Application Brief AB08

LUXEON

never before possible

Optical Testing for SuperFlux, SnapLED and LUXEON® Emitters

Introduction

Lumileds 100% tests the SuperFlux, SnapLED, SnapLED 70, SnapLED 150, and LUXEON® emitters for luminous flux, dominant wavelength (except white), correlated color temperature (white only), forward voltage, and reverse breakdown voltage. This document gives an overview of the production optical testing procedures.

Key Benefits

- LUXEON offers the most lumens per package for any commercially available white LED.
- LUXEON packaging offers better thermal properties than typical indicator LEDs.
- LUXEON can be operated at much higher operating currents than historically possible.
- Patented materials reduce yellowing compared to optical-grade epoxy resin.

PHILIPS

LUMILEDS

LIGHT FROM SILICON VALLEY

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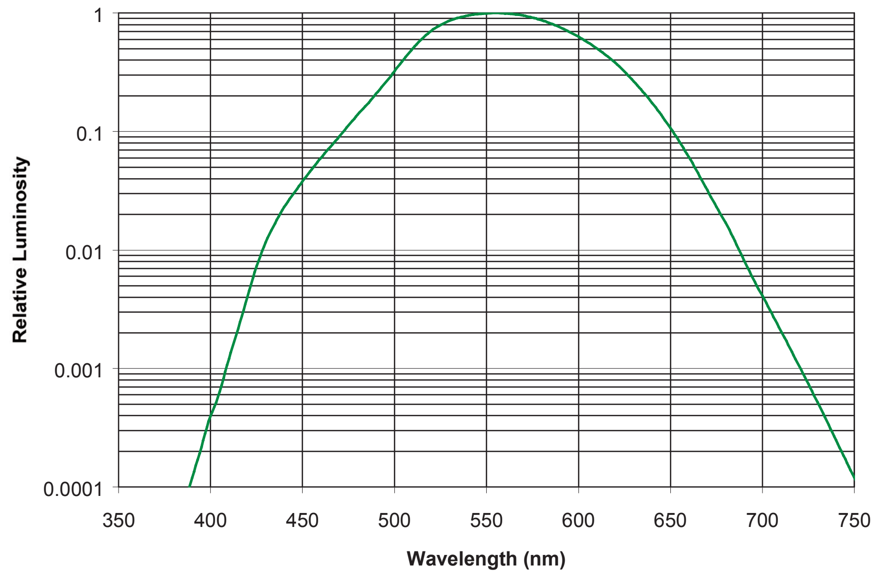

Figure 1. 1931 CIE luminosity function.

Radiant flux (ΦE) is defined as the total amount of electromagnetic energy per unit time emitted by a light source. The units of radiant flux are watts, W. Generally, the radiant flux is specified at all angles emitted into an imaginary 360° sphere drawn around the light source. However it is also possible to define the amount of radiant flux emitted into a specified angular range. If the radiant flux varies with wavelength, $\Phi_E(\lambda)$, (note: units are W/nm) then the radiant flux, Φ_E, is equal to:

$$\Phi_E = \int \Phi_E(\lambda)d\lambda$$

Luminous flux is defined as the total amount of electromagnetic energy per unit time emitted by a light source weighted by the human eye sensitivity to different wavelengths. The units of luminous flux are lumens, lm. Note that the human eye is most sensitive to light with a wavelength of 555 nm. At this wavelength, 1 watt of radiant flux is equal to 683 lumens of luminous flux. Similar to radiant flux, luminous flux is generally specified at all angles emitted into an imaginary 360° sphere drawn around the light source. However it is also possible to define the amount of luminous flux emitted into a specified angular range. As shown in Figure 1, the human eye weighting function was defined by CIE (Commission Internationale de L'Eclairage) in 1931 and commonly called the 1931 CIE luminosity function, L(λ).

If the total radiant flux emitted by the light source is known, $\Phi_E(\lambda)$, and L(λ) is the 1931 CIE luminosity function, then the luminous flux, Φ_V, is equal to:

$$\Phi_V = 683 \int_{\lambda=360}^{\lambda=830} L(\lambda)\Phi_E(\lambda)d\lambda$$

If the total radiant flux, Φ_E, emitted by the light source is known (note that the units of Φ_E are watts) and the normalized spectrum, S(λ), is known, then the luminous flux, Φ_V, is equal to:

$$\Phi_V = 683\Phi_E \frac{\int_{\lambda=360}^{\lambda=830} L(\lambda)S(\lambda)d\lambda}{\int_{\lambda=360}^{\lambda=830} S(\lambda)d\lambda}$$

Figure 2 shows a normalized spectrum of a white LED superimposed on the 1931 CIE luminosity function and the product of the two functions. Note that the spectrum has considerable radiant energy at wavelengths around 450 nm and at wavelengths beyond 650 nm. However, since the luminosity function is very small at these wavelengths, then the product of the two functions is also relatively small at these wavelengths. For this example, the area under the curve S(λ)L(λ) is about 47% of the area under the curve S(λ), so that 1 W of radiant flux would generate about 320 lm of luminous flux [i.e. 320 lm = (1W)(683lm/W)(0.47)].

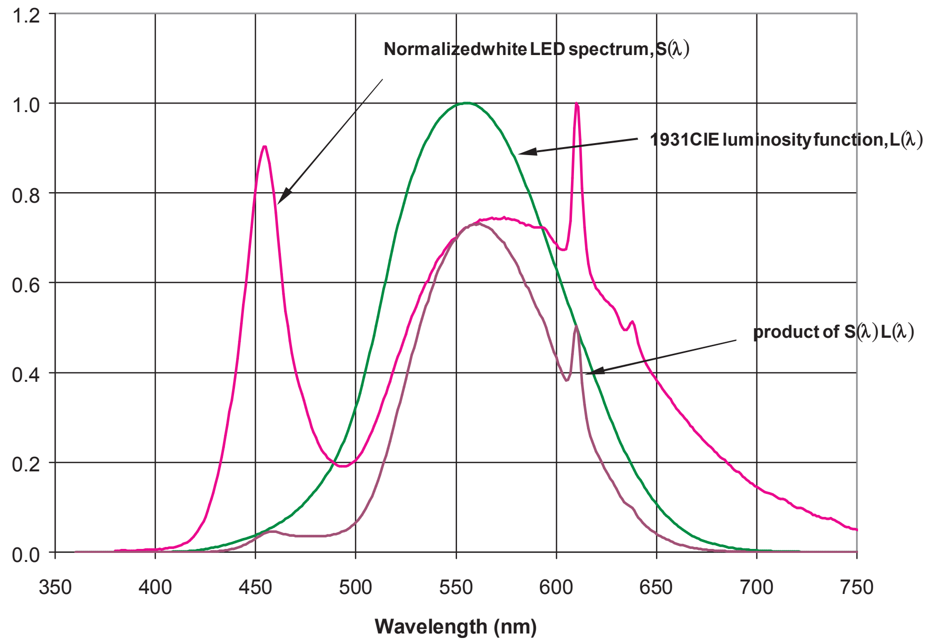

Figure 2. Spectrum of white LED.

Color Coordinate Calculations

As shown in Figure 3, the color of any light source can be plotted as an (x, y) point in a two dimensional color space defined by CIE in 1931. This color space is called the 1931 CIE (x, y) color space. Figure 3 also shows the names given to different regions of the color space as adopted by the Inter-Society Color Council—National Bureau of Standards (ISCC—NBS)[1] and the corresponding Lumileds color names. Note that Lumileds Cyan is at the short wavelength range (505 nm) of the ISCC-NBS green color region and Lumileds Green is at the long wavelength range (520 nm) of the ISCC-NBS green color region.

Symbol	ISCC - NBS Color Name	Lumileds Color Name
R	Red	Red
rO	Reddish-orange	Red-orange
O	Orange	Amber
yO	Yellowish-orange	
Y	Yellow	
gY	Greenish-yellow	
YG	Yellow-green	
yG	Yellowish-green	
G	Green	Green, Cyan
bG	Bluish-green	
BG	Blue-green	
gB	Greenish-blue	
B	Blue	Blue
pB	Purplish-blue	Royal blue
P	Purple	
rP	Reddish-purple	
RP	Red-purple	
pR	Purplish-red	
pPK	Purplish-pink	
PK	Pink	
OPK	Orange-pink	
W	White	White

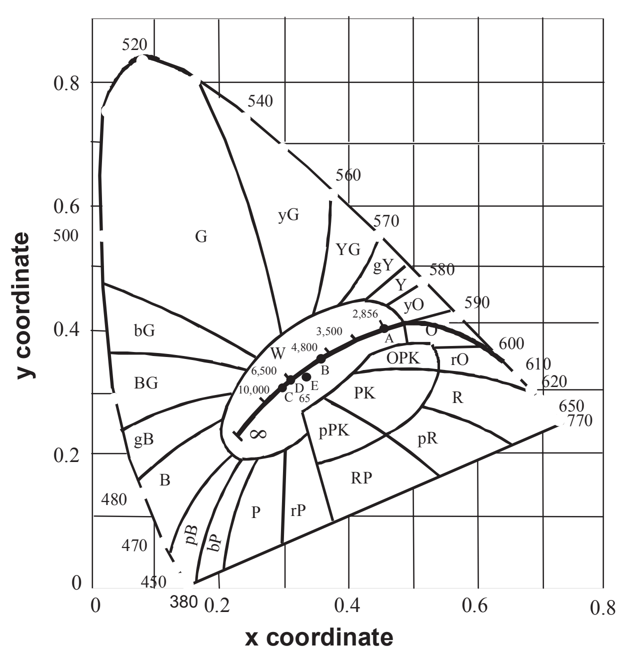

Figure 3. 1931 CIE Color Space.

Figure 3 also shows the color coordinates of Planckian black-body radiators as a function of temperature. Planckian black-body radiators have a well defined spectrum defined by the surface temperature (measured in °K) of the glowing object (e.g. tungsten filament bulbs, glowing hot metal, etc.). An easy experiment to observe the color of Planckian black-body radiators is to drive a filament bulb with a variable voltage. As the voltage increases, the color of the filament changes from red to yellow to yellow-white to a bluer-white until the tungsten filament melts at 3410°C (3783°K).

Over the years, a number of different color spaces have been developed. In 1960 CIE adopted a new color space that has more uniform chromaticity spacing. This means that the same distance between any two points in the color space correlates more closely to the human eye perception of equally perceived color difference. This space is called the 1960 CIE UCS (u, v) color space and is shown in Figure 4. While the 1960 CIE UCS (u, v) color space has been updated by the 1976 CIE UCS (u', v') color space, it is still used for correlated color measurements as described in the next section.

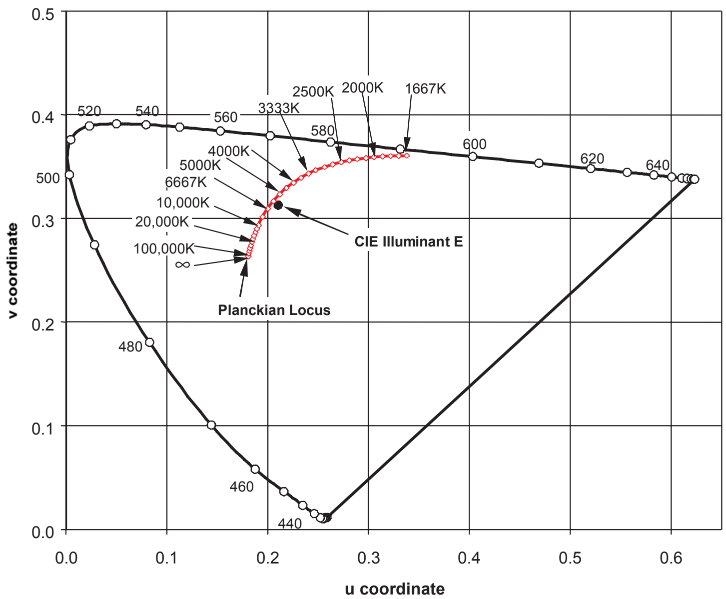

Figure 4. 1960 CIE UCS (u, v) color space.

The (x, y) coordinate can be determined by integrating the spectrum of the light source with three color-weighting functions defined by CIE. These response curves are called the 1931 CIE $\bar{x}$, $\bar{y}$, and $\bar{z}$ color-weighting functions and are plotted in Figure 5. A rough analogy is that these functions are the red, green, and blue components of light. Please note that the 1931 CIE color weighing function in Figure 5 is exactly the same function as the 1931 CIE luminosity function shown in Figure 1. The only difference is that the 1931 CIE luminosity function is plotted on a logarithmic scale in Figure 1 and the $\bar{y}$ color weighing function is plotted on a linear scale in Figure 5.

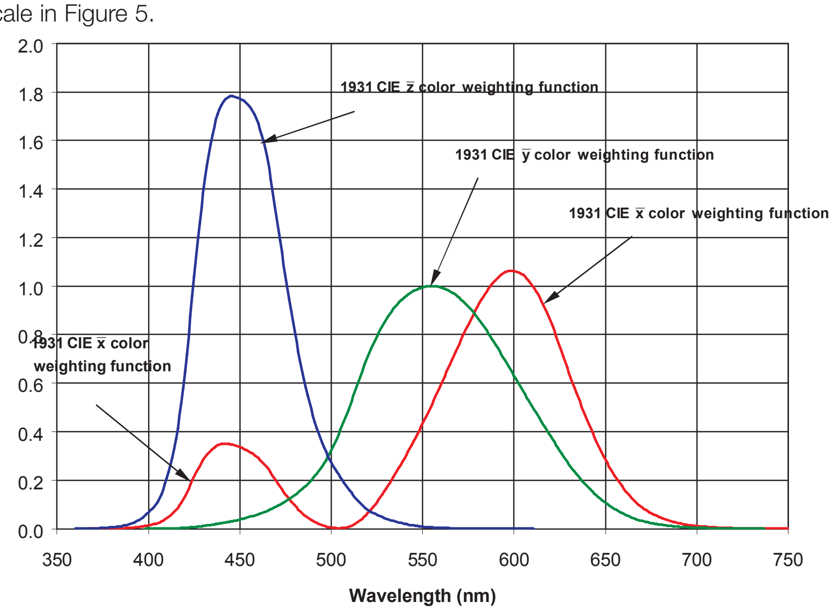

Figure 5. 1931 CIE $\bar{x}$, $\bar{y}$, and $\bar{z}$ color weighting functions.

Given that the normalized spectrum of the light source is denoted as S(λ), then these integration's are shown below:

$$X = \int_{\lambda=360}^{\lambda=830} \bar{x}(\lambda)S(\lambda)d\lambda \qquad Y = \int_{\lambda=360}^{\lambda=830} \bar{y}(\lambda)S(\lambda)d\lambda \qquad Z = \int_{\lambda=360}^{\lambda=830} \bar{z}(\lambda)S(\lambda)d\lambda$$

The results of these integration's are three numbers X, Y, and Z. Note that X, Y, and Z represent the area under each of the three curves $\bar{x}(\lambda)S(\lambda)$, $\bar{y}(\lambda)S(\lambda)$, and $\bar{z}(\lambda)S(\lambda)$. Finally, the 1931 CIE (x, y) color coordinate is determined by calculating the X and Y portions of the total area as shown below:

$$x\ coordinate: \quad x = \frac{X}{X+Y+Z} \qquad y\ coordinate: \quad y = \frac{Y}{X+Y+Z}$$

Figure 6 shows the normalized spectrum of the same white LED shown in Figure 2 superimposed on the $\bar{x}$ color-weighting function. Since the $\bar{x}$ color-weighting function has about the same shape as the white LED spectrum, the product of the two curves looks similar to the original spectrum. For the example shown, the area X under the curve $\bar{x}(\lambda)S(\lambda)$ is equal to 66.58. The normalized spectrum of the white LED and the $\bar{y}$ color-weighting function is shown previously in Figure 2. The $\bar{y}$ color-weighting function attenuates the short wavelength peak and the long wavelength tail of the white LED spectrum. For this example, the area Y under the curve $\bar{y}(\lambda)S(\lambda)$ is equal to 65.05. Figure 7 shows the normalized spectrum of the white LED superimposed on the $\bar{z}$ color-weighting function. The $\bar{z}$ color-weighting function truncates all of the white LED spectrum except the short wavelength peak. For this example, the area Z under the curve $\bar{z}(\lambda)S(\lambda)$ is equal to 46.40. Thus, the x color coordinate is equal to 66.58/(66.58 + 65.05 + 46.40), or 0.3740, and the y color coordinate is equal to 65.05/(66.58 + 65.05 + 46.40), or 0.3654.

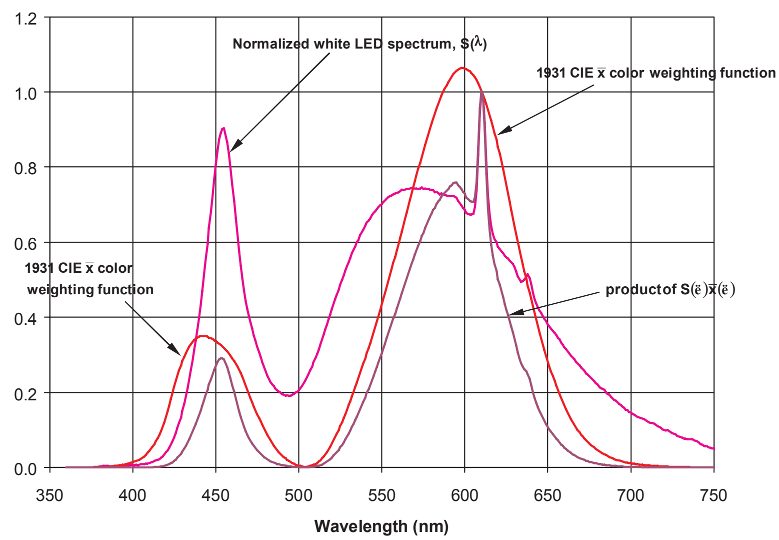

Figure 6. Spectrum of white LED and $\bar{x}$ color weighting function.

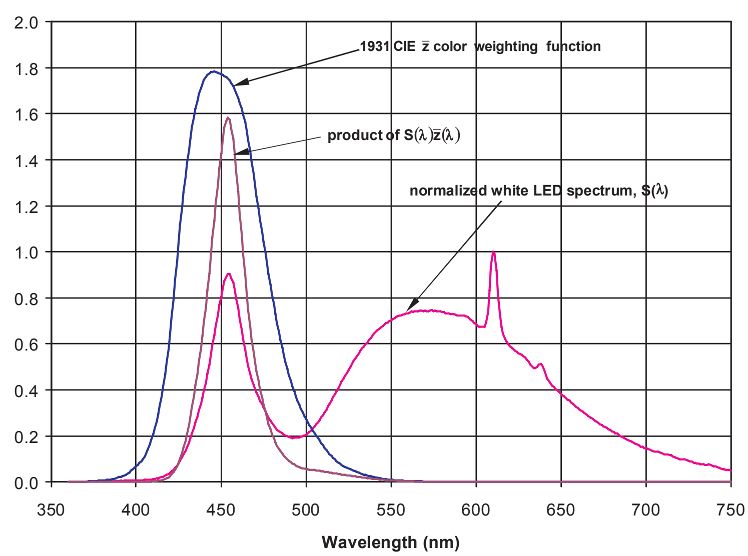

Figure 7. Spectrum of white LED and $\bar{z}$ color weighting function.

Dominant Wavelength

The dominant wavelength is defined as the wavelength of a pure saturated color which is perceived by the human eye as the same color as the (x, y) color coordinate of the light emitted by the light source. The (x, y) coordinate of the light source can be considered to be a mixture of saturated light of a specific dominant wavelength and white light, called an Illuminant, as defined by CIE. Figure 8 shows the graphical method to determine dominant wavelength. After measuring the (x, y) color coordinate of the light source, a line is drawn from one of the 1931 CIE white Illuminants, through the calculated 1931 CIE (x, y) coordinate to the edge of the 1931 CIE color space. CIE has defined the color coordinates of several different white Illuminants, but within Lumileds, CIE Illuminant E is used for all color calculations. The dominant wavelength is the interpolated wavelength on the outer edge of the color space. The color purity is the relative distance from the (x, y) color coordinate to the 1931 CIE white illuminant compared with the relative distance from the edge of the color space to the 1931 CIE white illuminant. A color purity of 100% means that the light source is a pure color (i.e. the light is nearly monochromatic). A color purity of 0% means that the light source is white with the same color as the illuminant. Note that when using dominant wavelength to define color that it is most meaningful when the color purity is high.

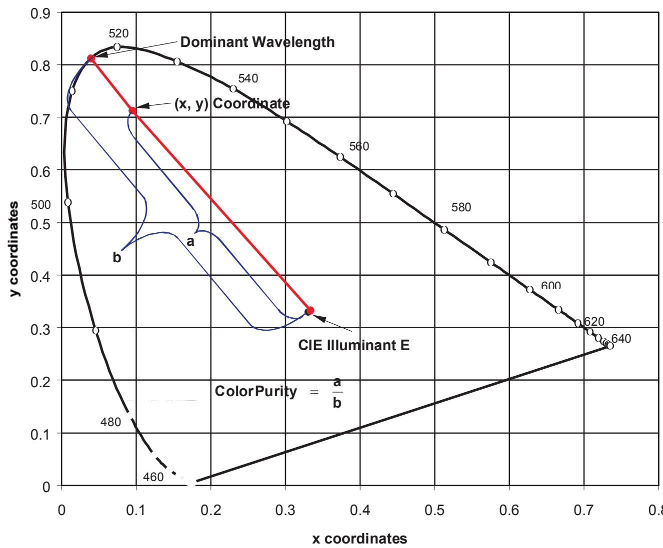

Figure 8. Measurement of dominant wavelength and color purity.

Figure 8 shows an example of the dominant wavelength calculations. In the example shown, the 1931 CIE color coordinate of the light source is equal to (x, y) = (0.0944, 0.7130). The color coordinate of 1931 CIE Illuminant E is equal to (x, y) = (0.3333, 0.3333). Thus, the intercept of the line with the edge of the color space is coordinate (x, y) = (0.0389, 0.8120), which corresponds to a dominant wavelength of 515 nm. It is also possible to calculate the color purity as follows:

Note that the length of line "a" is equal to:

$$\sqrt{(0.0944 - 0.3333)^2 + (0.7130 - 0.3333)^2} = 0.4486$$

Similarly, the length of line "b" is equal to:

$$\sqrt{(0.0389 - 0.3333)^2 + (0.8120 - 0.3333)^2} = 0.5620$$

Thus, the color purity is equal to 0.4486/0.5620, or 80%.

Correlated Color Temperature (CCT)

Many different light source technologies generate "white" light. One common class of light sources are called Planckian black-body radiators. However, many other "white" light source technologies generate "white" light with very different radiated spectrums than Planckian black-body radiators (e.g. fluorescent light sources, gas-discharge light sources, and "white" LEDs). Many of these light sources define the color of their light in terms of correlated color temperature (CCT). The concept of CCT is to extrapolate the color of the light source to the color of a Planckian black-body radiator of a given color temperature (°K) such that they appear the same shade of "white" to the human eye. Judd first proposed the use of CCT measurements for white light in 1936.[2]

The color of "white" LEDs can be defined in a number of ways. One method is to use the 1931 CIE (x, y) color coordinate as previously defined. Then, LEDs would be binned into small boxes within the 1931 color space. The method used by Lumileds is to bin white LEDs for correlated color temperature (CCT). Thus it is important to explain how CCT measurements are made.

The CCT isothermal lines shown in Figure 9 are perpendicular to the tangent of the Planckian black-body locus when drawn in the 1960 UCS (u, v) color space. The 1960 UCS (u, v) color space was picked because the distance between any two points in this color space gives more consistent perceived color differences than the previous 1931 CIE color space. Note that 31 CCT isothermal lines are defined for the range of color temperatures from + ∞ to 1667°K. Then the CCT for any white color within this range can be determined by drawing a perpendicular line from the measured (u, v) UCS coordinate to the Planckian black-body locus to determine the (u, v) Planckian intercept. Then the CCT of the white color would correspond to the surface temperature of a Planckian black-body radiator with the same (u, v) color coordinate.

While it is possible to extend the CCT isothermal lines all the way to the edge of the color space, it is better to use dominant wavelength measurements instead of CCT measurements for saturated colors. Similarly, while it is possible to extend dominant wavelength lines all the way to the center of the (x, y) color space as shown in Figure 8, it is better to use CCT measurements instead of dominant wavelength measurements for "off-white" colors. However, one exception is for yellow and amber light sources because the Planckian locus approaches the edge of the color space.

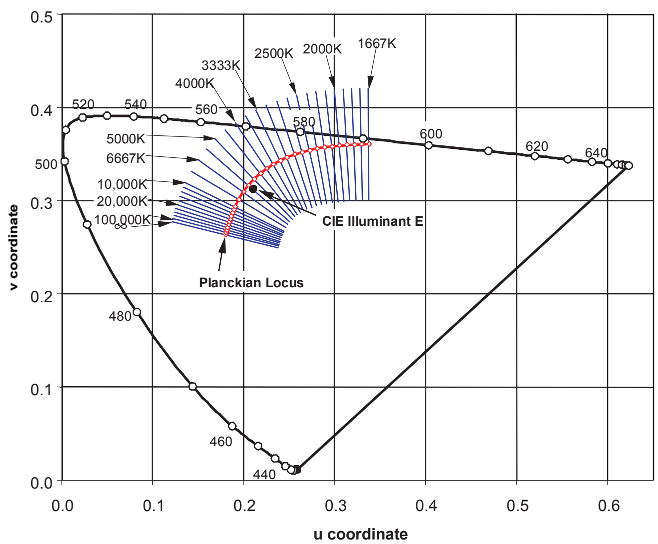

Figure 9. Correlated color temperature isothermal lines plotted in 1960 UCS color space.

Figure 10 shows the same graph of CCT isothermal lines plotted in the more familiar 1931 CIE color space. Note that in the 1931 CIE color space that the CCT isothermal lines are not perpendicular to the Planckian black-body locus. This means that the simple angular method for linear interpolation between two known isothermal lines cannot be done in the (x, y) color space without causing large errors in the result.

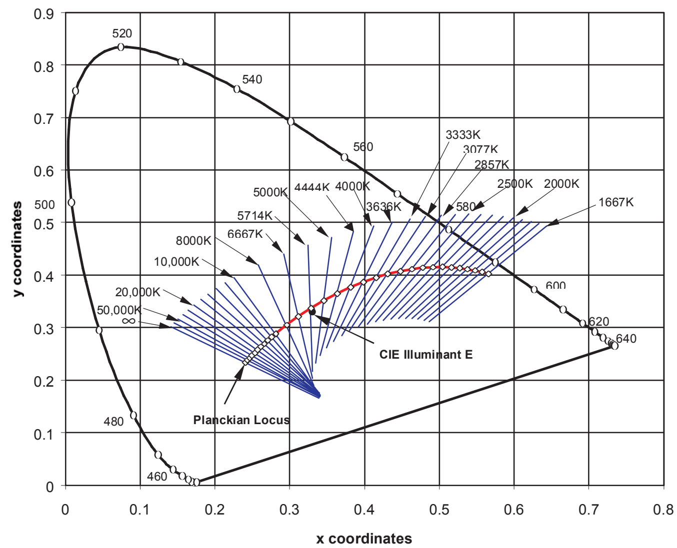

Figure 10. Correlated color temperature isothermal lines plotted in 1931 CIE color space.

The CCT can be determined by first measuring the 1931 CIE (x, y) color coordinate of the light source and then converting into the equivalent 1960 UCS (u, v) color coordinate. Note that the calculation is a simple linear transformation as shown below:

$$u\ coordinate: \quad u = \frac{4x}{-2x + 12y + 3} \qquad\qquad v\ coordinate: \quad v = \frac{6x}{-2x + 12y + 3}$$

Next, it must be determined which pair of isothermal lines in the 1960 UCS color space lie on either side of the measured (u, v) coordinate. Figure 11 shows the graphical method for determining CCT. The CCT is determined by assuming that in the region between the isothermal lines that the Planckian black-body locus is an arc of a circle with the center of the circle being the intercept point between the pair of isothermal lines. Then the angle subtended between the pair of isothermal lines (θ_2) must be determined. Similarly, the angle formed by the line from the measured (u, v) coordinate and the intercept point of one of the isothermal lines (θ_1) must be determined. The convention used is that the isothermal line used in the θ_1 calculation is the one with the higher color temperature than the measured (u, v) coordinate.

Finally, the CCT can be determined by assuming that the reciprocal of the color temperature function is proportional to the relative angular distance along this arc. Thus the equation for CCT is equal to:

$$CCT = \left[\frac{1}{T_i} + \frac{\theta_1}{\theta_2}\left(\frac{1}{T_{i+1}} - \frac{1}{T_i}\right)\right]^{-1}$$

The reader is directed to Wyszecki and Stiles[2] for more information on the measurement of CCT. Wyszecki and Stiles also shows an approximation of the CCT formula that replaces θ_1 and θ_2 with non-trigonometric distance calculations from the (u, v) to the isothermal lines.

Figure 11 shows an example for a hypothetical light source with a 1931 CIE (x, y) color coordinate of (0.20, 0.50). Note that this color coordinate transforms to (u, v) = (0.09302, 0.34884) in the 1960 UCS color system. For this example, the two isothermal lines on either side of the measured (u, v) point correspond to 10,000 K and 8000 K. The equations for these lines are equal to:

Isothermal_i = 10,000°K
Planckian (u, v) = (0.19032, 0.29326)
v = -0.47888u + 0.38440

Isothermal_{i+1} = 8000°K
Planckian (u, v) = (0.19462, 0.30141)
v = -0.58204u + 0.41469

The intercept point for the two isothermal lines can be calculated to be:

(u, v) = (0.29357, 0.24381).

The included angle between the two isothermal lines is equal to:

$\theta_2 = 4.61229°$

The included angle between the 10,000°K isothermal line and the line from the measured (u, v) point extended to the intercept between the pair of isothermal lines is equal to:

$\theta_1 = 2.05113°$

Then, the CCT is equal to:

$$CCT = \left[\frac{1}{10,000} + \frac{2.05113}{4.61229}\left(\frac{1}{8000} - \frac{1}{10,000}\right)\right]^{-1} = 8999°K$$

This example was picked for easy clarity in the 1960 UCS (u, v) color space. However, the color coordinate that was picked is not very close to the Planckian black-body locus. Thus, when using CCT to define the white color, it is also important to determine the relative distance from the measured (u, v) point to the Planckian black-body locus. The larger this distance, the more "tinted" the color of light will appear.

For this same example, it is also possible to calculate the dominant wavelength and color purity of the same point. A 1931 CIE color coordinate (x, y) of (0.20, 0.50) corresponds to a dominant wavelength of 509 nm with a color purity of 41%.

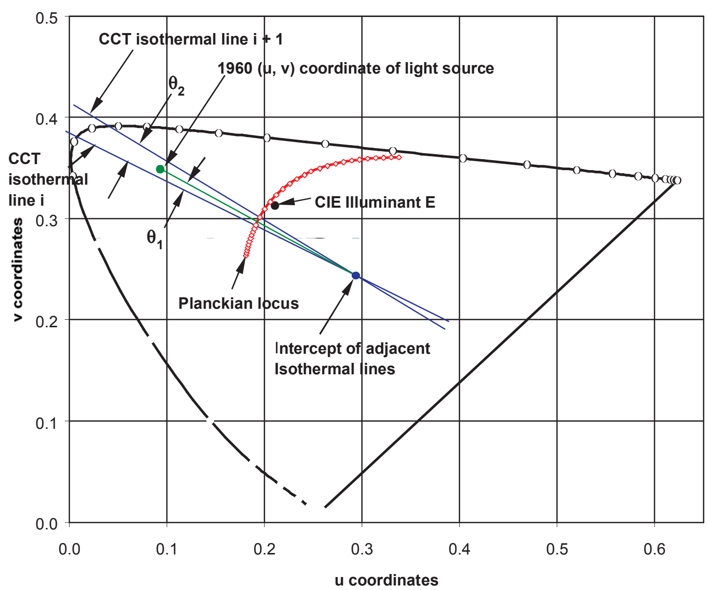

Figure 11. CCT example.

Optical Measurement Equipment

Operation of Integrating Spheres

The basic piece of optical test equipment used for testing SuperFlux, SnapLED, SnapLED70, SnapLED150 and Luxeon emitters is a small integrating sphere that is shown in Figure 12. An integrating sphere is a hollow ball with a very highly reflective white coating on the internal surface. Light emitted into the integrating sphere is reflected multiple times such that the light reflected off the white surface is uniform throughout the sphere. A baffle inside the integrating sphere prevents direct rays of light from the emitter from striking the optical detector. Then an optical detector is mounted on the wall of the integrating sphere to sample the light signal.

Thus, if the spectral response of the optical detector mounted on the integrating sphere matches the 1931 CIE luminosity function ($\bar{y}$ color-weighting function) then the electrical signal from the optical detector will be proportional to the luminous flux emitted by the light source.

Dominant wavelength can be measured by using three optical detectors mounted on the integrating sphere. The first optical detector, which is also used to measure luminous flux, has a spectral response that matches the 1931 CIE $\bar{y}$ color-weighting function. The second optical detector has a spectral response that matches the 1931 CIE $\bar{x}$ color-weighting function. The third optical detector has a spectral response that matches the 1931 CIE $\bar{z}$ color-weighting function. The ratio of signals from these three optical detectors can be used to determine the1931 CIE (x, y) color coordinate of the emitted light. Then the dominant wavelength can be calculated from the 1931 CIE (x, y) color coordinate.

The spectral response of the 1931 CIE $\bar{z}$ color-weighting function is primarily in the range of 385 to 550 nm. Amber, red-orange and red AlInGaP LEDs have virtually no spectral energy at wavelengths less than 550 nm. Thus, the output from the $\bar{z}$ color-weighted optical detector can be ignored with no loss in accuracy for (x, y) color coordinate and dominant wavelength calculations. On the other hand, blue, cyan, green, and white InGaN LEDs do have significant spectral content in the region of the $\bar{z}$ color-weighting function and require all three CIE color-weighted filters.

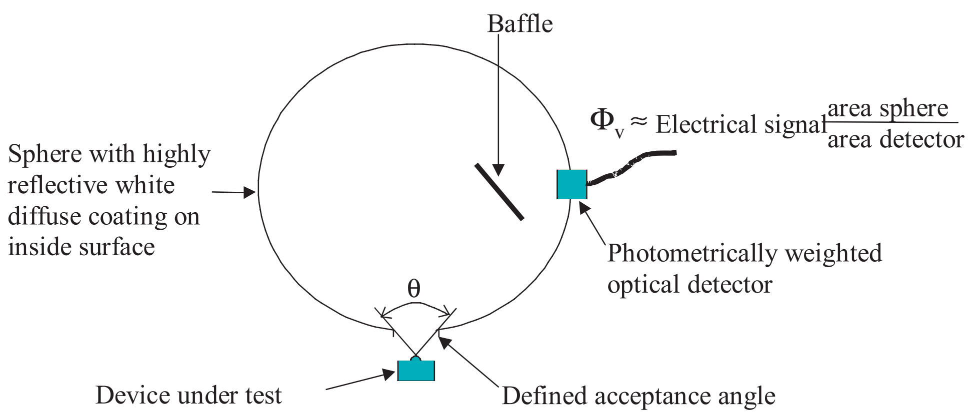

Figure 12. Luminous Flux Test System.

Production Testing of SuperFlux and SnapLED Emitters

The Lumileds production test system used for amber, red-orange, and red SuperFlux and SnapLED LEDs incorporates only two optical detectors. A picture of the optical sensor of this test system is shown in Figure 13. This system uses a custom 3-inch Labsphere integrating sphere that is internally baffled. The first optical detector, which is used to measure luminous flux, has a spectral response that matches the 1931 CIE $\bar{y}$ color-weighting function. The second optical detector has a spectral response that matches the 1931 CIE $\bar{x}$ color-weighting function. Thus, the luminous flux is directly proportional to the reading from the $\bar{y}$ optical detector and the dominant wavelength is proportional the ratio between the $\bar{y}$ and $\bar{x}$ optical detectors.

Figure 13. Optical detector assembly used for amber, red-orange and red SuperFlux and SnapLed emitters. Note the small integrating sphere in the lower area of the picture. The two optical detectors (gray rectangular boxes) are mounted to the integrating sphere with a beam splitter (black cube).

Optical testing of all InGaN emitters requires a different approach to determine either the dominant wavelength or CCT. As mentioned previously, it is possible to test by using three different optical filters. The approach used by Lumileds is to replace the detector array on the integrating sphere with an optical fiber attached to a spectrophotometer. The advantage of this approach is that the spectrophotometer actually measures the spectrum of the device under test so that the dominant wavelength and CCT calculations are performed numerically instead of based on the optical transmission of filters. Thus, the overall accuracy of the measurement is improved. In addition, the luminous flux is measured directly by the spectrophotometer and corrected for wavelength by numerically integrating the spectrum with the $\bar{y}$ color-weighting function. Even the best $\bar{y}$ optical detectors can exhibit some errors in spectral responsivity versus wavelength, which can cause errors in luminous flux measurements if different LEDs have different dominant wavelengths. Using a spectrophotometer can eliminate this type of error.

A second-generation Lumileds production test system used for some of the SuperFlux and SnapLED LEDs is shown in Figures 14 and 15. This system uses an Instrument Systems CAS140B spectrophotometer and Instrument Systems ISP80 80 mm inside diameter integrating sphere. The CAS140B is interfaced to a system controller and the ISP80 is mounted in the tester.

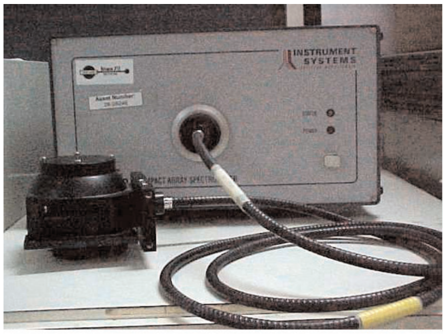

Figure 14. View of Instrument Systems CAS140B and ISP80.

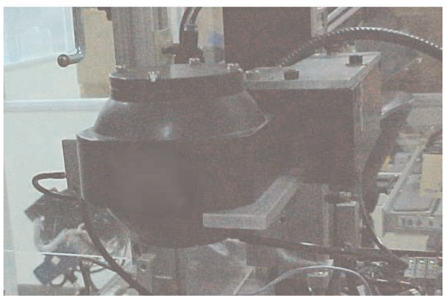

Figure 15. View of Instrument Systems ISP80 mounted in tester.

Production Testing of Luxeon Emitters

The Lumileds production test system used for Luxeon emitters is shown in Figures 16 and 17. This system uses an Instrument Systems CAS140B and a custom 6 inch Labsphere integrating sphere. The CAS140B is interfaced to a system controller and the integrating sphere is mounted in the tester. Figure 16 shows a close-up view of the integrating sphere. Note that the optical fiber exits the top of the sphere and the device under test is mounted below the sphere. Figure 17 shows a view of the production test system that shows some of the mechanical handling required for production testing. Untested units are track-fed underneath the integrating sphere. After testing, the unit is sorted by test output value, or bin, at the lower left of the picture.

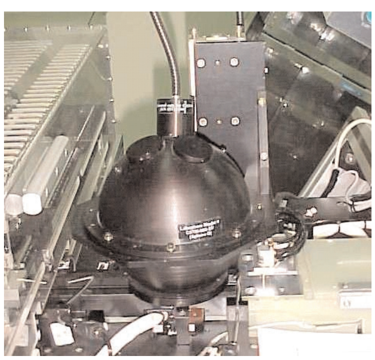

Figure 16. Integrating sphere used in Luxeon tester.

Figure 17. Luxeon tester.

Optical Calibration and Potential Sources of Error

Note that in general for LED emitters that the luminous flux output (or luminous intensity) of an LED is inversely proportional to temperature. The variation in light output is larger for AlInGaP devices than for InGaN and white devices, but generally must be considered when doing optical testing. The internal self-heating at the data sheet test conditions of 70 or 150mA forward current for AlInGaP SuperFlux and SnapLED emitters can cause differences of up to 2:1 between the instantaneous luminous flux and the thermally stabilized luminous flux. For AlInGaP Luxeon emitters, the internal self-heating at the data sheet test conditions of 350 mA can cause similar variations in light output.

In addition, the internal self-heating also affects the dominant wavelength of LED emitters. In general, the dominant wavelength of LED emitters shifts slightly to slightly longer wavelengths at elevated temperature. However, depending on the internal temperature rise, this variation is generally less than 1 nm so these errors are much smaller than the change in luminous flux.

Finally, for Luxeon emitters, the internal self-heating for prolonged testing times can even damage the units without proper thermal control of the heat-sink slug on the bottom of the emitter.

Calibration of SuperFlux and SnapLED Testers

All SuperFlux, SnapLED, SnapLED70, and SnapLED150 LEDs are tested under thermally-stabilized conditions as defined in the data sheet ($R\theta_{j-a}$ = 200°C/W, T_A = 25°C, for the SuperFlux, SnapLED and SnapLED70 and $R\theta_{j-a}$ = 100°C/W, T_A = 25°C, for the SnapLED150). Because it is impractical to wait a few minutes to test each unit in production, the production tester makes pulsed measurements using a single 20 ms pulse per test, but is correlated to measure the thermally stabilized result.

The calibration procedure for luminous flux of SuperFlux, SnapLED, SnapLED70, and SnapLED150 LEDs is to measure both the instantaneous and thermally stabilized luminous flux for a number of units in a reference test system. These units were picked to span the expected range of luminous flux and dominant wavelength of the particular type of production units to be tested. The reference test system has a special socket for the LED that generates the $R\theta_{j-a}$ = 100°or 200°C/W test conditions specified. Each LED is driven at a constant current and allowed to self-heat to thermal equilibrium. This usually takes 1½ to 3 minutes. Then the luminous flux is recorded. Then the luminous flux of each LED is measured in the reference test system at the same peak current with a pulsed condition using a 1% duty factor at 1 kHz. Note that under these later conditions, that negligible heating occurs, and the instantaneous luminous flux is equal to the 1% duty cycle luminous flux reading times the reciprocal of the duty cycle (i.e. for a 1% duty cycle, then would multiply by 100). The ratio of the thermally stabilized reading divided by the instantaneous reading is called the hot/cold factor. Then the average hot/cold factor is determined for these units. Different average hot/cold factors are determined for each package outline and die color.

After this hot/cold factor has been determined, a group of calibration units is selected and tested on the reference test system. In practice, a number of calibration units which span the expected range of luminous flux and dominant wavelength are used for calibration of the production test system. Note that a different calibration set is generated for each package outline and die color. Each unit is tested at the specified peak current with a pulsed condition using a 1% duty factor at 1 kHz. The 1% duty cycle readings are converted into instantaneous luminous flux by multiplying the readings at 1% duty factor times the reciprocal of the duty cycle. The thermally stabilized luminous flux of each calibration unit is determined by multiplying by the average hot/cold factor determined previously. Then these calibration units are tested on the production test system under a pulsed condition of about 20 ms. Finally, the production test system is calibrated such that the production tester reading is made to agree with the thermally stabilized luminous flux measurements from the reference test system.

The calibration procedure for dominant wavelength of SuperFlux, SnapLED, SnapLED70, and SnapLED150 LEDs is to measure calibration units that are thermally stabilized in a reference test system using the same socket used for luminous flux. Then these calibration units are tested on the production test system using a single 20 ms pulse. Then, the production test system is calibrated such that the production tester reading is made to agree with the thermally stabilized readings from the reference test system.

Because of the relatively small shift of forward voltage and reverse breakdown voltage due to temperature, the SuperFlux/SnapLED production tester makes pulsed measurements for forward voltage and reverse breakdown voltage at 25°C and does not correlate to thermally stabilized readings.

Calibration of Luxeon Testers

All electrical/optical test parameters for the Luxeon emitters are specified in the data sheet at a junction temperature of 25°C. Thus, unlike the SuperFlux and SnapLED emitters, Luxeon emitters are tested for instantaneous luminous flux and dominant wavelength (and CCT for white) instead of thermally stabilized luminous flux and dominant wavelength. All Luxeon emitters are tested for luminous flux, dominant wavelength (except white), correlated color temperature (white only), forward voltage, and reverse breakdown voltage using a single 20 ms pulse per test.

The calibration procedure for Luxeon emitters is to measure luminous flux, dominant wavelength (except white) and CCT (white only) in a reference test system at the specified peak current with a pulsed condition with a 1% duty factor at 1 kHz. A number of calibration units are tested that span the expected range of luminous flux, dominant wavelength, and CCT of the particular type of production units to be tested. Finally, these calibration units are tested in the production test system under a pulsed condition of about 20 ms and the production tester readings are made to agree with the reference test system readings.

In practice, optical testing of LED emitters is quite complicated. In addition to having a properly calibrated integrating sphere and spectrophotometer, the optical test system needs to have provisions for stimulating the device under test under pulsed conditions and to properly synchronize the data acquisition (both electrical and optical parameters) to the stimulus portion of the test system. In addition, since the readings are affected by internal self-heating, then the thermal properties of the test fixture need to be known (this is less important for pulsed measurements). Finally, production testing requires automatic feeding of the device under test to the test head and a means to sort the LED emitters into the different flux, color, and forward voltage categories.

References:

1. Color: Universal Language and Dictionary of Names, K. L. Kelly and Deane B. Judd, Publication NBS-SP-440, (National Bureau of Standards, Department of Commerce, Washington, D.C., 1976)

2. Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd edition, Gunther Wyszecki and W.S. Stiles, (John Wiley and Sons., Inc, New York, 1982), pages 224 - 229.

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Company Information

LUXEON® is developed, manufactured and marketed by Philips Lumileds Lighting Company. Philips Lumileds is a world-class supplier of Light Emitting Diodes (LEDs) producing billions of LEDs annually. Philips Lumileds is a fully integrated supplier, producing core LED material in all three base colors (Red, Green, Blue) and White. Philips Lumileds has R&D centers in San Jose, California and in The Netherlands and production capabilities in San Jose and Penang, Malaysia. Founded in 1999, Philips Lumileds is the high-flux LED technology leader and is dedicated to bridging the gap between solid-state LED technology and the lighting world. Philips Lumileds technology, LEDs and systems are enabling new applications and markets in the lighting world.

Philips Lumileds may make process or materials changes affecting the performance or other characteristics of our products. These products supplied after such changes will continue to meet published specifications, but may not be identical to products supplied as samples or under prior orders.

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