Pulsed Over-Current Driving of XLamp® LEDs: Information and Cautions

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INTRODUCTION

The Applications Engineering team at Cree LED is often asked whether it is safe to operate XLamp® LEDs with pulsed currents above the maximum data-sheet rating. This question is usually asked in the context of legitimate product requirements such as those posed by emergency-vehicle applications, specialized stroboscopic illumination and even pulsed modulation for general-illumination dimming applications.

The short answer is "it depends." Multiple variables affect both initial and long-term performance and reliability of an LED. These include thermal resistance, pulse duration, as well as current amplitude, frequency and duty cycle.

The XLamp LED product portfolio is sufficiently broad to accommodate the vast majority of illumination and pulsed-current illumination requirements.

However, to explore the limits of the possible, but not necessarily reasonable, we'll review three types of over-current conditions:

1. Single-pulse events, e.g., electrical overstress or EOS.
2. Repetitive pulsing, e.g. pulse-width modulation.
3. Ripple-current effects.

Electrical overstress (EOS) is often associated with catastrophic failures such as an electrostatic discharge (ESD), in-rush current, or other types of transient electrical surge.[1] Designers of LED drivers should be sure to take all necessary precautions to protect the LEDs from EOS. The second type of over-current condition

1 See the Electrical Overstress application note for a discussion of recommended design practices to avoid EOS damage.

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occurs with applications in which the LEDs operate in a flashing mode such as emergency-vehicle lights, strobe lights, or signaling beacons. High-frequency pulsing, i.e., greater than 120 hertz, is often used to control the brightness of LEDs in dimming applications. Finally, ripple current is a repetitive, cyclical peak-to-peak variation in a direct-current waveform that may be derived from an insufficiently filtered alternating-current source or switched-mode power supply.

Within specification boundaries, none of these conditions is cause for concern in regard to the long-term lumen maintenance or reliability of the LED. But any of these in an "over-current" situation, i.e., beyond data-sheet specification, can decrease LED lifetime.

SINGLE-PULSE OVER-CURRENT EVENTS

Single-pulse over-current events are often the result of an unintentional application of excessive electrical energy to one or more LEDs and can lead to a catastrophic failure of the device(s). XLamp LEDs are capable of withstanding current transients that are several times higher than the maximum rated current. But, the exact amplitude that a particular LED device can withstand is also a function of the duration and frequency of the transient. Beyond a certain threshold, a single-pulse event will lead to an immediate catastrophic failure of the LED with two general failure modes: a short circuit or an open circuit.

The main factor limiting an LED's ability to withstand an EOS event is the current-carrying capability of the LED chip and internal interconnections. Current density is given as the electric current per cross-sectional area and is usually measured in amperes-per-square-meters (A/m^2). Conventional electrical conductors have a finite resistance, causing them to dissipate power in the form of heat. Current and therefore current density must be kept sufficiently low to prevent the conductors from melting or fusing, or the insulating material from breaking down. For example, at high current densities material forming the interconnections can move. This phenomenon, known as electromigration, occurs when some of the momentum of moving electrons is transferred to nearby ions, causing them to dislocate from their original lattice positions. Electromigration does not occur in semiconductors directly, but in the metal contact interconnects deposited onto them. Over time, electromigration can transport a significant number of atoms far from their original positions and contributes to a device breakdown.

A localized increase of current density, known as current crowding, is an inhomogeneous distribution of current density through a conductor or semiconductor, especially at the vicinity of the contacts and over the p-n junctions of an LED. One of the known factors that limit the efficiency of LEDs, and materials with low charge-carrier mobility, such as indium gallium nitride (InGaN), are especially prone to current crowding.

Current crowding can lead to localized overheating and formation of thermal hot spots, which in catastrophic cases can lead to thermal runaway, and can also aggravate electromigration effects and formation of voids, causing localized, unevenly distributed current density. The increased resistance around a void is a self-feeding cycle, causing further localized temperature rise, which in turn accelerates the formation of the void and eventually can lead to an open-circuit failure.

Conversely, localized lowering of current density, with an implied current-density gradient, may lead to deposition of migrated atoms from current-"crowded" regions. In a similar self-propagating cycle, this can lead to further lowering of current density and further deposition of migrated ions, even the formation of small protuberances, which in turn can cause short circuits.

Figure 1 below depicts two examples of metal migration. The picture on the left shows an XLamp LED device subjected to repeated transient currents below the maximum threshold; the picture on the right shows a device subjected to roughly 20 times the normal forward voltage, resulting in a dramatic, instantaneous failure.

These effects can always be mitigated with proper current-driver design, which prevents electrical transients from reaching the LED component.

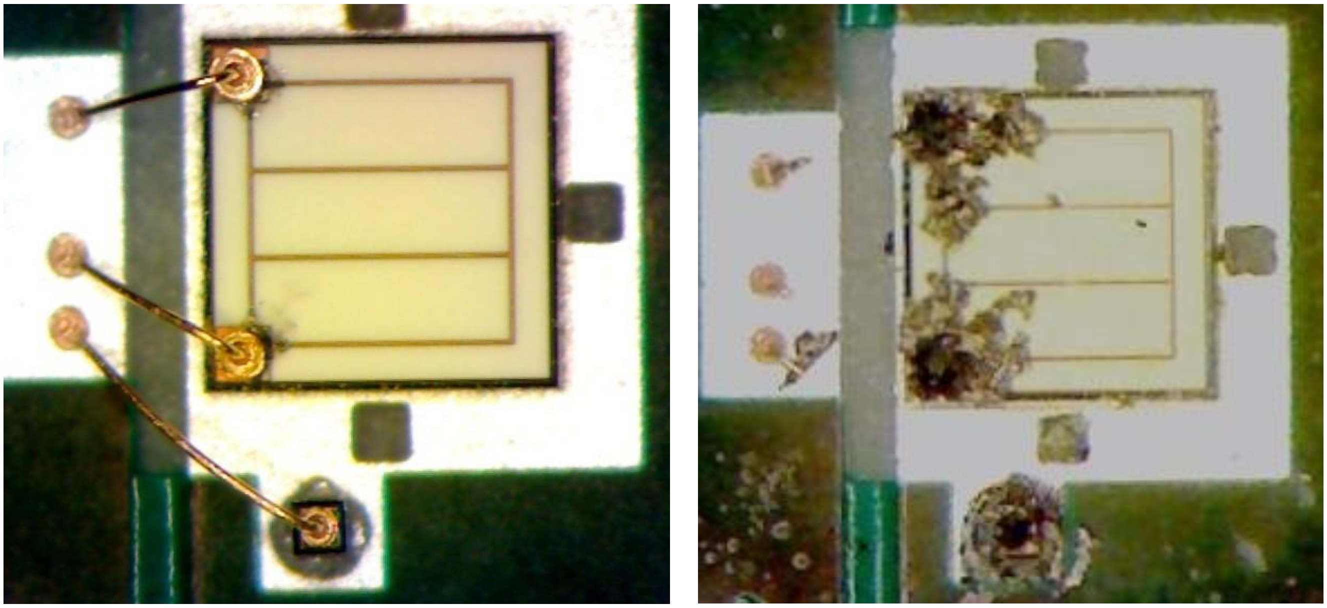

Figure 1: Two examples of metal migration

Another theoretically limiting factor is the current-carrying capacity of the bond wire(s) to the LED chip. If the current-carrying capacity is exceeded (as in a massive EOS), the conductor(s) fuse and cause an open circuit. While the exact physics involved in the fusing of a metal wire or conductive pad are beyond the scope of this document, the factors include the wire length and diameter, the type of bonds (ball or wedge), and physical material properties of the metal, including melting point, thermal conductivity, electrical resistivity, etc. Fusing of the bond wire is a highly uncommon, secondary failure that occurs only after the chip has already failed short and continues to be subjected to excessive current, which in turn leads to overheating of the bond wire(s).

REPETITIVE PULSING

The second type of over-current condition, high-current repetitive pulsing, may or may not result in an early catastrophic failure of the LED. Repetitive high-current pulsing may result in a shortened life expectancy for the LED compared to the usual expected lifetime, on the order of tens or hundreds of thousands of hours. A particular device subjected to repeated transients at an amplitude some percentage above the data-sheet limits but below the threshold required for single-pulse failure will still eventually fail. The failure mechanism will most likely be due to electromigration as enough metal ions are eventually shifted away from their original lattice positions. The other factor that can lead to a reduced lifetime is excessive heating of the p-n junction, which causes the LED's output to degrade below 70 percent of its original luminous flux.

In addition to degradation in light output, other properties that may be affected by high-current operation over the long term are color-point stability, reverse-leakage current and forward voltage. Cree LED recommends that customers perform their own long-term testing to ensure the reliability of their design.

RIPPLE CURRENT

Ripple current is a periodic peak-to-peak variation of mean current level. Unfiltered, rectified 120-Hz signals are routinely used to drive LED illumination applications and within specification boundaries pose no problems whatsoever for the LEDs. However, excessive ripple current is cause for concern, but not just for the LEDs. It can also be a concern for electrolytic capacitors on the output filter stage of an LED driver. High ripple currents can lead to overheating of the capacitors and exacerbate early failure of the driver circuitry. There is also a chance that, if the filter capacitors fail, transient currents that would otherwise have been attenuated become present and may in turn damage the LED. Figure 2 and Figure 3 show ripple current of a typical LED driver.

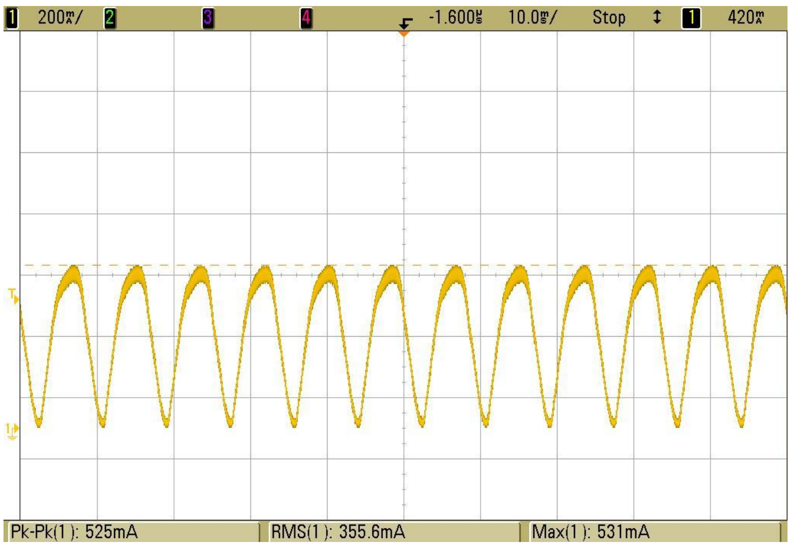

Figure 2: High ripple current, 525 mA, peak-to-peak

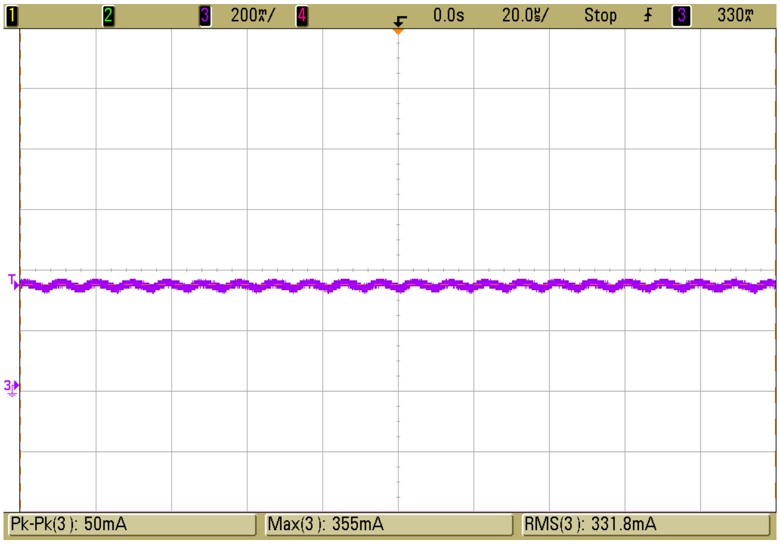

Figure 3: Low ripple current, 50 mA peak-to-peak

MAXIMUM SWITCHING FREQUENCY

The maximum switching frequency for pulsing LEDs is limited by the turn-on time of the device as well as the rise- and fall-time limits of the switching circuitry. The typical turn-on time for an device is on the order of 10 nanoseconds or less, which provides the maximum switching frequency of approximately 100 MHz.

SUMMARY

While XLamp LED products are capable of withstanding current transients well above the maximum rated continuous current, there are physical limits that must not be exceeded in order to avoid EOS. It is possible to operate LEDs in a continuous pulsed mode at higher levels, but there are trade-offs that may adversely affect efficiency, chromaticity and long-term reliability.

For certain specialized applications, there may be a good reason to exceed maximum-current ratings to achieve a desired level of performance. However, for these cases, Cree LED recommends that customers perform their own lifetime testing when proving out a design that will deliver any of the three over-current conditions described here. It is the customer's responsibility to determine if the trade-offs will be acceptable. Cree LED cannot make any guarantees regarding reliability or performance when using our products outside the published specification limits.[2] Customers who have questions or concerns about their unique applications are encouraged to contact Cree LED's applications support team for technical guidance with respect to product selection and system design.

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2 Operating XLamp LEDs outside the published specifications negates the warranty as published in Cree LED's Sales Terms and Conditions.