Methods and techniques for the absolute and accurate determination of the luminous efficiency of today high power LEDs

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1 Introduction

For a light planning the luminous flux and the luminous efficiency are important values. Datasheets of modern high power LEDs are not accurate regarding to these values. The values given in these datasheets are measured at surrounding conditions that does not apply to the practical experience. All data is given at a junction temperature T_j of 25 °C obtained due to a pulsed drive current.

To achieve more accurate values for the luminous flux and the luminous efficiency that apply to the practical experience all measurements, carried out in this investigation, are made with a stabilized junction temperature between 80 °C and 115 °C. These temperatures relate to the expected junction temperatures at general lighting and automotive applications. The LEDs are driven with their nominal current to achieve the nominal luminous flux. The drive current and the forward voltage of the device are measured during the flux measurement to obtain the total input power of the LED.

Different types of modern high power LEDs from leading manufacturers are measured. The following devices are part of the investigation:

- LUMILEDS K2
- NICHIA NJ5W075
- OSRAM Platinum Dragon
- OSRAM Ostar Lighting
- SEOUL SEMICONDUCTOR Z-Power LED P3

The luminous flux is measured using an integrating sphere with a diameter of 300 mm equipped with an auxiliary LED. The device under test is placed inside the wall of the sphere. Separated from the direct beam of the LED with a shutter, a photometer is placed inside the wall of the sphere. When measuring the luminous flux of a LED, some particularities with reference to flux measurements using an integrating sphere have to be considered.

2 LED luminous flux measurement using an integrating sphere

The first step in order to measure luminous flux with an integrating sphere is the calibration. Normally the integrating sphere is calibrated using a standard calibrated by a national institute of standards.

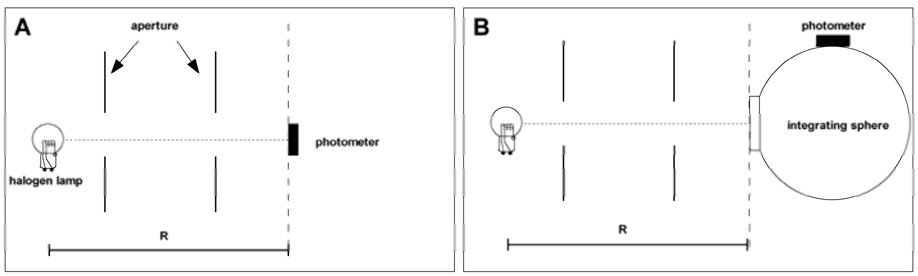

Figure 1: Calibration of an integrating sphere using an external light source

There are only a few standard LEDs for luminous flux available on the market so an alternative method to calibrate the sphere, that is not using a standardized light source, is required. In this investigation the calibration procedure depicted in figure 1 is used. This method is, in a much more sophisticated version, also used at the NIST [1]. A photometer is placed in a known distance in front of a halogen lamp and the illuminance E is measured. Afterwards the sphere is placed in the same distance in front of the lamp and the illuminance E_N in the sphere wall is measured. The luminous flux Φ_N that beams into the integrating sphere can be calculated using equation (1).

$$\Phi_N = E \cdot A \tag{1}$$

In this connection A is the area of the opening of the sphere where the beam of the lamp enters. The sphere factor can then be obtained by dividing Φ_N by the illuminance E_N. A very important thing one has to remind when measuring LEDs with an integrating sphere is the adaptation of the combination of photometer and sphere to the V(λ)-function. Photometer and sphere form a measuring unit. The spectral transmission factor of the sphere τ multiplied with the V(λ)-adaptation of the photometer represent the relative spectral responsivity $s_{rel}(\lambda)$ of the measuring unit which never perfectly matches the V(λ)-function. Figure 2 shows the relative spectral responsivity $s_{rel}(\lambda)$ of the measuring unit used in this investigation.

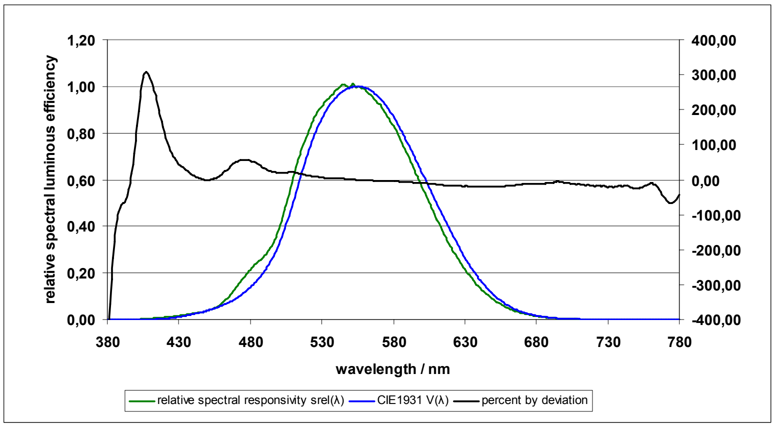

Figure 2: Relative spectral responsivity $s_{rel}(\lambda)$ and its deviation to V(λ)

The spectra of incandescent lamps and LEDs are very different. Whereas the spectrum of incandescent lamps is wide banded the spectrum of a LED is very narrow. When measuring a wide banded source with a slightly inaccurate V(λ)-adapted measuring unit this is not a big problem. With narrow banded LED this problem might get worse because the spectrum of a LED can be located in a badly adapted area of the V(λ)-function resulting in big error in illuminance measurement. The error caused by this spectral mismatch is particularly big for red and blue LEDs and can get up to 25 % when measuring luminous flux. Table 1 shows the expectant measurement error *E* for different LED colors if there is no correction. These errors apply only to the measuring unit used in this investigation but give a tendency for all units available on the market.

Table 1: Measurement errors without correction

Color	E
red	20 %
amber	14 %
white	2 %
green	10 %
blue	25 %

The spectral mismatch error of the measuring unit can be corrected by the spectral mismatch correction factor F [2]. To calculate this factor the spectral distribution of the device under test (DUT) and the relative spectral responsivity of the measuring unit has to be known. The spectral mismatch correction factor is then given by

$$F = \frac{\int S_{LED}(\lambda)\, V(\lambda)\ d\lambda \cdot \int S_{cal}(\lambda)\, s_{rel}(\lambda)\, d\lambda}{\int S_{LED}(\lambda)\, s_{rel}(\lambda)\ d\lambda \cdot \int S_{cal}(\lambda)\, V(\lambda)\, d\lambda} \qquad (2)$$

where $S_{LED}(\lambda)$ is the spectral power distribution of the DUT, $S_{cal}(\lambda)$ is the spectral power distribution of the used standard source, $s_{rel}(\lambda)$ is the relative spectral responsivity of the measuring unit and $V(\lambda)$ is the spectral luminous efficiency function. The luminous flux Φ_{corr} using the correction factor is calculated with equation (3).

$$\Phi_{corr} = \Phi \cdot F \qquad (3)$$

The luminous flux Φ is derived by the generally known procedure of measuring luminous flux with an integrating sphere. The luminous efficiency η one receives by dividing the luminous flux Φ_{corr} by the total input power of the DUT. The total input power of the DUT is measured during the luminous flux measurement separately.

3 Measurement results

In table 2 the luminous efficiency of the measured white LEDs in comparison to the values specified in the datasheets is shown. The luminous efficiency decreases between -8,6 % and -19,8 % if the junction temperature is increased from 80 °C to 115 °C. First measurements of a SEOUL SEMICONDUCTOR Z-Power LED P4 show that with a single chip LED and a driving current of 1 A there is already a luminous flux of 195 lm and 55 lm/W possible [3].

4 Conclusion

For an accurate luminous flux measurement of LED devices it is very important to be aware of the measurement error one can make when no spectral correction

Table 2: Luminous efficiency of different white LEDs

LED Typ	η_{typ} luminous efficiency T_j = 25°C (Datasheet) [lm/W]	$\eta_{80\,°C}$ luminous efficiency T_j = 80°C [lm/W]	$\eta_{115\,°C}$ luminous efficiency T_j = 115°C [lm/W]	$\Delta\eta$ [%]
OSRAM Ostar (6 Chips) I_N = 700 mA	18	25,63	22,66	-11,6
LUMILEDS K2 I_N = 1500 mA	22,51	23,63	21,60	-8,6
SEOUL SEMICONDUCTOR Z-Power LED P3 I_N = 700 mA	14,00	26,29	21,13	-19,6
NICHIA NJ5W075 I_N = 700 mA	32,14	26,79	23,39	-12,7

is used. The measurement unit composed of integrating sphere and photometer is never perfectly adapted to the *V(λ)*-function. This results in measurement errors for narrow banded light sources, like LEDs, of up to 25 %. For the correction of the adaptation error the measurement unit has to be properly characterized. For this characterization the transmission factor of the sphere and the *V(λ)*- adaptation of the photometer has to be determined. After the characterization the spectral mismatch correction factor for each DUT must be calculated. This factor corrects the insufficient *V(λ)*-adaptation of the measurement unit and allows a accurate luminous flux measurement. Modern single chip LEDs operated at T_j=115 °C, an expected junction temperature for automotive application, have a luminous flux between 60 lm and 108 lm and a luminous efficiency between 21 lm/W and 23 lm/W.

Literature:

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