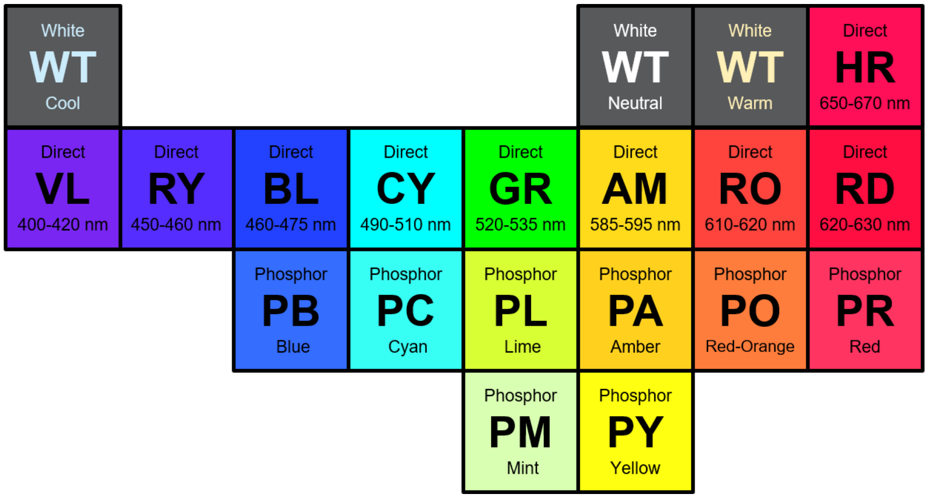
XLamp® Element G (XE-G) LED Design Guide



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INTRODUCTION

The XLamp® Element G (XE-G) LED is a new package design for Cree LED that is optimized to enable maximum light output and optical performance with new levels of precision and control. XE-G LEDs provide next-level performance in color mixing applications, with unmatched output and efficiency for LEDs of this size.

This design guide provides technical guidance on how to best unlock the potential of the XLamp XE-G LED family for all applications.

OVERVIEW OF BASIC XE-G LED ARRAY CONFIGURATIONS

4-LED Pinwheel

In a 4-LED configuration where achieving the smallest and most uniform light surface is important, Cree LED recommends using the pinwheel design shown below using the industry standard 200-µm component spacing. Cree LED has found the pinwheel configuration to have small thermal advantages over other 2x2 configurations.

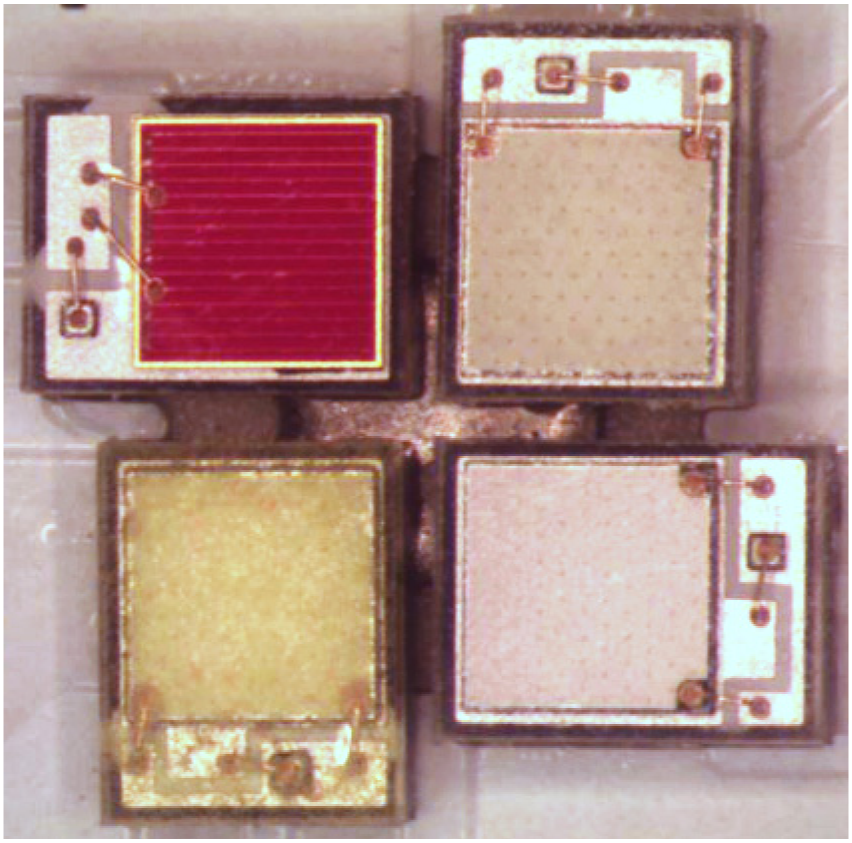

Figure 1: XE-G RGBW array with average gap between LEDs of 200 µm

Linear 2xN array

The asymmetric footprint of XE-G LEDs works well in tightly packed 2xN linear arrays to allow for more than 4 LEDs to be used in a tightly spaced configuration.

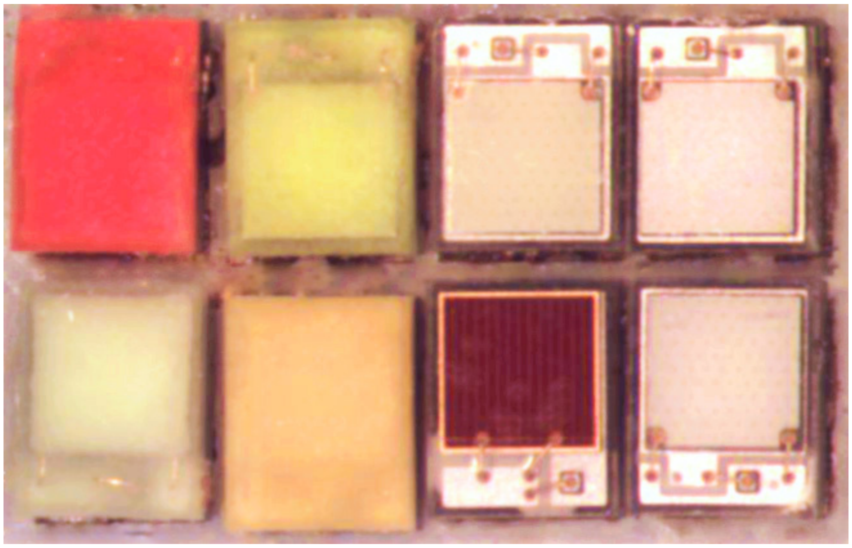

Figure 2: A 4x2 array of XE-G LEDs with average spacing of 200 µm. Note that the blue and cyan LEDs (right side) are kept far from the LEDs with heavy phosphor coverage to reduce unintended phosphor excitation and improve blue saturation.

XE-G LED “0-µm” Component Spacing

Cree LED has developed a patented PCB layout and reflow process to achieve a component-to-component spacing of less than 50 µm using XE-G LEDs and standard pick and place equipment normally capable of only 200-µm spacing. Contact your Cree LED sales representative for more process details.

This ultra-compact array is designed to a 0-µm spacing and referred to as “0 µm” throughout this document. However, Cree LED’s average measured spacing of this design is closer to 40 µm. Advantages and disadvantages of the 0-µm spacing will be discussed later.

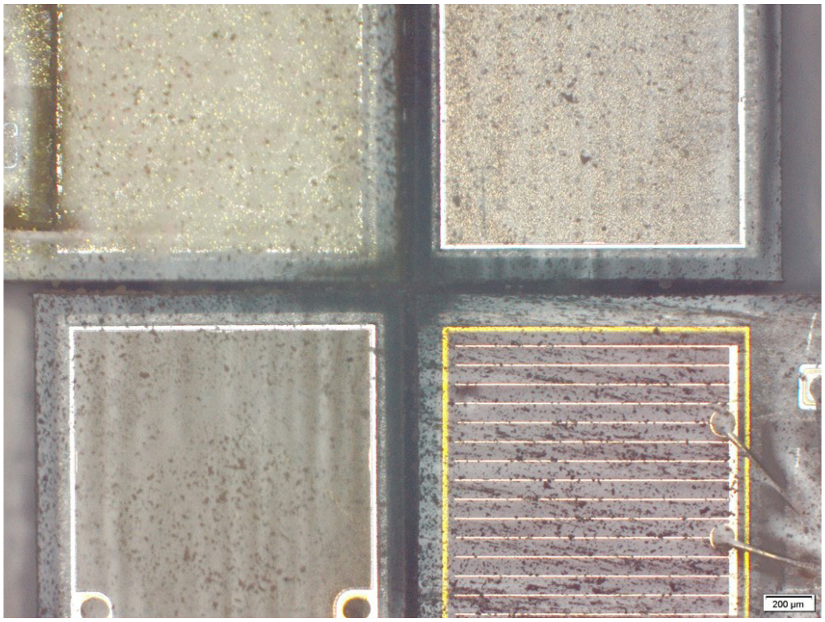

Figure 3: XE-G 4-LED pinwheel array with designed 0-µm spacing. Actual spacing is about 50 µm, as shown by the scale bar in the lower right. This array was created using standard pick and place equipment normally capable of a minimum 200-µm spacing.

Considerations for Optimal Arrangement of Color LEDs for Color Mixing

When choosing how to arrange LEDs in a color-mixing application, Cree LED has two recommendations:

1. Avoid positioning colors with high short-wavelength content (Violet, Royal Blue, Blue or PC Blue) near components with heavy phosphor coatings (e.g., PC Lime, PC Yellow, PC Amber, PC Red Orange or PC Red). The light emitted from the short-wavelength colors can excite the phosphor in the neighboring components and cause a loss of blue saturation or unintended optical artifacts.
2. When mixing arrays of more than 4 colors to generate white light, position components in pairs that are on opposite sides of the black-body line. This will balance the hues going through the color-mixing optic to avoid asymmetric color. For example, Cyan and Red could be paired, or Green and Royal Blue.

OPTICAL DESIGN

LED Chip Spacing & Optical Mixing

XLamp XE-G LEDs offer the industry's smallest die-to-die spacing from mixing individual LEDs, delivering category-leading color mixing and optical control. The LED chip edge-to-edge spacing for various LED components is shown in the table below:

LED	Component Spacing	LED Chip Edge-to-Edge Spacing
XLamp XQ-E High Intensity LED	200 µm	800 µm
Competitor LED (200-µm reflector edge)	200 µm	600 µm
XLamp XE-G LED	200 µm	400 µm
XLamp XE-G LED	"0 µm"	250 µm
XLamp XM-L Color Gen 2 LED	Single component	100 µm

The package design of XLamp XE-G LEDs enables the smallest possible LED chip edge-to-edge spacing when using multiple individual LEDs in an array configuration.

Peak Intensity Displacement of Each Color in the Array

When cycling between LEDs in an array, it is important that the peak illuminance does not shift by large distances over the illuminated surface. The industry-leading die-to-die spacing of XE-G LEDs minimizes this distance and maximizes optical control. The peak illuminance of each RGBW color in a 2x2 array was projected on a screen at 1 meter in the LEDiL Gabriella Spot "S" and Medium "M" optics. The peak intensity position was calculated by fitting a 90% density ellipse to the most intense 50% of pixels in the projection, and then tabulating the coordinates of the ellipse centers. Several duplicate arrays were tested in both 200-µm spacing and "0-µm" spacing, shown below.

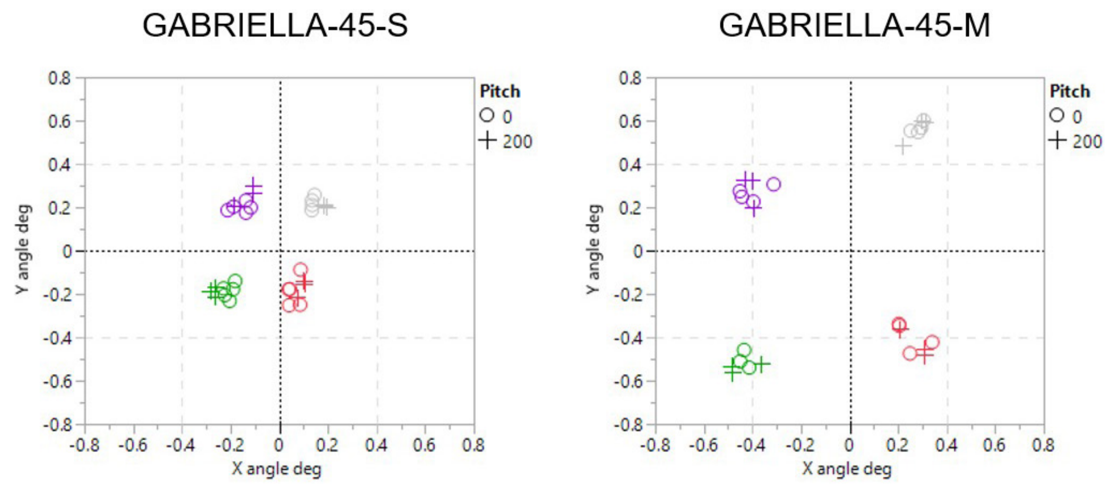

Figure 4: Location of peak intensity of each color in the array, shown as displacement from center in degrees. The Spot optic had an average of 0.2° displacement per color and the Medium optic had an average of 0.4° displacement per color. Very little difference was observed between 200-µm spacing and the "0-µm" spacing.

The results of the peak displacement show consistent optical performance, even when the spacing between LEDs is varied. Rotational skew and positional offsets up to 50 µm were included in this data set to gauge how placement accuracy affected beam control and only insignificant shifts were observed.

This means that an application using the Spot optic with a 10-meter throw would only see a 3.5-cm shift in the peak intensity of each color on the illuminated surface. The tight beam control of these arrays in these two optics demonstrate how well-suited XE-G LED arrays are to color-changing architectural and entertainment spot and feature lighting.

Spot Size in XE-G 4-LED RGBW Pinwheel Array

The size of the projected beam is just as important as the beam placement. The figure below plots the 50% intensity (light red) and 10% intensity (blue) contour lines of an XE-G LED RGBW pinwheel array with 200-µm spacing.

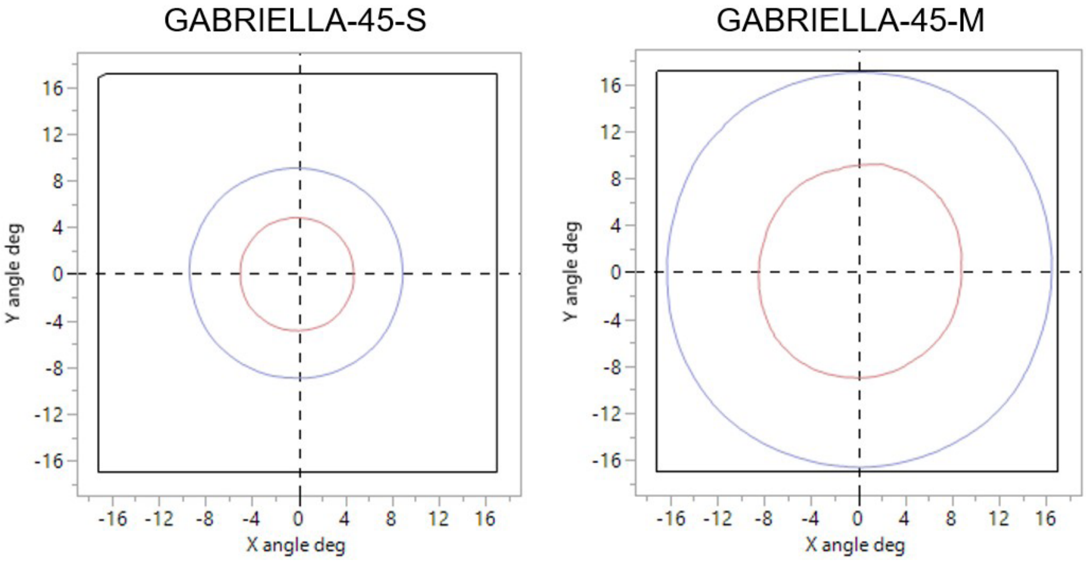

Figure 5: 50% intensity (light red) and 10% intensity (blue) contour curves for an XE-G RGBW pinwheel array with 200-µm spacing in the Gabriella-45-S optic (left) and Gabriella-45-M optic (right) projected onto a flat surface. The Spot optic gives a roughly 9° beam angle and 19° field angle, while the Medium optic gives a roughly 17° beam angle and 32° field angle.

In a 10-meter throw application, the spot optic would give a 3-meter-wide beam as defined by the line of 10% max intensity. In a 2-meter throw application, the medium optic would give a 1.2-meter-wide beam by the same definition.

Cree LED also explored the effects of array spacing on view angle in these 2x2 RGBW groupings. In the Spot optic, the smaller spacing resulted in a ~0.5° narrower view angle, coinciding with higher peak candela. In the Medium optic, Cree LED did not observe a difference between the two spacings.

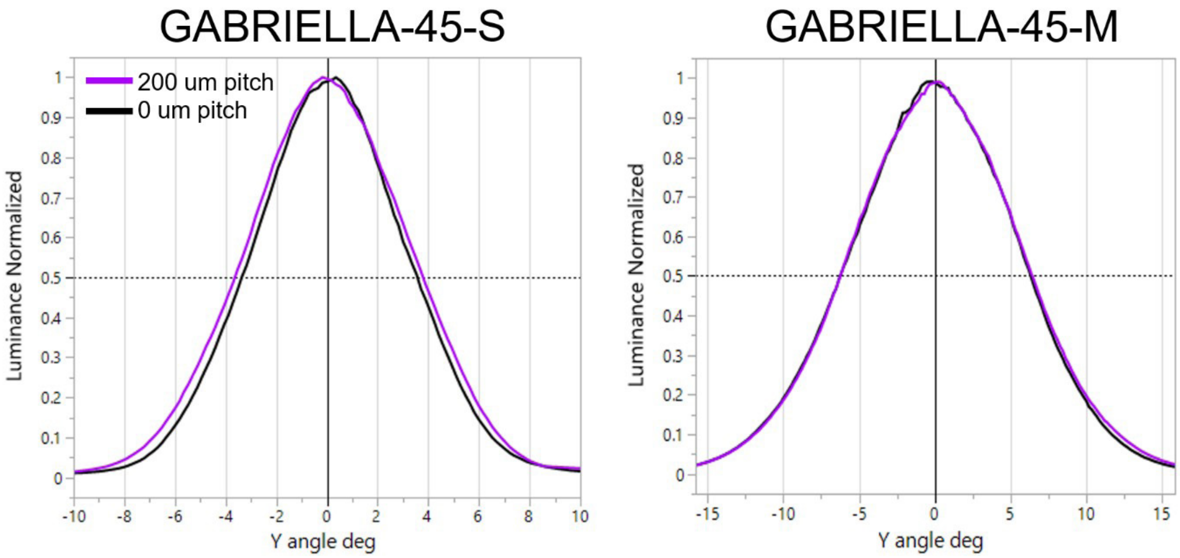

Figure 6: Effects of array spacing on view angle

Color Shift and Optical Losses of Close-Packed White Arrays

When LEDs are tightly packed in an array, nearest-neighbor optical and thermal interactions may cause color shifts between the factory-binned values and the measured values of the final array. Below is an example of the LED array color shift with “0-µm” spacing (50 µm actual) using neutral white 4000 K 90 CRI XE-G LEDs at 1 A and 3 A current per LED.

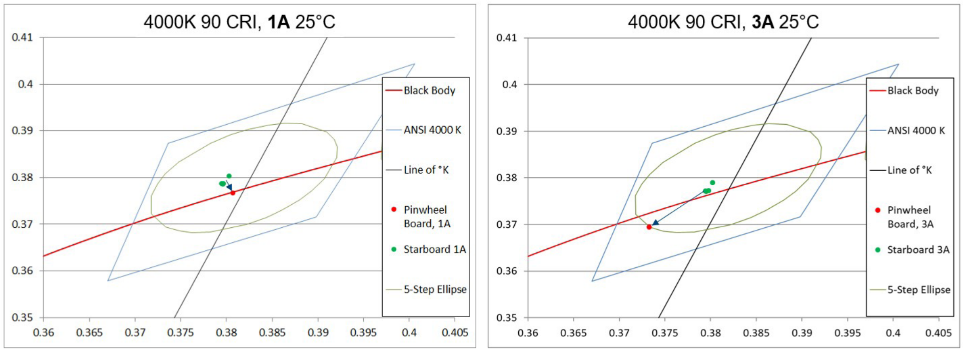

Figure 7: Color shift of close-packed 2X2 array (50-µm pitch)

The LED chips in XLamp XE-G LEDs produce high peak candela normal to the diode and do not throw light sideways as much as many flip-chip LED die. This directed emission keeps the color shift extremely small when run in an array at lower drive currents, as seen in the left side of Figure 7. At higher drive current like 3 A shown in the right side of Figure 7, thermal effects start to play a role. The small blue shift at 3 A is due to the decreased efficacy of the phosphor. Using wider component spacing, lower drive current, or better heat sinking will decrease this CCT shift.

Optical losses from the 50-µm spacing array were about 2-4% at 1 A and 6-8% at 3 A. A few percent of this is from optical losses in neighboring packages. The remaining losses, especially at 3 A, are due to natural thermal droop as the heat takes longer to dissipate in a tightly packed array.

XE-G RGBW Pinwheel Compared to XM-L Color Gen 2

The closest possible die-to-die spacing (100 µm) and smallest total RGBW LES in the industry is available in the XLamp XM-L Color Gen 2 LED, available in High Density (HD) and High Intensity (HI) versions. However, XE-G LEDs provide a much wider palette of color options to meet a broader range of applications with only a slightly larger LED chip edge-to-edge spacing (250 µm-400 µm). XLamp XE-G LEDs also have much higher maximum current ratings and higher maximum light output than the XM-L Color Gen 2 LEDs.

The peak illuminance translation (in degrees) between the XE-G RGBW pinwheel array and XM-L Color Gen 2 LEDs is shown in Figure 8. The XE-G pinwheel array in the Spot optic has similar optical control to XM-L Color Gen 2 HI and even better than the HD version. In the medium optic, the XE-G pinwheel optical control falls in between the XM-L Color Gen 2 HI and HD versions.

These results demonstrate that XE-G arrays designed with 200-µm spacing or less can give optical control on par with the best single-component multi-color LEDs.

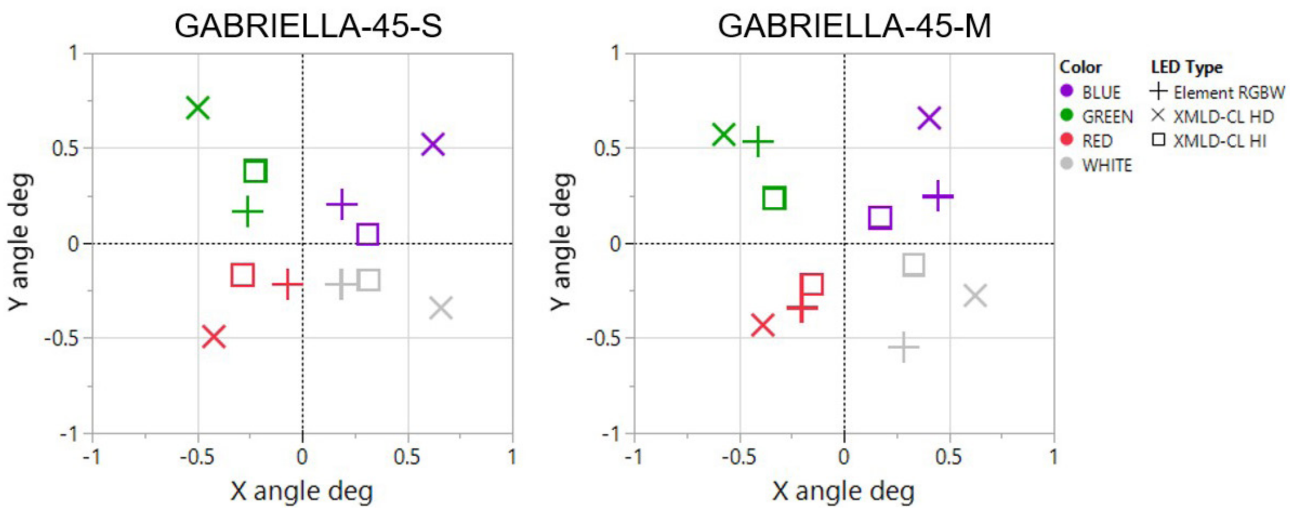

Figure 8: Optical peak intensity displacement of each color diode in an RGBW array, in degrees from center. The XE-G RGBW array at 200-µm spacing has similar performance to XM-L Color Gen 2 HI.

PCB DESIGN

The industry standard minimum spacing for close-packed arrays is 200 µm between components, which is typically limited by the tolerances of common pick and place tools. Below are the recommended solder pad dimensions and solder application stencil opening dimensions for 2x2 arrays at 200 µm spacing.

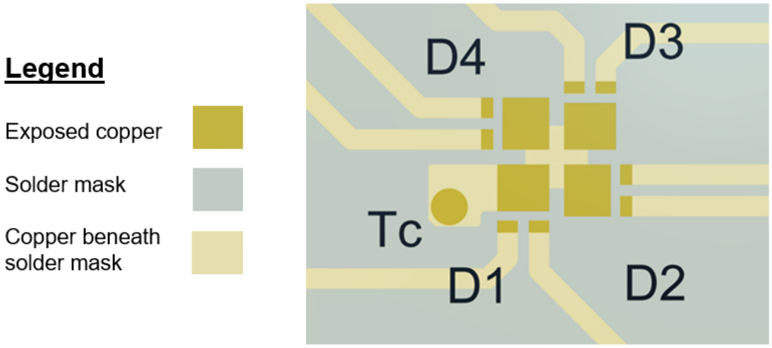

Figure 9: XE-G 200-µm spacing PCB design

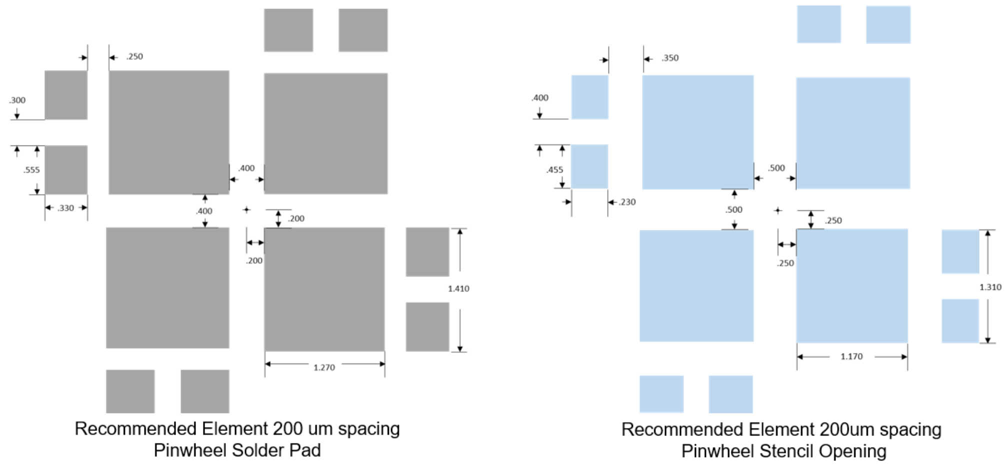

Figure 10: Copper pad layout (left) and stencil dimensions (right) used for a 200-µm spacing in a 2x2 array

PCB Design Rules and Solder Application for 200-µm Spacing Arrays

In general, Cree LED's recommended dimensions for arrays match those of the single component dimensions on the data sheet.

- The solder pad dimensions should exactly match the bond pads on the LEDs.
- The stencil dimensions should use a 50-µm pull-back on all edges compared to the solder pads.
- Cree LED does not recommend connecting the thermal pads with exposed copper when the goal is 200-µm spacing because it can cause drifting of components on reflow and affect optical control.
- A solder-mask-defined component pad layout is recommended for a 200-µm spacing pinwheel design to ensure that the LED will not drift or skew during reflow. This is because the exposed copper has the exact same dimensions as the component's pads, thus constraining the position of the LED during reflow.

Please refer to the XLamp XE-G LED Soldering & Handling document for more information on reflow soldering.

THERMAL MANAGEMENT

PCB Material Choice

XLamp XE-G LEDs are optimized for breakthrough levels of light output at high currents and the LED package's large, electrically-isolated thermal pad is key to unlocking the best performance of these LEDs. Most LED packages that are similar in size to XE-G LEDs do not have any thermal pad, which limits the design choices for PCB materials and technology.

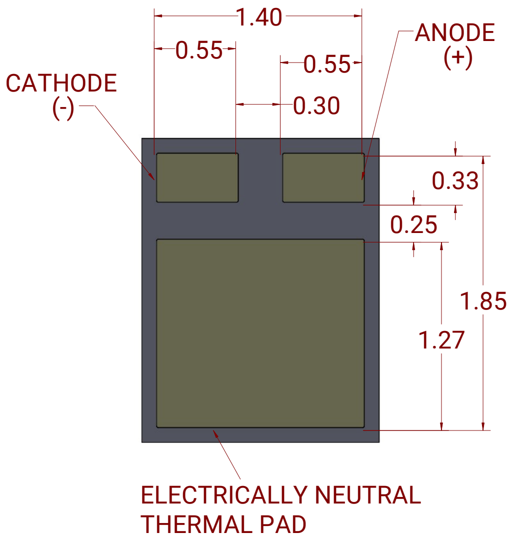

Figure 11: Bottom View of XE-G LED

XLamp XE-G LEDs are unique in this LED size class by enabling the use of a new PCB technology often referred to as "Direct Thermal Path" (DTP) or "Copper-pedestal" that allows direct thermal connection between the LED thermal pad and the base copper layer of the PCB. Figure 12 below illustrates the DTP technology in cross-section with an XE-G LED soldered onto a Rayben MHE®301 starboard.

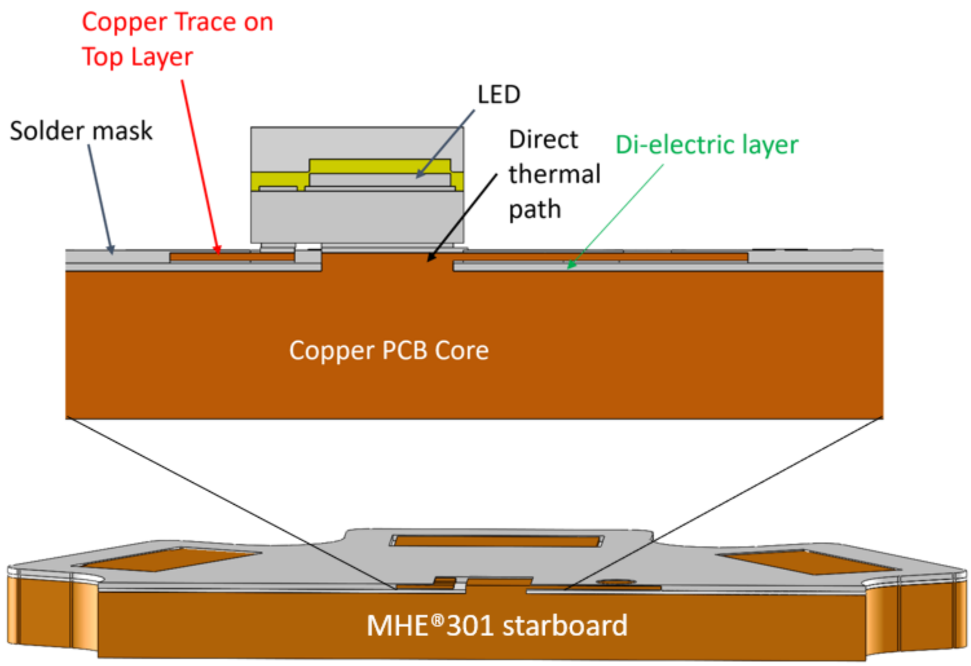

Figure 12: Cross-sectional view of an XE-G LED soldered onto a single-component starboard designed with Rayben's MHE® 301 direct thermal path technology. The copper core protrudes upward only in the thermal pad location to make direct contact to the LED for better heat sinking.

The copper core of the star board extends up through the solder mask layer in a continuous piece, allowing the large neutral thermal pad of XE-G LEDs to directly solder onto the copper core for maximum heat dissipation. The anode and cathode are soldered onto 2-ounce copper traces that are electrically isolated from the copper core by the dielectric layer. In testing, Cree LED has found that

Rayben's MHE®301 DTP PCB technology outperforms standard aluminum-core MCPCBs in both light output and thermal management for higher-current applications of XLamp XE-G LEDs.

Cree LED has carried out extensive testing of XLamp XE-G LEDs on Rayben's MHE®301 technology and the advantages are demonstrated in the following sections. These data in the following sections were collected by fixing the PCBs onto a thermoelectric cooler (TEC) set to 25 °C mounted in a 2-meter sphere. The LEDs were energized at the specified current for 30 seconds to let the TEC come to equilibrium before recording measurements. LES temperature data was captured using a FLIR thermal imaging camera. The PCB temperature (Tc) was measured with a thermocouple about 1 mm from the LED base on an exposed metal pad. This temperature floated above 25 °C to a new equilibrium as power to the LEDs was increased.

Single-LED Measurements (5700 K 70 CRI)

The thermal improvement of the DTP approach is shown clearly by Figure 13. The DTP star board keeps the LED encapsulant about 10 °C cooler at 2 A and 30 °C cooler at 3 A (the maximum current rating). In the plot on the right, this lower temperature translates to a 7% higher luminous flux output at 3 A. Cree LED recommends using a DTP PCB when designing a system to run at or above 2 A per LED to realize these flux gains and maximize LED lifetime.

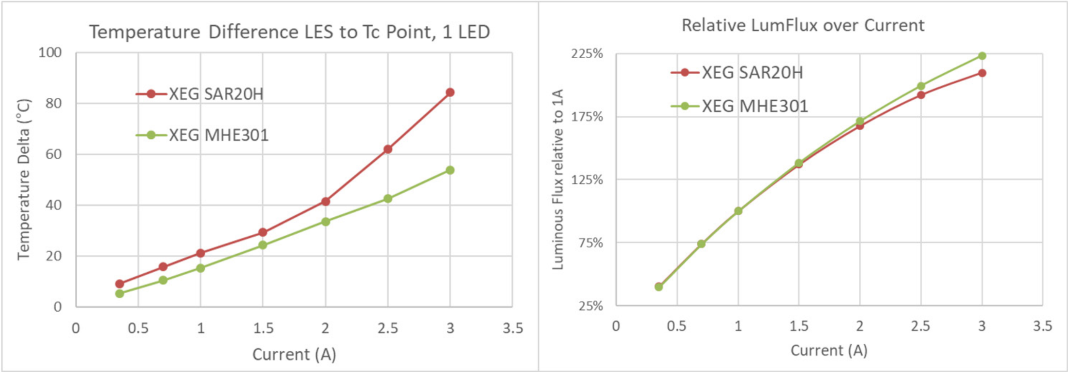

Figure 13: Difference between LES temperature and Tc measuring point (left) and luminous flux (right) of individual white XE-G LEDs mounted on starboards with a direct thermal path (MHE®301) and without a direct thermal path (SAR20H)[1].

Pinwheel 4-LED Measurements

When building close-packed arrays such as the RGBW pinwheel mentioned above, thermal design is even more important. Cree LED collected LES temperature and flux data on RGBW pinwheels at the 200-µm spacing and "0-µm" spacing (roughly 50 µm in reality) with each LED at the current below simultaneously resulting in power input of up to 50 W. The same two PCB materials were used as discussed above.

Figure 14 shows the two PCB materials built in both 200-µm and "0-µm" spacing. The MHE®301 has a clear thermal advantage at 200-µm spacing with LES temperature again about 30 °C cooler than the SAR20H at 3 A resulting in 15% greater flux output. The tighter spacing also has a thermal advantage of nearly 30 °C in this design. Cree LED believes this is because the center of the pinwheel formation is a large copper direct thermal path, which the LEDs are more closely situated on top of, with a shared pool of solder to make the connection.

1 SAR20H is a 1.6-mm thick aluminum-core board with 2 W/m-K thermal conductivity, 2-ounce Cu foil and HASL finish with a white solder mask. MHE®301 is a 1.5-mm-thick copper-core board with 398 W/m-K thermal conductivity (of the thermal pad), 2-ounce Cu foil and ENIG finish with a white solder mask.

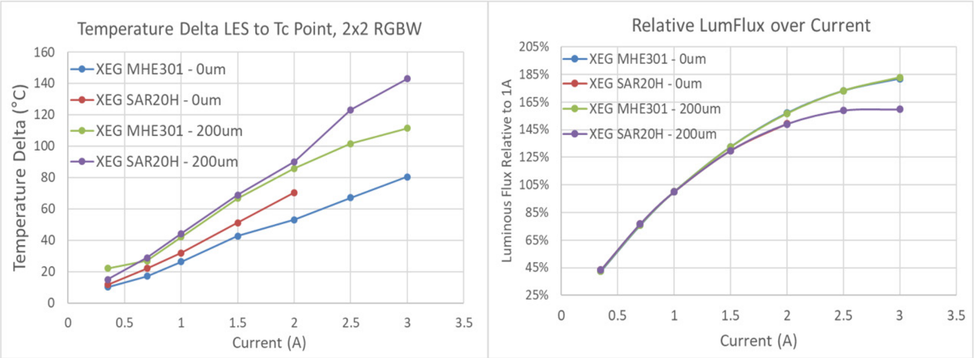

Figure 14: Difference between LES temperature and Tc measuring point (left) and luminous flux (right) of a RGBW Pinwheel array of XE-G LEDs mounted on 50 mm PCBs with a direct thermal path (MHE®301) and without a direct thermal path (SAR20H).

Note that data for SAR20H at "0-µm" spacing are not shown above 2 A. Cree LED does not recommend running this configuration over 2 A per LED due to the thermal and optical stresses involved.

Thermal Design Guidelines for XE-G LEDs

Cree LED's general recommendations for thermal management of XE-G LEDs are:

1. When operating at or above 2 A drive current per LED, use a direct thermal path PCB design to improve flux output and maximize lifetime.
2. When a DTP design is not being used, use at least 2-ounce Cu foil and 2 W/m-k materials. Carefully measure the junction temperature in your system at operating conditions to prove that better heat dissipation is not needed.
3. To use component spacings less than 200 µm, contact your regional Cree LED FAE for information and guidance.

GUIDELINES FOR PULSING XE-G LEDS ABOVE MAXIMUM CURRENT

For pulsed, strobed or cyclic lighting applications, Under certain specific conditions, XLamp XE-G LEDs can be driven above their maximum current rating without significant loss of reliability. Cree LED cannot guarantee performance or lifetimes above the maximum current rating but provides the below guidance for reference purposes only. Cree LED always recommends customers perform their own testing to validate fixture performance and lifetimes under expected use conditions.

Duty Cycle	White & Non-PC Colors	PC Colors
10% (100 ms on, 900 ms off)	3.50 A maximum	3.50 A maximum
25% (250 ms on, 750 ms off)	3.25 A maximum	3.25 A maximum
50% (500 ms on, 500 ms off)	3.25 A maximum	3.00 A maximum