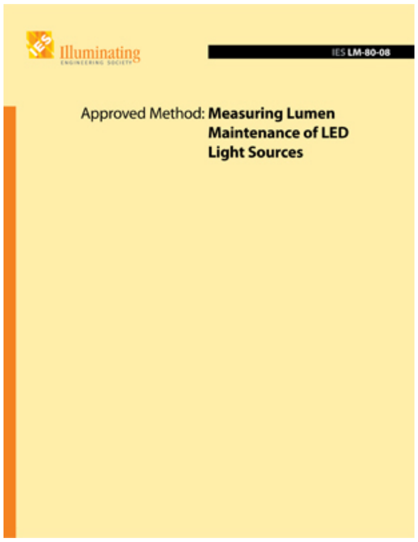
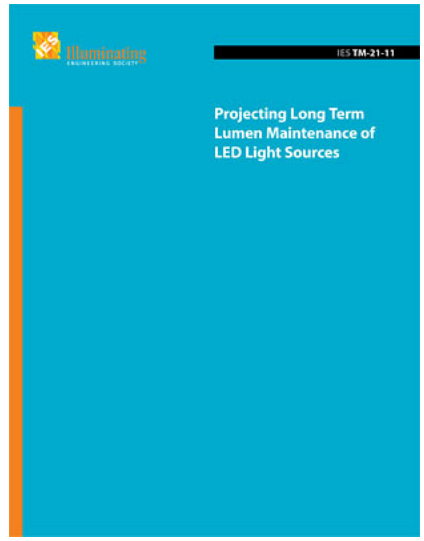
CREE LED

XLamp® LED Long-Term Lumen Maintenance





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INTRODUCTION

High-power LED lamps typically do not fail catastrophically, i.e., fail to emit light, but slowly decrease in light output over time. To characterize this gradual light loss, Cree LED uses Illuminating Engineering Society (IES) LM-80 compliant test configurations and procedures. Because many high-power LED lamps do not reach their L70 lifetime[1] even after thousands of hours of testing, Cree LED uses the methods recommended in IES TM-21 to project long-term lumen maintenance behavior of its LEDs.

1 The duration of time until the LED light output has decreased to 70% of its initial light output.

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DEFINITIONS & CONCEPTS

Forward current (IF): The amount of current flowing through an LED lamp operating in forward bias, typically measured in milliamps (mA).

Forward voltage (V_F): The voltage potential across an LED lamp operating in forward bias, typically measured in volts (V).

Lumen depreciation: The luminous flux output lost (expressed as a percentage of the initial output) at any selected elapsed operating time. Lumen depreciation is the converse of lumen maintenance.

Lumen maintenance: The luminous flux output remaining (expressed as a percentage of the initial output) at any selected elapsed operating time. Lumen maintenance is the converse of lumen depreciation.

Lumen maintenance life: The elapsed operating time at which the specified percentage of lumen depreciation or lumen maintenance is reached, expressed in hours. The elapsed operating time does not include the time when the light source is cycled off or periodically shut down.

Rated lumen maintenance life (Lρ): The elapsed operating time over which the LED light source maintains a given percentage of its initial light output. This is expressed as Lρ where ρ is the percentage value. For example,

- L50 = Time to 50% lumen maintenance, in hours.
- L70 = Time to 70% lumen maintenance, in hours.
- L85 = Time to 85% lumen maintenance, in hours.

For LED lamps, lumen maintenance is often shown as curves of relative lumen output over time for the LED under various operating conditions, such as drive current and junction temperature.

Temperature, ambient air (T_{AIR}): The temperature of the air immediately surrounding the LED. In general, this temperature should be measured outside the full-width half-maximum (FWHM) beam angle of the LED and within the enclosure that contains the LED.

Temperature, junction (T_J): The temperature of the junction of the LED die inside the LED lamp. Measuring the LED die temperature by direct mechanical means is difficult and attempting to do so may lead to erroneous results. Cree LED recommends determining T_J indirectly through measurement of T_{SP}, V_F and I_F and using the following equation.

$$T_J = T_{SP} + (R_{th\ j\text{-}sp} \times V_F \times I_F)$$

Note: $R_{th\ j\text{-}sp}$ is the thermal resistance between the LED junction and the solder point of the LED lamp. This parameter is provided on all Cree LED XLamp® LED data sheets.

Temperature, solder point (T_{SP}): The temperature of the thermal pad on the bottom of the LED lamp. Cree LED shows the recommended T_{SP} for all XLamp LEDs in each applicable soldering & handling document. T_{SP} is also called case temperature (T_C).

Figure 1 shows the lumen maintenance temperature parameter measuring points.

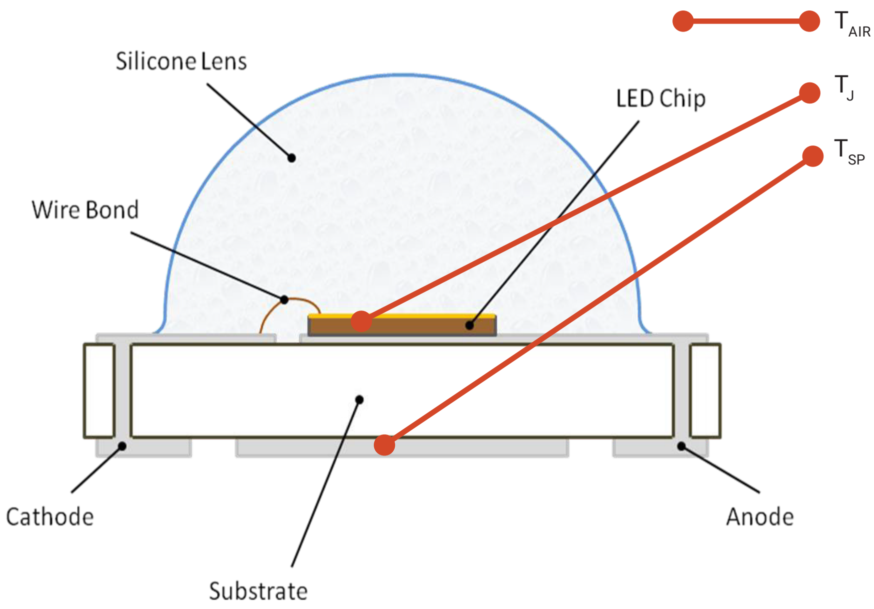

Figure 1: Lumen maintenance temperature parameter measuring points

IES LM-80-2008 AND IES TM-21-2011

IES LM-80-2008, "Measuring Lumen Maintenance of LED Light Sources" ("LM-80") is the industry standard that defines the method for testing LED lamps, arrays and modules to determine their lumen depreciation characteristics and report the results. The goal of LM-80 is to allow a reliable comparison of test results from different laboratories by establishing uniform test methods. Cree LED's solid-state lighting (SSL) testing laboratory in Durham, NC, USA is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP®) to perform LM-80 testing. All LM-80 results produced by Cree LED are generated in Cree LED's accredited laboratory, listed as NVLAP lab code 500041-0.

IES TM-21-2011, "Projecting Long Term Lumen Maintenance of LED Light Sources" ("TM-21") is the technical memorandum that recommends a method of using LM-80 test results to determine the rated lumen maintenance life (Lρ) of LED lamps.

The US Environmental Protection Agency (EPA) recognizes the validity of these methods and requires their use for the approval of luminaires for ENERGY STAR® compliance. As a recognized ENERGY STAR partner, Cree LED has used and will continue to use the methods defined in LM-80 and TM-21 to test the long-term lumen maintenance of XLamp LEDs and to project their lumen maintenance life.

LM-80 COMPLIANT LUMEN MAINTENANCE TESTING

Cree LED's SSL testing laboratory, accredited by NVLAP, tests XLamp LED lamps for long-term lumen maintenance consistent with LM-80 methods. Specifically, sets of XLamp LED lamps are first mounted onto metal core printed circuit boards (MCPCB). A set typically contains thirty individual XLamp LED lamps. The boards are then attached to heat sinks in environmental test chambers. The T_{SP} of each LED lamp is actively monitored and controlled by continuously regulating the temperature of the heat sink. Ambient air temperature (T_{AIR})

in the chambers is also actively monitored and controlled by regulating the temperature of the air flowing through the chambers. Per LM-80 4.4.2, T_{AIR} in the environmental chamber is controlled to be held within -5 °C of T_{SP}. Per LM-80 4.4.3, care is taken to minimize any drafts in the immediate vicinity of the devices under test.

The electrical and photometric properties of each of the XLamp LED lamps are initially measured in an integrating sphere before the testing begins (at t=0). The LED lamp sets are then placed into the environmental chambers – with various sets of lamps being operated at various drive currents (from nominal to maximum as specified in the XLamp LED data sheets). At regular intervals (per LM-80, at least every 1,000 hours), the LED lamps are removed from the environmental test chambers and re-measured in an integrating sphere.

FACTORS AFFECTING LED LUMEN MAINTENANCE

Operating temperature and drive current are two well-known variables that affect the long-term lumen maintenance of high-power LED chips. Over thousands of hours of use, high temperatures reduce the efficiency of the quantum wells in the chip causing a slow loss in light output. This is why precise temperature control during LM-80 testing is so important. In addition to the LED chip, the manufacturing methods and the materials used in the construction of the LED lamp components are also critical variables that are affected by temperature and drive current and are the primary factors that impact the lumen maintenance behavior of LEDs. As all of these variables are interrelated, the topic of LED lumen maintenance is quite complex.

The primary factors that can influence the lumen maintenance of this type of product include (but may not be limited to) the following.

- The silicone material used as the lens on the LED lamp
- The LED chip materials and fabrication technology
- The phosphor used and the phosphor application method

These factors are illustrated in the high-power LED lamp cross-section drawing in Figure 2. Taken as individual sub-components within the LED lamp, they each are influenced by the operating conditions (temperature and current) and each might degrade differently over time.

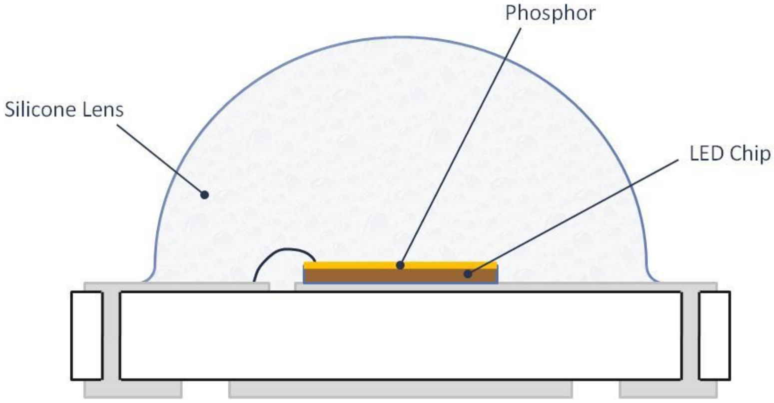

Figure 2: Cross-section of high-power LED lamp showing primary factors that affect lumen depreciation

The silicone encapsulants are a good example of this degradation. The silicones used in the LED industry are polyorganosiloxanes (or siloxanes).[2] Depending on their exact chemical composition, these siloxanes may be very sensitive to operating temperatures. At higher

2 For additional information, refer to Cree LED's Chemical Compatibility Application Note.

temperatures the transparent nature of the materials can quickly degrade causing an overall loss in light output from the LED lamp. The energy of the photons emitted from the chip itself can also damage the siloxane material, further reducing its transparency, causing additional lumen depreciation. Thus, the higher the drive current, the more light being emitted from the chip and the faster the lumen depreciation of the lamp. Higher drive currents also result in higher operating temperatures of the LEDs, compounding the depreciation issue.

Like the high-power LED lamps previously discussed, mid-power LED lamps, shown in cross-section in Figure 3, also use siloxanes as encapsulants and so are similarly sensitive to heat and photonic energy. However, unlike high-power LED lamps, which are constructed with ceramic substrates, most mid-power (and low-power) LEDs are packaged in polyphthalamide (PPA) plastic polymers. PPA polymers are even more susceptible to damage from heat and photonic energy than some of the most sensitive silicones used as LED encapsulants. Exposure to temperature and light causes these PPAs to darken. Since much of the light emitted from plastic-packaged LEDs is reflected off the interior walls of the package, the inevitable darkening of the PPA results in rapid lumen depreciation. The quick lumen depreciation that results from operating mid-power LED lamps at higher temperatures and drive currents limits their use to non-critical lighting applications, where long lumen maintenance is not necessary.

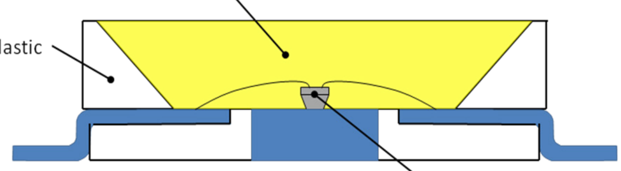

Figure 3: Cross-section of mid-power LED

An understanding of the construction of LED components, their sensitivities to operating conditions and the desired long-term lumen maintenance are important in selecting the correct LED to be used in a specific application.

USING TM-21 TO PROJECT RATED LUMEN MAINTENANCE LIFE

Once a minimum of 6,000 hours of LM-80 testing has been completed, the test results can be used to project the rated lumen maintenance life (Lρ) of the LED. Per TM-21, the data collected at each measurement point is averaged and normalized to 1 (or 100%) at time 0. An exponential least squares curve fit to each of the averaged data points between 1,000 and 6,000 hours is then performed. The curve can then be projected forward to determine the point at which it crosses the desired Lρ. The Lρ values can also be calculated using the equation of the exponential curve that is fit to the data. One stipulation with TM-21 is that the reported Lρ for a data set is limited to six times the actual test duration. Thus, when using 6,000 hours of actual test data, any maximum Lρ can be reported only as "> 36,000" hours.

In the example shown in Figure 4, the exponential curve is fit to all of the data points between 1,000 and 6,000 hours. The calculated L85 lifetime is 23,200 hours and the calculated L70 lifetime is 50,000 hours. However, since only 6,000 hours of testing have been completed, the L70 lifetime can be reported only as > 36,000 hours. Since the calculated L85 lifetime of 23,200 hours is less than 36,000 hours, the actual L85 lifetime value can be reported. When reporting LM-80 results using TM-21 projection methods, specific nomenclature is required: the Lp values and completed test times are both shown. So for the data set shown in Figure 4, the L85(6K) lifetime = 23,200 hours and the L70(6K) lifetime > 36,000 hours.

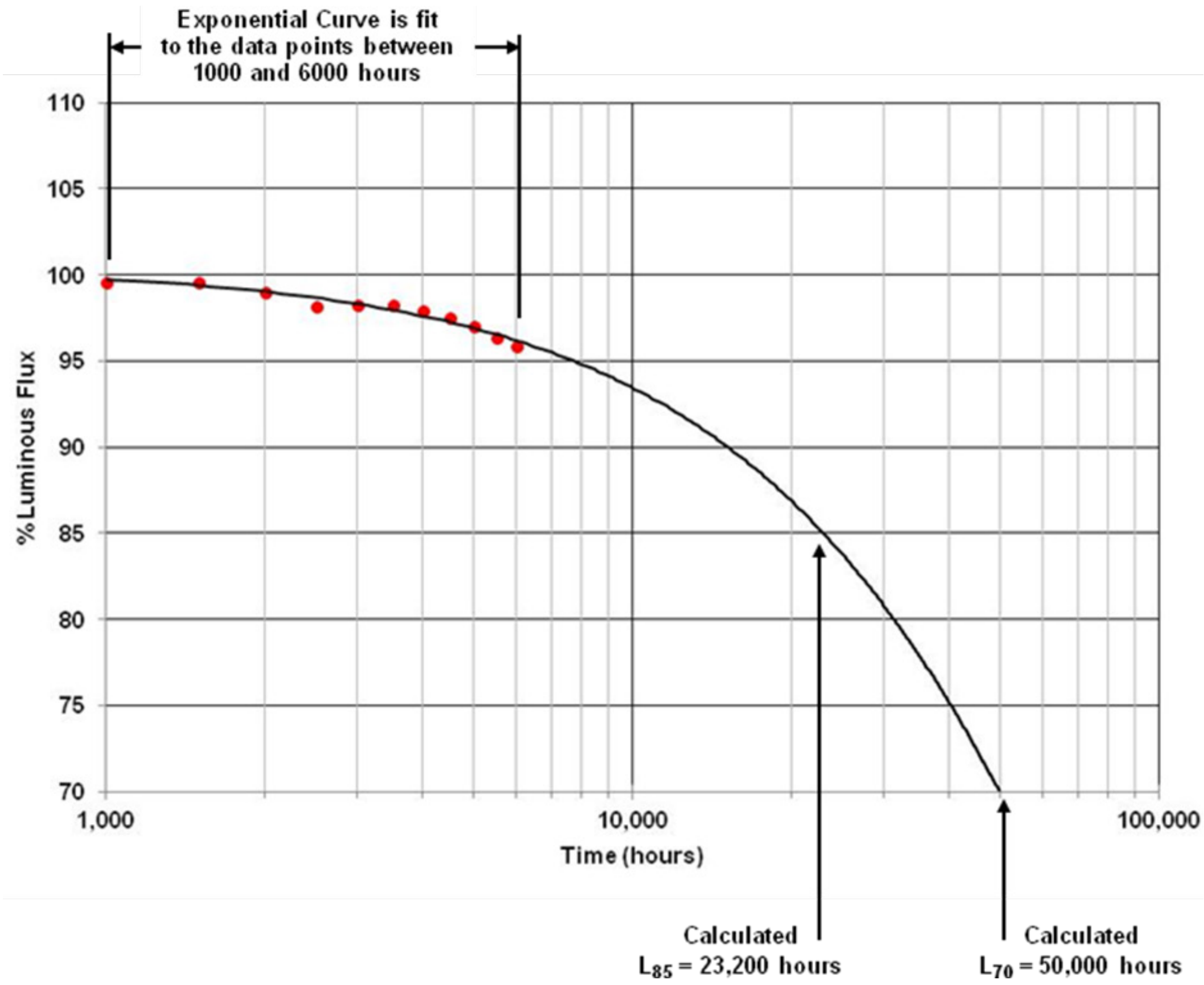

Figure 4: Example lumen maintenance lifetime at 6,000 hours

As LM-80 testing continues, more data is obtained. When 6,000 to 10,000 hours of testing has been completed, the exponential curve fit is made to the last 5,000 hours of average points rather than all the points. This is done because the rate of lumen depreciation of LEDs frequently slows as testing progresses, which can result in higher projected Lρ values. The example in Figure 5 shows the same data set as in Figure 4 now that 10,000 hours of testing have been completed. Fitting an exponential curve to the points between 5,000 and 10,000 hours results in the calculated Lρ values shown. Once again, per TM-21, the reported L70 lifetime is limited to six times the test duration of 10,000 hours, or 60,000 hours. So for this data the reported L85(10K) lifetime = 28,500 hours and the L70(10K) lifetime > 60,000 hours.

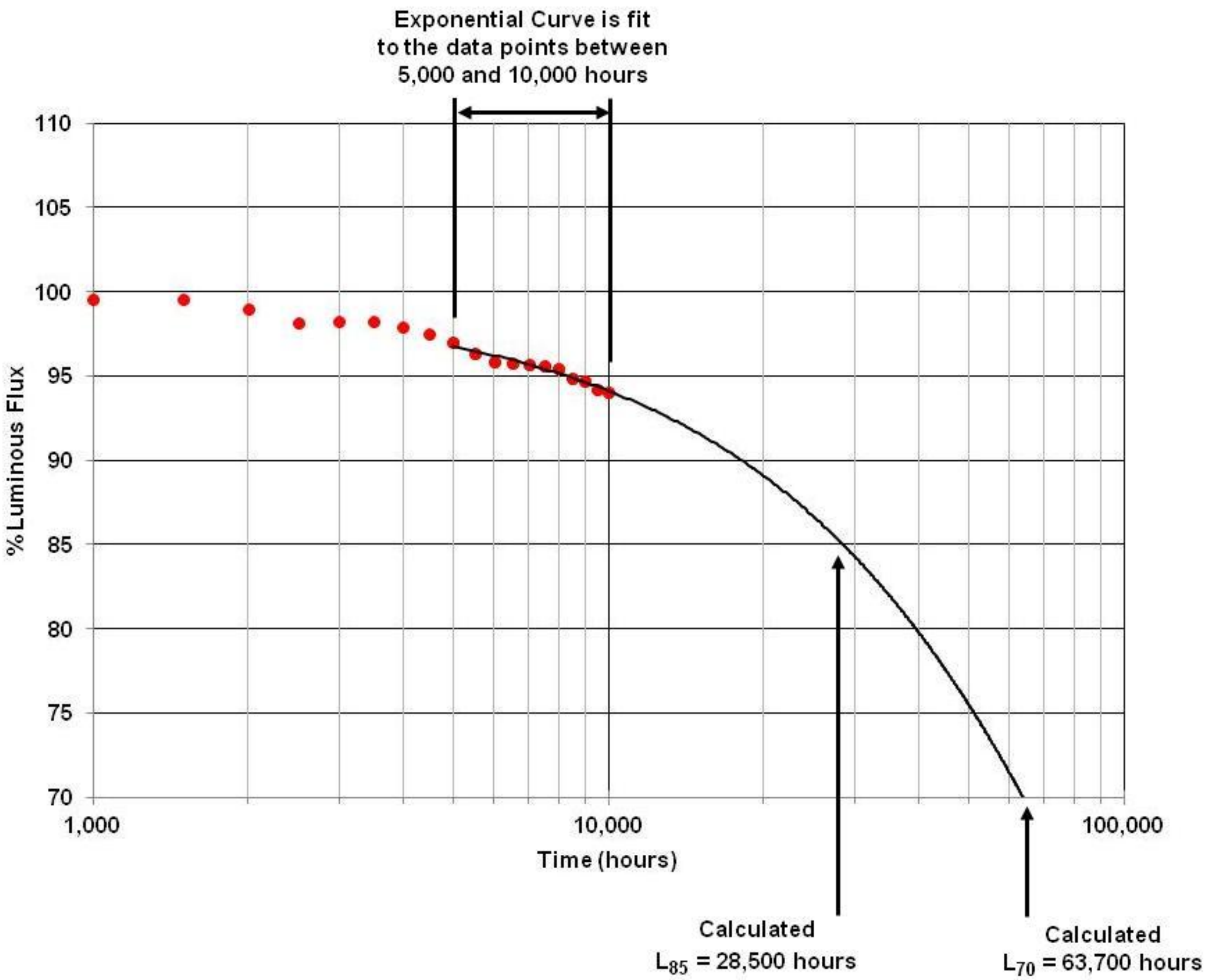

Figure 5: Example lumen maintenance lifetime at 10,000 hours

As LM-80 testing progresses beyond 10,000 hours, the last 50% of the data points is used for the exponential curve fit. If 12,000 hours of testing have been completed, the last 6,000 hours of data (12,000/2 = 6,000) are used for the curve fit. If 16,000 hours of testing have been completed, the last 8,000 hours of data are used for the curve fit. In all cases, the maximum six times Lρ projection limit is used.

LM-80 REPORTS

Cree LED publishes LM-80 test reports for XLamp LED products. A summary of these reports can be found in the LM-80 Testing Results application note. The full LM-80 test report for each individual XLamp LED product can be requested from Cree LED sales. These detailed reports can be used for the submission of lighting products to ENERGY STAR or the DesignLights Consortium® for product approval. Cree LED updates the XLamp LED LM-80 reports on a regular basis as additional LM-80 testing is completed.