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White Light LEDs –

Importance of Accepted Measurement Standards

White Light LEDs – Importance of Accepted Measurement Standards

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The breathtaking development of white light LEDs in recent years has led to significant market potential for a range of brand new applications. The high efficiency of these LEDs now means that solutions for room lighting, automotive headlights and backlighting for LCD displays can be realized. The advantages of their reduced energy requirements are apparent - for example, the running time of battery operated devices such as mobile phones and notebook computers can be extended considerably.

For general room lighting, the ability to vary the color temperature of a LED lamp allows new lighting designs. In automotive applications, the reduced energy requirement helps to reduce petrol consumption and CO2 emissions. Moreover, their long lifetime minimizes service requirements for headlights - i.e. the LEDs will in all probability outlive the lifetime of the car itself. And lastly, the technical characteristics of LEDs also bring significant advantages for adaptable headlight technology when compared to conventional forms of lighting. All of these aspects additionally mean that these developments in automotive safety may also find application in a wider market.

Attaining and maintaining the necessary regulatory lighting standards still represents challenges for LED manufacturers, and much research is currently being made into methods to reduce and control the varying quality inherent in the production process. Indeed, the proper characterization of the light emission parameters forms an important aspect of the quality control process. However, this characterization, in particular for white light LEDs, is as a consequence of their optical properties somewhat complicated.

Optical Properties of White Light LEDs

The intercomparability of measurement results is influenced by a variety of factors. Both the fundamental technology underlying the structure of the LED itself and the measurement system used for characterization can play a decisive role. In order to ensure precise measurement of the LED emission, spectroradiometers have now become the preferred tool of choice over photometers and colorimeters. Spectroradiometers achieve better accuracy by obviating the need for optical filters and by making a computational calculation for the photometric and colorimetric parameters.

Inherent properties of the LEDs directly resulting from the manufacturing process also influence the measurement results. White light LEDs, usually comprising a blue emitting LED-chip coated with a yellow emitting phosphor, are particularly difficult to manufacture with consistent characteristics. Furthermore, well known factors such as burn-in time, operating temperature, aging behavior, etc., each make their own contribution to the emission performance of the LED.

Dependence on Temperature

Above all for modern high-power LEDs, proper thermal management and the operating temperature of the LED play a critical role in terms of reproducibility of operation. The energy density in such devices is considerably higher than that for conventional LEDs, resulting in the generation of significantly more heat. Continuous operation of high-power LEDs remains a major technical challenge, as varying temperature can be responsible for changes in the emission spectrum.

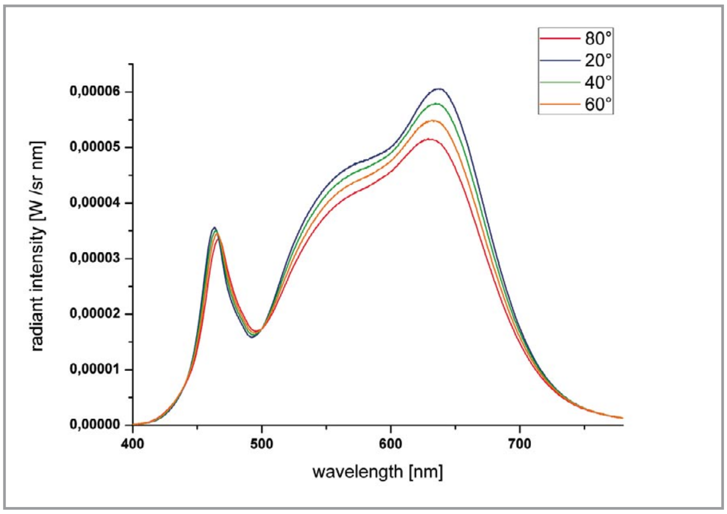

Figure 1: Dependence of the spectral emission of white light LEDs on temperature

Figure 1 illustrates the spectral dependence of an LED emitting warm white light over a temperature range from 20° to 80°C. Generally, in order to maintain a constant and uniform impression of brightness and color in continuous operation, the heat generated in high-power LEDs must be effectively dissipated. For characterization purposes, however, unambiguous indication of the thermal behavior of an LED is best gained through active cooling, for example through the use of a Peltier element, thus allowing examination of the LED at predetermined temperatures. As can be clearly seen in Figure 1, for increasing temperature the blue emission peak shifts to longer wavelengths and the total emission intensity decreases (the latter effect being typical of LEDs in general). These spectral and intensity changes also cause an alteration in the perceived color. In all industries associated with light emission, perceived color has long been described by the concept of color temperature. Table 1 below shows the calculated effective (i.e. nearest) color temperature for the LED emission illustrated in Figure 1.

Operating Temperature [°C]	Color Temperature [K]
80	3222
70	3203
60	3187
50	3173
40	3161
30	3151
20	3144
10	3141

Table 1: Change in the color temperature Tn for changing operating temperature of a white light LED

Between 20° and 80° C, the effective color temperature is shifted considerably and leads to a significant change in the perceived color. This property of white light LEDs is especially problematic in general lighting applications and hinders the development of qualitative high-grade products.

An additional issue is visible during the burn-in process for LEDs. That is, as long as thermal equilibrium has not yet been reached, the electrical and optical characteristics of the LED also undergo change.

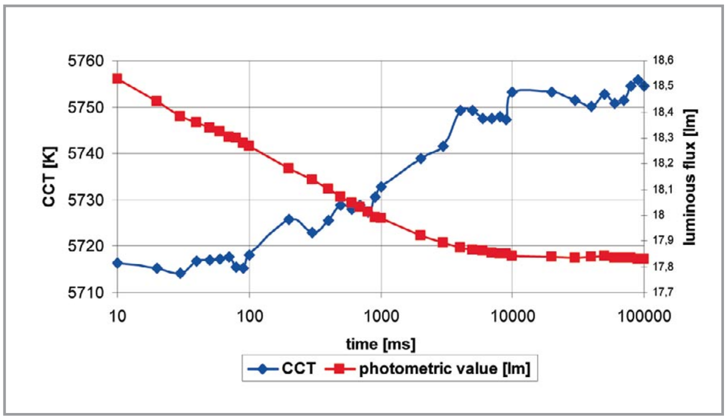

Figure 2: The red squares show the dependence of the total irradiance of a white light LED after switching on, the blue squares show the changing color temperature Tn

Figure 2 illustrates the burn-in process of a white light LED stabilized to 40°C - the photometric luminous flux (black squares) of the LED falls over a period of 10 seconds, while at the same time the effective color temperature rises (white squares). This relatively long stabilization phase must be accounted for if comparison of measurement data is to be made, i.e. measurements made in the production environment can differ from those made under stable laboratory conditions.

The final production step for LEDs is the optical characterization and the subsequent sorting into so-called BINS. Typically, this measurement and classification process occurs 20 to 30ms after the LED is switched on, even if the LED has not yet been thermally stabilized. Nonetheless, the specifications given by the manufacturer in the data sheet usually correspond to this type of production environment measurement. Customers receiving the LED must then often perform their own measurement under stable conditions in order to appropriately characterize the LED for the intended use.

Spatial Radiation Pattern

In order to properly determine their color temperature, the spatial radiation pattern of white light LEDs has to be considered. Contrary to single color LEDs, the perceived color of a white light LED can change as a function of the emission angle. This is a direct consequence of the nature of the technology utilized by the manufacturer to coat the blue LED-chips with phosphors. Differing standards among manufacturers mean that this change can amount to more than 1000 K.

Using a combination of goniometer and spectroradiometer, the luminous intensity distribution and the color temperature can be measured over the spatial radiation pattern of a white light LED. Figure 3 depicts these measurements for both a modern high-power white light LED and a standard 5mm LED.

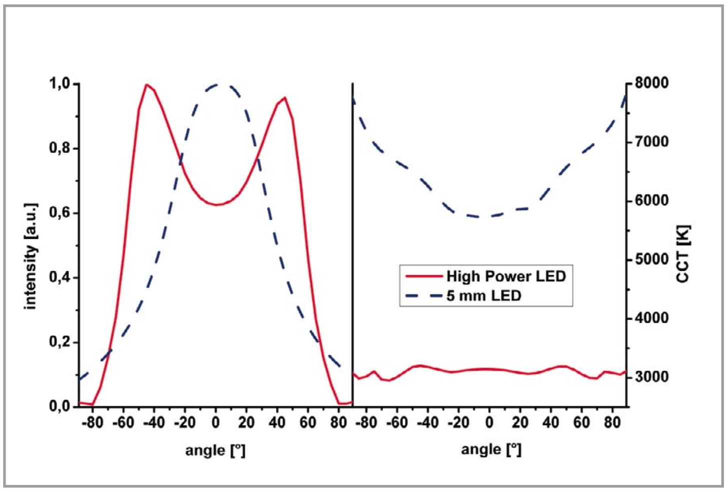

Figure 3: Spatial radiation pattern and color temperature of the emission of white light and standard LEDs, measured at a distance of 250mm

The luminous flux of high-power LEDs is usually measured with an integrating sphere, alternatively the averaged luminous intensities ILED-A or ILED-B. With an integrating sphere, the measured spectrum is integrated over the entire emission hemisphere, whereas a simple luminous intensity measurement only gathers light over a narrow solid angle. If the color temperature is determined under conditions for measuring ILED- B, the result is different to that obtained with an integrating sphere (table 2).

	Color temperature high-power LED [K]	Color temperature 5mm LED [K]
ILED B	3145	5748
Integrating sphere	3112	6804

Table 2: The effective color temperatures for both LEDs as determined from measurement conditions appropriate to that for an integrating sphere and for ILED-B

Were the discrepancy for the measured effective color temperatures of a white light LED as apparent as that for the standard LED (table 2), the measurement geometry used to determine the specifications would have to be indicated appropriately in the data sheet.

Aging of white light LEDs

Modern high-power LEDs require a relatively long burn-in phase until little or no further change occurs over time. The aging process of a 1W white light LED over a time period of 2000 hours is shown in Figure 4 [1].

Over this time frame not only the brightness varies, but also the spectral distribution. During the aging process, the effective color temperature changes by several 100K from 6900 to 6200K.

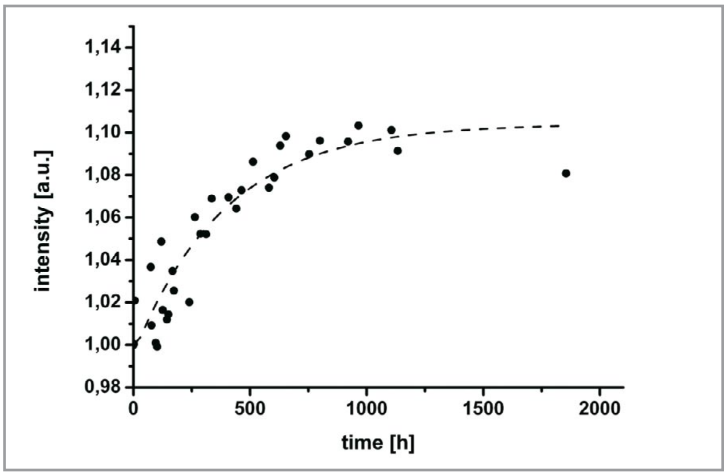

Figure 4: Aging of a high-power white light LED

Lighting manufacturers have to take this behavior into account at the design stage of the product in order to ensure that there are no quality issues associated with degradation of performance. Intelligent feedback and control of the LED over its entire lifetime is one solution to this problem.

Measurement Technology

As highlighted above, spectroradiometers have now become the standard for the measurement of the optical parameters of LEDs. Compared to currently available photometers and colorimeters, spectroradiometers obviate the need for the spectral filters that, through tolerances in the manufacturing process, are often not spectrally matched to the tristimulus curves. However, the optical performance of the spectrometer is also a determining factor for the validity of the measurement result. Two critical parameters are the spectral resolution and the suppression of stray light.

Spectral Resolution

In general, the spectral resolution of a spectrometer can be determined by measuring laser light whose spectral linewidth is much smaller – the resulting "full width half maximum" of the spectrum then corresponds to the spectral resolution of the spectrometer.

For broad-band continuous light sources such as halogen lamps, the spectral performance of a spectrometer has no recognizable influence on the measurement. However, for narrow-band LED sources, insufficient spectral resolution can artificially broaden the measured emission spectrum and thus lead to falsification of the color values.

The emission from white light LEDs usually consists of a relatively narrow band of blue emission superimposed on the spectrally broad emission of the coating phosphor. For proper determination of the effective color temperature, it is important to know the exact height and width relationship for the blue component of the light relative to that of the spectrally broader yellow phosphor. If the spectral resolution of the spectrometer is too low, the blue range can be falsely represented. Just as for a laser line, the measured blue spectrum of the LED is broadened and the peak reduced. In contrast, the broader, yellowish component of the phosphor emission is not affected. The net result however is a change to the overall spectrum.

The effect that the spectrometer resolution can have on a measurement is illustrated in table 3. The same LED was measured using a spectrometer with variable resolution.

Spectral resolution [nm]	Photometric Integral [cd]	Color Temperature [K]
1	0.877	5699
2	0.875	5695
5	0.872	5692
10	0.873	5676

Table 3: Dependence of the effective color temperature on the spectral resolution

While the photometric value remains more or less unchanged, the effective color temperature shifts by 24 Kelvin. In order to guarantee sufficient accuracy for the measured color coordinates, the spectral resolution of the spectrometer should generally be in the range of 2 to 3nm.

Stray Light

In addition to the spectral resolution, the stray light performance of a spectrometer also plays a critical role for the correct measurement of color coordinates for white light LEDs.

The exact determination of the stray light behavior of a spectrometer over the entire spectral range normally requires the use of a tunable laser source in a complex measurement scheme [2]. However, with help from a halogen lamp and a suitable 450nm long pass optical filter, the stray light suppression afforded by a spectrometer for broad-band light sources can be adequately assessed. Figure 5 shows measurement of the filtered light from the halogen lamp for 3 different spectrometer types - 2 array spectrometers and a double monochromator. The former achieve 2.5 or 3.5 orders of magnitude for stray light suppression, the double monochromator significantly more.

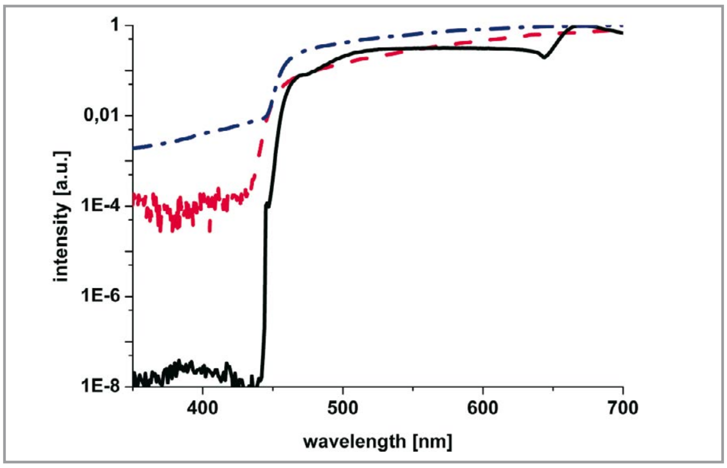

Figure 5: Stray light suppression for different spectrometers for filtered light from a halogen lamp: double monochromator (black), array spectrometer #2 (blue), array spectrometer #1 (red)

In the case of spectroradiometers, these are usually calibrated with the use of halogen lamps with broad-band emission. A common standard, available from almost all national laboratories, is a 1000W FEL lamp with a color temperature of approx. 3100 K.

Halogen lamps have the disadvantage that the emission energy in the blue spectral range only reaches roughly 10% of that at 800nm. The total signal measured per wavelength interval during the calibration process is the sum of the light from the halogen lamp in that same interval plus the stray light component. Insufficient stray light suppression in the blue can thus lead to erroneous values in this region of the calibration file. For the array spectrometer #1, the stray light contribution around 430nm amounts to almost 5%, while that for the reference double monochromator is negligible due to its superior stray light suppression.

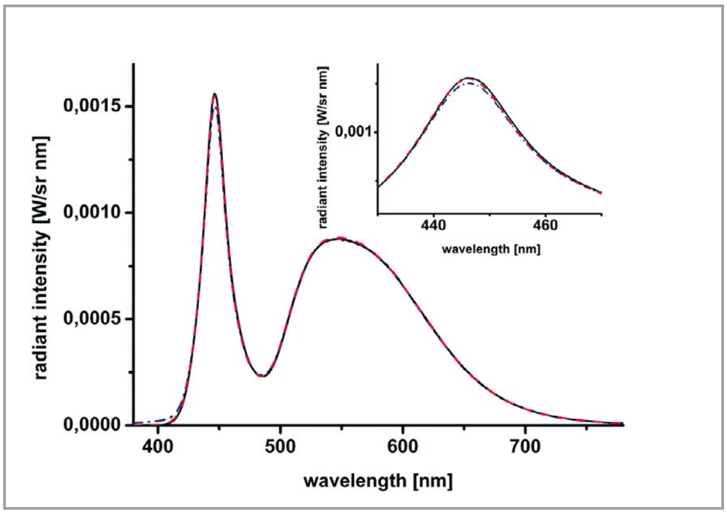

Figure 6: Spectrum of a white light LED measured with three calibrated, but different spectrometers

The effect this can have on measured values for white light LEDs is seen in Figure 6. The spectrum from the same LED as in Figure 5 is recorded by the same 3 spectrometers using coupling optics corresponding to those required for ILED-B measurements. For the array spectrometer #2 (the one with the highest stray light contribution), the blue spectral peak is noticeably smaller than for the other two spectrometers. Normalization of the actual measurement values is made through use of the calibration file, but the erroneous values in the blue spectral region within this file lead to wrongly normalized data in this part of the spectrum.

The color coordinates and the color temperature are affected directly (see table 4), while the photometric values are not.

Spectrometer	Photometric Integral [cd]	x-coordinate	y-coordinate	Tn[K]
Double Monochromator	51.9	0.3169	0.3425	6209
Array Spectrometer #1	52.1	0.3173	0.3444	6186
Array spectrometer #2	51.8	0.3181	0.3453	6138

Table 4: Effect of the stray light suppression of the different spectrometers on the color values

Summary

As the key light source for the future, white LEDs represent a major challenge for optical measurement methods. Factors directly affecting the light source itself, such as operating temperature, the burn-in phase, aging behavior, etc., have to be analyzed and specified properly in order to ensure good reproducibility of the measurements. Furthermore, proper optical parameters for the measurement system also determine whether characterization of LEDs can be made accurately and reproducibly. Differing measurement geometries for the very same LED can also lead to entirely different results. All of these factors have to be accounted before proper internationally comparable quality standards can be established. ■

References:

[1] Dr. Adrian Mahlkow; O.U.T e.V.; private communication; May 2008

[2] Yuqin Zong et al; NIST; Simple spectral stray light correction method for array spectrometers, Applied Optics, Vol 45, No 6; Feb. 2008