Crystal IS
High Performance UVC LEDs

APPLICATION NOTE:

Measuring the Light Output (Power) of UVC LEDs

November 1, 2016

THIS APPLICATION NOTE OUTLINES AN APPROACH FOR CUSTOMERS TO MEASURE UVC LED POWER OUTPUT WITH A PULSE MODE METHOD. THE OBJECTIVE IS TO REPRODUCIBLY MEASURE THE LIGHT OUTPUT (POWER) OF THE DEVICE IN A WAY THAT MINIMIZES THE IMPACT OF HEAT GENERATION WITHOUT NECESSITATING THE ATTACHMENT OF A THERMAL MANAGEMENT SYSTEM WHILE CAPTURING AN OUTPUT POWER MEASUREMENT THAT IS REPRESENTATIVE OF CONTINUOUS WAVE OPERATION WITH THERMAL MANAGEMENT.

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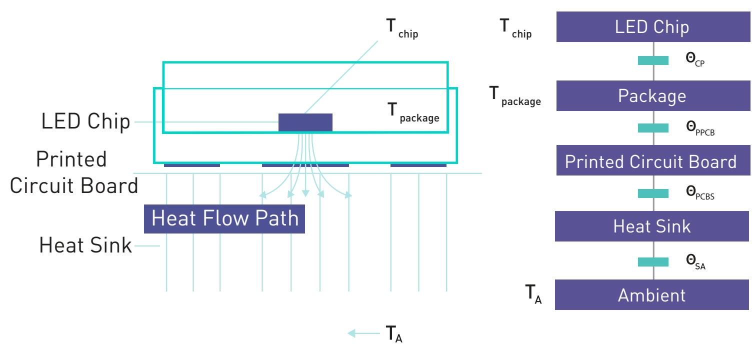
Introduction

Many factors influence the light output and lifetime of LEDs—a primary factor being the operating temperature of the device. When electrical energy is applied to an LED, it's converted into both light and heat. As the heat increases, the LED junction temperature increases ("junction" refers to the p-n junction within the LED die, where the photons are generated and emitted) and as the junction temperature increases, the LED's light output decreases. It's crucial, therefore, that the heat be properly managed.

With visible LEDs, roughly 40-60% of the electrical energy is converted to heat. That number jumps to 90% or more for deep ultraviolet (UVC) LEDs, making thermal management even more important. For example, an energized UVC LED that's not mounted to a heat management system can reach a temperature of 200 °C in less than a second. This concern is amplified by the market drive to decrease LED footprint, resulting in compact products, which limit built-in heat absorption or dissipation design options.

Figure 1 shows a simplified drawing of the thermal path and management system for a UVC LED. (For the purposes of this paper, the temperature of the LED chip and junction are assumed to be the same.)

FIGURE 1



A simplified illustration indicating the Chip Temperature (T_{chip}), Package Temperature ($T_{package}$) and Ambient Temperature (T_a).

UVC LEDs must be mounted to a proper thermal management system to achieve maximum performance. For customers seeking to characterize diodes without soldering them to a thermal management system, Crystal IS recommends a pulse measurement approach that limits heat generation in the device and provides reliable, repeatable output power measurement.

This is the same characterization process Crystal IS and other manufacturers are adopting to measure UVC LED output. We recommend that customers make the following practices part of their own LED quality control and product development processes.

Methodology for Measuring UVC LED Power Output

There is an industry-wide effort to employ reliable standardized measurements to provide customers with a way to compare UVC LEDs offered by different manufacturers—standards that will ensure accurate and repeatable measurements of optical properties.

However, at this point, such standards do not exist and it falls to the individual UVC LED manufacturer to accurately measure and represent the optical properties of their products. LED manufacturers (for both visible and non-visible LEDs) typically measure the LED output with a pulse mode method to minimize the impact of heat during the product measurement process.

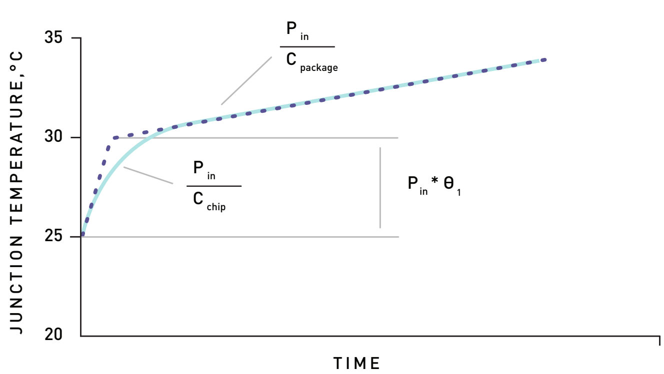
When current is applied to an LED, the chip warms up rapidly. A very simple model (Figure 2) illustrates the temperature rise in a typical Crystal IS Klaran diode as a function of pulse length or duration. The LED chip has a heat capacity of approximately 0.13 mJ/K (which is labeled C_{chip} in Figure 2) and has a high thermal conductivity. Thus, it is reasonable to assume the chip will heat up very quickly and (nearly) uniformly.

Heat is carried away from the chip by the gold bump bonds used to attach the chip to the rest of the LED package. This thermal resistance is labeled θ_1 in Figure 2. Because the thermal resistance within the chip is less than θ_1 and the heat capacity of the chip (C_{chip}) is less that the heat capacity of the package ($C_{package}$), the chip temperature will rise rapidly. This will occur until the temperature difference between the chip and the package is approximately equal to the product of the input power (P_{in}) times the thermal resistance (θ_1)—which is approximately 5 K/W based on measurements made by Crystal IS.

Thus, at a 4 W input (400 mA at 10 V), this temperature difference will be around 20 °C. The characteristic time that it will take to reach this temperature difference is approximately $C_{chip}\theta_1$, which will be less than 1 ms after power is applied to the chip.

Once this initial and rapid rise in temperature occurs, the junction temperature (T_j) will subsequently rise slower as the package heats up. After a few milliseconds, the slope of the temperature rise will approach the power in (P_{in}) divided by ($C_{package}$) and continue to rise until some significant amount of heat can flow into the ambient. For Klaran, $C_{package}$ is approximately 20 mJ/K, so the slope of the temperature rise is approximately (200 K/s) for a 4 W input power as shown in Figure 2.

FIGURE 2



A very simple model for the rise in junction temperature for a typical Crystal IS Klaran diode after power is applied to the device.

As the junction temperature rises, the light output from the device will decrease, thus by maintaining a consistent junction temperature one can achieve predictable light output. The curve illustrated in Figure 2 shows the general behavior of the junction temperature increase over time. After the first few milliseconds of the LED chip being heated, keeping the package temperature cool relies on the ability of heat to flow away from the package to the heat sink. The actual thermal resistance between the package and the thermal management system is determined by quality of the solder to the heat sink and the ability of the heat sink to either absorb energy or radiate it to the environment.

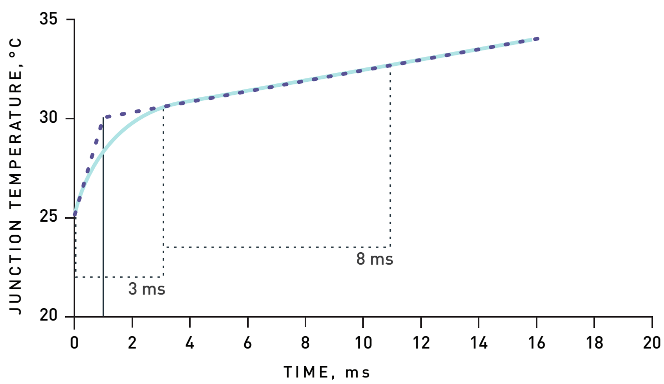
When this behavior occurs without a heat sink, it mimics the behavior of a diode with a heat sink in the first few milliseconds of the LED chip being heated. Therefore, by measuring the output power with a very short pulse, manufacturers can measure diode output without a heat sink and reasonably extrapolate it to a device operated continuously (CW mode) with a heat sink.

For a Klaran diode without a heat sink, the steep rise in temperature occurs in 1 millisecond, followed by a gradual rise of 0.2 °C per millisecond for 4 W input power. This impacts the light emitted from the LED as there is a 0.5% reduction in power for every 1 °C rise in junction temperature of the LED.

When measuring output power, Crystal IS measures the output of the Klaran diodes in pulse mode by capturing the power output during the gradual increase portion of the curve, not in the steep incline of the first millisecond (Figure 3). This allows the temperature difference between the chip and the package to stabilize at approximately the same value it will have between the Klaran device chip and solder pads.

The power measurement is then taken at the shortest time possible—just enough to capture the diode's power output while minimizing the Klaran package's heat induced temperature rise. We measure our devices by waiting 3 ms after the start of the current pulse and then integrate the output for 8 ms, which means we stop integrating 11 ms after the start of the pulse (Figure 3).

FIGURE 3



Crystal IS measures Klaran device power by waiting 3 ms after the start of the current pulse and then integrate the output for 8 ms.

Measuring diode power—the impact of measurement time

The following examples demonstrate how measurement time can impact the power value when thermal management measures are not applied. The examples are based on the properties of Crystal IS Klaran UVC LEDs, without a heat sink and an ambient temperature of 25 °C. The Klaran diode is specified to have a thermal derating of 0.5%/K. That means that the power will be reduced by 5% if the junction temperature is raised by 10 °C.

Example 1: A UVC LED, with a manufacturer-specified power output of 10 mW, is run with an 80 millisecond pulse.

In this scenario the LED output power is measured after 40 ms for 40 ms. Within the first 40 ms the junction temperature will have increased 8 °C (0.2 °C per millisecond). After 80 ms the junction temperature will increase by 16 °C. Thus, the instantaneous power of the diode dropped 4% in the first 40 ms (0.5%/K) and a further 4% in the second 40 ms. This translates to a measured decrease in the power of 6% assuming that measured power is obtained by averaging the power between 40 ms and 80 ms.

In practical terms this is done by integrating the power for 40 ms and dividing the measured energy detected by the integration time of 40 ms. Thus, the measured integrated power of the diode is 9.4 mW (a reduction of 6%).

Example 2: A UVC LED with a manufacturer-specified power output of 10 mW is run with a 1 second pulse.

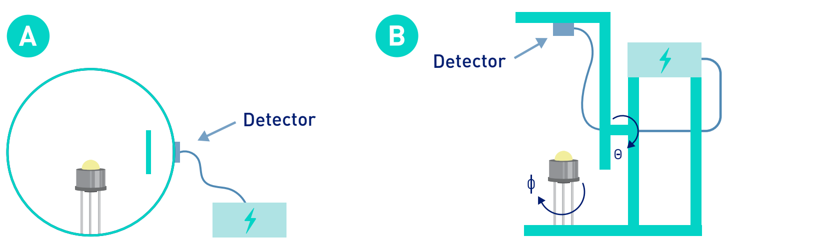
Under this scenario, the output power is measured for 1 second. In that one-second time span there will be a rise in junction temperature of 200 °C (0.2 °C per ms). This translates to a decrease in the power of 100% at the end of 1 second. Thus, average power of the diode over the 1-second pulse will be 5 mW.

In this case it may appear that the diode does not meet the manufacturer's specification. However, by looking at the thermal derating characterization data, we see that the diode has performed as expected.

How UVC LED manufacturers measure power: Typical methodology without standardized processes

There are two ways manufacturers measure the spectral radiant flux (see Appendix A) distribution of a light source: They can use an integrating sphere, which collects all the light from a light source placed inside the sphere; or a goniophotometer, which measures the spectral radiant flux distribution of a light source from many different angles around the source and integrates the results to yield a combined spectral radiant flux distribution for the light source (Figure 4).

FIGURE 4



Typical measurement equipment for optical performance of LEDs—an integrating sphere (A) or a goniometer (V).

At Crystal IS, we measure the output of our products with an integrating sphere. The sphere provides a uniform scattering, or diffusing effect. Light rays incident on any point of the inner surface are, by multiple scattering reflections, distributed equally to all other points. This minimizes the effects of the original direction of light (the radiation pattern).

An integrating sphere can be viewed as a diffuser that preserves power but destroys spatial information. Typically used with some light source and a detector for optical power measurement, it is a standard instrument in photometry and radiometry.

Its advantage over a goniophotometer is that, when measuring the light produced by a source, the total power can be obtained in a single measurement. That's critically important because LEDs can have quite different spatial distributions depending on how they are manufactured and packaged. For instance, the Cyrstal IS Optan LEDs, with a ball lens, have a radiation pattern sharply peaked in the forward direction, while our Klaran LEDs are approximately "Lambertian" in spatial distribution.

In a production or laboratory environment—where LEDs are characterized on a routine basis—the integrating sphere must be calibrated regularly to ensure consistent, accurate measurements. Crystal IS tracks its sphere performance on a weekly basis using special "Monitor LEDs."

In UVC LEDs the typical power output measurement error as recognized by the industry is +/- 10% of the absolute value. If the difference between the measured output and the "golden" recorded performance of the Monitor LEDs falls outside acceptable tolerances (set by Crystal IS' ISO 9001:2008 certified Quality Management System), the integrating sphere is recalibrated using NIST-calibrated deuterium lamps.

How Crystal IS Measures UVC LED Power

UVC LEDs are specified to run at a maximum input power and operate within a pre-determined design temperature range. The maximum input power may be higher if the device is run in pulse mode rather than continuously (i.e., cw). These design specifications are outlined on the diode's product data sheet and manufacturers calibrate their testing equipment to ensure the product shipped to customers meets these specifications.

During testing, customers may periodically see a difference in the measured output compared to the output specified on the data sheet. Most inconsistencies occur when customers test UVC LEDs in a standalone fashion—that is, when the LED is not mounted on a metal-core printed circuit board (PCB), or attached to a heat sink/thermal management system.

To ensure component quality, customer quality control engineers should test/measure an LED like the OEM. In the case of Crystal IS products, that means measuring the diode with an integrating sphere in a pulse mode to ensure the power output meets data sheet specifications.

Business Case:

CONSIDERING POWER FOR A SPECIFIC APPLICATION

Design engineers, need to focus on the power delivered in a system, or the power delivered by a diode for their specific application. Rather than testing in an integrating sphere or a detector, design engineers need to focus on thermal management and how the pulse mode/time on impacts the total power required for measurement or disinfection.

Crystal IS application notes AN002, AN008 and AN011 demonstrate how to optimize designs using UVC LEDs to meet measurement and disinfection objectives. Once the required power and electrical input is identified, design engineers can determine what type of thermal management system is needed to maintain the LED's performance.

By balancing the cost of thermal management system components with the necessary power output, design engineers can create and build systems that meet their performance and cost requirements (Figure 5).

FIGURE 5

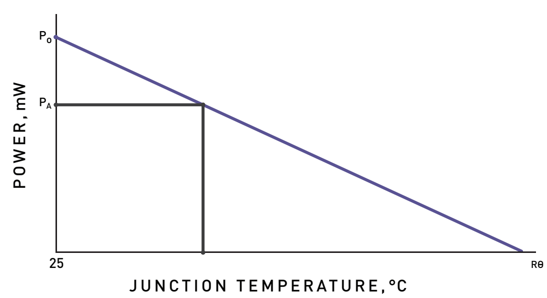


Illustration of how a design engineer can determine the tradeoff of maintaining junction temperature to achieve required UVC output power.

Summary

Many factors influence the light output and lifetime of LEDs, a principal factor being the temperature of the device. The increasingly small footprint of UVC LEDs means that the heat capacity of their packages is very small (approximately 20 mJ/K for a typical Klaran device) and the thermal resistance to the ambient will be very large unless the package is properly soldered to a good heat sink.

When it's necessary to simply measure the output of an individual diode before soldering it to a heat sink, Crystal IS recommends a pulse measurement approach—which reduces heat generation in the device and provides consistent, repeatable output power measurements.

Further, customers seeking to replicate Crystal IS factory measurements should measure and determine the output of our products using an integrating sphere and the pulse schedule outlined in this note.

NOTE: where LEDs are characterized on a routine basis—the integrating sphere must be calibrated on regularly basis (weekly) to ensure consistent, accurate measurements.

APPENDIX A

DEFINITIONS

Energy

Energy is the integral over time of power, and is used for integrating detectors and pulsed sources. Power is used for non-integrating detectors and continuous (in a time sense) sources.

Input electrical power

Power that is presented to the input terminals of a component or device.

Irradiance

Irradiance (a.k.a. flux density) is another SI derived unit and is measured in W/m^2. Irradiance is power per unit area incident from all directions in a hemisphere onto a surface that coincides with the base of that hemisphere. A similar quantity is radiant exitance, which is power per unit area leaving a surface into a hemisphere whose base is that surface. The symbol for irradiance is E and the symbol for radiant exitance is M. Irradiance (or radiant exitance) is the derivative of power with respect to area, dΦ/dA. The integral of irradiance or radiant exitance over area is power.

Light Output (Power)

Power (a.k.a. radiant flux) is the rate of flow (derivative) of energy with respect to time, dQ/dt. The recommended symbol for power is Φ. Power is measured in W or mW.

Spectral power distribution (SPD)

Spectral power distribution—in radiometry, a spectral power distribution (SPD) measurement describes the power per unit area per unit wavelength of an illumination (radiant exitance). More generally, the term spectral power distribution can refer to the concentration, as a function of wavelength, of any radiometric quantity (e.g., radiant energy, radiant flux, radiant intensity, radiance, irradiance, radiant exitance).

Knowledge of the SPD is crucial for optical-sensor system applications. Optical properties such as transmittance, reflectivity, and absorbance as well as the sensor response are typically dependent on the incident wavelength.

Spectral radiant flux

The spectral radiant flux distribution of a light source describes how much radiometric power is emitted per unit of wavelength across the electromagnetic spectrum. Knowing the spectral radiant flux distribution allows the user to obtain other useful optical light source properties, including dominant wavelength, purity, peak wavelength, centroid wavelength, and full width at half maximum (FWHM).

APPENDIX B

General Thermal management principles

A thermal management system that helps control the junction temperature of an LED is the key to achieving reliable test results.

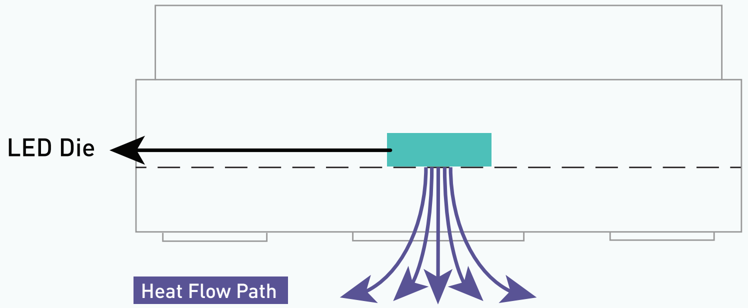
As discussed, the junction temperature increases with the generation of heat. The rate of increase depends on the amount of heat dissipated to the ambient. The heat is transferred away from the junction to the ambient via various elements that make up a thermal management system.

For example, Crystal IS Klaran LEDs generate less than 4 W of heat in addition to UV light, depending on the current within the suggested operating range. Unlike conventional UV light sources, which radiate heat forward, this heat is dissipated through the back end of the LED using or via thermal conductivity

To increase the rate of heat dissipation from the LED's backside, Crystal IS Klaran LEDs employ a special ceramic package with high thermal conductivity. This "heat flow path" is illustrated in Figure A.

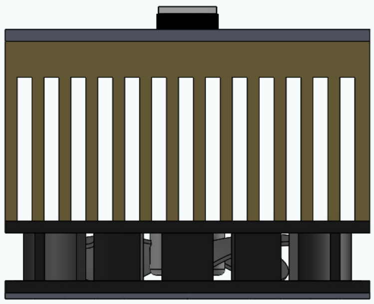
Attaching a heat sink is strongly recommended to facilitate further thermal transfer, as shown in Figure B.

FIGURE A



Schematic of Crystal IS Klaran LED Heat Flow Path.

FIGURE 2



Schematic of Crystal IS Klaran 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 Klaran package.*
- *Heat is then conducted from the thermal and electrical pads through solder to the Printed Circuit Board (PCB).*
- *Heat is then conducted from the PCB to the heat sink, through a thermal interface material, such as thermal paste.*
- *Finally, heat is conducted through the heat sink and transferred to the ambient via air convection around the heat sink.*

For further information, refer to the Crystal IS thermal management notes AN003, AN007 and AN010.

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We invite you to learn more about our UVC LEDs.

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