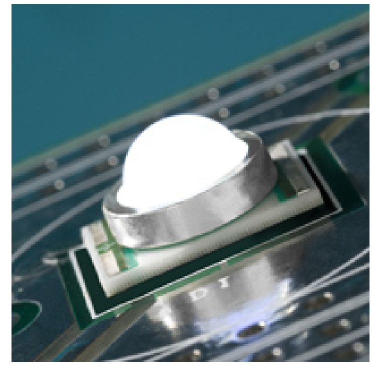
Cree® XLamp® LED Reliability

September 2007



This application note describes the types of failures common to high-power LEDs, details Cree's pre-release qualification testing, and contains the results of ongoing, long-term testing regarding lifetime projections and white point stability. Due to lack of standardization in the high-power LED industry for reliability and pre-qualification testing, understanding the reliability measures of each LED company is very important in selecting the right LED for each application.

Because this application note contains long-term testing data, it will be updated as new information becomes available.

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Application Note: CLD-AP06.005

LED Failure Types

Catastrophic failures are failures that result in the LED emitting no light or very little light at normal current levels (e.g. 350 mA for XLamp XR-E LEDs). Catastrophic failures are not expected for XLamp LEDs that are handled and operated within the limits specified in XLamp documentation. Please refer to the product's datasheet and the application note XLamp Soldering & Handling for more information on design limits.

Parametric failures are failures that cause key characteristics to shift outside of acceptable bounds. The most common parametric failure, for a high-power LED, is permanent light output degradation over operating life. Most other light sources experience catastrophic failure at the end of their useful life, providing a clear indication that the light source must be replaced. For instance, the filament of an incandescent light bulb breaks and the bulb ceases to create light. In contrast, high-power LEDs generally do not experience catastrophic failure but simply become too dim to be useful in the intended application. Further discussion of this matter can be found in the Long-Term Lumen Maintenance Testing section of this document.

Another parametric failure common to white LEDs is a large and permanent shift in the exact color of white light output, called the white point or color point. A shift in white point may not be detectable in one LED by itself, but would be obvious in a side-by-side comparison of multiple LEDs. Since each lighting installation commonly uses many high-power LEDs, white point stability is a point of concern for lighting designers. Typically, white high-power LEDs, created by combining blue LEDs with yellow (and sometimes red) phosphor, will shift towards blue over operational life. This shift can be accelerated by high temperatures and high drive currents. For example, a cool white (e.g., 6500K CCT) LED with a white point failure will typically appear light blue instead of white. In some high-power LEDs, this failure mode can occur after just 1,000 hours of operational life.

Just as with fluorescent light sources, all white high-power LEDs will experience shifts in white point over their operating lives. It is possible for the design of the phosphor and packaging systems to minimize these shifts and contain the shifts to be less than what is detectable by the human eye. As with catastrophic failures, parametric failures can be minimized by adhering to limits specified in XLamp documentation.

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XLamp Package Design

A high power LED is a system that combines an LED chip, electrical and thermal connections, encapsulating substances, an optical element, and (in the case of white LEDs) a phosphor system. The term "package" refers to all the elements except the LED chip and phosphor. The design of the LED package plays a very important role in determining how robust the packaged LED is in extreme conditions.

For example, small-signal LEDs, such as a 5-mm round LED, cannot run at higher currents due to thermal expansion of the encapsulating epoxy. At high current, the LED itself heats up, causing the surrounding epoxy to expand due to temperature. At some point, the thermal expansion of epoxy breaks the internal electrical connection to the LED, a catastrophic failure.

High-power LEDs are packaged differently than small-signal LEDs and are designed to operate at much higher currents and in much harsher ambient conditions than small-signal LEDs. The following are several key highlights of the XLamp package design that enable this high level of reliability:

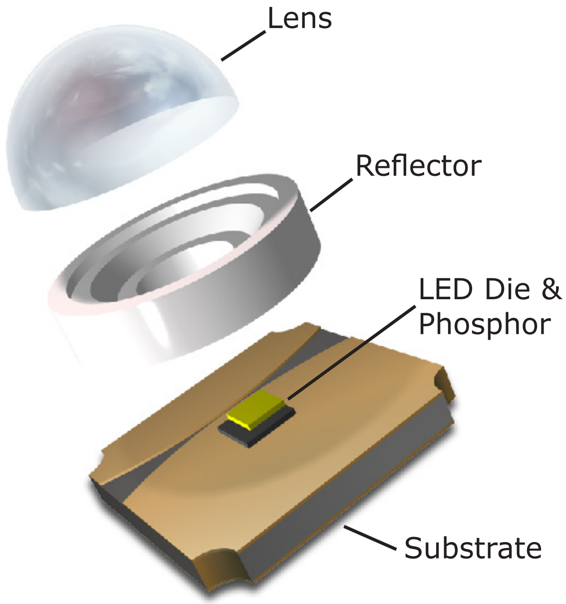
Floating Lens

The XLamp LED lens is said to "float" because the lens rests on top of the encapsulant material and is not fixed to the package. As the encapsulant expands and contracts with temperature, the lens is allowed to move in the axis perpendicular to the LED mounting surface. This feature allows XLamp LEDs to be used in extreme and varied temperature conditions without placing stress on the internal electrical connections.

Low-Thermal-Resistance Substrate

High LED junction temperatures will accelerate the loss of light output over operating lifetime, already mentioned as the cause of the most common parametric failure for high-power LEDs. Therefore, extracting heat away from the LED junction is a very important element of proper LED system design. Thermal resistance is a measure of how easily heat passes through a material, with low numbers meaning heat flows through more easily.

The XLamp LED package uses a substrate with an extremely low thermal resistance (e.g. 8°C/W for XLamp XR & XR-E LEDs). This low thermal resistance means XLamp LEDs are efficient at channeling heat away from the LED junction and into the package's thermal path. For more information, please read the application note Cree XLamp Thermal Management.



Leadless & Reflow Solderable

XLamp LEDs are leadless packages designed for standard, surface-mount technology (SMT) processes, including pick-and-place and lead-free reflow soldering. The ease-of-use of XLamp LEDs ensures lighting manufacturers that they can use standard, mechanical assembly processes when designing XLamp LEDs into their products.

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Pre-Release Qualification Testing

Before releasing a new XLamp LED to production, Cree puts a representative product sample set through an entire suite of pre-release qualification tests. There is no unified standard for qualification testing in the high-power LED industry. Each LED company must decide what tests and conditions to use to qualify new products.

Cree's pre-release qualification test suite, shown on the next page, is based on standard semiconductor pre-release qualification test conditions and methods defined by JEDEC (Joint Electron Device Engineering Council). Cree's testing methods differ from the rest of the high-power LED industry in several key areas:

Wet High-Temperature Operating Life

The most stressful test for high-power LEDs is the Wet High-Temperature Operating Life (WHTOL) test as defined by JEDEC JESD22 Method A101-B. The goal of the test is to cycle the LED temperature in high humidity to test how well the LED keeps moisture from penetrating into the package and causing damage.

When a high-power LED is operating in steady state at its maximum current in high ambient temperature, the heat generated by the LED will keep any moist air from penetrating the package. For this reason, JESD22 Method A101-B calls for the LED to turn on and off periodically to allow the LED to cool and for moisture to penetrate the package. Cree tests all color and cool white LEDs under this cycled condition to test for high reliability.

Furthermore, JESD22 Method A101-B calls for the WHTOL test conditions to be 85°C and 85% relative humidity for 1,000 hours. Cree follows this testing methodology for all color and cool white LEDs to ensure its products are qualified in the harshest of environments.

Acceptance Criteria

Every qualification test must have acceptance criteria, to determine which parts passed each test. Cree adheres to very stringent acceptance criteria that ensure XLamp LEDs have a high level of quality. After each operating life test, Cree measures every sample LED for forward voltage shift, luminous flux degradation, forward leakage and reverse leakage.

To pass the non-operating-life tests, every sample part must light up after testing.

Ongoing Production Monitoring

Cree regularly takes samples from XLamp production lots and performs the same WHTOL and thermal shock tests performed in pre-release qualification to verify that all production parts consistently meet the same high level of performance. These two tests are used because they represent the most severe tests for high-power LEDs.

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Pre-release Qualification Test List (Operating Life Tests)

Test	Applicable Standards	Test Conditions & Failure Criteria
Room Temperature Operating Life Test (RTOL)	JESD22 Method A108-C	**Test Conditions:** • Ambient Temperature : 45°C • Forward Current : Maximum in datasheet • Test Period : 1008 hours **Failure Criteria [1] :** • Forward Voltage shift [2] : > 200 mV • Luminous Flux degradation [2] – InGaN LEDs [3] : > 15% – AlInGaP LEDs [4] : > 25% • Forward or Reverse Leakage [5] : > 10µA • Catastrophic failure [6]
High Temperature Operating Life Test (HTOL)	JESD22 Method A108-C	**Test Conditions:** • Ambient Temperature : 85°C • Forward Current : Maximum in datasheet • Test Period : 1008 hours **Failure Criteria [1] :** • Forward Voltage shift [2] : > 200 mV • Luminous Flux degradation [2] – InGaN LEDs [3] : > 15% – AlInGaP LEDs [4] : > 25% • Forward or Reverse Leakage [5] : > 10µA • Catastrophic failure [6]
Wet High Temperature Operating Life Test (WHTOL)	JESD22 Method A101-B [7]	**Test Conditions:** • Forward Current : Maximum in datasheet • XR-C & XR-E White (<5000K CCT) LEDs – Ambient Temperature : 60°C – Humidity : 90% relative humidity (RH) – Time : 500 hours (cycled) • All other XLamp LEDs – Ambient Temperature : 85°C – Humidity : 85% relative humidity (RH) – Time : 1008 hours (cycled) **Failure Criteria [1] :** • Forward Voltage shift [2] : > 200 mV • Luminous Flux degradation [2] – InGaN LEDs [3] : > 15% – AlInGaP LEDs [4] : > 25% • Forward or Reverse Leakage [5] : > 10µA • Catastrophic failure [6]
Low Temperature Operating Life Test (LTOL)	JESD22 Method A108-C	**Test Conditions:** • Ambient Temperature : -40°C • Forward Current : Maximum in datasheet • Test Period : 1008 hours **Failure Criteria [1] :** • Forward Voltage shift [2] : > 200 mV • Luminous Flux degradation [2] – InGaN LEDs [3] : > 15% – AlInGaP LEDs [4] : > 25% • Forward or Reverse Leakage [5] : > 10µA • Catastrophic failure [6]

Notes:

1. The entire test has failed if one LED (or more) from the sample set satisfy the listed failure criteria. If no LED satisfies the listed failure criteria, the test is successful.
2. Comparison is made between [value at time 0] and [value at the end of the test period]
3. InGaN LEDs are white, blue, green and cyan LEDs
4. AlInGaP LEDs are red, red-orange and amber LEDs
5. Criteria applies to leakage of the LED die and not to leakage due to the LED package
6. A catastrophic failure is a failure that causes the LED to become non-functional (i.e., open or short)
7. JEDEC method applies for all XLamp LEDs except for XR-C & XR-E White (<5000K CCT) LEDs

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Procedures for Operating Life Tests

The following procedures are followed for RTOL, HTOL, WHTOL, and LTOL tests:

- XLamp LEDs are reflow soldered onto metal-core printed circuit boards (reference application note Cree XLamp LED Soldering & Handling).
- PC boards are mounted onto heat sinks within reliability test chambers.
- While the LEDs are powered off, internal conditions within the test chambers are brought to those specified for the individual tests (i.e., 85°C/85% RH for WHTOL).
- Heat-sink temperature is maintained at the test-chamber temperature during the test.
- Power is applied to the lamps. In the case of WHTOL, power is applied in one-hour intervals that are followed by one-hour intervals without power in order to let the moisture penetrate the package as much as possible. This procedure results in a test that is more rigorous than one that calls for applying continuous power.
- At regular intervals power is turned off and the sample boards are removed from the tester according to JEDEC testing protocol.
  - The lamps are characterized according to reliability test criteria and inspected for visual defects.
  - The boards are placed back into the test chambers and the procedure is repeated until the test has concluded.

Pre-release Qualification Test List (Non-Operating Life Tests)

Test	Applicable Standards	Test Conditions & Failure Criteria
Thermal Shock	MIL-STD-202G Method 107G	**Test Conditions:** • Temperature Range : -40°C to 125°C • Dwell Time : 15 minutes • Transfer Time : < 20 seconds • Cycles : 200 cycles **Failure Criteria [1] :** • LED no longer lights up after test
Mechanical Shock	JESD22 Method B104-C Condition B	**Test Conditions:** • Shock : 1500 G • Pulse Width : 0.5 ms • Direction : 5 each, 6 axis (30 total) **Failure Criteria [1] :** • LED no longer lights up after test
Salt Atmosphere (Corrosion Test)	JESD22 Method A107-B Condition B	**Test Conditions:** • Ambient Temperature : 35°C • Salt Deposit : 30 g/m²/day • Test Period : 48 hours **Failure Criteria [1] :** • LED no longer lights up after test

Notes:

1. The entire test has failed if one LED (or more) from the sample set satisfy the listed failure criteria. If no LED satisfies the listed failure criteria, the test is successful.

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Long-Term Lumen Maintenance Testing

As described in the Parametric Failure section of this document, a common failure mode for high-power LEDs is gradual dimming over a long period of time – about 50,000 hours for XLamp LEDs. To better describe this failure mode, lumen maintenance establishes a relationship between a light source's light output level and its operational life. Every application with high power LEDs is going to be different and have unique design constraints. Therefore, the definition of useful LED lifetime will vary from application to application.

As with all LEDs, there is a direct relationship between the LED junction temperature and the permanent loss of light output over time. Running XLamp LEDs at higher junction temperatures will decrease the useful LED lifetime. In general, the following three system-level factors greatly influence the LED junction temperature:

- operating current
- ambient temperature
- thermal resistance of the thermal path to the ambient environment

As a light-source manufacturer, Cree is responsible for providing data on how these different factors affect XLamp LED lifetimes so that lighting designers can optimize their systems for their application.

To date, Cree has tested and accumulated long-term lumen maintenance data for XLamp 7090 LEDs using industry-recognized test and extrapolation methods. In April 2006, ASSIST (the Alliance for Solid-State Illumination Systems and Technologies), of which Cree is a member, defined a new LED lumen maintenance test methodology in the document "LED Life for General Lighting" in the section "Measurement Method for LED Components." Given that our test methods pre-dated the ASSIST recommendations, Cree's methodology has some differences in the specific testing temperatures. Cree does follow the same testing and extrapolation method as ASSIST, and our testing temperatures act as outer boundaries for the ASSIST recommendation. Therefore, Cree is able to base its long-term lumen maintenance projections on our existing long-term data sets.

IESNA (Illuminating Engineering Society of North America), ANSI (American National Standards Institute), and the United States Department of Energy are working together to also define standards for how to measure LED lumen maintenance. This standard is not yet ratified but, as of the date of this publication, is almost identical to the ASSIST standard mentioned above. The release of the new standard is expected to be no later than December 2007.

Lumen Maintenance Projections

Cree has accumulated operating data in excess of 20,000 hours. Cree has extrapolated LED lifetime according to the ASSIST method described in the last section. Based on this method, Cree projects XLamp LEDs to maintain an average of 70% lumen maintenance after 50,000 hours, provided the LED junction temperature is maintained at or below 80ºC.

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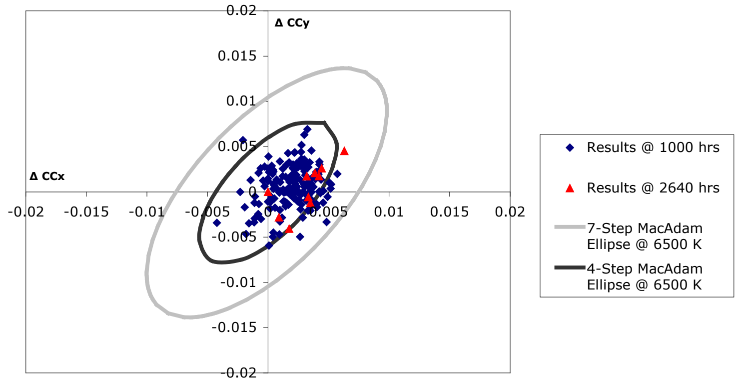
White Point Stability

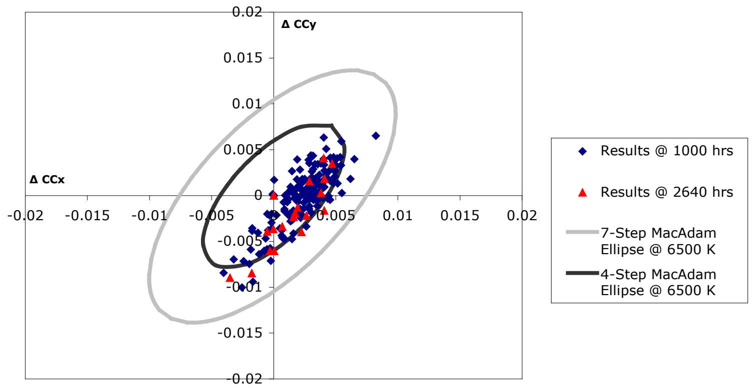
The lighting industry demands both high lumen maintenance and very stable color output from the incumbent lighting technologies. As described in the LED Failure Types section, white high-power LEDs will experience shifts in white light output over operational life. High-temperature conditions will accelerate these white point shifts. Therefore, Cree monitors the white light output of the XLamp XR-E LED over time under high-temperature conditions.

Specifically, the exact color of the white light output, expressed in terms of the CIE 1931 color space, is measured periodically while the XLamp LEDs are operating in high-temperature conditions. The following graphs show the change in color after the specified time in the specified conditions, in terms of change in x and y in the CIE 1931 color space. Included in the graphs for reference are 4-Step and 7-Step MacAdam ellipses for 6500K CCT. MacAdam ellipses are derived from subjective testing and are a measure of how sensitive the human eye is to slight changes in color. For the average human eye, color changes within a 4-Step MacAdam ellipse are undetectable.

XLamp XR-E Cool White LED - White Point Stability : I_f = 350 mA @ 85°C



XLamp XR-E Cool White LED - White Point Stability : I_f = 700 mA @ 85°C



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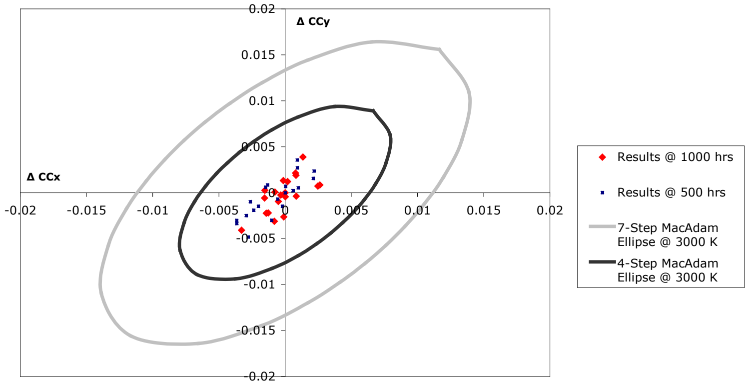
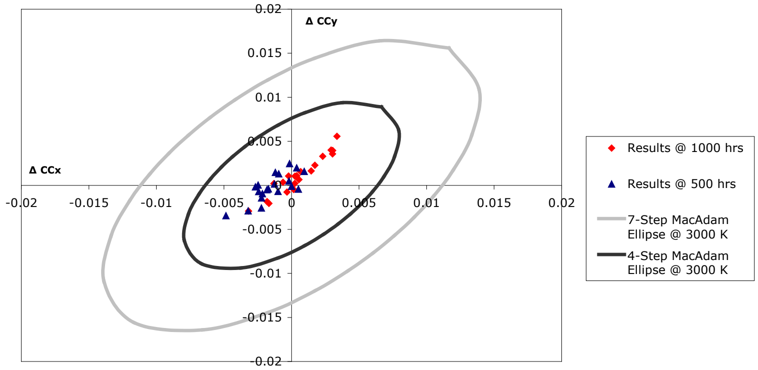
White Point Stability (cont.)

XLamp XR-E Warm White LED - White Point Stability : I_f = 350 mA @ 85°C



XLamp XR-E Warm White LED - White Point Stability : I_f = 700 mA @ 85°C



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