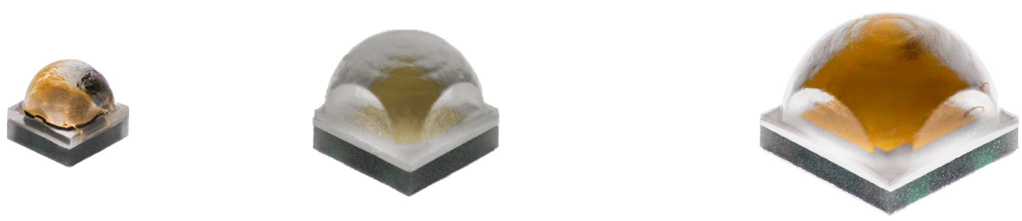
XLamp® HD Discrete LED Design Guide



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Cree LED / 4001 E. Hwy. 54, Suite 2000 / Durham, NC 27709 USA / +1.919.313.5330 / www.cree-led.com

INTRODUCTION

This guide simplifies the high density (HD) discrete luminaire design effort by providing basic information on the requirements to use XLamp® HD discrete LEDs successfully in luminaire designs, with appropriate consideration for mechanical, electrical, thermal and optical design and chemical compatibility.

In this document, the term HD discrete LEDs refers to XLamp XB-H, XP-L and XQ-E LEDs.

XLamp HD discrete LEDs deliver high lumen output and efficacy in single, easy-to-use components. HD discrete LEDs enable lighting manufacturers to quickly add LED products to their product portfolio. With XLamp HD discrete LEDs, lighting manufacturers can have performance, reliability and ease-of-use in a single LED.

This design guide explains how HD discrete LEDs and assemblies containing these LEDs should be handled during manufacturing. Please read this entire document to understand how to properly design with and handle HD discrete LEDs.

OPTICAL CONTROL FACTOR

Optical control is a key concept for directional lighting applications such as retail display, roadway and indoor spotlights. In general, the term optical control means either concentrating lumens onto a target or across a long distance, or spreading lumens over a target plane or along a roadway surface.

Optical control factor (OCF) is a new metric for LEDs that measures the effectiveness of an LED package in the context of directional lighting. OCF takes the concept of luminous emittance (sometimes referred to as lumen density) and applies it in a practical way to LED lighting so the relationship between light output and size is understandable. OCF is based on the simple concept that a smaller light source is easier (and cheaper) to work with than a larger one, and is calculated as the ratio of lumens over a scaled area, measured in mm^2.

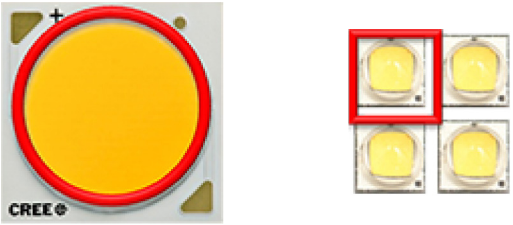
$$\text{Optical Control Factor} = \text{Lumens/Scaled Area } (mm^2) = \text{Performance/Size}$$

Equation 1: OCF calculation

- As shown in Figure 1, for a chip-on-board (COB) array, the scaled area is the area of the light emitting surface (LES), i.e., ∏ * radius2 for a circle.
- For a discrete LED, the scaled area is determined by adding the LED pitch to each side of the package and calculating the area. For example, the scaled area for Cree LED's XP package at 3.45 mm square with a 0.5 mm pitch is (3.45+0.5) * (3.45+0.5) = 15.6 mm2. The 0.5 mm is added to each side to account for the pitch between LEDs that is necessary when placing several LEDs near each other in an array configuration.

COB Arrays
Scaled area = LES area

Discrete Arrays
Scaled area* = package area + pitch



* takes into account the spacing between LEDs needed when put in an array

Figure 1: OCF

A higher optical control factor at the LED level (in other words, an LED with more light in a given space) opens up a new spectrum of system design options that lead to higher performance and lower cost. On one end of the spectrum, a design of a certain size can now create much more light than it did before. On the other end, a design of a certain light output can now be made much smaller than it was before.

To provide a sense of the small size of the HD discrete LEDs, Figure 2 shows an XQ-E LED next to a common wooden pencil.

Figure 2: XQ-E LED is small

Cree LED's HD class of LEDs, including the HD discrete LEDs covered by this design guide, deliver the industry's highest optical control factor to greatly reduce the size and cost of the entire LED lighting system: optics, drivers and thermal management.

IMPORTANT DOCUMENTS

The following documents provide information on the HD discrete LEDs.

Table 1: HD discrete LED documents

Data Sheet	Soldering & Handling Document
Product Specifications, Order Code & Bin Code Information	**Soldering Guidelines**
XB-H	XB-H
XP-L	XP-L
XQ-E	XQ-E

A summary of the LM-80 test results with reported TM-21 lifetimes is available on the Cree LED website. Contact your Cree LED sales representative to request an LM-80 report for an HD discrete LED. Contact your Cree LED Field Applications Engineer (FAE) to request TM-21 projections.

ABOUT THIS DESIGN GUIDE

This design guide provides critical design guidelines, principles and best practices for successfully integrating the XLamp HD discrete LEDs into new and existing luminaire designs.

- For additional product information or samples, please contact your Cree LED sales representative.
- For technical information and support, please e-mail us at CS@cree-led.com.

Consult the appropriate HD discrete family soldering and handling document for additional information on the proper procedures to solder and handle HD discrete LEDs.

THANK YOU

Thank you for choosing to incorporate XLamp HD discrete LEDs into your luminaire designs.

HD DISCRETE PRODUCT CAUTIONS

- XLamp HD discrete LEDs must be electrically connected to an unenergized driver before applying power. “Hot plugging,” i.e., making a connection from a HD discrete LED to an energized driver, might cause irreparable damage and could void the product warranty.
- All installations and applications of HD discrete-based luminaires are subject to the electrical, construction and building codes in effect in the final installation location. Installation by professionals having experience in the area of electrical lighting and formal inspection by the Authorities Having Jurisdiction (AHJ) is strongly recommended.
- Thermal characteristics of HD discrete LEDs are affected by the luminaire and by the conditions in which the luminaire is installed. All final luminaire products should be evaluated in actual worst case installation conditions. Thermal limits of the HD discrete LED must be maintained for warranty consideration.
- ⚠ HD discrete LED surfaces may be hot during operation. Take care during handling to avoid burns.
- ⚠ Do not look directly at an energized HD discrete LED without proper eye safety precautions or diffusive shielding.

Failure to follow the design guidelines in this document may void the product warranty and may present a hazard to property or personnel.

STORAGE & HANDLING

Store XLamp HD discrete LEDs in their original packaging to minimize potential for unintended contact and contamination.

HD discrete LEDs must be handled with proper electrostatic discharge (ESD) handling protocols. Remove HD discrete LEDs from their package at an ESD-safe workstation and use appropriate handling protocols and precautions when handling and soldering connections to an HD discrete LED.

- Handle HD discrete LEDs in a clean environment, i.e., free from particulates, oil residues, etc.
- Do not touch the lens of an HD discrete LED with tools (other than a pick & place nozzle) or fingers.
- Do not allow foreign material to touch the lens of an HD discrete LED.
- Do not assemble HD discrete LED-based luminaires in an environment in which foreign material can come in contact with the LED.

- Material should be cleaned from an HD discrete LED by gently blowing the material off the LED with clean dry air (CDA) or by wiping the LED with a lint-free swab dipped in isopropyl alcohol (IPA).

MECHANICAL CONSIDERATIONS

Typical Assembly

HD discrete LEDs are generally reflow soldered to a metal-core printed-circuit board (MCPCB) which is then attached to a heat sink. Discrete wires are used to deliver power to the LED. A thermal interface material (TIM) must be applied between the MCPCB and the heat sink to properly maintain thermal performance.

Handling/Assembly

Figure 3 shows proper and improper handling of HD discrete LEDs with tweezers. Wear clean, lint-free gloves when handling HD discrete LEDs. Doing so helps to keep the lens clean. Do not touch the lens with fingers, gloved fingers or tools other than a pick & place nozzle. Do not push on the lens. Avoid putting excessive mechanical stress on the LED lens.

Figure 3: Correct and incorrect handling of HD discrete LED with tweezers

Use tweezers to grasp HD discrete LEDs at the base. Do not apply more than 1000 g of shear force onto the lens of XB-H and XP-L LEDs or more than 600 g of shear force onto the lens of XQ-E LEDs. Excessive force on the lens could damage the LED.

Pick & Place

Whenever possible, Cree LED recommends the use of a pick & place tool to remove HD discrete LEDs from the factory tape & reel packaging. Consult the soldering and handling document for each HD discrete LED for information on a pick & place nozzle that fits the individual LED.

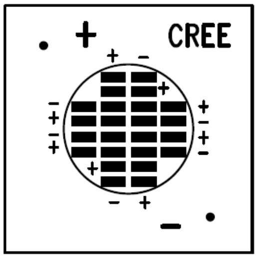
HD discrete LEDs are picked out of the carrier tape by contact with the dome and the pick & place operation imposes no board layout limitations. As shown in their respective soldering & handling documents, these LEDs are picked by a nozzle that is smaller than the LED. If a pick & place nozzle is used that has an outer diameter greater than the width of the HD discrete LED's dome, the LEDs can be located no closer than half the difference between the nozzle diameter and the LED width.

Board Layout Guidelines

Table 2 shows some typical tolerances for a single-layer MCPCB, an example of which is shown on the right of the table. Tolerances vary for different PCB manufacturers and lighting manufacturers are advised to consult their PCB manufacturer for its exact specifications.

Table 2: Typical MCPCB tolerances

Copper Thickness	Minimum Line Spacing
1 oz.	0.18 mm
2 oz.	0.23 mm
3 oz.	0.30 mm
4 oz.	0.36 mm
5 oz.	0.51 mm
6 oz.	0.61 mm



Stencil Printing Guidelines

A guideline for the stencil opening when soldering HD discrete LEDs is that the area ratio (AR), the stencil aperture opening divided by the area of the aperture side walls, should be 0.66 or greater. Figure 4 shows the area ratio calculation.

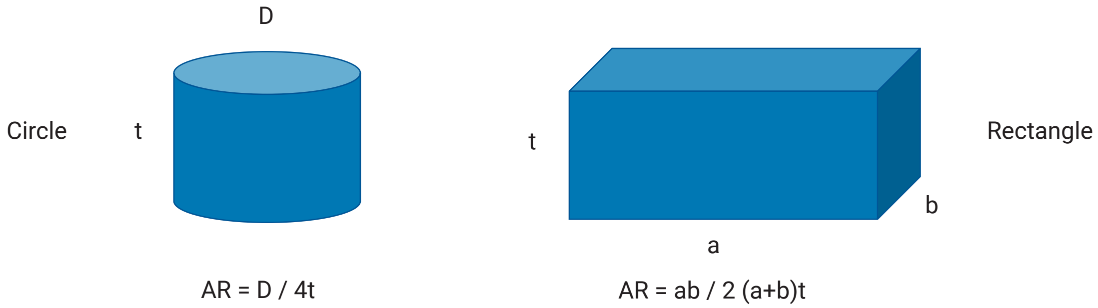


Figure 4: Area ratio calculation

Solder-Joint Reliability

The reliability of the solder joint between the LED and the PCB is critical in ensuring the overall reliability of an LED lighting fixture. To avoid premature solder-joint failures, always use the recommended solder-pad layout, solder paste and solder-reflow profile for HD discrete LEDs that can be found in each LED's soldering and handling document. Consult the Solder-Joint Reliability application note for additional information.

Avoid Mechanical Damage

At no time should anything (tools other than a pick & place nozzle, optics, hands) come in contact with the lens of a HD discrete LED. Such contact can damage the LED.

Take care to avoid the following situations in which a printed-circuit board (PCB) can bend or flex, resulting in cracks in an LED chip attached to it, subsequently leading to an LED failure.

1. Over-tightening or over-torquing screws attaching an LED board to the heat sink assembly during LED luminaire manufacturing.
2. An uneven, warped or convex PCB or heat sink surface.
3. PCB flexing or bending during the LED board assembly reflow soldering process.
4. PCB flexing or bending when a punching tool or a manual process separates LED boards after the reflow and/or test process.

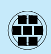
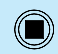
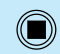
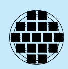
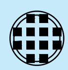
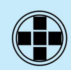
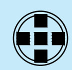
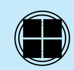
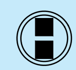
5. Operator mishandling the LED board assembly.

Additional information on PCB bending and flexing can be found in the PCB Bending and Flexing application note on the Cree LED website.

Layout/Packing Recommendation

Table 3 shows the number of HD discrete LEDs that will fit in the circle of the dam that surrounds the LES of the XLamp CXA LEDs. At a 0.5 mm pitch, there is approximately a 3% optical loss in these arrangements; at a 1 mm pitch, the optical loss is approximately 1%.

Table 3: CXA/HD discrete board layout equivalencies

CXA LED			XQ-E		XB-H		XP-L	
	LES (mm)	Diameter (mm)	0.5 mm Pitch 3 % Optical Loss	1.0 mm Pitch 1 % Optical Loss	0.5 mm Pitch 3 % Optical Loss	1.0 mm Pitch 1 % Optical Loss	0.5 mm Pitch 3 % Optical Loss	1.0 mm Pitch 1 % Optical Loss
CXA13XX	6	7.5	7	7	4	4	1*	1*
								
CXA15XX	9	10.5	17	12	5	5	4	2
								
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			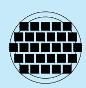	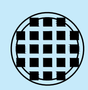	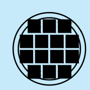	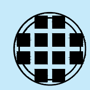	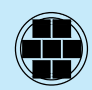	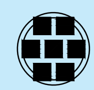
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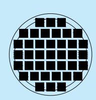
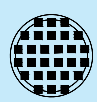
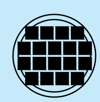
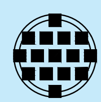
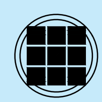
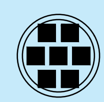
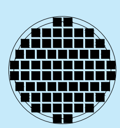
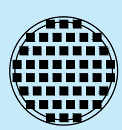
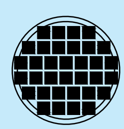
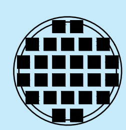
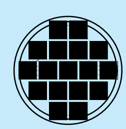
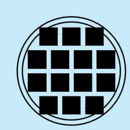
								
CXA25XX	19	21	70	48	34	26	17	14
								
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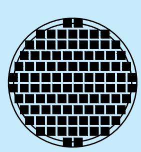
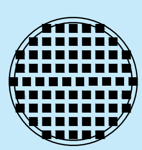
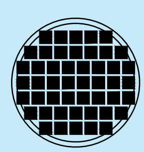
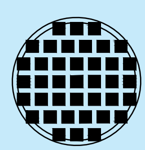
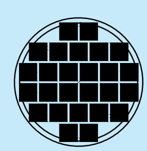
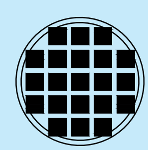
								
CXA35XX	30	32	170	118	82	65	44	35

* There is no optical loss due to the proximity of other LEDs when only one HD discrete LED is on a PCB.

Shadowing

Prevent shadowing/light blockage by keeping luminaire components out of the light path of the HD discrete LED. Figure 5 shows how components too near an LED can block light from exiting the lamp or luminaire, resulting in less light output than expected. Figure 6 shows components far enough away from the LED that light is not obstructed.

Figure 5: Red checkered pattern indicates light blocked by components near the LED

Figure 6: Light not blocked by components near the LED

THERMAL CONSIDERATIONS

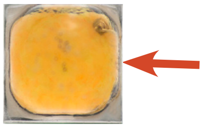
Heat & Lifetime

HD discrete LEDs are designed to perform over a range of operating temperatures. As with all LEDs, their expected lifetimes depend on their operating temperature. When designing a luminaire that incorporates HD discrete LEDs, careful consideration must be taken to ensure a sufficient thermal path to ambient is provided.

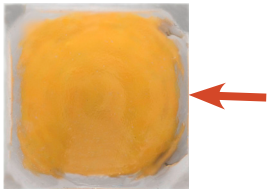
Solder-Point Temperature Measurement Point

Verification of a proper thermal path is done on the finished luminaire in the intended application by attaching a thermocouple at the solder-point temperature (Tsp) measurement point indicated in Figure 7 for each HD discrete LED.

XQ-E



XB-H



XP-L

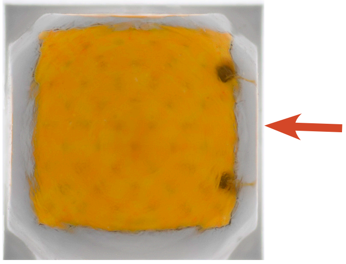


Figure 7: Tsp measurement point for HD discrete LEDs

When multiple HD discrete LEDs are tightly spaced, it may not be possible to attach a thermocouple near the center LED, which will be the hottest. As shown in Figure 8, the most likely scenario in this case is to measure an exterior solder-point temperature (Tsp) to get an estimate of the thermal performance.

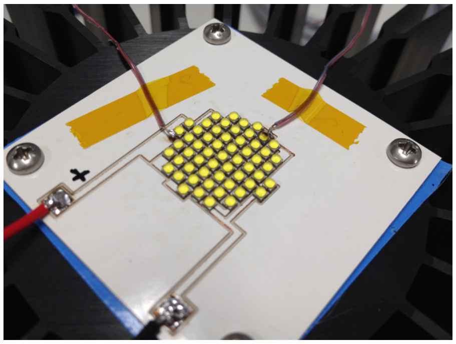


Figure 8: Thermocouple attachment

There will be a thermal gradient from the center Tsp to an edge Tsp. Depending on the thermal design, power level, LED spacing and the LED component used, this varies in magnitude and can be significant.

Thermal imaging, as shown in Figure 9, may help visualize and quantify the thermal gradient. In the image in Figure 9, the edge Tsp is 91 °C and the center Tsp is 106 °C. Cree LED recommends using a thermocouple to measure the edge Tsp and correlating the infrared (IR) image to the known measured point, since IR imaging is relative to the emissivity setting of the camera setup.

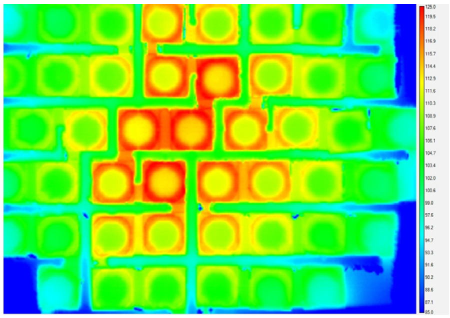


Figure 9: Thermal image

Ambient Temperature Measurement

The ambient temperature of the test environment must be monitored and recorded with the required data during a temperature test. The preferred ambient temperature measurement apparatus is described in UL1598-2008 Rev January 11, 2010, Section 19.5. The intent of this requirement is to ensure that the temperature monitored does not fluctuate. Note that bare thermocouple wires in open air is not an acceptable method of recording the ambient temperature.

Thermocouple Attachment

Attach a thermocouple to the Tsp point indicated in Figure 7. The attachment method described in UL1598-2008 Rev January 11, 2010, Section 19.7.4 is preferred; using silver-filled thermal epoxy is an acceptable alternative. Ensuring that the tip of the thermocouple properly contacts the LED at the Tsp location and that the attachment method does not add thermal resistance to the test is critical to correct and acceptable testing. A thin (>30 AWG, 0.05 mm^2) Type T thermocouple can be easily and quickly soldered directly to the Tsp point. Type J and K thermocouples are also very popular, however, they cannot be soldered and must be attached with an adhesive.

Do not place the thermocouple tip directly on the lens. A temperature measured at the lens will be inaccurate and taking a measurement this way can damage the LED.

> **Note** - Quick-drying adhesives and other cyanoacrylate-based products are known to be destructive, over time, to the components and adhesives used in solid-state lighting products. The use of cyanoacrylate-based products is at the discretion of the testing organization. Cyanoacrylate adhesives should not be used in any luminaire design or for any long-term testing.

Luminaire Case Temperature Measurement

Once the thermocouple is properly attached at the Tsp location, assemble the HD discrete LED into the luminaire. The luminaire must then be tested in its intended environment or that environment which will result in the highest recorded temperature. Take care during assembly to ensure that the thermocouple remains properly attached and that the thermocouple wire is not in the light emission path from the LED. One precaution to ensure the thermocouple remains attached to the LED is to use tape to provide strain relief. Energize the luminaire and allow the assembly to reach thermal equilibrium. Thermal stabilization may require several hours, depending on the mechanical design. Once thermal equilibrium is achieved, record the room ambient and case temperatures. Measure the HD discrete LED case temperature at the designated case temperature measurement point, adjacent to the anode. This measurement point is shown in Figure 7.

For additional information on Tsp measurement, refer to the Solder-Point Temperature Measurement application note.

Heat & Light Output

HD discrete LEDs are rated for their nominal lumen output at a junction temperature of 85 °C. Temperature change from this point inversely affects the lumen output of the LED.

The Relative Flux vs. Current and Relative Flux vs. Junction Temperature sections of each HD discrete LED's data sheet give the maximum current and junction temperature conditions under which the LED operates successfully. At operating temperatures above a certain point, different for different LEDs, the current level must be de-rated, i.e., lowered, to allow the LED to operate at peak effectiveness.

Board Design Guidelines

Using an MCPCB is required when HD discrete LEDs are tightly packed on a circuit board. An FR4 board will not dissipate the heat from the LEDs well enough to realize optimal performance. Thick copper is best, to help spread and even out the heat. Cree LED recommends a high-performance dielectric to minimize the impedance and conduct the heat out of the MCPCB.

Low Temperature Operation

The minimum operating temperature of HD discrete LEDs is -40 °C. To maximize HD discrete LED lifetime, Cree LED recommends avoiding applications where the lamps are cycled on and off more than 10,000 cycles at temperatures below 0 °C.

Heat Sink Flatness and Cleanliness

The use of an appropriate heat sink will improve thermal performance in LED-based luminaire designs and help maximize the LED lifetime. A heat dissipation path is required; HD discrete LEDs should not be operated without a properly tested heat dissipation path. Luminaire designs with a direct thermal path to ambient are desired and will provide the best results. Attaching an MCPCB with an HD discrete LED to a clean, flat, smooth heat sink is required for good thermal transfer. The use of a TIM between the MCPCB and the heat sink is required.

A quick way to check the flatness of a heat sink is to use a razorblade as a straight edge and touch the edge to the heat sink. Look for any gaps between the razorblade edge and heat sink. Figure 10 shows the procedure.

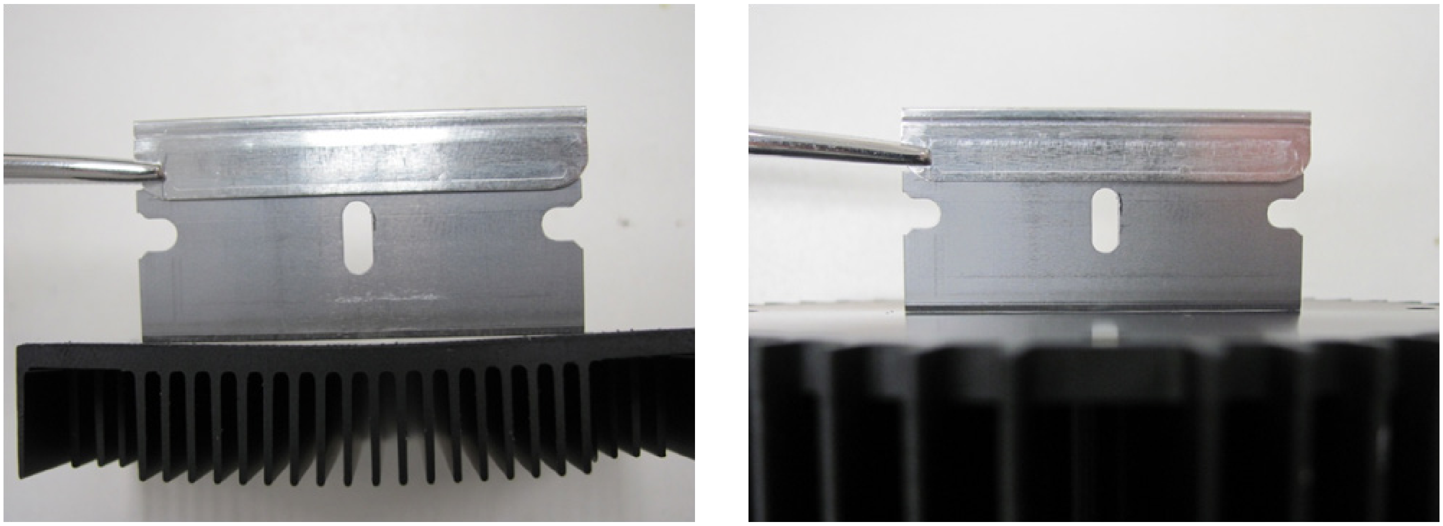


Figure 10: Checking heat sink flatness, left: a gap below the razorblade edge, right: no gap below the razorblade edge

Cree LED recommends that the heat sink used with an HD discrete LED has an average roughness value (Ra) less than 10 µm. Figure 11 shows typical roughness values resulting from various manufacturing processes.[1] Once a heat sink is manufactured, finishing the heat sink by polishing or milling, for example, is important to achieve a smooth, flat surface. For comparison purposes, Table 4 contains size measurements for several grit sizes in several standards systems.[2]

1 E. Paul DeGarmo, J.T. Black and Ronald A. Kohser, *DeGarmo's Materials and Processes in Manufacturing*, Ninth Edition, John Wiley & Sons, Inc. (2003)
2 Orivs, Kenneth H. and Grissino-Mayer, Henri D., *Standardizing the Reporting of Abrasive Papers Used to Surface Tree-Ring Samples*, Tree-Ring Bulletin, Volume 58 (2002)

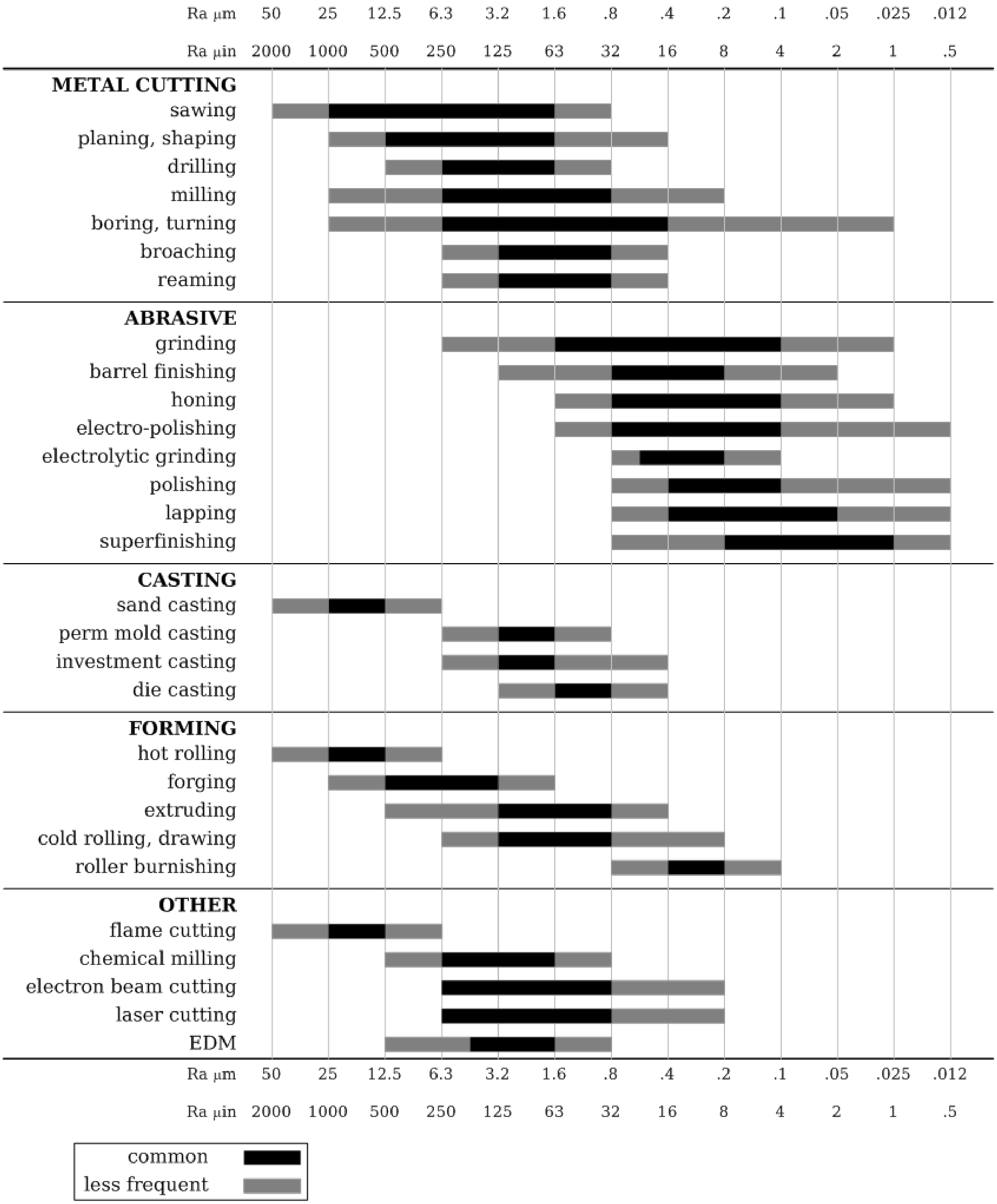


Figure 11: Roughness values from various manufacturing processes

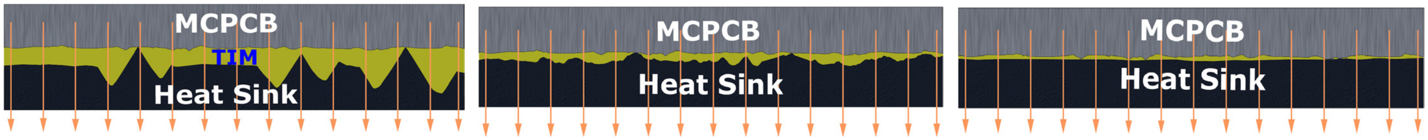
Table 4: Sandpaper grit sizes

International		US		Europe		Japan		China	
ISO (86)	µm	ANSI (74)	µm	FEPA (93)	µm	JIS (87)	µm	GB2478 (96)	µm
P100	125-150	100	125-149	P100	162	100	125-150	100	125-150
P220	53-75	220	53-74	P220	68	220	53-75	220	53-75
P400	33.5-36.5	320	32.5-36.0	P400	33.5-36.5	400	32.0-36.0	W40	28.0-40.0
P1000	17.3-19.3	500	16.7-19.7	P1000	17.3-19.3	800	17.0-19.0	W20	14.0-20.0
P2500	7.9-9.1	1000	6.8-9.3	P2500	7.9-8.9	2000	7.8-9.2	W10	7.0-10.0

Thermal Interface Materials

A good thermal connection between the MCPCB and the heat sink is critical for successful designs. A TIM is required for optimal performance. Air is a thermal insulator so a TIM is needed to fill any voids between the MCPCB and the heat sink, as shown in Figure 12. Without a TIM, there are a limited number of spots for heat transfer from the HD discrete LED through the MCPCB to the heat sink to occur. With the voids filled by a TIM, heat flows much more freely from an HD discrete LED to the heat sink.

Interstitial air between HD discrete LED and rough (left), semi-rough (center) and smooth (right) heat sink



TIM between HD discrete LED and rough (left), semi-rough (center) and smooth (right) heat sink

Figure 12: TIM fills the voids between HD discrete LED and heat sink

Make sure the TIM does not come into contact with the LED lens. There is a risk of failure of the HD discrete LED if this occurs.

The thermal resistance calculation is as shown in Equation 2. Cree LED's Thermal Management application note provides additional information.

$$\Theta_{TIM} = \frac{L}{k\ A}$$

Equation 2: TIM thermal resistance calculation

where:

Θ_{TIM} is the thermal resistance of the TIM
L is the thickness of the TIM (m)
k is the thermal conductivity of the TIM (W/m K)
A is the contact area (m^2)

Table 5 contains examples of recommended TIMs from several suppliers. This is not an all-inclusive list of available TIMs. The presence of a TIM in the table is not a guarantee or warranty of the TIM's performance in any particular installation. The absence of a TIM from the table does not necessarily imply non-performance. Contact your Cree LED Field Applications Engineer or the TIM supplier for help with specific case-by-case recommendations.

Table 5: TIM examples

Supplier	Thermal Grease	Thermal Pad	Thermal Phase-Change	Thermal Tape	Thermal Adhesive	Thermal Gap Filler
3M	TCG-2035 Grease	5590H		8810	TC-2810 Epoxy	
Bergquist	TIC1000A	Q-Pad® II	Hi-Flow 565UT	Bond-Ply® 800	Liqui-Bond® SA 3505	Gap Filler 4000
Dow Corning	TC-5622 TC-5629	TC-4025			SE 4485	TC-4025
GrafTech		HITHERM 1205/1210				
Henkel	LOCTITE® TG100		LOCTITE® PSX-D	Hysol® CF3350	LOCTITE® TCP-3003	
Lord	TC-426				MD-140SP	

Thermal Simulations

Cree LED simulated the thermal effects of tight LED spacing. Figure 13 shows the thermal simulations of example 4 x 4 MCPCB layouts of HD discrete LEDs at various pitches. Figure 13 also shows a pictorial representation of the pitch measurement, represented as d.

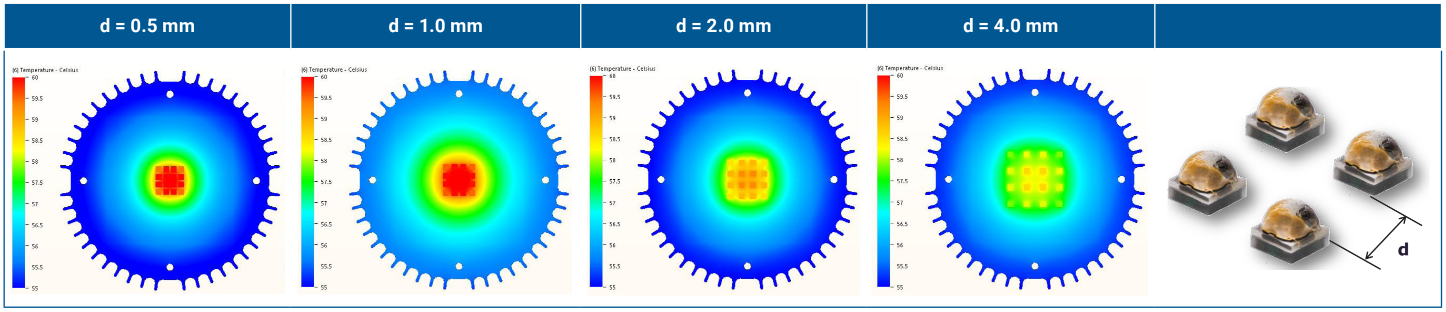


Figure 13: HD discrete thermal simulations

Figure 14 shows the maximum Tsp at various pitches relative to the Tsp at 4-mm spacing.

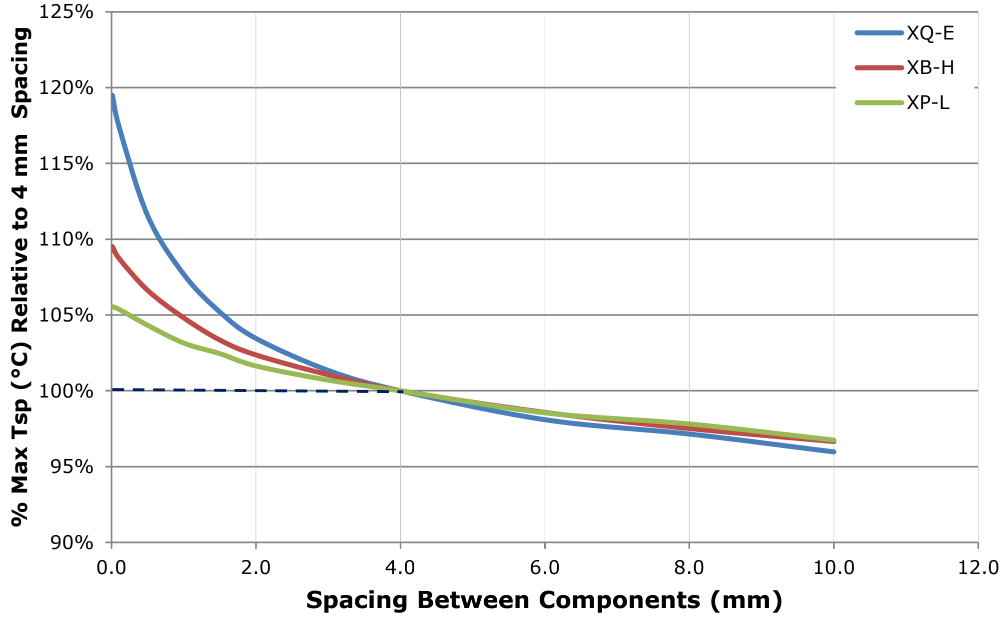


Figure 14: Relative Tsp at various pitches

Thermal Loss

Depending on the system design, LED component and power level, a slight thermally induced optical loss will occur when HD discrete LEDs are closely spaced. A thermally induced optical loss of up to 5% for 0.5 mm spacing was measured for the example 4x4 MCPCB configurations, relative to a wider 4 mm spacing. For this test, all components were operated at 1 W per component (16 W for the total system) attached to a Cree LED heat sink designed for the LMH2 LED module and the steady-state lumen output was compared to the instant-on lumen output to measure the thermal effect.

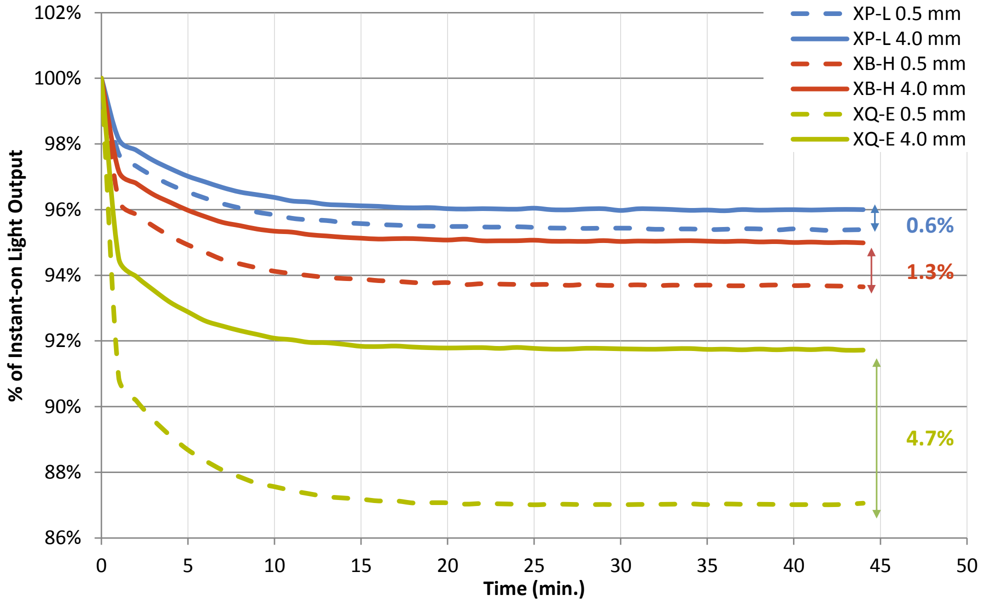


Figure 15: Thermally induced optical loss

he MCPCBs were thermally imaged to validate the thermal loss seen in the previous measurements. Figure 16 shows the XQ-E images.

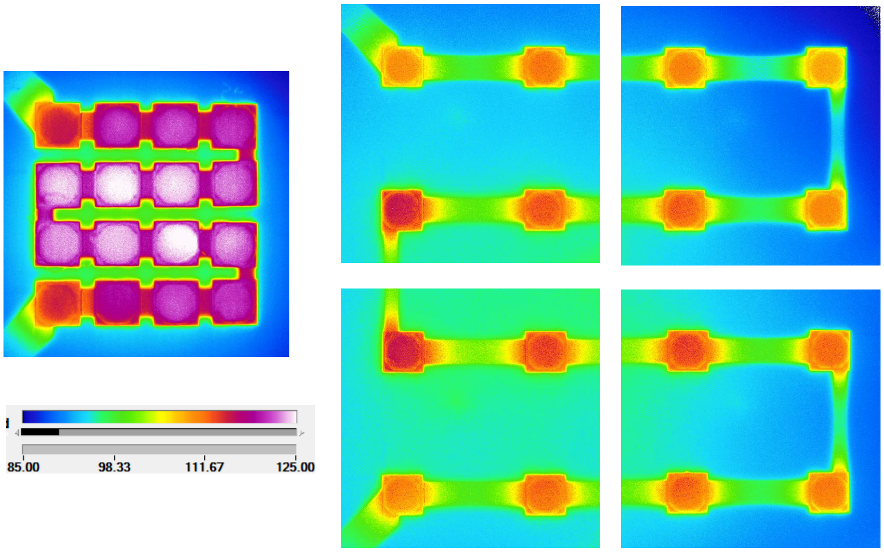


Figure 16: XQ-E thermal images - left: image at 0.5 mm spacing, right: images at 4.0 mm spacing

Cree LED used the Tsp measurements from the thermal images and Cree LED's Product Characterization Tool (PCT)[3] to calculate the anticipated optical loss due to thermal effects. Table 6 shows these results. The data validate the optical measurements.

Table 6: Optical loss due to thermal effects

LED	Spacing	Maximum Tsp (°C)	Average Tsp (°C)	% Lumens vs. 4-mm Spacing
XQ-E	4.0 mm	109.1	106.1	
	0.5 mm	123.0	119.7	96.0%
XB-H	4.0 mm	96.0	94.6	
	0.5 mm	104.4	102.8	97.9%
XP-L	4.0 mm	94.0	92.9	
	0.5 mm	97.5	95.8	99.4%

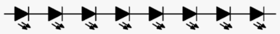
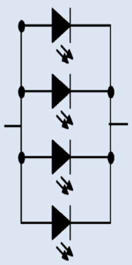
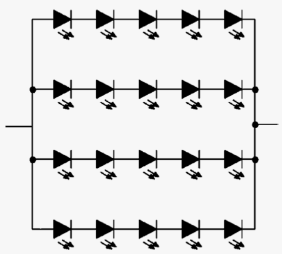
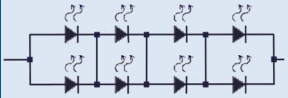
3 Contact a Cree LED Field Application Enineer (FAE) for PCT information.

ELECTRICAL CONSIDERATIONS

Circuit Design

Table 7 gives advantages and disadvantages for several LED circuit layouts.

Table 7: Circuit layout advantages and disadvantages

Circuit Layout		Advantages	Disadvantages
Series array		• All LEDs at same current and same relative luminous flux.	• One LED failing to open circuit causes entire string to cease light output. • Long series strings may exceed Class 2 voltage levels for safety.
Parallel array		• Many LEDs powered from just one voltage drop. • One LED failing open will not affect any other LEDs.	• Potential for current hogging. This type of parallel array is not recommended. • One LED failing to short circuit will cause the entire array to cease light output
Series-parallel array		• Relationship between number of LEDs and voltage is configurable. • One LED failing to open circuit affects only one LED string, not all LEDs.	• Current balancing may be an issue. • Potential for thermal runaway. • A shorted LED exacerbates current hogging, leading to cascading failures.
Cross-link or matrix		• One LED failing to open circuit affects only one LED string, not all LEDs.	• In such a configuration every single pair of LEDs will have some variation in current and therefore also in lumen output.

Electrical Overstress/Hot-Plugging

Electrical overstress (EOS) occurs when an LED is exposed to any current exceeding the maximum current specified in the LED's data sheet. The effect on the LED varies in severity depending on the duration and amplitude of the exposure, however, any single EOS event has the potential to damage an LED. This damage can result in an immediate failure or in a gradual failure many hours after the event. A number of EOS protection devices are available to absorb electrical energy that would otherwise be dissipated in the LED or to block current from flowing in the reverse direction if the load is connected backwards. A good way to avoid EOS is to use a good quality driver.

Cree LED recommends adding EOS protection to luminaires that do not include an on-board power supply. The use of a simple, low-cost protection circuit can dramatically reduce the rate of returns from lighting customers. EOS, and hot-plugging, i.e., making a connection from a HD discrete LED to an energized driver, in particular, is the most common problem Cree LED has observed in returned LEDs. In addition, Cree LED recommends extensive testing of LED luminaires that includes surge immunity, power cycling and electromagnetic compliance.

Some steps to prevent EOS events at a work station or assembly line include:

- Connecting a metal table to a common ground point

- Anti-static wrist straps for personnel
- ESD table mats
- ESD floor mats

Additional information on EOS can be found in the EOS and Pulsed Over-Current application notes.

CHEMICAL COMPATIBILITY

Consult Cree LED's Chemical Compatibility application note for lists of recommended chemicals, conformal coatings and harmful chemicals and materials to be used or avoided in LED manufacturing activities. Consult your regional Cree LED Field Applications Engineer for assistance in determining the compatibility of materials considered for use in a particular application.

Avoid getting material, e.g., thermal grease, thermal adhesive or solder, on the lens of an HD discrete LED. Material contacting the lens will compromise the lumen output and can negatively react with the materials in the HD discrete LED to shorten the component's lifetime.

Hermetically Sealing Luminaires

For proper LED operation and to avoid potential lumen depreciation and/or color shift, LEDs of all types must operate in an environment that contains oxygen. Simply allowing the LEDs to ventilate to air is sufficient; no extraordinary measures are required. Hermetically sealing LEDs in an enclosed space is not recommended.

OPTICAL CONSIDERATIONS

Optical Design

All HD discrete LEDs have a Lambertian light distribution. The optical center and mechanical center are same on HD discrete LEDs. The small light emitting surface (LES) allows for easier optical control, particularly for narrow beam applications. The small LES and high luminous flux of the HD discrete LEDs provide unrivaled lumen density for spotlight applications.

Cree LED provides optical source models and ray files for HD discrete LEDs on the Cree LED website. All rays are originated on a plane. As shown in Figure 17, the Z = 0 point is on top of the LED substrate.

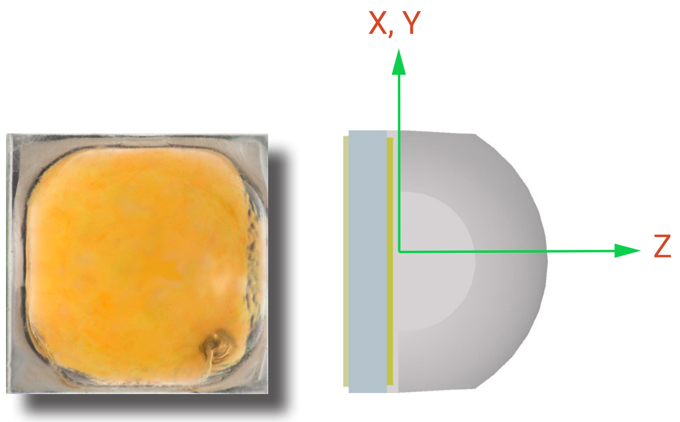


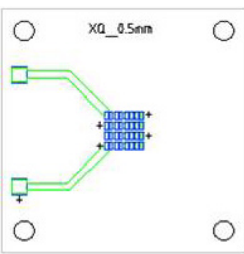
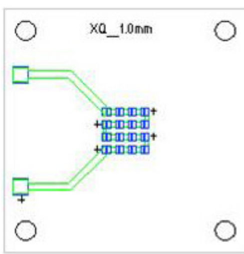
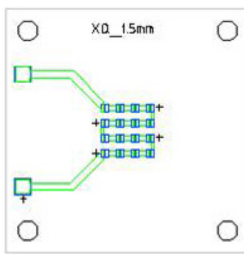
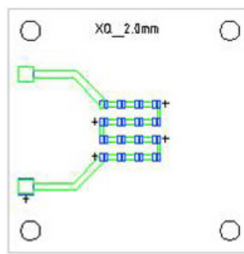
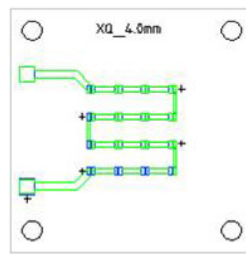
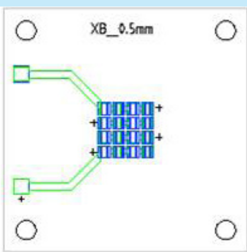
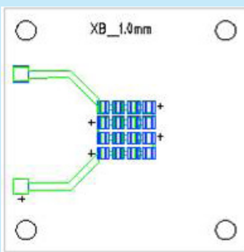
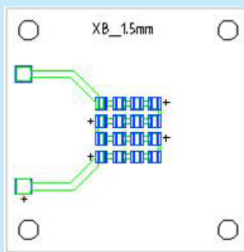
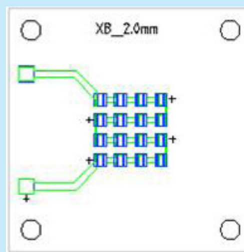
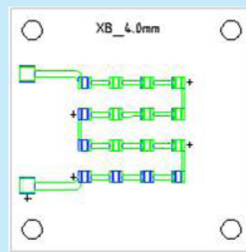
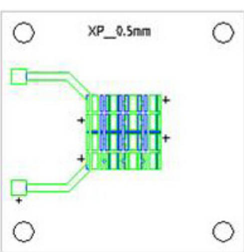
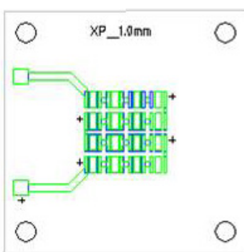
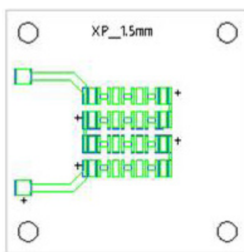
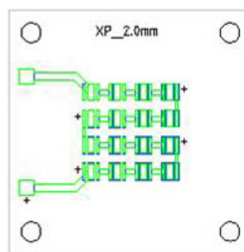
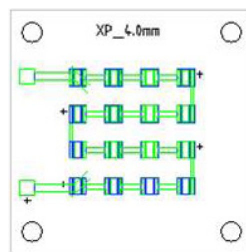
Figure 17: X, Y and Z axes in HD discrete LED ray files

When applying secondary optics to HD discrete LEDs, make sure the optics opening matches the lens. All light coming from the HD discrete LED needs to be collected by optics. Be sure there are no gaps between the optic and the lens that allow light to not be collected by the optics and that the optic does not obstruct the lens.

Optical Loss from LED Pitch

Closely arranging LEDs in a luminaire can result in optical loss, i.e., optical crosstalk. To quantify this optical loss for HD discrete LEDs, Cree LED soldered sixteen HD discrete LEDs in a 4 x 4 arrangement on a 50 mm x 50 mm MCPCB with various LED spacings: 0.5 mm, 1 mm, 1.5 mm, 2 mm, and 4 mm, as shown in Table 8.

Table 8: HD discrete optical density test arrangements

LED	Pitch				
	0.5 mm	1 mm	1.5 mm	2 mm	4 mm
XQ-E					
XB-H					
XP-L					

Cree LED used instant-on measurements to determine each arrangement's luminous flux and compared it to the luminous flux of sixteen individual LEDs. The test showed that there is some optical crosstalk with HD discrete LEDs in these arrangements. The resulting optical loss increases as the LED spacing decreases and the loss varies from 1.5% to 3%. The results for the different HD discrete LEDs are similar but slightly different due to size and aspect ratio, i.e., the chip size compared to the dome size compared to the package's vertical wall. Figure 18 shows the results.

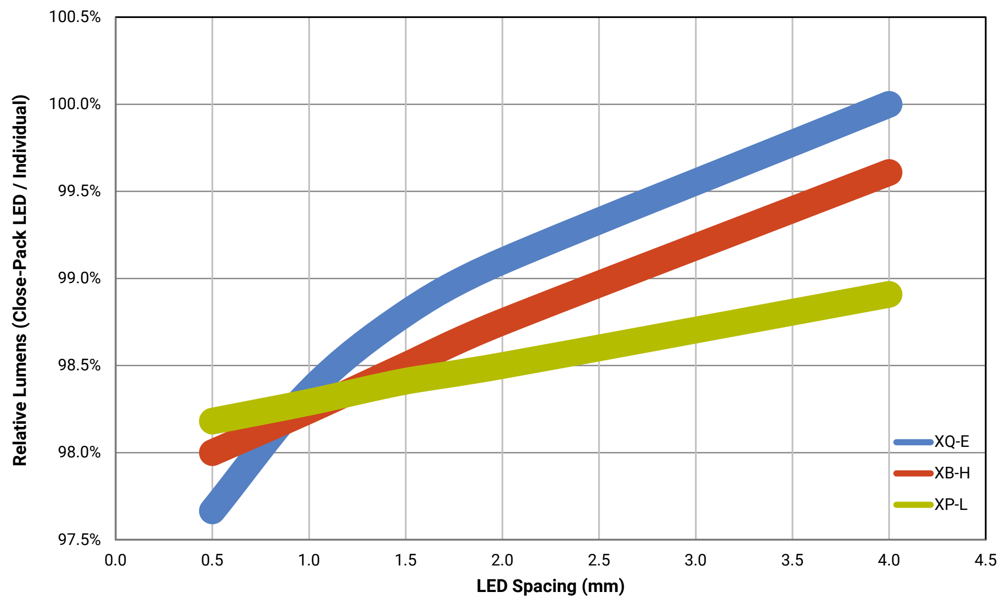


Figure 18: HD discrete optical density test results

Compatibility with Existing Single-LED Optics

The XQ-E LED has a similar chip and optical source size as the XP-E2 LED. The XB-H LED has a similar chip and optical source size as the XP-G2 LED. The XP-L LED has a similar chip and optical source size as the XM-L2 LED. The HD discrete LEDs are smaller but the optical source size remains the same. Based on Cree LED's testing and simulation, most existing XP-E optics work with XQ-E LEDs and provide performance similar to the XP-E LED. Additionally, XP-G optics work with XB-H LEDs and XM-L optics work with XP-L LEDs.

Figure 19 shows how HD discrete LEDs provide similar optical performance as larger XLamp LEDs while using the same footprint as other members of the LED's family.

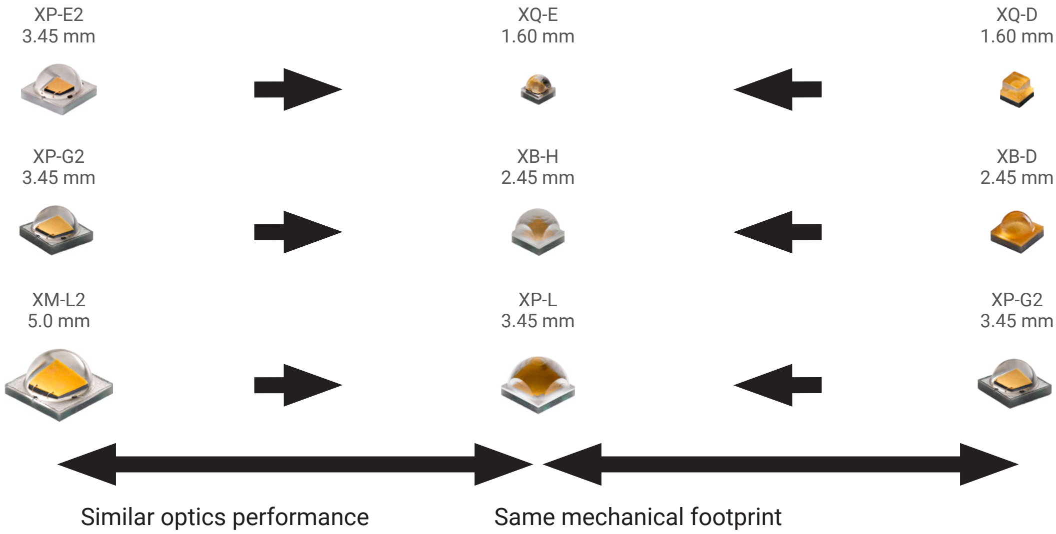


Figure 19: HD discrete comparison with single LEDs

Figure 20 shows that the illumination from the HD discrete LEDs is nearly identical to the illumination from the LEDs having the same chip.

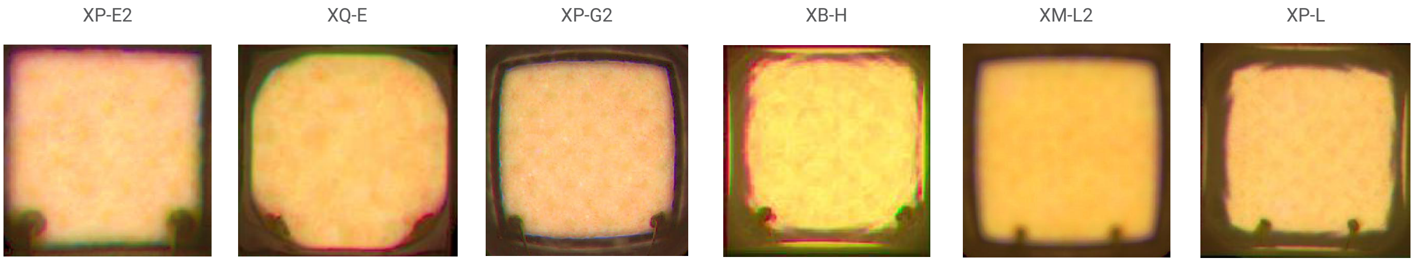


Figure 20: HD discrete illumination comparison

Table 9 shows the results of optical simulation of the XQ-E and XP-E2 LEDs with two standard optics. The XQ-E LED results are a close match for the XP-E2 LED results.

Table 9: XQ-E vs. XP-E2 optical simulation

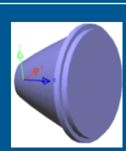
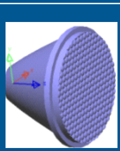
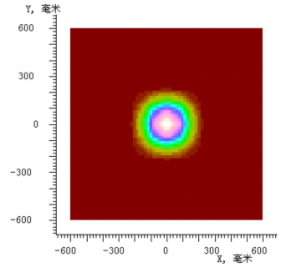
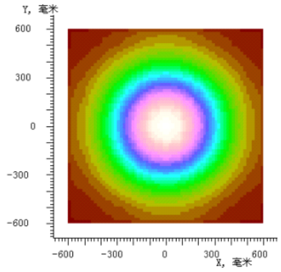
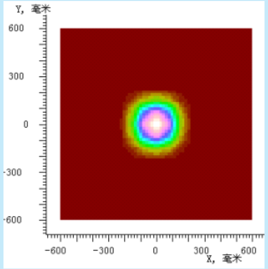
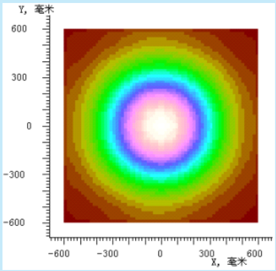
		TIR Lens	TIR Lens (Micro Lenses)
			
Beam angle (FWHM)	XP-E2	8.8°	33.8°
	XQ-E	8.2°	32.6°
cd/lm	XP-E2	32.1	2.1
	XQ-E	34.8	2.3
Beam Pattern at 1 Meter	XP-E2		
	XQ-E		

Table 10 shows the results of optical simulation of the XB-H and XP-G2 LEDs with two standard optics. The XB-H LED results are a close match for the XP-G2 LED results.

Table 10: XB-H vs. XP-G2 optical simulation

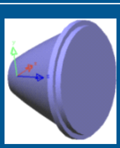
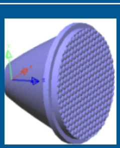
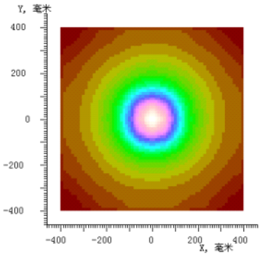
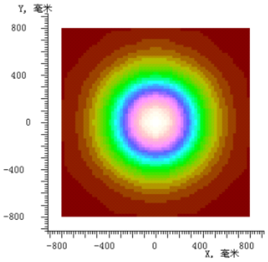
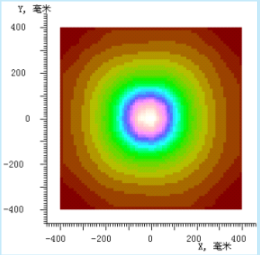
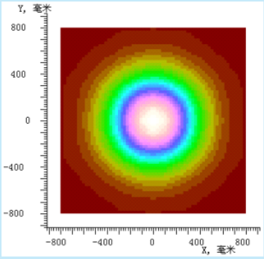
		TIR Lens	TIR Lens (Micro Lenses)
			
Beam angle (FWHM)	XP-G2	12.6°	34.5°
	XB-H	12.5°	33.7°
cd/lm	XP-G2	18.0	2.0
	XB-H	17.7	2.1
Beam Pattern at 1 Meter	XP-G2		
	XB-H		

Table 11 shows the results of optical simulation of the XP-L and XM-L2 LEDs with two standard optics. The XP-L LED results are a close match for the XM-L2 LED results.

Table 11: XP-L vs. XM-L2 optical simulation

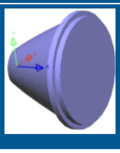
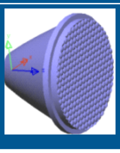
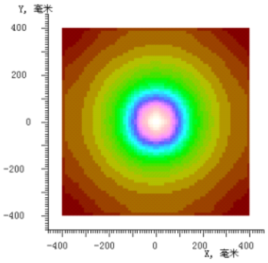
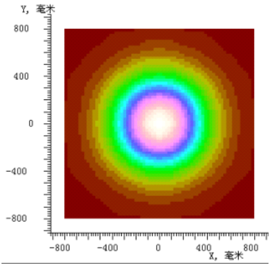
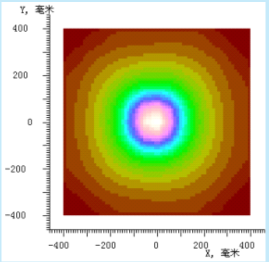
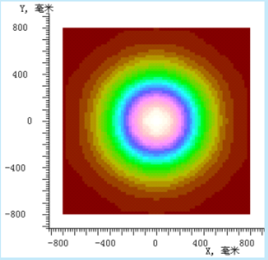
		TIR Lens	TIR Lens (Micro Lenses)
			
Beam angle (FWHM)	XM-L2	17.6°	35.8°
	XP-L	17.2°	35.6°
cd/lm	XM-L2	8.5	1.9
	XP-L	8.9	1.9
Beam Pattern at 1 Meter	XM-L2		
	XP-L		

Table 12 shows that HD discrete LEDs and LEDs having the same chip produce nearly identical illumination when matched with the same optic. The measured data presented in this table verifies the simulated data.

Table 12: HD discrete optics comparison

LED	Optic	Illumination	
XP-E2	LEDiL Leila		10° beam
XQ-E			9° beam
XP-G2	Ledlink LL01CR-AY10		6.7° beam 18.8 cd/lm
XB-H			6.3° beam 24.1 cd/lm
XM-L2	Ledlink LL01CR-AY10		9.0° beam 13.7 cd/lm
XP-L			8.5° beam 16.4 cd/lm

Compatibility with Existing Multiple-LED/Array Optics

Table 13 shows the results of simulating the illumination of several HD discrete LED combinations compared to a CXA LED having the same LES. The reflector used in the simulations was computer generated.

Table 13: Simulated multiple HD discrete illumination comparison

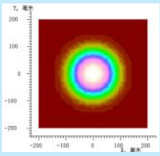
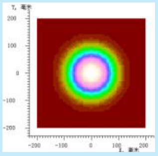
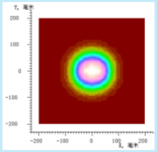
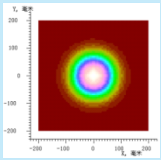
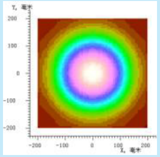
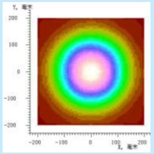
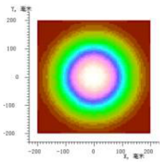
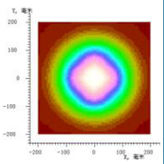
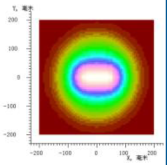
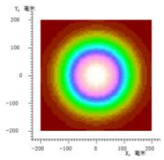
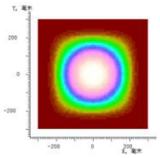
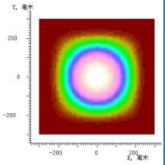
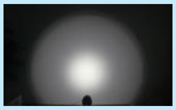
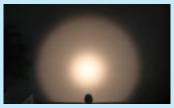
		12 XQ-E LEDs	5 XB-H LEDs	2 XP-L LEDs	CXA1512 LED	56 XQ-E LEDs	CXA2520 LED
Reflector 1 (120x60 mm)	LES (mm)	9	9	9	9	19	19
	Beam Angle (FWHM)	6.6°	6.6°	5.8° x 6.1°	6.7°	14.4°	13.2°
	cd/lm	23.1	23.9	35	26	7.8	10.4
	Beam at 1 meter						
Reflector 2 (100x50 mm)	Beam Angle (FWHM)	13.6°	13.7°	8.5° x 11.8°	12.2°	21.5°	19.6°
	cd/lm	8.5	9	14.3	11.2	4.1	5.1
	Beam at 1 meter						

Table 14 shows the illumination provided when various numbers of HD discrete LEDs are used with commercially available reflectors designed for use with CXA LEDs. The HD discrete LED results are very similar to the CXA results.

Table 14: HD discrete LEDs with CXA reflectors

LED	LES (mm)	Reflector	Beam Angle	cd/lm	Beam Pattern
12 XQ-E	9	Nata 2972-E (75 mm + 43 mm) with Lumigear connector	9.6°	11.3	
5 XB-H	9		9.4°	11.7	
2 XP-L	9		8.5°	14.3	
CXA1520	9		10°	11.8	
12 XQ-E	9	Nata 2973-E (75 mm + 43 mm) with Lumigear connector	22.7°	3.5	
5 XB-H	9		23°	3.4	
2 XP-L	9		21.3°	4.0	
CXA1520	9		22.8°	3.6	

Color Mixing

Due to their small size, the HD discrete LEDs lend themselves very well to color mixing.

HD Discrete Lens Material Considerations

Polymers, i.e., plastics and polymethyl methacrylate (PMMA), and glass are the most common materials used for optical lenses. Although glass typically has better optical properties than plastic, glass is used less frequently because it is heavier, more expensive and more fragile than plastic. The light absorption, reflection and transmission properties of plastics can vary considerably, even within the same class of material, e.g., polycarbonate. Cree LED recommends the use of optical grade plastics for lenses used with HD discrete LEDs to ensure good optical efficiency and long-term reliability. The use of non-optical grade plastics is to be avoided. This includes materials used as a luminous opening, i.e., a window, in a luminaire. The flammability rating of a polymer material should also be taken into consideration when designing and specifying optical components. UL 94, the Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances Testing, can be helpful in providing guidance.

HD discrete LEDs transmit no significant IR light, but, as do all high-powered light sources, do transmit significant photonic energy that, if absorbed by the lens material, can cause the material to heat up. The focusing effect of the lens material can cause the lens to reach a temperature higher than the Tsp of the HD discrete LED producing the light.

HD Discrete LEDs and Silicone

All LED components should be designed into a lighting application that allows the LEDs to ventilate. Silicone is a gas-permeable polymer material that is commonly used as an encapsulant and primary optic in LED packaging and can absorb volatile organic compounds (VOCs) during operation of the LED. VOCs, in the presence of thermal and photonic energy, may cause charring near the phosphor layer, changes in chromaticity, or a reduction in light quality and intensity of the LED. Silicone optics are often molded into various shapes and sizes utilizing light and/or heat to cure the polymer. LED sources produce light and heat, so both these characteristics can contribute to further curing of the silicone while the LED device is operating.

Outgassing of VOCs and advancement of the polymer cure must be considered during the design stages of an LED luminaire. Ventilation of the LED is recommended for all LED-based luminaire designs, including those utilizing HD discrete LEDs.

Optical Design Resources

Cree LED works with all major LED optical companies around the world to offer different types of optics for HD discrete LEDs.

HD DISCRETE LED HOW-TO

Contact a Cree LED Field Application Engineer for assistance in combining HD discrete LEDs with the other components of a lighting system.

SAFETY & COMPLIANCE

As a matter of course, HD discrete LEDs are submitted for safety and compliance testing to standards such as European Union (EU) Registration, Evaluation, Authorisation and Restriction of Chemicals (REACh) and restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) and such organizations as UL.

HD discrete LEDs that have completed UL testing have a Level 4 enclosure consideration. The LED package or a portion thereof has been investigated as a fire and electrical enclosure per ANSI/UL 8750 so a luminaire based on a HD discrete LED does not need to cover the LED. Level 4 HD discrete LEDs are recognized to be able to operate in damp environments and with non-isolated or isolated LED drivers. Information on UL certification of HD discrete LEDs is available on the UL website. Contact your Cree LED sales representative for the UL Conditions of Acceptability (COA) document for a HD discrete LED.

SUMMARY

Observe the following practices to maximize the performance of HD discrete LEDs.

- Work with HD discrete LEDs in a clean environment, free from any foreign material that could come into contact with and damage the LED.
- Do not touch the lens of an HD discrete LED.
- Wear clean, lint-free gloves when handling HD discrete LEDs.
- Apply a TIM, preferably thermal grease or thermal pad, between the MCPCB and the heat sink.
- Use optical grade plastics for lenses used with HD discrete LEDs.
- Operate an HD discrete LED within its operating limits, as shown in the LED's data sheet, to maximize light output and LED lifetime.