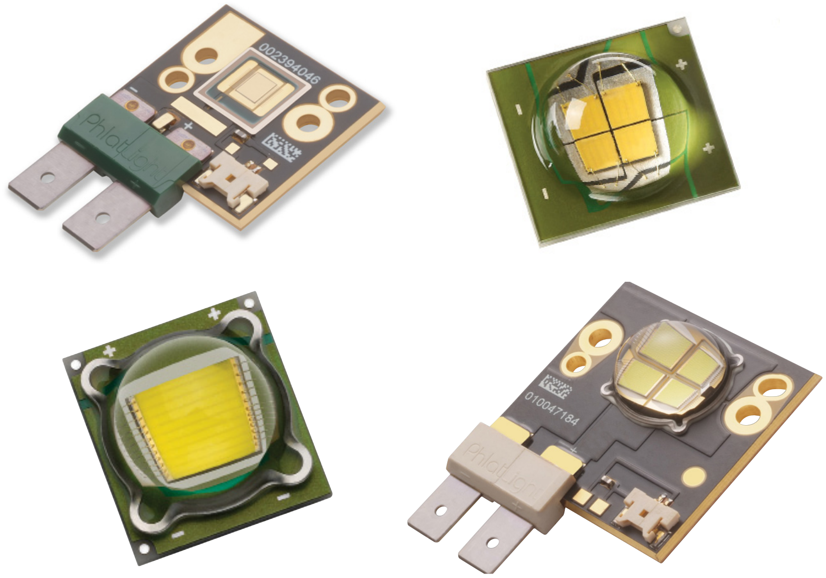
# Testing Big Chip LEDs



## Table of Contents



Luminus Devices manufactures high performance Big Chip LEDs for a variety of illumination applications, previously thought impossible for solid state lighting. Big Chips, by virtue of their size, are rated at relatively high drive currents and require unique electrical and thermal solutions; addressing the LED's electrical and thermal requirements is crucial in accurately specifying its performance. This application note explains how Big Chip LEDs are tested at Luminus, the techniques, protocols and equipment used to report their performance. LEDs, though known their long lifetimes, are sensitive to drive currents, and electrical overstress can significantly reduce their lifetime. This note explains how to regulate drive currents and avoid electrical overstress when energizing Big Chip LEDs; and gives suggestions on how LEDs can be tested for functionality.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## 1. Production Testing of LEDs

A Big Chip, 12 mm$^2$ LED such as the PT-120 can generate up to 74 W of heat when driven at its maximum rated current density of 1.5 A/mm$^2$, and systems using these LEDs are likely to operate at temperatures higher than the ambient. To report the performance characteristics of these Big Chip LEDs in a manner that would replicate their performance in an actual system, Luminus production tests all chip on-board LEDs (PT, CBM, CBT, CSM and CST series) by mounting them on a heat sink at 40° C, and allowing the LEDs to reach equilibrium while fully powered on, before measuring their electrical and optical performance. While the temperature is controlled in chip-on board products, this is not the case in surface mount products (SST, SSM, SBT, SBM series) since the choice of mounting the LED on a circuit board lies with the end-user; these LEDs are tested with a single pulse (~20 ms) at drive currents listed in product datasheets. The parameters that are characterized during production testing are current, voltage, radiometric power, FHWM, peak lumens, peak, dominant and centroid wavelength, CIE x, CIE y, and where applicable, CCT and CRI. Custom test stations, designed to precisely maintain operating current and temperature of the device under test (DUT), are used to measure and specify the LED's performance. The test station, whose schematic is shown in Fig.1, consists of an integrating sphere with a port large enough to capture most of the light emitted by the DUT, a fast broadband photo-detector for flux measurements and a spectrometer for spectral analysis.

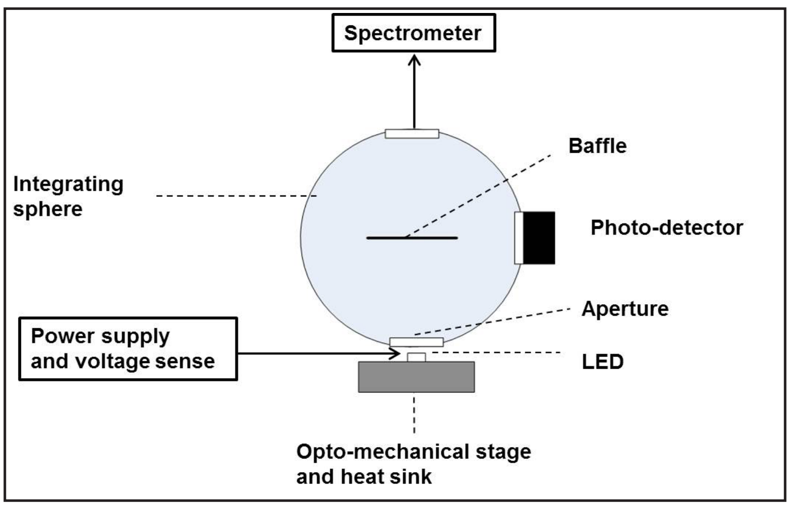


Figure 1: Schematic of Test Station

## 2. Accuracy and Calibration

To report the electrical and optical characteristics of the DUT accurately, the test station's components are calibrated on a regular basis and compared to NIST traceable sources. In addition, Luminus externally validates the LED's reported performance parameters for independent verification. The following sections explain how different electrical and optical characteristics of LEDs are measured at Luminus:

### 2.1. Current and Voltage

The preferred method of driving LEDs is to use a current source, and since the brightness of LEDs depends on drive current, maintaining accurate drive currents is critical. To maintain accurate drive current, the drive electronics in the Luminus test system use feedback-loop control of the voltage drop across an in-line precision sense resistor. Further, a calibrated current sensor monitors the drive current to ensure the driver's accuracy in sourcing the specified current. Voltage measurements are performed with commercial precision meters using a 4- wire (Kelvin) configuration, to eliminate the voltage drop across the leads, which becomes increasingly important at high drive currents.



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### 2.2. Spectral Distribution

Light from the excited DUT enters the integrating sphere where a small fraction of it is directed via an optical fiber to a spectrometer, which determines the spectral distribution of light. The spectrometer has a CCD array detector, with each pixel in the array corresponding to a certain wavelength of light. The relationship between a pixel and wavelength is established by a NIST traceable calibration source that produces multiple narrow first-order mercury and argon spectral lines in the 253-922 nm range.

### 2.3. Radiometric Flux

A fast broadband photo-detector with a transimpedance amplifier mounted on the integrating sphere of the test station is used for radiometric flux measurements. The wavelength dependent response of the photo-detector - in volts of output signal per watt of captured flux at a given wavelength-is calibrated against a NIST-traceable reference power meter using the substitution method (Figure 2). A stable, tunable, monochromatic (~ 3 nm line-width) light is first produced by filtering the light from a high-power discharge lamp using a scanning monochromator. The wavelength of this light is then varied across the visible range, and at each wavelength, the monochromator's output is captured alternately by the integrated sphere with the detector and by the integrating sphere with a NIST-traceable reference optical power meter. The output of the photo-detector is compared to the output of the

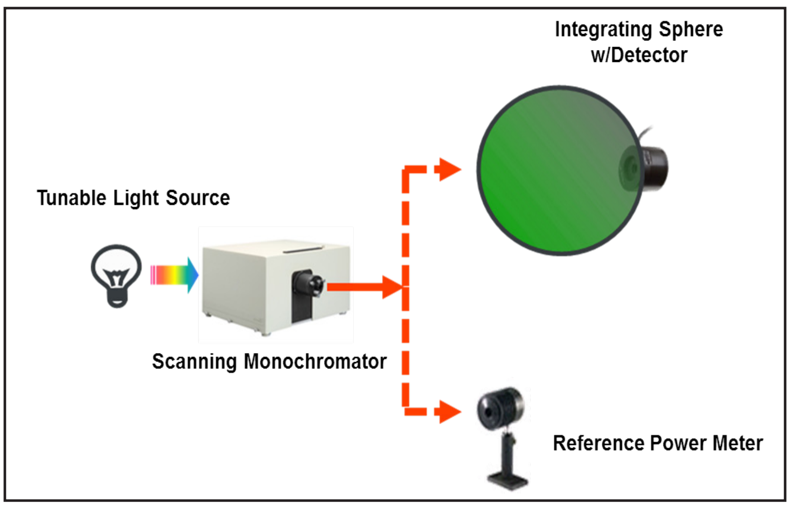


Figure 2: Substitution method of calibration

power meter for all wavelengths, resulting in a calibrated response curve. During production testing, the detector's output, in volts, is converted to absolute watts using the response curve. Once the spectral distribution and absolute power at each wavelength are determined, other quantities like FWHM, peak, dominant and centroid wavelength, peak lumens, CCT, CRI, CIE x, CIE y are computed.

## 3. Uncertainty

The calibration procedures ensure traceability and accuracy of measurements, but as with any measurement, some sources of uncertainty remain. Factors such as temperature and relative humidity, stability of current sources, and measurement noise all contribute to uncertainty. Some additional factors include:

a) The angular distribution of light output from the monochromator incident on the reference detector fills a solid angle defined by a numerical aperture of the instrument. Light rays hitting the reference detector surface at different angles contribute differently to the overall response since the reflectivity of the detector surface depends on the angle of incidence. Meanwhile, reference detectors are typically calibrated with normally incident light.



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b) LED test fixtures and calibration sources differ in geometry and construction; and integrating spheres are sensitive to different geometries in front of their input port.

These and other factors introduce up to a +/- 6 % uncertainty in flux measurements. Therefore, Luminus follows the industry-wide practice of specifying its flux values with a +/- 6 % uncertainty.

## 4. Maintenance Protocol

Once a test system is calibrated, it is essential to ensure that fixtures, equipment, instruments and test conditions don't drift over time. Luminus Devices employs a documented Statistical Process Control method to ensure long-term stability and accuracy of the test stations. A set of Golden LED Modules is periodically tested on the test systems, and verified to be within acceptable control limits prior to production use of the test stations.

## 5. Energizing LEDs

Though LEDs can have a lifetime as high as 60,000 hours, they are sensitive to drive currents and electrically overstressing them would result in irreversible damage and lead to much shorter lifetimes. Regulating the drive current in LEDs is critical because the current in an LED varies exponentially with voltage, in contrast to resistors such as an incandescent bulbs where the current - voltage relationship is linear (Ohm's law, V= IR), and small changes in voltage can result in a large variation in current through the LED. Figure 3 shows the I-V curve of a CBT-90 Big Chip LED with a typical forward voltage (Vf) of 3.6 V at 9 A; but the forward voltage can vary anywhere from 3.3 V to 4.3 V- this variation is common in semiconductor manufacturing. If a voltage regulated driver is set to 3.3 V, a value within the tolerance specified in the datasheet, and is used to drive two CBT-90 LEDs with Vf 3.3 V and 3.6 V, the resulting drive current would be 9 A in one LED and 4.5 A in the second LED, based on the I-V curve in Figure 4. Thus with the same driver, an 8 % difference in forward voltages of the two LEDs could translate to a 200 % difference in drive currents through them, an unacceptable situation in many applications. Temperature and aging also cause the forward voltage of LEDs to drift over time and using a voltage regulated driver to supply a constant voltage would result in drastic variation in the currents through the LEDs when operating conditions change. Brightness, being proportional to the drive current, would also exhibit drastic variations. The preferred method of ensuring that LEDs are a) driven at appropriate current levels and b) different LEDs in a system have the same brightness is to use a current regulated LED driver.

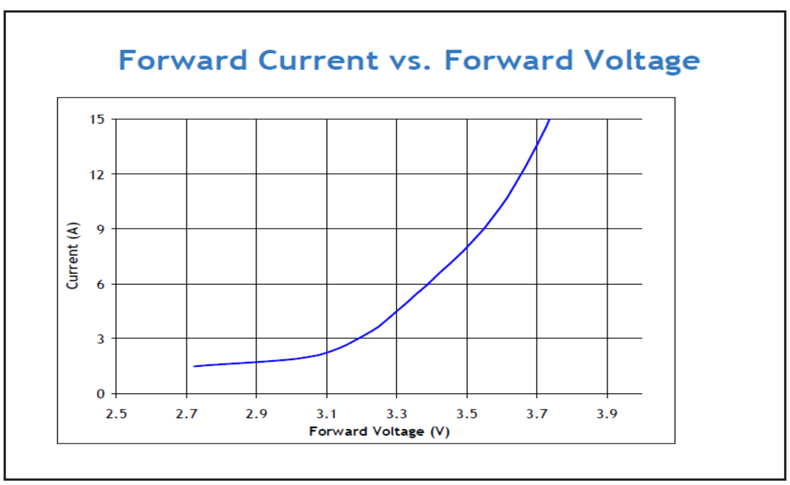


Figure 3: Typical I-V curve of a Big Chip LED

Once an appropriate current driver is selected, the next step is to energize the LED. An LED should never be introduced into an energized circuit or "hot switched" since this causes dangerous inrush currents that would irreversibly damage the LED. As an example, assume a red



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Big Chip LED rated at 5 A; and with a typical forward voltage of 2.5 V, connected to a current driver set to supply 5 A, with the voltage compliance set to 20 V. Before the LED is plugged in, an open circuit exists at the output of the driver and its voltage rises to the compliance limit of 20 V as it tries to source 5 A. When the LED is plugged into this energized circuit, the voltage across the LED is 20 V momentarily, and the exponential nature of the I-V relationship would result in transient surge currents that could be much higher than rated current , for a short period of time before the supply would regulate the current to 5 A. The energy supplied by the surge currents, even for short periods of time, is likely to permanently damage the LED. The correct approach is to "soft start" or "cold start" the LED which entails presetting the power supply to 0 V, connecting the LED to the driver and gradually increasing the drive current to the desired value while increasing the compliance voltage, typically to a value just greater than the maximum forward voltage of the LED. Using a current driver that includes the "soft start" feature is recommended.

## 6. Testing the Functionality of LEDs

In contrast to real-time applications where a small number of LEDs are run at rated drive currents, there may be circumstances where hundreds of LEDs need to be tested for functionality in a short period of time. To soft start each LED by pre-setting the driver to 0 V, 0 A, and slowly increasing the current to the rated value, then resetting to 0 V, 0 A before the next LED is tested is both time consuming and unnecessary. A quick test to check if the LED is functional can be carried out at relatively low currents-this simplifies driver requirements and requires no heat-sinking. To conduct a quick functionality check and simplify the logistics of implementing soft start, a circuit consisting of a regulated current source and a Make Before Break (MBB) switch as shown in Figure 4 can be employed. The driver output is dictated by the chip area, with recommended drive currents listed in Table 1. Note that the test currents listed in the table are only for the functionality check, during regular operation the drive current of the LEDs must be based on respective product data-sheets.

Table 1: Recommended Test Currents for Various Die Sizes

| Big Chip Die Size ($mm^2$) | Recommended Test Current (mA) |
|---|---|
| 12.0 | 100 |
| 9.0 | 75 |
| 8.5 | 70 |
| 5.4 | 45 |
| 5.0 | 40 |
| 3.9 | 35 |
| 1.6 | 15 |

To illustrate, if PT-120 LEDs (12 $mm^2$ chip area) are to be tested for functionality, the current driver is first set to supply 100 mA, and the MBB switch closed, shorting terminals A and B. The LED is then connected across A-B, with the voltage across the terminals being ~0 V, and the MBB switch is opened. The current shifts from the switch to the LED, and the output voltage rises from ~0 V to the forward voltage of the LED. Once the test is complete, the switch can be closed, the LED removed, and next LED can be connected across terminals A and B to repeat the test. This method is quick, easy to implement, and ensures that unacceptably high voltages are not applied across the LED.

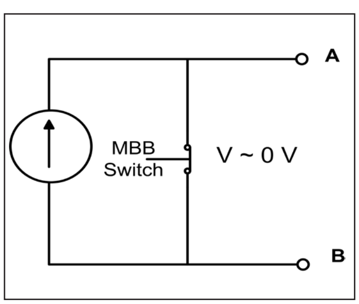


Figure 4a: MBB switch closed

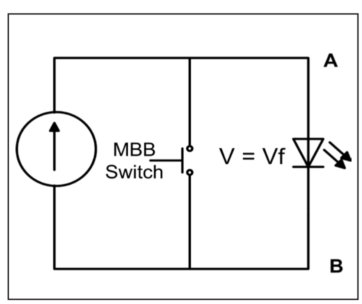


Figure 4b: MBB switch open



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