/W at 1 lpm of water flow.

Therefore from Equation 2 we can calculate the maximum allowed ambient temperature.

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

$85 = T_A + (10 + 0.1 + 2 + 0.06) * 3.4$

$85 = T_A + (41.3)$

$T_A = 85 - 41.3 = 43.7$

To work within the maximum allowable junction temperature of the Klaran UVC LED, the ambient temperature cannot exceed 43.7 °C during operation.

The examples outlined in this note are provided for reference to show various methods for thermal management based on the operating conditions of a single LED in an application. In practice, many designs utilized multiple LEDs in an arrangement. The Crystal IS application engineering team is available to help customers determine the needs of their thermal management systems. Please contact us to discuss your specific application needs at sales@ cisuvc.com.

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

Koolance (water cooled heat sink) www.koolance.com/cold-plate-40mm-plt-un40f

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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