Silanna
UV

APPLICATION NOTE

THERMAL MANAGEMENT OF UVC LEDs

Silanna UVC LED is a powerful, small footprint for applications including sterilization, disinfection, curing, chemical and biological analysis. Careful thermal design is essential for maximizing the output power and longevity of UVC LEDs. This application note provides a guide for understanding and managing the thermal properties of UVC LEDs, in order to achieve their full performance potential.

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1. Introduction

The Silanna UVC LED is a powerful, small footprint Deep/Far UVC LED emitting device. The SMD packaged device possesses long lifetime, its short UVC wavelength provides an optimal germicidal effect. The other key advantage of the Silanna UVC LED is its low thermal resistance of 7.5 C°/W for an effective thermal management. The features of the SMD type LED make it the ideal UVC emitter to be designed in a wide range of applications.

The performance of a UVC LED application circuit is dependent of the quality of its thermal design. UVC LEDs are typically operated with high currents per area, yet they are less efficient than visible LEDs. The vast majority of power supplied to a UVC LED is dissipated as heat, so special care must be taken to prevent overheating.

The junction temperature (T_J) of a UVC LED can be thought of as the internal temperature at the light-generating region of the device. Many properties of the UVC LED such as voltage, wavelength, and efficiency are influenced by T_J. Design efforts which minimize T_J are rewarded with increased light output power and improved reliability. The thermal design must always ensure that T_J stays below the specified absolute maximum junction temperature. Failure to do so can result in permanent damage to the device.

This application note provides an introduction to thermal design for UVC LEDs. It begins with a review of heat transfer concepts, followed by discussion of a simple resistor model of heat transfer for a UVC LED assembled to a printed circuit board (PCB). The impact of thermal design on the maximum allowable UVC LED current is presented, leading to a review of PCB design techniques for minimizing T_J. The application note concludes with a discussion on using the temperature of a solder point (T_S) on the PCB for practical measurements of T_J.

2. Heat transfer concepts

Heat is transferred between objects or environments by conduction, convection, or radiation.

2.1 Conduction

Heat conduction in a material occurs between areas having different temperatures. In metals, collisions of free electrons with each other and metal atoms are responsible for heat conduction. Heat transfer by conduction in a UVC LED system occurs from the UVC LED chip to the package, and then from the package to the printed circuit board (PCB).

2.2 Convection

Convection is heat transfer due to mass movement of molecules. Although air and water are poor conductors of heat, they can effectively transfer heat by convection. Convective heat transfer from the PCB to air is often the primary way that heat is extracted from the PCB to the surrounding ambient.

2.3 Radiation

Radiation is a type of heat transfer which does not require any medium to transfer heat. While all objects radiate energy through electromagnetic waves, the rate of heat transfer by radiation is strongly dependent on the temperature of the object. In a UVC LED system, temperatures are strictly maintained below the maximum junction temperature, so heat transfer by radiation is usually a minor component of the total heat transfer.

3. Thermal model

The electrical and thermal designs of a UVC LED system are closely connected. Fittingly the electrical resistor has a thermal analogy known as the ‘thermal resistance’ with units of °C/W. The thermal resistance is frequently denoted as R_{TH} in the LED industry, though θ is also a commonly used symbol for thermal resistance in the wider electronics community.

The thermal path of a UVC LED system contains many materials which all contribute to the total thermal resistance between the UVC LED junction and the ambient ($R_{TH\text{-}JA}$). Components of the UVC LED system contributing to $R_{TH\text{-}JA}$ can include the UVC LED die, die attach, package, package solder joint to the PCB, PCB, heatsink, and the thermal interface material between the PCB and the heatsink. The junction-ambient thermal resistance is defined by the equation:

$$R_{TH\text{-}JA} = (T_J - T_A)/P_D \qquad (1)$$

where T_J is the junction temperature of the UVC LED, T_A is the ambient temperature, and P_D is the power dissipated in the UVC LED. In a UVC LED almost all of the applied electrical power is dissipated as heat in the device. Therefore, the rate of heat transfer can be approximated as $P_D = V_F \times I_F$, where V_F is the voltage (V) of the UVC LED, and I_F is the current (A) of the UVC LED.

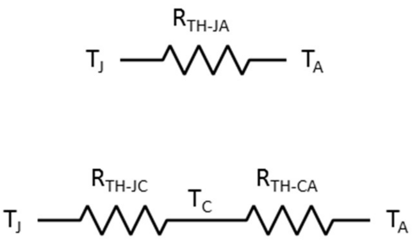

Figure 1 Simplified thermal resistance model.

The junction-ambient thermal resistance consists of a component for the junction-case thermal resistance ($R_{TH\text{-}JC}$), and a component for the case-ambient thermal resistance ($R_{TH\text{-}CA}$). The junction-case thermal resistance $R_{TH\text{-}JC}$ represents the lowest thermal resistance path between the UVC LED junction and the UVC LED package. The lower the $R_{TH\text{-}JC}$, the better the thermal performance of the package.

Heat flows from the package to the PCB, and then from the PCB to the ambient. The case-ambient thermal resistance $R_{TH\text{-}CA}$ is the equivalent thermal resistance between the package of the LED and the surrounding ambient. Minimization of $R_{TH\text{-}CA}$ through careful thermal design of the PCB is necessary for minimization of $R_{TH\text{-}JA}$ and T_J. The case-ambient thermal resistance $R_{TH\text{-}CA}$ is influenced by the materials used in the PCB construction, the physical dimensions of the PCB, and heat sinks that may be attached to the PCB. Cooling sytems based on forced air or flowing water can also reduce $R_{TH\text{-}CA}$.

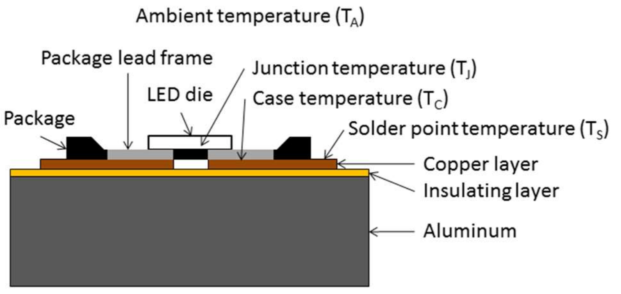

Figure 2. UVC LED mounted on a single layer Aluminum MCPCB.

4. Current de-rating curves

A key design requirement for any UVC LED system is that T_J stays below the absolute maximum value specified in the data sheet. The T_J of a UVC LED is influenced by the ambient temperature, the power applied to the UVC LED and the junction-ambient thermal resistance. Rearranging equation (1), and substituting P_D with $V_F \times I_F$ gives the following equation for T_J:

$$T_J = V_F I_F R_{TH\text{-}JA} + T_A \qquad (2)$$

The first step towards a thermal design solution is to determine the allowable $R_{TH\text{-}JA}$ while ensuring that T_J stays below the absolute maximum value (T_{JMAX}). Silanna UVC LED has a T_{JMAX} of 85°C. The recommended I_F is 20mA, and the maximum V_F is 7 V. Assume that the maximum T_A that the UVC LED system will operate in is 60°C. For $T_J < 85°C$, equation (2) implies:

$$V_F I_F R_{TH\text{-}JA} + T_A < 85°C$$

Rearranging for $R_{TH\text{-}JA}$ and substituting the values for I_F, V_F and T_A gives:

$$R_{TH\text{-}JA} < (85\text{-}60)/(7.0\times0.02) = 178.6\ °C/W$$

From the data sheet, the typical $R_{TH\text{-}JC}$ is 7.5 °C/W, which means that in this example $R_{TH\text{-}CA}$ must be less than 171.1°C/W to ensure T_J stays below T_{JMAX}.

If size constraints on the PCB make it difficult to achieve the required $R_{TH\text{-}JA}$, an alternative solution is to de-rate the operating current of the UVC LED. Reducing I_F allows higher values of $R_{TH\text{-}JA}$ for the same T_J; however, the consequence of reducing I_F is a lower light output power.

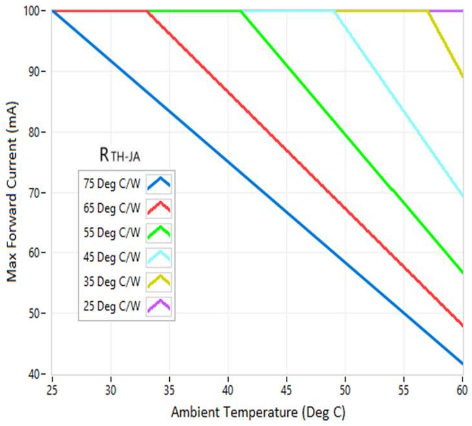

Figure 3. Current de-rating curves

The maximum UVC LED current depends on $R_{TH\text{-}JA}$ and T_A.

Using equation (2), current de-rating curves can be calculated which illustrate the trade-off between I_F and $R_{TH\text{-}JA}$. Figure 3 illustrates the current de-rating curves as a function of T_A for different values of $R_{TH\text{-}JA}$.

5. PCB design

The PCB of a UVC LED system should be designed to effectively conduct heat away from the UVC LEDs, and transfer heat to the ambient environment. Managing the thermal load is especially important for UVC LEDs because compared to visible LEDs, UVC LEDs have higher voltages and are less efficient. The higher voltages and the industry trend towards higher currents, means that the input power is high. The PCB must perform the essential function of transferring heat away from the UVC LED, to prevent it from overheating.

5.1 PCB construction

Printed circuit boards can be based on a variety of materials. The options available include FR4 PCBs, ceramic PCBs and metal-core PCBs (MCPCBs). For the majority of UVC LED application circuits, the best compromise between price and thermal performance is provided by MCPCBs. As the name suggests, the bulk of an MCPCB consists of a highly thermally conductive metal such as aluminum or copper.

The basic construction of a single-layer MCPCB is shown in Figure 4 for the case of an aluminum core board. Single-layer MCPCBs have a copper layer on only one side of the MCPCB.

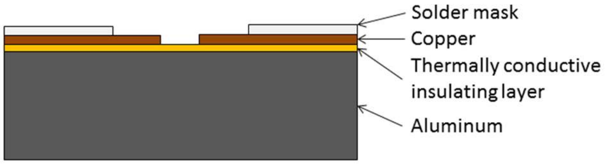

Figure 4. Single-layer MCPCB

Copper tracks on the top of the MCPCB are electrically insulated from the aluminum core by a thermally conductive insulating layer, which is usually about 100 µm in thickness. Heat from the UVC LED flows to the copper tracks and traverses the insulating layer to reach the metal core.

The thermal conductivity of the insulating layer is an important design parameter because the insulating layer makes a high contribution to the total thermal resistance of the MCPCB. Printed circuit board manufacturers typically offer MCPCBs with thermal conductivities in the range of 1-9 W/m°C.

The metal core of the MCPCB does an excellent job of spreading heat away from the UVC LED. Aluminum 1-2 mm in thickness is a common choice for the metal core. Copper cores have an even higher thermal conductivity than aluminum, but they come at a higher price.

5.2 PCB size

Correctly sizing a PCB for the UVC LED power dissipation is a key step towards preventing UVC LED overheating. As the PCB size increases, so do the rates of convective and radiative heat transfer. Consequently, a larger PCB results in cooler UVC LEDs. In the absence of a heat sink, the PCB area should be at least 3 cm^2 per Silanna UVC LED, in order to limit T_J to 25°C above T_A. This PCB area guide assumes the power dissipated in the UVC LED is P_D = 0.14 W, and that convective and radiative heat transfer occurs from both sides of the PCB.

Use of thermal modelling software is recommended for validating the PCB design, preferably in the early stages of the design process.

5.3 Copper thickness

The copper tracks of the PCB are in direct thermal contact with the UVC LED package, and have a high thermal conductivity. For these reasons it makes sense to use the copper tracks to help transfer heat from the UVC LED. Maximizing the copper coverage helps to spread heat across the PCB, and lateral heat transfer can be improved by increasing the thickness of the copper tracks.

Specifying the thickness of the copper layer can be confusing at first, because the unit of the copper layer thickness is ounces. A specification of 1 oz. copper means the copper thickness after taking 1 oz. of copper and rolling it into an area of 1 square foot. It's simplest to remember that each ounce of copper corresponds to a thickness of about 35.5 µm. For example, a specification of 4 oz. copper means a thickness of 142 µm. Most PCB manufacturers routinely use 1 oz. copper for outer board layers. Thermal performance can be improved by moving to 2 oz. or 4 oz. copper layers.

5.4 Heat sinks

Heat sinks are frequently used to lower $R_{TH\text{-}JA}$ of a UVC LED system, especially when space constraints limit PCB size, preventing adequate thermal dissipation from the PCB alone. The role of the heat sink is to conduct heat from the MCPCB and transfer it to the ambient by convection or radiation. When choosing a heat sink, normally its surface area should be 30-65 cm^2 per Watt of heat power to be dissipated.

Heat sinks should always be positioned in the lowest possible thermal resistance path to the UVC LED junction. For designs based on a single-layer MCPCB, the heat sink should be positioned on the aluminum side of the MCPCB, directly beneath the UVC LED.

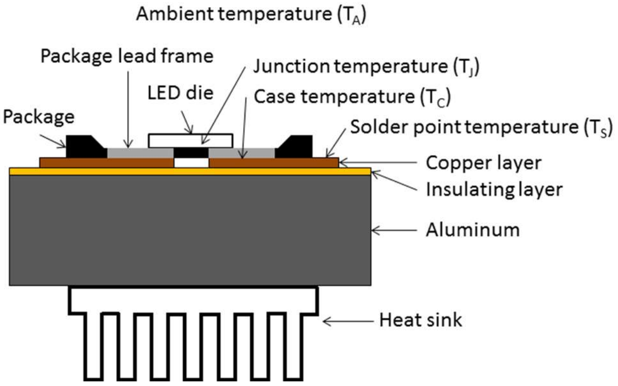

Figure 5. Heat sink attached to the MCPCB.

A heat sink on the aluminum side of the MCPCB results in the thermal resistance model shown in Figure 6. Two new thermal resistance values have been introduced, and $R_{TH\text{-}CA}$* represents a modified value of the original $R_{TH\text{-}CA}$ before heat sink attachment. The thermal resistance of the direct thermal path between the UVC LED case and the heatsink is denoted as $R_{TH\text{-}PCB}$, whereas the thermal resistance of the heat sink is $R_{TH\text{-}HS}$. Heat sink manufacturers report $R_{TH\text{-}HS}$ values for natural convection and forced air flow.

Forced air flow, such as that from a cooling fan, can dramatically reduce $R_{TH\text{-}HS}$. Forced air flow maximizes heat sink performance; however, the cooling benefit must be weighed against added system cost and maintenance requirements.

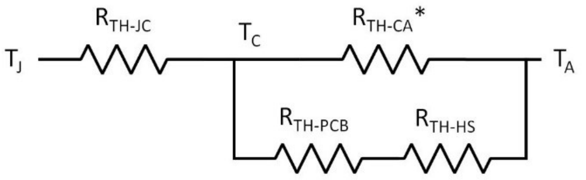

Figure 6. Heat sink thermal resistance model.

In general, the greater the heat sink surface area, the lower the $R_{TH\text{-}HS}$. Many heat sinks have fins which increase their surface area. It is important to not block air flow between the fins, and if forced air flow is used, it should be oriented to draw air between the fins. Special attention should also be given to the interface between the MCPCB and the heat sink. Use of a thermally conductive paste between the MCPCB and the heat sink reduces air gaps to assist heat conduction from the MCPCB to the heat sink.

An example calculation of the upper limit for $R_{TH\text{-}HS}$ is now provided using a number of simplifying assumptions. The first assumption is that the PCB area is too small to dissipate the full heat load by convention and radiation. Instead, the heat is conducted from the UVC LED, through the PCB to the heatsink. In this scenario the thermal resistance model can be simplified to that of Figure 7.

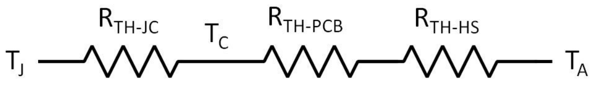

Figure 7. Simplified heat sink thermal resistance model.

Assume that we wish to limit T_J to 25°C above T_A, and take $R_{TH\text{-}JC}$ as 7.5 °C/W and P_D as 0.14 W as before. Multiplying $R_{TH\text{-}JC}$ by P_D gives a 1.05°C temperature difference between the junction and the case. This means that the temperature difference between the UVC LED case and the ambient should be less than 25 – 1.05 = 23.95°C to meet the design goal.

It follows that the heat sink should be chosen to satisfy the equation:

$$P_D(R_{TH\text{-}PCB}+R_{TH\text{-}HS})<23.95°C \tag{3}$$

Assuming an $R_{TH\text{-}PCB}$ value of 6 °C/W, and substituting P_D = 0.14W into equation (3), gives $0.14(6+R_{TH\text{-}HS}) < 23.95$, resulting in $R_{TH\text{-}HS}<165.1$ °C/W.

When selecting a heat sink, thermal modelling software is a useful tool for validating analytic calculations and exploring the impact of the heat sink size and placement on T_J. Thermal simulations allow evaluation of multiple heat sink designs in a fraction of the time it would take to trial them experimentally.

6. Validation

6.1 Importance of the solder-point

Direct junction temperature measurement of a UVC LED in an application circuit is usually impractical. An alternative approach is to measure the temperature at a reference point on the PCB next to the UVC LED. The solder point is an accessible pad on the PCB, located close to the thermal path of the UVC LED. The position of the solder point on Silanna UVC LED evaluation star board BC-PCB-0064-A-001 is shown in Figure 8. Normally the solder point is an extension of one of the UVC LED PCB pads beyond the footprint of the UVC LED. Measurement of the solder point temperature (T_S) provides a way to infer the T_J of the UVC LED, if the junction to solder point thermal resistance ($R_{TH\text{-}JS}$) is known. The relationship between T_J , T_S , and $R_{TH\text{-}JS}$ is given by:

$$T_J=T_S+R_{TH\text{-}JS}\times V_F\times I_F \tag{4}$$

The $R_{TH\text{-}JS}$ value of Silanna UVC LED evaluation star board BC-PCB-0064-A-001 is approximately 0.2 °C/W higher than the specified $R_{TH\text{-}JC}$. For example, a specified $R_{TH\text{-}JC}$ value of 7.5 °C/W means that $R_{TH\text{-}JS}$ can be taken as 7.7 °C/W.

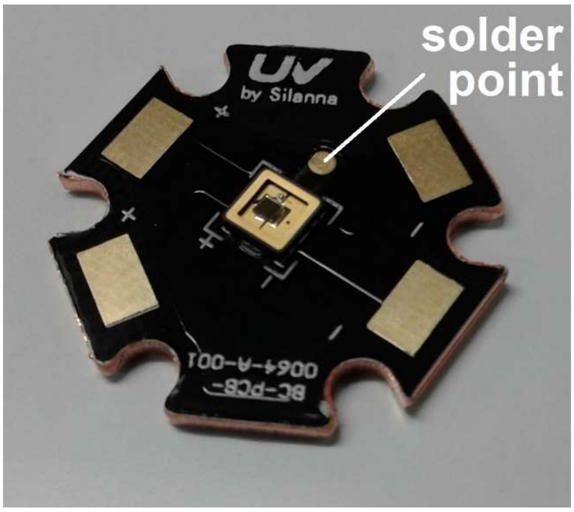

Figure 8. Silanna UVC LED evaluation star board.

6.2 Thermocouple attachment

Accurate T_S measurements require good thermal attachment of the thermocouple tip to the solder point. A suitable attachment method is to use Arctic Silver® thermal epoxy to affix the thermocouple junction to the solder point.

Attachment of a thermocouple junction to the solder point should begin with inspection of the solder point. Ensure that the solder point is free of foreign materials. A small amount of isopropanol and a low-lint wipe may be used to clean the solder point. Place the thermocouple junction on the solder point and use adhesive tape to secure the thermocouple lead, so that the thermocouple junction doesn’t move.

Arctic Silver® thermal epoxy is supplied as a resin and a curing agent in separate tubes. Dispense equal proportions of resin and curing agent onto a clean plastic sheet and thoroughly stir the two ingredients together.

With the thermocouple junction flat against the PCB pad, apply a dab of Arctic Silver® thermal epoxy. There should be enough thermal epoxy to cover the thermocouple junction and attach it securely to the solder point. Allow the thermal epoxy to cure fully before using the thermocouple.

7. Conclusion

A successful UVC LED system design requires careful thermal management. Understanding the operating environment and creating a suitably low junction-ambient thermal resistance are key aspects of good thermal design. Through suitable choices of PCB construction, PCB size, and appropriate heat sink usage, the UVC LED junction temperature can be maintained below the specified absolute maximum value for reliable UVC LED operation. Measurements should be performed to validate the thermal solution and identify areas for improvement. Sound thermal design enables UVC LEDs to perform at their potential and supports long term stability and reliability of the UVC LED system

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