Optimizing PCB Thermal Performance for XLamp® XQ & XH Family LEDs

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INTRODUCTION

This application note outlines how to design a thermally effective printed circuit board (PCB) to use with the XQ and XH families of XLamp® LEDs.

One of the most critical design parameters for an LED-based illumination system is its ability to conduct heat away from the LED junction. High operating temperatures at the LED junction adversely affect the performance of LEDs, resulting in decreased light output and lifetime.[1] Specific practices should be followed in the design, assembly and operation of LEDs in lighting applications to properly manage this heat.

This application note provides guidelines for designing a PCB layout that optimizes heat transfer from XQ and XH family LEDs. Guidelines are provided for FR-4 and metal-core printed-circuit boards (MCPCB). Cree LED encourages its customers to consider these guidelines when evaluating the many LED thermal management techniques available. For additional guidelines on LED thermal management, refer to the Thermal Management application note.

1 See the Long-Term Lumen Maintenance application note

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BACKGROUND

Prior to the introduction of the XQ and XH families of LEDs, XLamp LEDs were designed with an electrically isolated thermal path. The neutral thermal pad simplifies the design of PCBs for thermal considerations. The pad provides a path for heat transfer away from the LED chip junction to the thermal pad. Being electrically isolated from the anode and cathode of the LED means the pad can be soldered or attached directly to the PCB or heat sink. With a neutral thermal pad, thermal vias can be placed directly under the thermal pad, but because they have electrically conductive pads, this cannot be done for XQ and XH family LEDs. Figure 1 shows this difference.

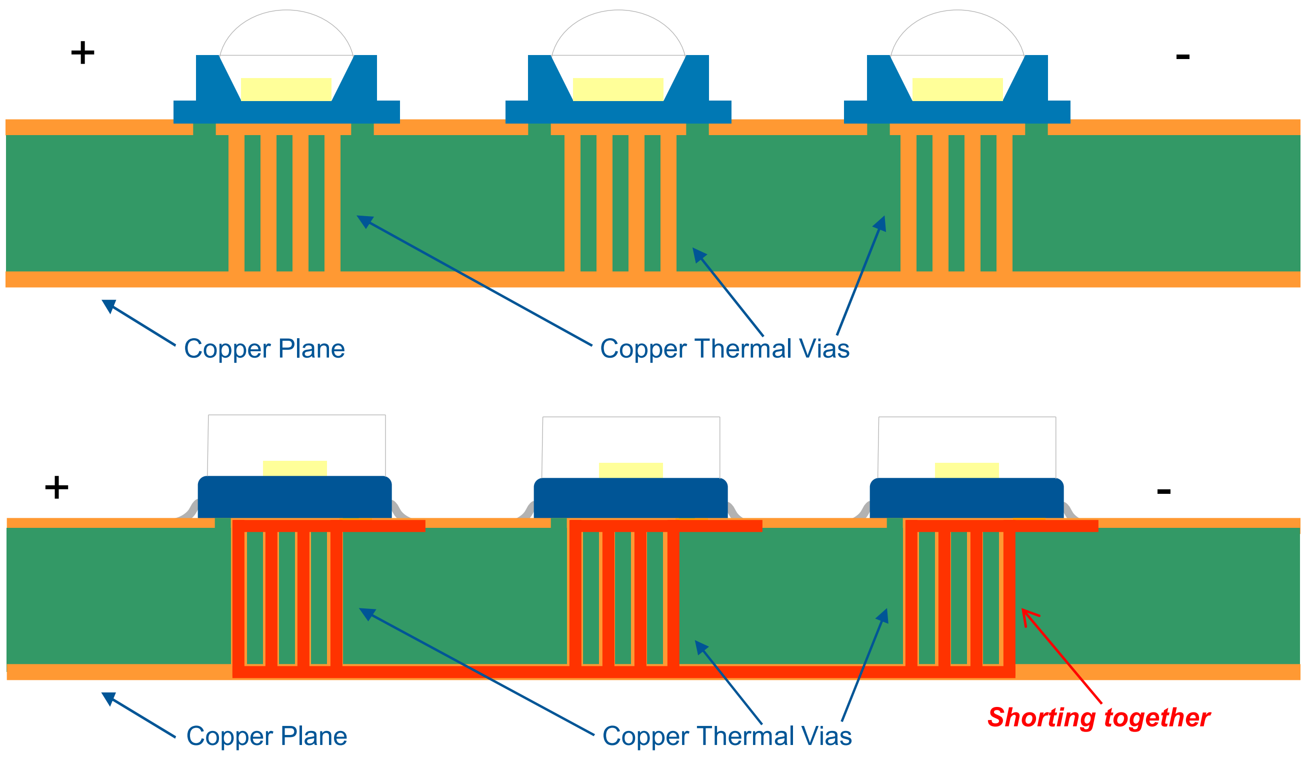


Figure 1: LEDs with electrically isolated (top) and non-isolated (bottom) thermal pads mounted on a circuit board

THERMAL SIMULATION

The data presented here are the results of simulations conducted using ANSYS DesignSpace[2] and Autodesk Simulation CFD[3] software. A standard off-the-shelf heat sink[4] with a pre-attached thermal interface material (TIM) was used for all the simulations, with convection set to 7 W/m^2 °C and 1 W of total input for all scenarios.

Notes:

- Actual results may vary with different geometries and materials. Cree LED recommends performing actual verification testing to validate the thermal management of any LED-based illumination system.

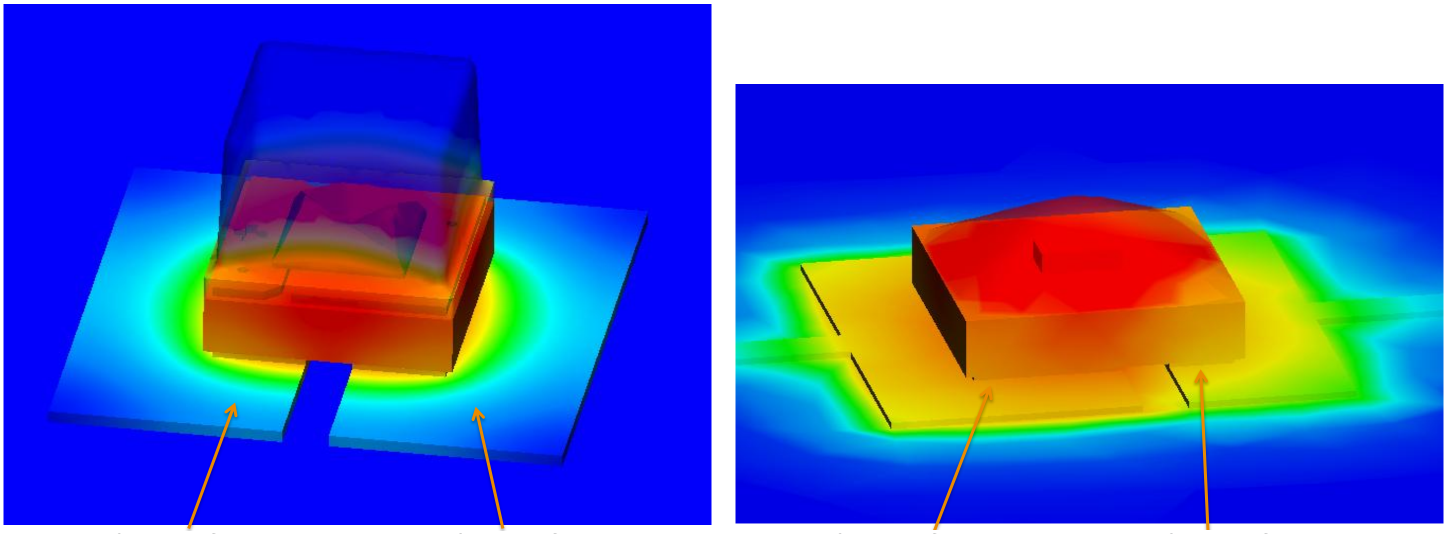
2 ANSYS, Inc., www.ansys.com/Products/Simulation+Technology/Structural+Mechanics/ANSYS+DesignSpace
3 Autodesk Inc., www.autodesk.com/products/autodesk-simulation-family/features/simulation-cfd
4 Model 374424B00035G, Aavid Thermalloy, www.aavid.com/products/bga/374424b00035g

- Modeling and simulation are attempts to predict future performance based on assumptions and criteria that may differ from actual device use and environment and slight modifications must sometimes be made to the design to enable the modeling and simulation process. Actual results may differ from the modeling and simulation results due to these modifications and actual device use and environment.

THERMAL SPREADING

We simulated thermal spreading to determine if it is proportional to the size of the contact pads of the XQ and XH family LEDs. If the thermal spreading is not proportional, the traces for each contact pad must be sized to account for the disproportionality.

Figure 2 shows simulated thermal spreading for a single XQ-D LED on a 3.3 mm X 3.3 mm trace and a single XH-G LED on a 5.0 mm X 5.0 mm trace, both mounted on an MCPCB with 2-oz thick copper and a dielectric thermal conductivity of 2.2 W/mK. The XQ-D LED contact pads are of equal size and the proportion of simulated thermal flux conducted through each pad is within 0.3% of being equal. There is a 68.3% to 31.7% size difference in the contact pads of the XH-G LED and the proportion of thermal flux conducted through each is within 3.7% of being the same (64.6% to 35.4%). In each case, the proportion of thermal flux conducted through each contact pad is in direct correlation with the relative sizes of the pads. Therefore it is logical to scale the sizes of the traces to be in proportion to the sizes of the contact pads.



49.7% of total heat flux through this contact pad

50.3% of total heat flux through this contact pad

64.6% of total heat flux through large contact pad

35.4% of total heat flux through small contact pad

Figure 2: Thermal spreading simulation for XQ-D (left) and XH-G (right) LEDs

THERMAL CROSSTALK

Thermal crosstalk occurs when the heat output from one LED affects an adjacent LED. We compared the thermal resistance, junction to ambient temperature (Θj-a) of the center LED in a 3 X 3 pattern of nine LEDs mounted on a 50 mm X 50 mm PCB on an arbitrary sink with a 3.3 mm X 3.3 mm trace to determine how closely together XQ family LEDs can be located without incurring a large thermal crosstalk penalty. For XH family LEDs, we used a 5 mm X 5 mm trace.

Figure 3 shows the inter-LED spacing measurements.

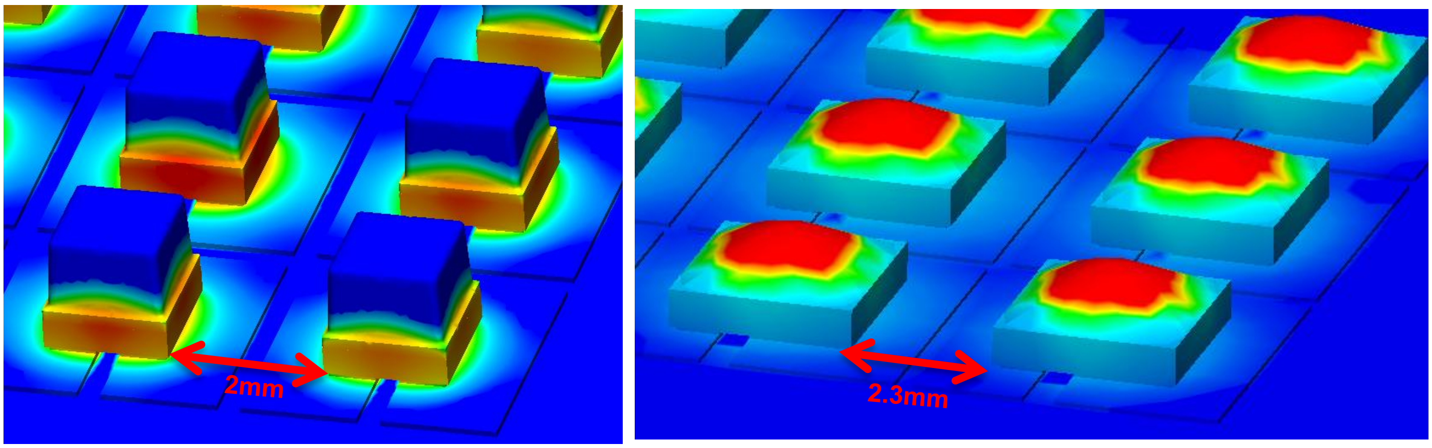
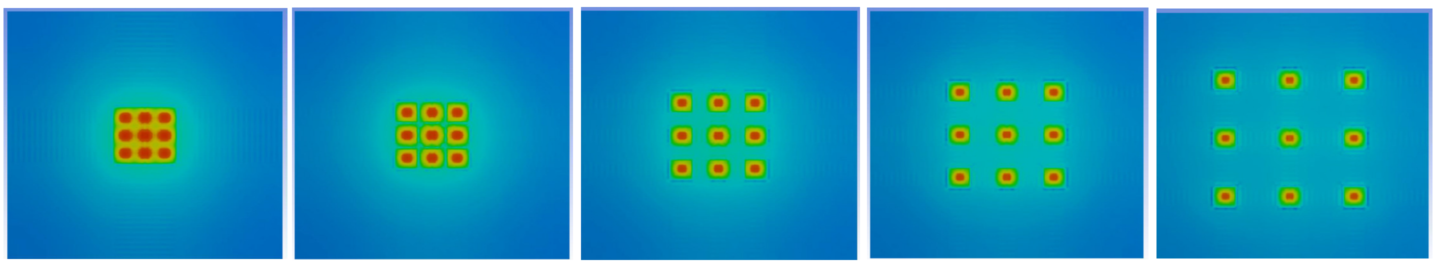


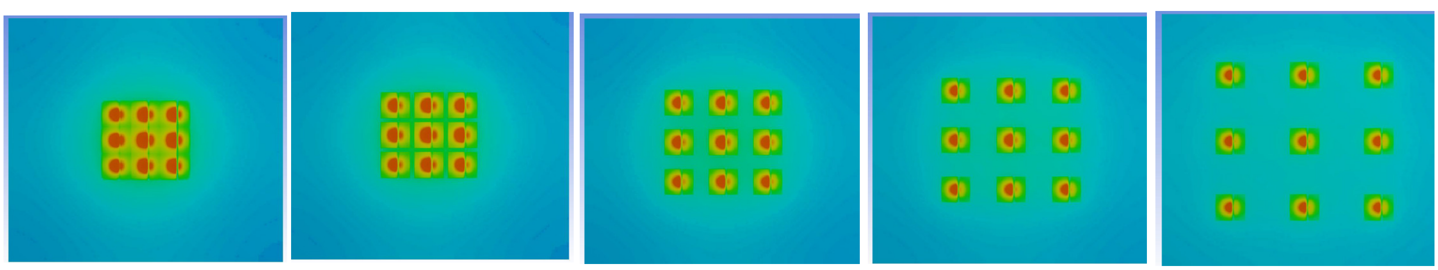
Figure 3: Inter-LED spacing for thermal crosstalk simulation for XQ-D (left) and XH-G (right) LEDs

Figure 4 and Figure 5 show thermal simulation images for various inter-LED spacings, defined as the gap between the LEDs.



2-mm spacing | 3-mm spacing | 5-mm spacing | 7-mm spacing | 10-mm spacing

Figure 4: Simulation of XQ-D thermal crosstalk



2.3-mm spacing | 3-mm spacing | 5-mm spacing | 7-mm spacing | 10-mm spacing

Figure 5: Simulation of XH-G thermal crosstalk

Chart 1 and Chart 2 show the relative $\Theta_{j\text{-}a}$ of various inter-LED spacings compared to a 10-mm spacing, the largest spacing that was simulated and where minimal cross-talk was observed. There was minimal thermal crosstalk for the LEDs mounted on an MCPCB. There was more thermal crosstalk for the LEDs mounted on an FR-4 PCB, however the amount of crosstalk was small even for the smallest spacings.

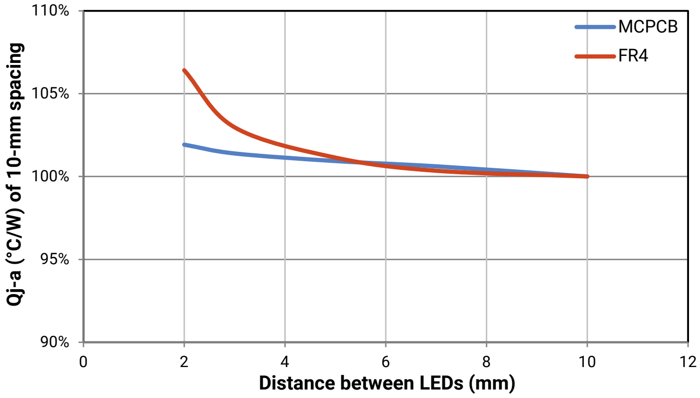


Chart 1: Thermal crosstalk simulation results for XQ family LEDs

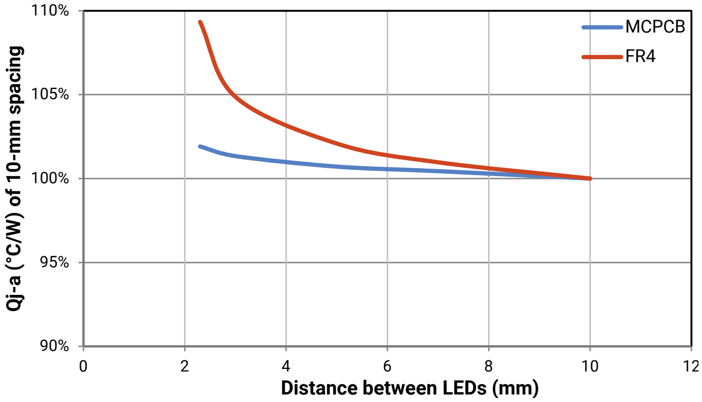


Chart 2: Thermal crosstalk simulation results for XH family LEDs

COPPER TRACE SIZE

We investigated the copper trace area needed below XQ and XH family LEDs to optimize thermal flow by comparing the $\Theta_{j\text{-}a}$ of a single XQ-D and XH-G LED with varying copper trace sizes. The trace size was defined as the area of the trace, kept square and centered on the board. Figure 6 and Figure 7 show images of the LEDs mounted on the various traces and the thermal simulation images.

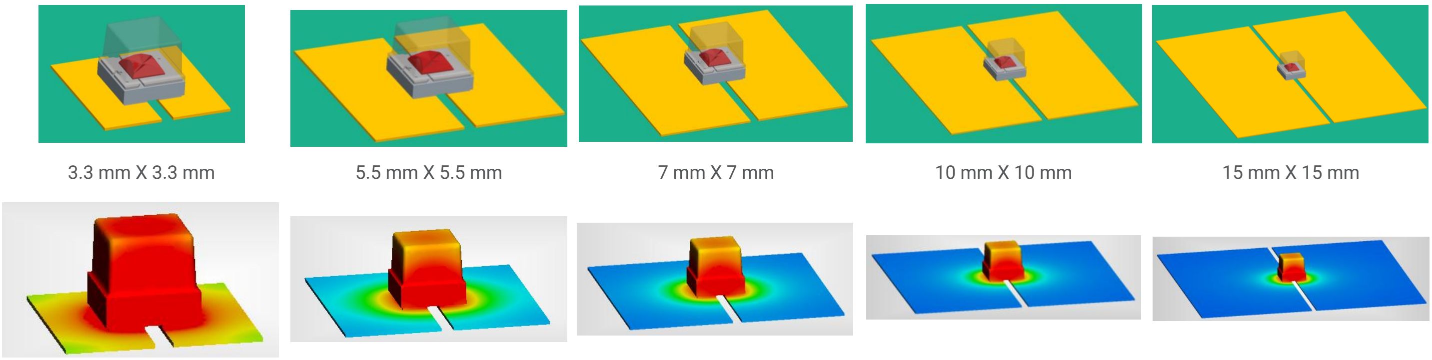


Figure 6: XQ-D LED mounted on various-size traces (top) and thermal simulation of XQ-D LED mounted on same various-size traces (bottom)

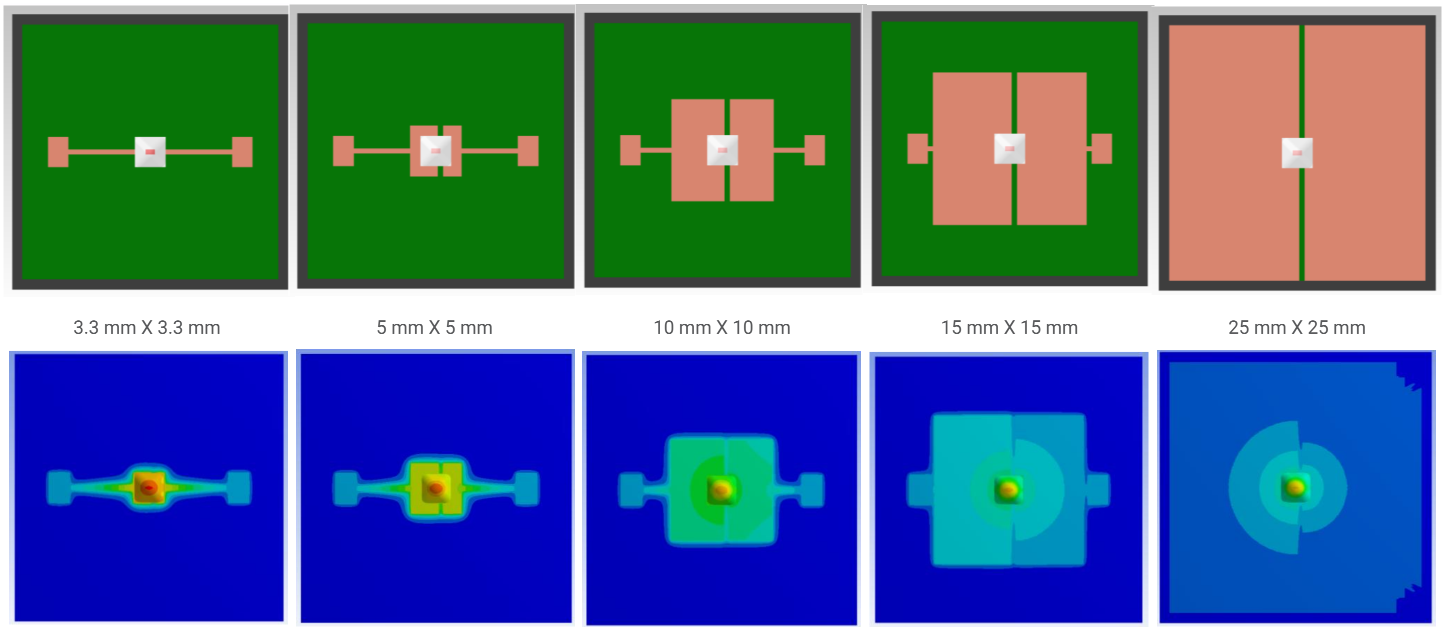


Figure 7: XH-G LED mounted on various-size traces (top) and thermal simulation of XH-G LED mounted on same various-size traces (bottom)

Chart 3 and Chart 4 show a comparison of the relative $\Theta_{j\text{-}a}$ of a single LED for each copper trace size on an MCPCB and an FR-4 PCB. There is a minimal difference in $\Theta_{j\text{-}a}$ for the various trace sizes on the MCPCB. There is a significant increase in $\Theta_{j\text{-}a}$ for small trace sizes and a significant decrease in $\Theta_{j\text{-}a}$ for larger trace sizes on the FR-4 PCB. The $\Theta_{j\text{-}a}$ difference is due to the much better thermal conduction of the MCPCB compared to the lesser thermal conduction of the FR-4 board.

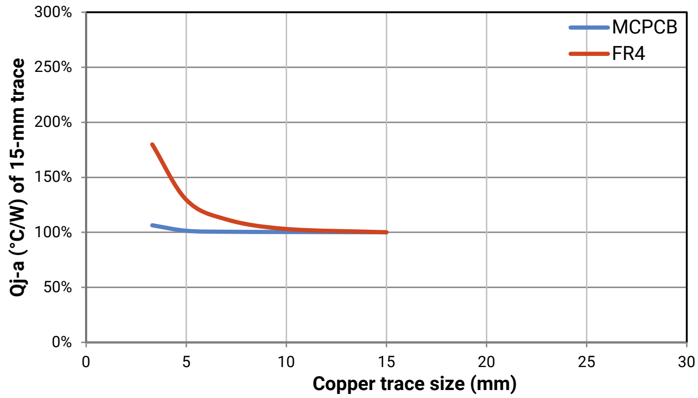


Chart 3: Copper trace size comparison for XQ family LEDs

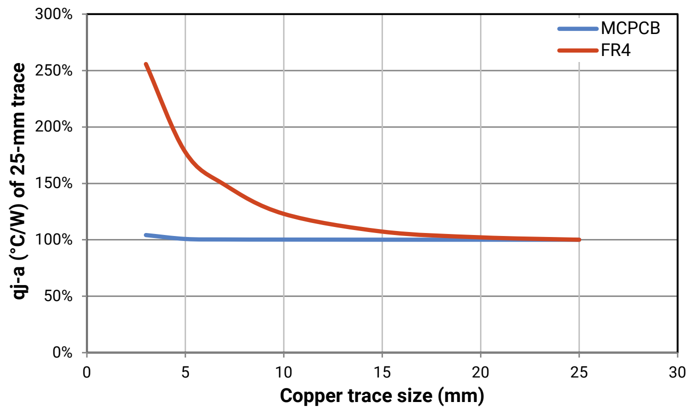


Chart 4: Copper trace size comparison for XH family LEDs

USEFULNESS OF THERMAL VIAS

An inexpensive way to improve thermal transfer for FR-4 PCBs is to add thermal vias - typically plated through-holes (PTH) between conductive layers. Vias are created by drilling holes and copper plating them. Because the XQ and XH family LEDs do not have an electrically isolated thermal pad, it is not possible to locate thermal vias directly underneath the LEDs, so we simulated locating thermal vias outside the trace. Figure 8 shows an XQ and XH family LED mounted on traces of three sizes with thermal vias around the outside of the trace.

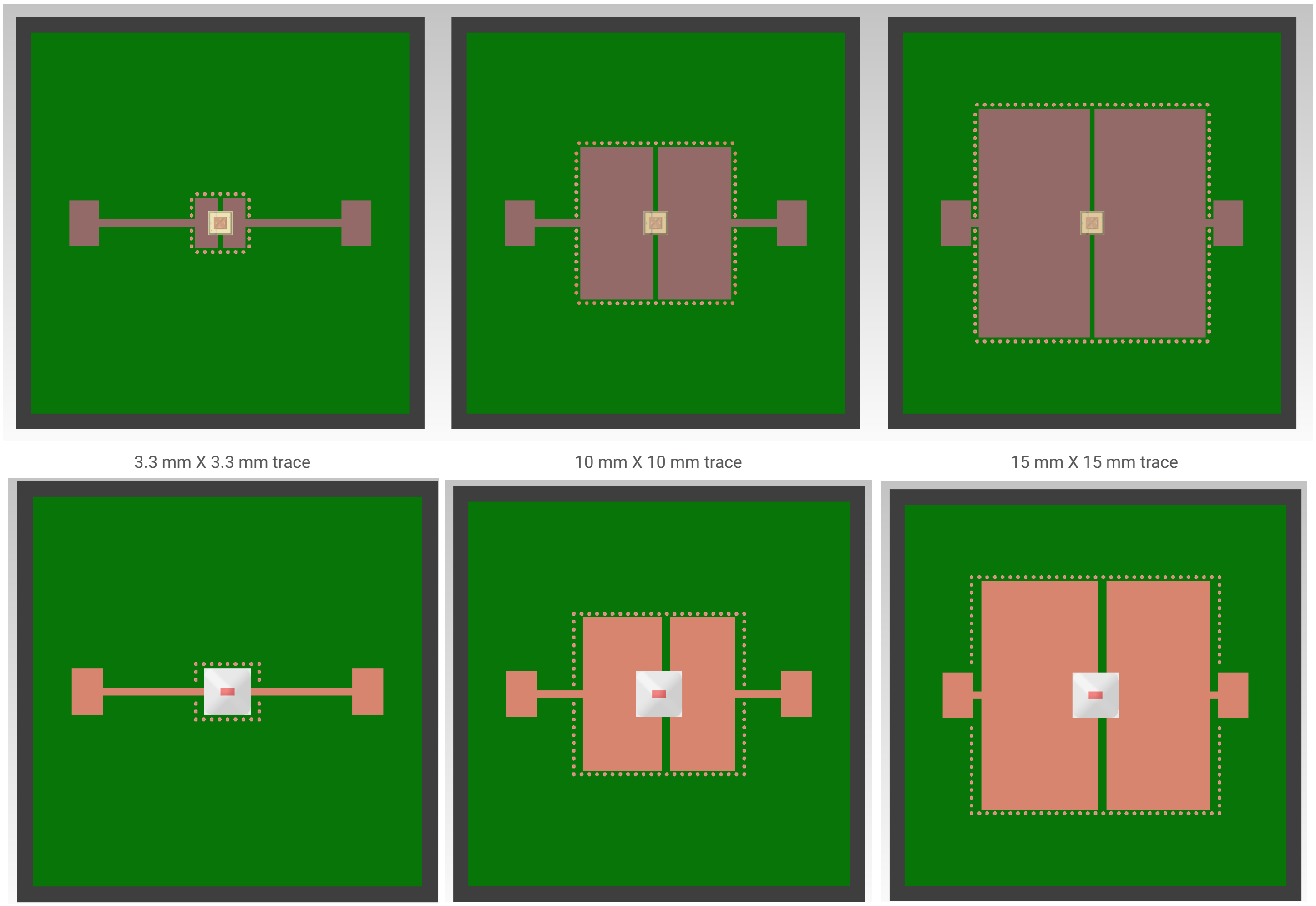


Figure 8: Thermal vias around the trace of XQ-D (top) and XH-G (bottom) LEDs

Chart 5 and Chart 6 show the Θ_{j-a} of plated and filled vias around various trace sizes compared to the Θ_{j-a} with no vias. Thermal vias can be helpful with smaller trace sizes, but are of decreasing help as trace size increases. We added a second row of traces for some of the scenarios, but the second row produced no difference in the Θ_{j-a}.

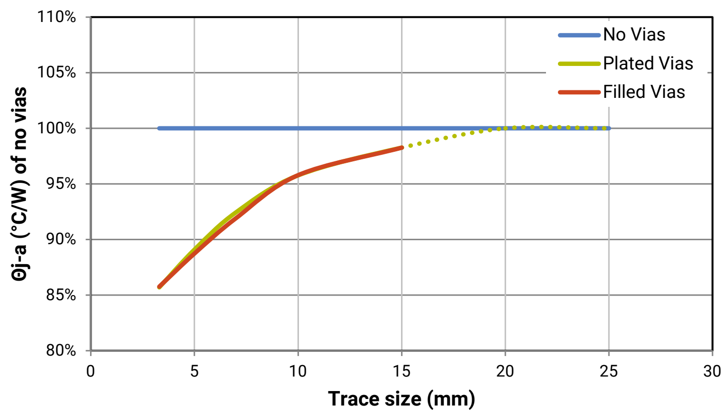


Chart 5: Thermal via results for XQ family LEDs

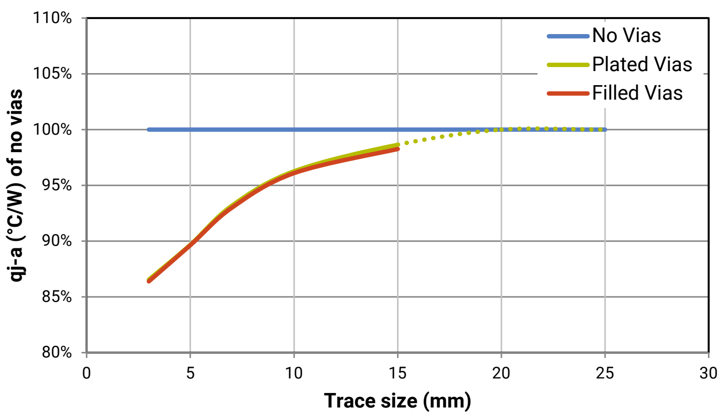


Chart 6: Thermal via results for XH family LEDs

FR-4 BOARD THICKNESS

Chart 7 compares the relative $\Theta_{j\text{-}a}$ of two standard thicknesses of FR-4 PCBs with various copper trace sizes to that of an 0.8-mm thick PCB with a 10 mm X 10 mm trace. The thinner FR-4 PCB had a lower $\Theta_{j\text{-}a}$ and is recommended for thermally demanding applications.

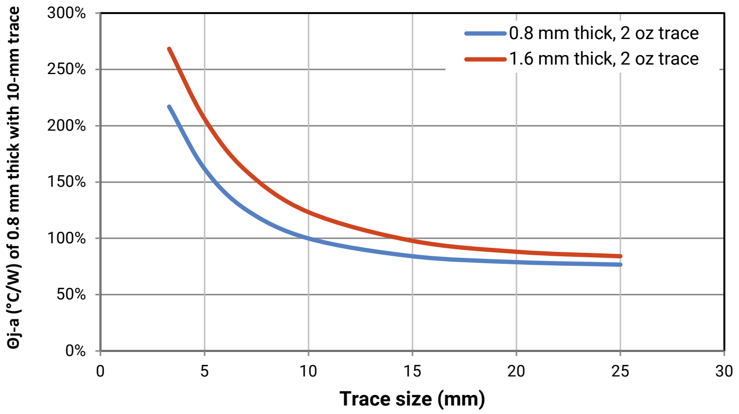


Chart 7: FR-4 PCB thickness comparison

FR-4 TRACE THICKNESS

To determine how useful thicker traces are for dissipating heat on an FR-4 PCB, Chart 8 and Chart 9 compare the relative $\Theta_{j\text{-}a}$ of three thicknesses of FR-4 traces with various copper trace sizes to that of a 2-oz copper trace. The thicker traces have better $\Theta_{j\text{-}a}$ than the thinnest trace, but increasing from 2 oz to 3 oz is a less significant improvement than increasing from 1 oz to 2 oz.

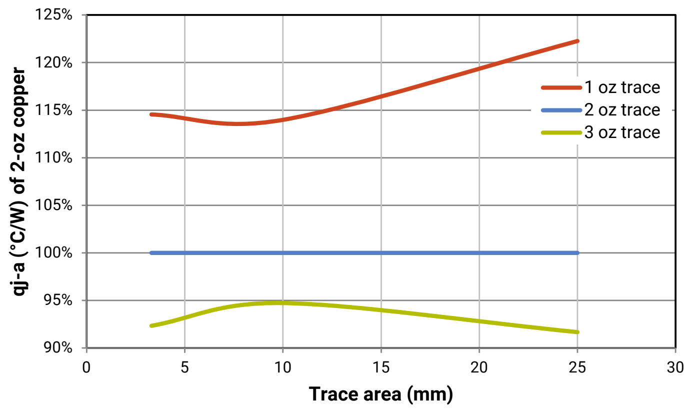


Chart 8: FR-4 trace thickness comparison for XQ family LEDs

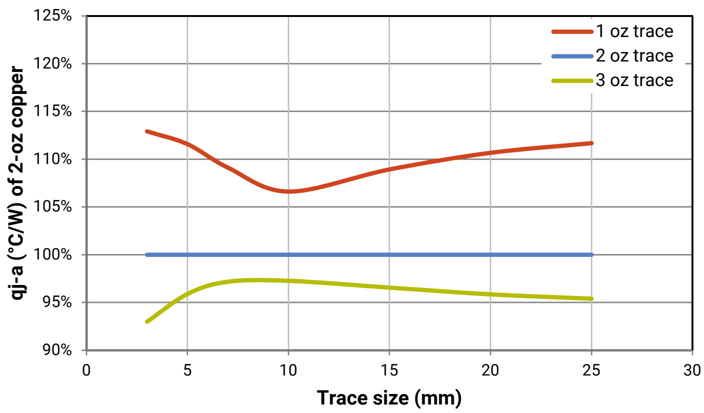


Chart 9: FR-4 trace thickness comparison for XH family LEDs

MCPCB TRACE THICKNESS

To determine how useful thicker traces are for dissipating heat on an MCPCB, Chart 10 and Chart 11 compare the relative $\Theta_{j\text{-}a}$ of three thicknesses of MCPCB traces with various copper trace sizes to that of a 2-oz copper trace. The thicker traces have better $\Theta_{j\text{-}a}$ than the thinnest trace but increasing from 2 oz to 3 oz is a less significant improvement.

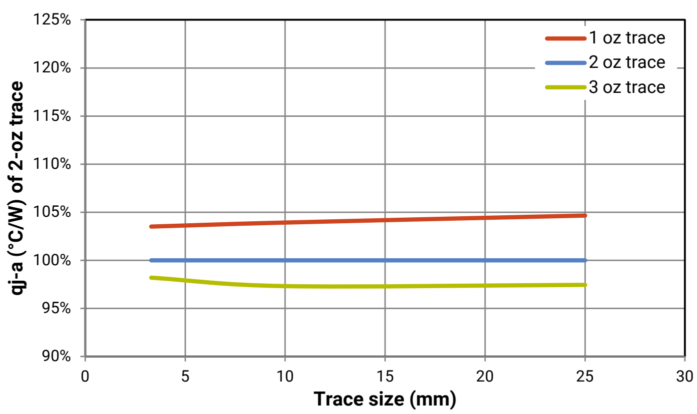


Chart 10: MCPCB trace thickness comparison for XQ family LEDs

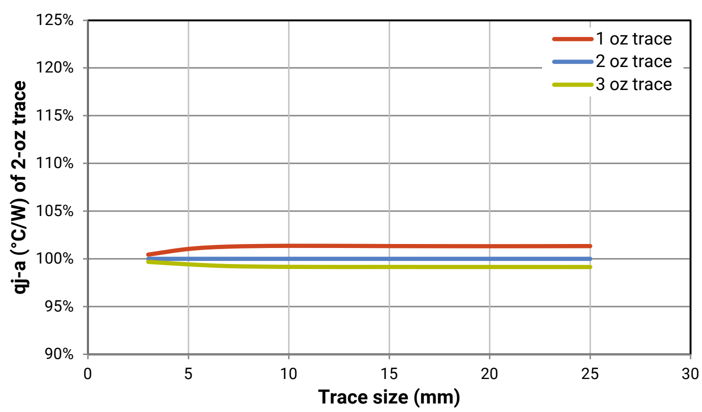


Chart 11: MCPCB trace thickness comparison for XH family LEDs

MCPCB DIELECTRIC THERMAL CONDUCTIVITY

Chart 12 shows the simulated $\Theta_{j\text{-}a}$ with varying thermal conductivity of the dielectric of an MCPCB. Although here is some improvement in performance when the dielectric conductivity increases above 2 W/mK, it is not particularly significant. However there is a large decrease in thermal performance below 2 W/mK.

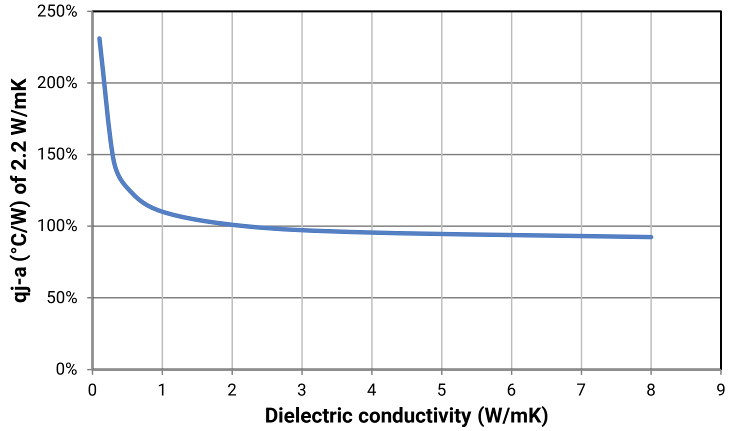


Chart 12: MCPCB dielectric thermal conductivity

FR-4 VS. MCPCB

Chart 13 and Chart 14 compare the relative $\Theta_{j\text{-}a}$ of four FR-4 PCBs with various copper trace sizes to that of an MCPCB. For smaller traces, there is a very large thermal conductivity penalty for using an FR-4 PCB, but the penalty decreases as the trace size increases.

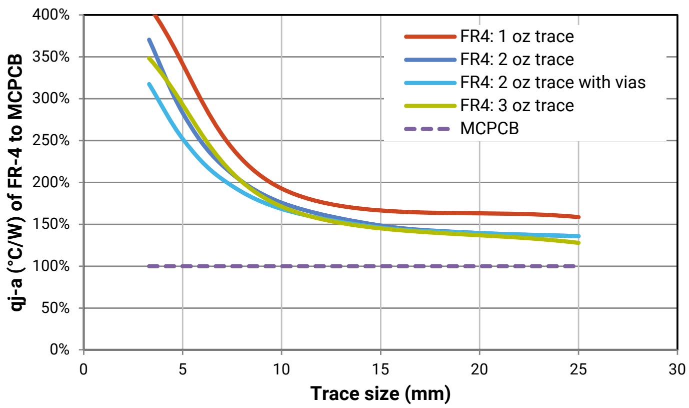


Chart 13: FR-4 vs. MCPCB comparison for XQ family LEDs

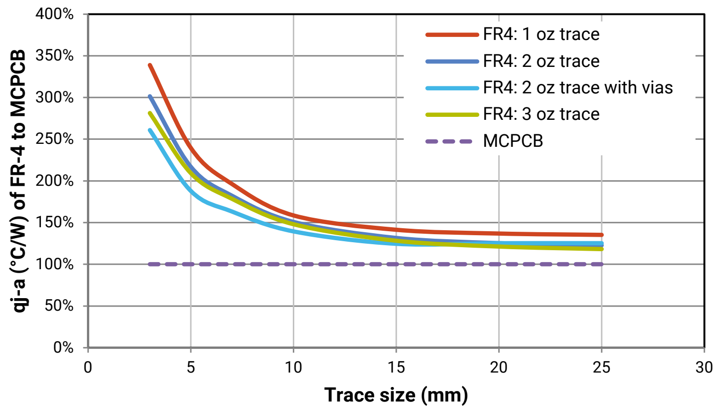


Chart 14: FR-4 vs. MCPCB comparison for XH family LEDs

MEASURED VS. SIMULATED RESULTS

To verify the validity of the simulations herein, we measured and simulated the $\Theta_{j\text{-}a}$ of an XLamp XQ-D and an XH-G LED, each mounted on a 25 mm X 25 mm FR-4 PCB on a heat sink, as shown in Figure 9. We measured and simulated FR-4 PCBs of 0.8 mm thickness with various trace sizes.

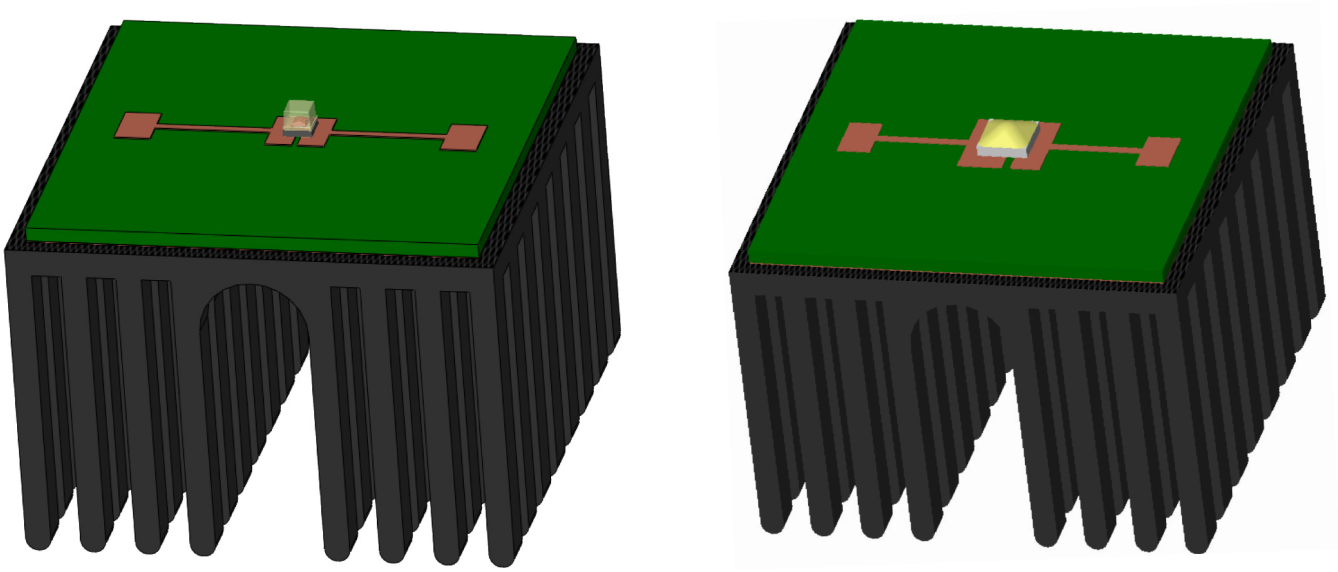


Figure 9: XQ-D (left) and XH-G (right) thermal measurement configurations

Chart 15 shows that the measured data very closely matches the simulation data.

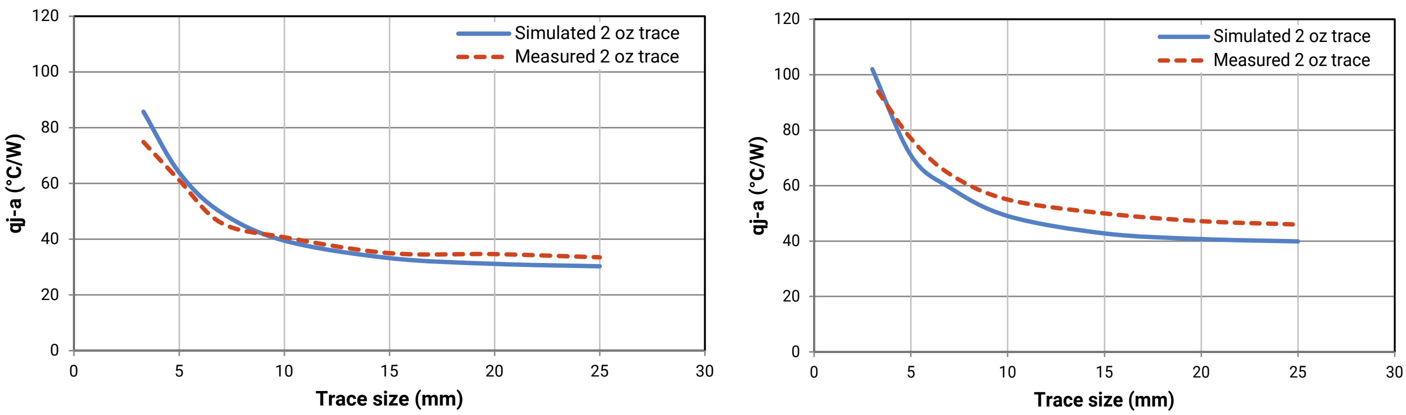


Chart 15: Comparison of measured and simulated $\Theta_{j\text{-}a}$ for XQ (left) and XH (right) 0.8 mm FR-4 PCB

TRACE SIZE RECOMMENDATIONS

Cree LED recommends the following trace sizes for optimized heat transfer without using vias or an overly large trace.

FR-4 PCB with XQ Family LED

- 2 oz copper
- 0.8 mm thick
- 10 mm X 10 mm trace

MCPCB with XQ Family LED

- 2 oz copper
- 1.0 mm thick
- 5 mm X 5 mm trace
- thin (75 µm) dielectric with thermal conductivity ≥ 2.0 W/mK

FR-4 with XH Family LED

- ≥ 2 oz copper
- ≤ 0.8 mm thick
- ≥ 15 mm X 15 mm trace

MCPCB with XH Family LED

- ≥ 2 oz copper
- ≤ 1.0 mm thick
- ≥ 5 mm X 5 mm trace
- thin (75 µm) dielectric with thermal conductivity ≥ 2.0 W/mK

CHEMICAL COMPATIBILITY

As with any LED-based illumination system, it is important to verify chemical compatibility when selecting thermal interface materials, as well as other materials to which the LEDs can be exposed. Certain materials can outgas and react adversely with the materials in the LED package, especially at high temperatures when a non-vented secondary optic is used. This interaction can cause performance degradation and product failure. Consult Cree LED's Chemical Compatibility application note for compounds and products safe for use with XLamp LEDs. Consult your PCB manufacturer to determine which materials it uses.