

THERMAL STUDY ON LED ARRAY FOR UVC EXPOSURE

Arrays of LEDs are often used to illuminate areas for application such as disinfection to achieve higher optical output, uniformity and for quick switching requirements. Thermal design is a key to the efficient utilization of **SILANNA**'s state-of-the-art UVC LED. This application note explores the behavior of LEDs and techniques to optimize performance.

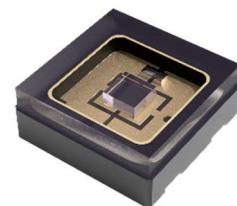
1. Introduction

While the first commercial light emitting diodes (LEDs) emerged in the 1960s as a source of infrared (IR) light, it was not until the development of LEDs based on gallium nitride (GaN) and subsequently aluminium gallium nitride (AlGaIn) semiconductor technology that these devices became practical sources of ultraviolet light.

Since then, there has been a rapid adoption of the technology, not least because using LEDs as a source of UVC light has numerous advantages over mercury lamp alternatives.

As a result, there is an increasing move to solid-state LED technology as a source of UVC light for a variety of applications. These include sterilization and disinfection, water quality monitoring of COD (chemical oxygen demand), SS (suspended solid) and nitrate (NO₃), gas sensing for ozone (O₃), emitting sources in medical analyzers and liquid and biological analysis of DNA.

Because of its germicidal properties and an ability to disinfect air, food, surfaces and water, the use of ultraviolet germicidal irradiation (UVGI) has become widely accepted over recent years. With a sufficient dose, UVC radiation can inactivate any micro-organism, including viruses, bacteria, fungi, and protozoa, making it a universal germicide.



**Figure 1: Silanna
235nm LED**

2. Why LED arrays?

Traditionally mercury lamps were the most common sources of UVC light. These suffer from a number of disadvantages including the required warm-up time, fragility, and limitations in deployment due to their size and potential contamination concerns which restrict their use in certain sterilization and sensing applications. Furthermore, environmental concerns around the use of mercury mean they are subject to ever-stricter regulations and growing calls for their eventual phase-out.

All these disadvantages are overcome with UVC LEDs. Not only do these LEDs turn on instantaneously, but they can also be pulsed like any other LEDs. Despite their many advantages, the LEDs are continuously

evolving in the pursuit of higher power levels like the UV-A or UV-B LEDs. To address the demand for higher power, an array of these LEDs packages can be used to achieve the power level required for the application. An LED array has always been a solution for many illumination applications such as water purification, street lighting etc. as they not only provide higher optical power but can also provide uniform exposure with limited optics.

3. Challenges with LED arrays

LED arrays have been a proven way to achieve the required optical power level for germicidal applications including surface, air, and liquid disinfection. Most disinfection applications require a certain energy, which is defined as the optical power integrated over time, to achieve the desired efficacy. Although LEDs require low operating power, the new generation UVC LEDs are still evolving to achieve better wall plug efficiency, as they currently generate a lot of heat. This heat, if not removed from the LED, will derate itself causing the output power to drop. In most LED applications, the junction temperature is required to be maintained at a low and steady level for it to emit a constant optical output.

For an LED to maintain a low junction temperature, the most common techniques are using a Metal Core Printed Circuit Board (MCPCB) along with an active or passive heat sink. In addition, LEDs are required to be spaced out to allow for efficient heat transfer. In many scenarios, the application does not allow the use of a large PCB to space the LEDs nor the provision of space for a huge heatsink.

By dissipating the heat, the LED's maintain higher optical output, and achieve the required energy level more quickly. These improvements are limited by the spacing between the LEDs, available space for heat sink and the possibility of active cooling such as fans or coolant.

This article demonstrates how adding a heat sink and spacing the LEDs out will slow down the rate at which the LEDs' junction temperatures rise. The setup, theoretical calculation, simulation results and actual measurement results were derived from a 6x6 LED array mounted on a MCPCB.

4. Thermal model of a LED

Before getting deeper into the LED array, here is the theory about how the electrical and thermal designs of a UV LED system are intricately connected. The electrical resistor has a thermal analogy fittingly known as the 'thermal resistance' with units of °C/W. 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 UV LED system contains many materials which all contribute to the total thermal resistance between the UV LED junction and the ambient (R_{TH-JA}). Components of the UV LED system contributing to R_{TH-JA} can include the UV 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:

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

where T_J is the junction temperature of the UV LED, T_A is the ambient temperature, and P_D is the power dissipated in the UV LED. With the existing wall plug efficiency in a UVC LED, almost all 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 UV LED, and I_F is the current (A) of the UV LED.

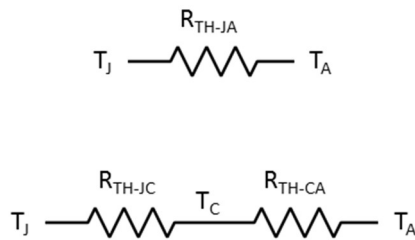


Figure 2: Simplified thermal resistance model.

As shown in Figure 2, the junction-ambient thermal resistance consists of a component for the junction-case thermal resistance (R_{TH-JC}), and a component for the case-ambient thermal resistance (R_{TH-CA}). The junction-case thermal resistance R_{TH-JC} represents the lowest thermal resistance path between the UV LED junction and the UV LED package. The lower the R_{TH-JC} , the better the thermal performance of the package.

Figure 3 shows the cross section of all the components of heat flow from die to the PCB. The heat flows from the package to the PCB, and then from the PCB to the ambient. The case-ambient thermal resistance (R_{TH-CA}) is the equivalent thermal resistance between the package of the LED and the surrounding ambient, and can be further broken down into a component coming from heat flow from the package into the PCB and from the PCB into the ambient. Minimization of R_{TH-CA} through careful thermal design of the PCB is necessary for minimization of R_{TH-JA} and T_J . The case-ambient thermal resistance R_{TH-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 systems based on forced air or flowing water can also reduce R_{TH-CA} .

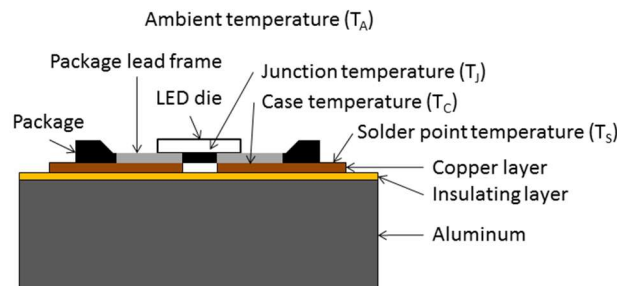


Figure 3: Cross section of UV LED mounted on a single layer Aluminum MCPCB.

5. Thermal Study – the setup:

To demonstrate thermal management, a 6x6 LED array board (emitter board) was developed. To achieve a low R_{TH-CA} , MCPCB and an optional heatsink are used in this study. The board is designed to power Silanna’s SF1 flat lid LEDs individually using a driver board that can supply a constant current. The driver board can also select the current from 10mA, 20mA, 30mA and 40mA. The driver board is connected to the LED board using a low profile FPC connector. Each driver board can power up to 6 LEDs independently. A total of 6 driver boards were used to power the 36 LED emitter board (Figure 4: Emitter board with 6x driver boards. Figure 4).

The LEDs on this emitter board are spaced 7mm apart from center-to-center. Each LED has a temperature sensing point close to its solder point. Multiple K-type thermocouples are attached to this



Figure 4: Emitter board with 6x driver boards.



Figure 6: Emitter board with thermocouples .

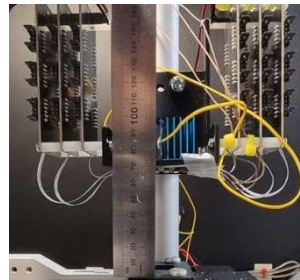


Figure 5: Emitter board mounted on a post and facing down.

emitter board (Figure 6). This single sided aluminum core PCB can mount different heatsinks at its back.

This setup is mounted on a vertical post and the LEDs looks straight down at a calibrated photodetector (Figure 5). The photodetector is mounted at a fixed distance from the emitter board to its center. The system is set up inside a light enclosure to avoid stray light and accidental exposure to personnel. For additional safety, the enclosure is interlocked to cut off the LED power supply when opened.

6. Thermal calculations for the array board

To determine thermal load and thus the maximum steady state temperature of the system, the following calculations are performed.

Step 1: Determine maximum temperature allowed for the component. In this case Silanna’s flat lid LED with R_{TH-JC} (Junction – Case) of $7.5^{\circ}\text{C}/\text{W}$ was used.

Step 2: Calculate the total power dissipated in the device (Power = Voltage * Current). Each LED is driven at 20mA at a forward voltage of 6V. So, the power per LED is 0.12W and 3.84W for all 36 LEDs on the emitter board.

Step 3: Rise in temperature is calculated as the product of power and thermal resistance. That is $3.84 * 7.5$ or 32.4°C . If the ambient temperature is 23°C , the solder point temperature is expected to be 55.4°C .

Figure 7 illustrates the thermal calculations performed below. Thus, the emitter board is expected to rise to about 55°C . The rate at which the temperature rises will be a critical factor for determining the time to achieve the required energy level. This calculation does not determine the rate at which the temperature rises nor the effect due to adjacent LEDs in an array.

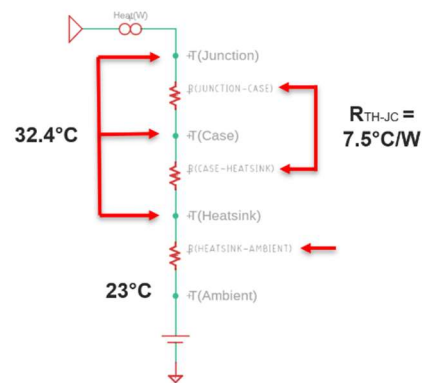
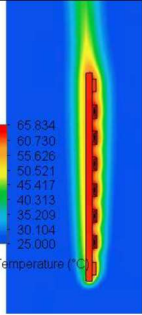
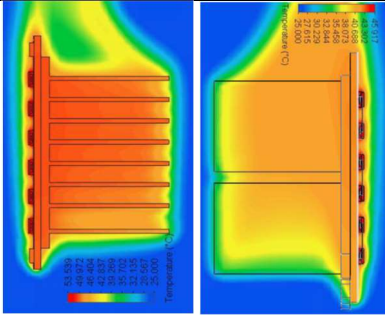
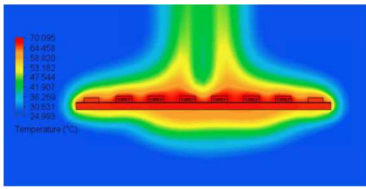
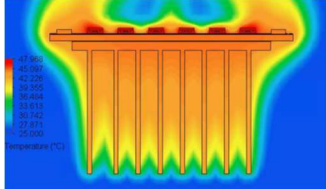
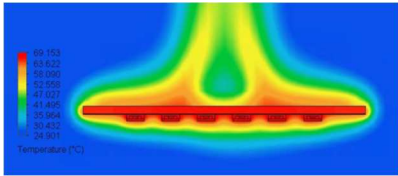
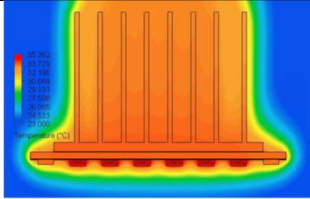


Figure 7: Thermal calculations.

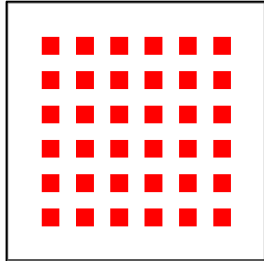
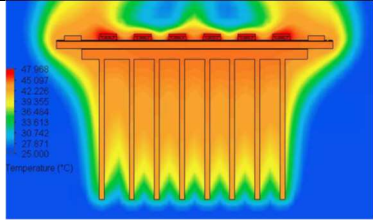
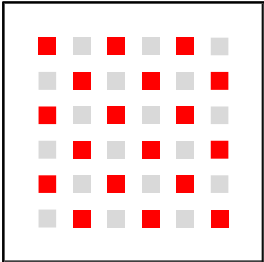
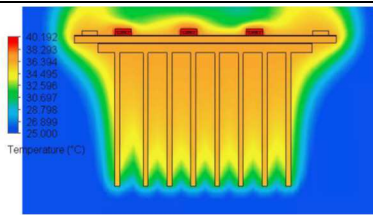
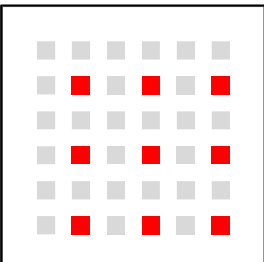
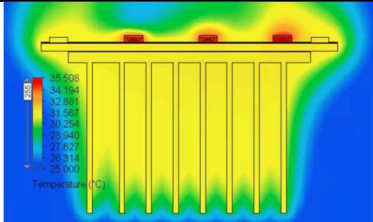
7. Simulation results

Before performing physical measurement, the design was simulated using a (method) thermal simulation software and the results are the array board’s maximum steady state temperature. Also, this method does not include the transient behavior of Silanna’s UVC LEDs. In this simulation, the emitter board is placed in different orientations. Simulations are performed with and without heatsink.

Emitter Board Orientation	Board temperature without heatsink	Board temperature with heatsink
Facing sideways	 <p style="text-align: center;">65°C</p>	 <p style="text-align: center;">51°C 44°C</p>
Facing up	 <p style="text-align: center;">67°C</p>	 <p style="text-align: center;">45°C</p>
Facing down	 <p style="text-align: center;">69°C</p>	 <p style="text-align: center;">35°C</p>

In summary, the simulation results show that without heatsink, at different orientations, the emitter board temperature is expected to vary marginally within 4°C (65°C to 69°C). In contrast, with the introduction of a heatsink, the direction of the board makes a stark difference. The temperature of the board can be reduced by over 30°C. It is also noted that all the simulation results are much higher than theoretical values.

More simulations are performed by changing the LED spacing. For this simulation, the LED was face up. Note that the spacing mentioned in the emitter board configuration represents the closest distance between the edges of two LEDs. The results show a considerable reduction in temperature with an increase in LED spacing.

Emitter Board configuration	Configuration representation	Board temperature with heatsink
36 LEDs spaced at 3.5mm apart		 45°C
18 LEDs spaced at 5mm apart		 38°C
9 LEDs spaced at 10.5mm		 33°C

8. Measurement results

The simulation results indicate that incorporating a heatsink will significantly impact performance. So, all the actual measurements are performed with the emitter board facing sideways and heatsink attached. An IR camera and multiple thermocouples attached to the emitter board were used to record the values. Different drive currents were used to perform the physical measurement.

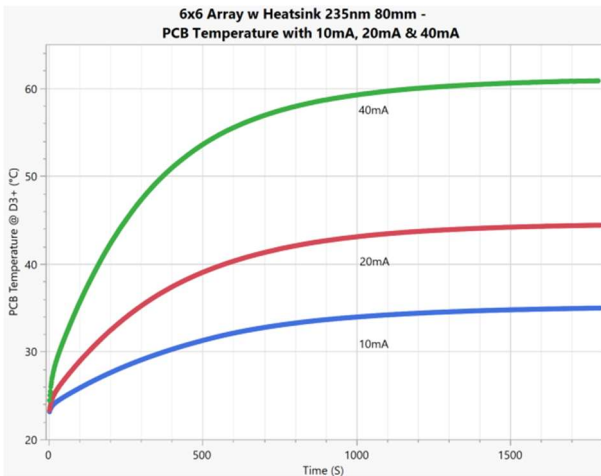


Figure 9: Board temperature vs. time.

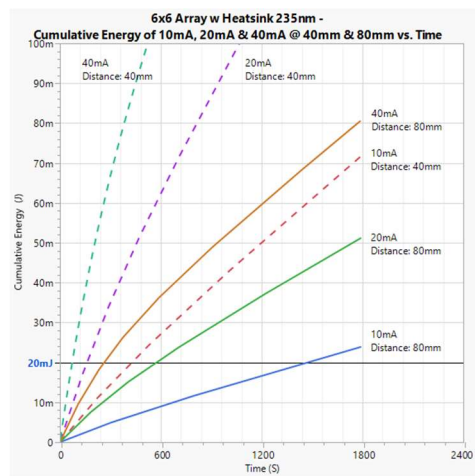


Figure 8: Energy (integrated power) over time.

The red line in the board temperature vs. time graph (Figure 9) measured at 20mA drive current shows a steady state temperature of 44°C. This aligns closely with the simulation. It also indicates that at a given spacing, the temperature’s rate of ascent escalates alongside the increase in current. The theoretical values did not match the measured and simulated values as they did not account for the influence of adjacent LEDs.

The measurements were performed at 80mm and at various drive currents. For this calculation, let us assume a 20mJ dose of 235nm light is required. When the power is integrated over time (Figure 8), at 80mm, it takes close to 10 mins to achieve a power level of 20mJ. If the current is doubled, it takes about 5mins to achieve the same energy level. If the current is halved it would take about 25 minutes. This indicates that with enough thermal budget, the doubling of current will halve the time required to achieve a given energy level.

This setup uses a flat lid package which has a light emission pattern of 120°. So, the distance of this LED array from the illuminating surface plays a crucial role in the duration required to attain the required energy level. At 40mm distance and driven at 20mA, the same energy is attained well under 3min. This correlates to the inverse square law of optics. Thus, keeping the subject close to the source will increase the effective exposure.

Note that using a parabolic lens package will minimize the effect of distance, but at the expense of uniformity.

This study is extended by changing the spacing between the LEDs while keeping the total input electrical power constant. For these measurements, 36 LEDs each driven at 10mA are used as a baseline. For the second scenario 18 LEDs are driven at 20mA each. The third scenario uses 9 LEDs driven at 40mA.

The results shown in Figure 10 demonstrate that increasing the spacing between the LEDs and increasing the drive current per LED accelerates the time to achieve 20mJ energy level. This clearly indicates that the rate at which the temperature increases can be altered by varying LED spacing and understanding the most efficient operating condition for the LED.

Care should be taken when operating the LED above the rated current level as this will affect the lifetime of the LED and may alter some operational characteristics that may affect the application.

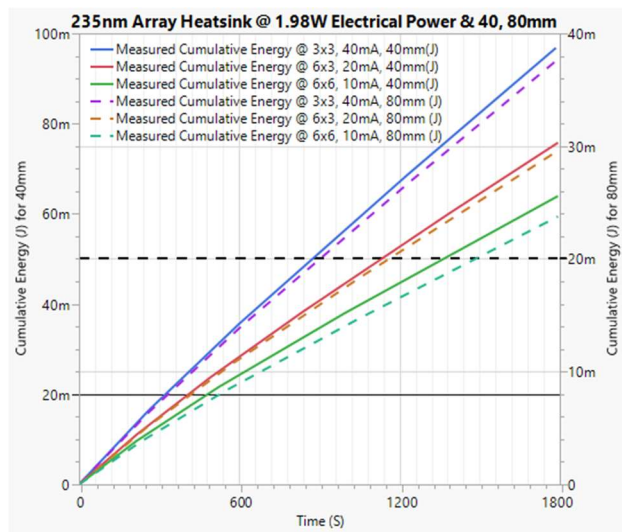


Figure 10: Comparison of same electrical power with different configuration over time to achieve target setpoint.

9. Conclusion

It is evident that an LED array board can be used to achieve higher power levels. With a carefully designed thermal budget, the LED array will provide better output power and uniformity than lamps. In addition, the LEDs require cheaper electronics to run and can be instantly switched. This application note illustrates how Silanna LEDs can be optimally used in a variety of exposure applications including surface, air, and liquid disinfection.

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