

Challenges of High Power LED Measurements

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With high power LEDs continuously increasing their lumens output they conquer new applications such as car headlamps, large size backlighting units and finally the interior and exterior lighting. These applications have very stringent requirements regarding homogeneity of color and intensity in order to ensure the high quality of the final products. Therefore, each LED is tested many times on its way from the first light from the chip until it is built into a product delivered to the end user.

However, high power LEDs have different optical and electrical properties than conventional 'low' power LEDs. Therefore, the testing equipment for high power devices must be specifically designed to deliver the accurate and reproducible results demanded by LED manufacturers and users.

Test Set-Up

A typical test set-up comprises a spectroradiometer, an integrating sphere for flux measurement, test sockets for the LED with thermal management, and if required, a pulsed current source to allow measurements at precisely defined junction temperatures. Each of these components must follow certain design requirements to contribute to the accuracy of the complete measurement setup.

Spectrometer Requirements

At the heart of the testing system the spectrometer is the central part determining the measurement accuracy. Spectrometers in general are to be preferred over filter based photometers, which tend to have low measurement accuracy in the blue and red spectral range. To overcome these problems photometers have to be used with complex calibration procedures banning them in practical use from most R&D labs or production floors.

State-of-the-art array spectrometers must meet certain requirements for accurate results with LEDs. The spectral resolution should be between 2 and 5 nm. At such band path the spectral shape of the LEDs does not show any significant broadening and the color results can be calculated accurately. Lower band paths will not increase the measurement accuracy but instead lower the signal-to-noise ratio and increase the measurement times. With optical outputs reaching beyond the 100 lm level, even for single emitters, the sensitivity of the spectrometer is not a big issue in the lab anymore. Much more important is the signal-to-noise ratio (SNR) of the spectrometer, which significantly affects the color and white measurement accuracy. A SNR of 3.5 to 4 orders of magnitude is needed to avoid errors in the blue and red spectral region caused by the integration of the noise floor of the measurements. Such SNR values can only be achieved with carefully designed spectrometers using state-of-the-art cooled and back-illuminated CCD detector arrays.

Integrating Sphere Design for Total and Partial LED Flux

The basic quantity for the light output of light sources is still the luminous flux measured in the unit lumen (lm). Integrating spheres are the adapters of choice for measuring this quantity, due to fairly easy handling and short

testing times. The design of standard integrating spheres is usually not well suited for LEDs and LED modules due to the linear arrangement of sample, baffle and detector port. This is working well for sources with spherically symmetric emission positioned in the center of the integrating sphere. However, for LEDs having a narrow angle emission this may lead to significant measurement errors, since a portion of the light will first hit the baffle in front of the detector leading to unpredictable errors. Accurate measurements require complex evaluations of the form factor for different sample types to correlate the results with goniometric measurements.

Instrument Systems has therefore introduced a new design of integrating spheres with detector port and auxiliary lamp arranged under 90° with respect to the optical axis.

Light from a narrow angle emitter placed in the port at the side of the integrating sphere first hits the BaSO₄ coated wall opposite the input port, ensuring a very stable response independent of the direction of the incoming light. An auxiliary lamp is available to compensate the self-absorption of larger LEDs and modules.

In many applications the total LED flux is not a meaningful quantity since only a part of the light emitted by the LED can be used effectively. Therefore the new quantity of Partial LED Flux has been introduced into the latest edition of the CIE-127 recommendations. Only the amount of light emitted into a defined emission cone with a full angle of 40°, 60° or 90° is measured. The integrating sphere design described above is also suitable for measuring the Partial LED Flux (figure 2).

Thermal Management of High Power LEDs

High power LEDs cannot be operated with continuous current without proper heat management. The heating caused by the consumed electrical power would destroy them in a matter of minutes. Furthermore, even small temperature changes will significantly change the optical parameters such as intensity, dominant wavelength and color coordinates. Reproducible measurements require stable-operating conditions, which are possible only if a well designed heat management system is used. Instrument Systems has designed a socket featuring a heat sink coupled to a bipolar Peltier element. This way the heat sink temperature of LEDs up to 10 W electrical power can be stabilized in a wide range from 5°C to 85°C independently of the ambient temperature.

Figure 3 shows the change of forward temperature and voltage for a 5 W LED operated continuously at full nominal power of 5 W. The temperature is monitored via a PT100 resistor mounted in the heat sink of the test socket. Even small changes in the heat sink temperature result in simultaneous changes of the forward voltage.

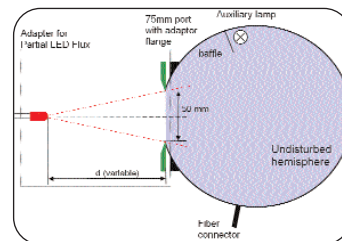


Figure 2. Integrating sphere with 250 mm diameter following the new CIE-127 design rules for measurement of Partial LED Flux.

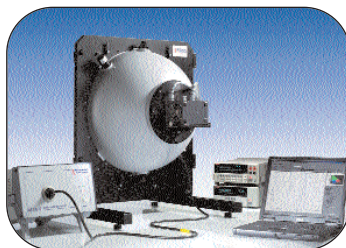


Figure 1. Test system for accurate high power LED testing as provided by Instrument Systems GmbH

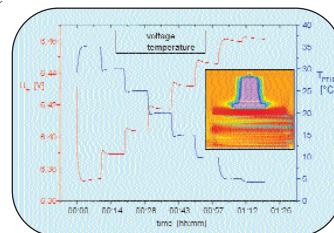


Figure 3. Forward voltage and heat sink temperature vs. time. Heat sink temperature was decreased in 5° steps every 10 minutes. The inset shows the heat flow from the LED through the test socket (Instrument Systems type LED-850).

Testing LEDs at Defined Junction Temperature

A well-defined and stabilized heat sink temperature is only one part of the story. Many properties of LEDs, including electrical and optical properties of LEDs, as well as their degradation behavior, strongly depend on the junction temperature. However, even for LEDs of the same package type the junction temperature can differ significantly from the heat sink temperature due to different thermal resistances within the LED package. While the heat sink temperature can be measured easily with a PT100 there is no direct access to the junction temperature.

One way to perform accurate measurements at precisely defined junction temperatures is to operate the LEDs in a pulse mode, reducing the self-heating of the LEDs to a minimum. Very short high current pulses, around one microsecond and up to 0.7 A, are used to prevent the LEDs from self-heating. Since measurements of a single short pulse provide too low signals, especially for the optical measurements, pulse trains with several hundred pulses are to be used to get a reasonable signal-to-noise ratio. To prevent self-heating of the LEDs by the accumulated heat of many pulses very low duty cycles are to be applied. During the fairly long intervals with the LED switched off the LED junction can quickly reach thermal equilibrium with its environment. Typically, duty cycles should be around 0.1 percent or less.

A possible test set-up for pulsed LED measurements is shown in Figure 4. The optical characteristics of the LED are measured with an array spectroradiometer and an integrating sphere with 250 mm diameter. The LED is fixed on a test socket (Instrument Systems model LED-850) with an integrated Peltier element as described above. The heat sink temperature

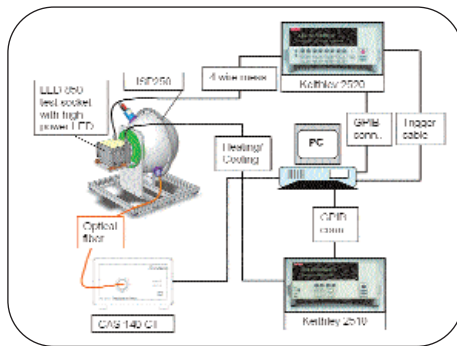


Figure 4. Test set-up for pulsed testing of high power LEDs.

is measured with a PT100 resistor and controlled by a TEC source meter (Keithley model 2510). The programmable current source (Keithley model 2520) generates short single pulses or pulse trains and measures the forward voltage with the four-

wire method. The very sensitive CCD spectrometer (Instrument Systems model CAS140CT) measures the optical radiation independently of the pulse length, only the effective dose is the relevant quantity. Several hundred pulses are accumulated for each single measurement. To obtain the "real" optical power per pulse the duty cycle must be taken into account.

The measurements below show the luminous flux of a green LED measured with 1 μ s and 10 μ s pulses and at continuous current (Figure 5). The temperature was varied from 0°C to 70°C. The individual curves show a well known effect: the output of the LED decreases with increasing temperature. The longer the pulses the lower the corresponding curve for the luminous flux lies, indicating an increased junction temperature caused by the self heating of the LED. Even pulses with a length of only 10 μ s lead to a significant self heating and a subsequent drop in efficiency (output).

Conclusion

Testing of high power LEDs requires specialized equipment in order to obtain accurate and reproducible results. Not only the spectrometer as the central piece of the measurement equipment needs to fulfill highest requirements, also the measurement adapters, such as integrating spheres for luminous flux measurement must be carefully designed to avoid measurement errors. Special care has to be applied to the thermal heat management, a critical point in all high power LED applications. Self-heating of LEDs by the electrical power can only be avoided, if LEDs are operated under pulsed conditions. Typically, pulse trains with 1 μ s pulses and low duty cycles (0.1 percent) are requirement for measurements at well defined junction temperatures.

Dr. Thomas Attenberger studied Physics at the University of Regensburg and received his PhD in 1992. Prior to 2001, Attenberger worked in R&D at a Munich company developing electrooptical sensors. Since 2001, he's worked at Instrument Systems, as a Sales Manager for Asia, Key Account Manger for LED manufacturers and a LED product manager. He can be reached at Attenberger@instrumentsystems.de.

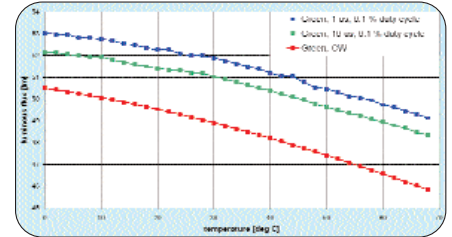


Figure 5. Luminous flux vs. heat sink temperature measured under pulsed conditions with 1 μ s and 10 μ s pulses and under continuous operation (cw).