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DEVELOPMENT OF A COMPACT-SIZE STANDARD LED FOR SPHERE-SPECTRORADIOMETER IN 2π GEOMETRY

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Abstract

For total luminous flux calibration by sphere-spectroradiometer with small-size integrating sphere in 2π geometry, compact-size LED-based standard source (standard LED) had been developed. The body diameter of the compact-size standard LED is ϕ25 mm that is useful size to be mounted on the ϕ1-inch port equipped in many commercial integrating spheres. The developed compact-size standard LED has sufficient spectral power over the full visible wavelength range using 365 nm UV-LED dies and four types of phosphors. Properties of the compact-size standard LED such as intensity distribution, stability, and reproducibility were also evaluated. The results indicate that the developed compact-size standard LED has good properties as a standard light source for the 2π total spectral radiant flux scale.

Keywords: Photometry, LED, total luminous flux, total spectral radiant flux, spectral measurement, sphere-spectroradiometer, 2π geometry

1 Introduction

Total luminous flux, which is necessary for energy efficiency evaluation, is an important value for LED products. For total luminous flux evaluation of LED products, total spectral radiant flux (TSRF) measurement is important because of the various spectra of the LED products. A convenient method of TSRF measurement is a comparative measurement using a sphere-spectroradiometer system that comprises an integrating sphere equipped with a spectroradiometer. There are two types of sphere-spectroradiometer measurement geometry, 4π geometry and 2π geometry. In 4π geometry, a light source is placed at the centre of the integrating sphere. This geometry is recommended for light sources that emit light in all directions, such as incandescent lamps. In 2π geometry, a light source is mounted on a port of the integrating sphere wall. In order to measure TSRF of light sources emitting light only to the forward direction, as many LED products, 2π geometry is recommended (CIE, 2015; IESNA, 2008).

The spectral responsivity of the sphere-spectroradiometer system should be calibrated by the reference source that is set on a same geometry as the test light source. In 4π geometry, the conventional standard lamps by incandescent lamps are used. However, in 2π geometry, it is difficult to use conventional standard lamps as a reference source because these lamps emit the light in all directions. In contrast, many LED products don’t have spectral power over the visible wavelength range, though these are good at emitting light only in the forward direction.

Recently, NMIJ and Nichia Corporation have developed a new LED based standard source (2π standard LED) that is suitable for TSRF measurements in 2π geometry (Nakazawa et al., 2018). The 2π standard LED has sufficient spectral power over the full visible wavelength range. This 2π standard LED was developed as a reference source for a sphere-spectroradiometer with a large-size integrating sphere which is used for measurement of LED module and LED luminaires, then the body diameter of the 2π standard LED is ϕ62 mm, emitting area of it is ϕ12 mm and the total luminous flux of it is about 200 lm.

On the other hand, LED package are recommended to be evaluated using a small-size integrating sphere of 20 cm to 50 cm diameter in CIE 127 (CIE, 2007) and CIE 225 (CIE, 2017).

Moreover, many manufactures evaluate LED package using a small-size integrating sphere in 2π geometry. Therefore, there is a demand from LED package manufactures for a new standard light source that can be used in the spectral measurement using a sphere-spectroradiometer with a small-size integrating sphere too.

The purpose of this study is developing a compact-size standard LED for the small sphere-spectroradiometer.

2 Methods

The compact-size standard LED had been developed to satisfy some requirements as well as the 2π standard LED. For example, the requirements are that, having sufficient spectral power over the visible range (380 nm – 780 nm), emitting light to the forward direction and having ideal luminous intensity distribution, etc.

Needless to say, the most different requirement from the 2π standard LED is that the size of a standard LED is preferably small to be mounted on a port of a small-size integrating sphere. Thus, the body diameter and the size of emitting area of the compact-size standard LED was decided to useful for ϕ1-inch port equipped in many commercial small integrating spheres.

For downsizing a body size and an emitting area from the size of 2π standard LED, peak wavelengths of LED dies and combination of phosphors in the compact-size standard LED was reconsidered to make spectrum which meets above requirements. To obtain sufficient spectral power over the visible wavelength range, the method that combining UV-LED dies of multiple peak wavelengths and RGB phosphors was used in the 2π standard LED development. In the compact-size standard LED development, however, we introduced a new method that combining single wavelength UV-LED (365 nm) dies, RGB phosphors and near UV phosphor (four type phosphors were used).

As a result, the compact-size standard LED was developed that satisfies both characteristics of size downsizing and sufficient spectral power over the visible range.

3 Results and discussion

3.1 Development of compact-size standard LED

Figure 1 shows the photograph of the developed compact-size standard LED for 2π geometry. The body diameter of the compact-size standard LED is ϕ25 mm. The size of the emitting area located at the centre is 3.2 mm square. A thermo-module that controls the temperature of the emitting area is installed inside the compact-size standard LED and connected to external thermo-controller. This thermo-controller is specified to ± 0.02 °C temperature stability.

Figure 1 – Developed compact-size standard LED

The properties of the compact-size standard LED was evaluated using the LED goniophotometer system in NMIJ. This evaluation was operated under two conditions, (a) constant current of 350 mA and temperature of the emitting area at 55 °C, or (b) constant current of 500 mA and temperature of the emitting area at 65 °C to determine the operating condition.

The evaluation results showed that total luminous flux was 5,9 lm and total radiant flux was 50,5 mW under condition (a), and total luminous flux was 7,8 lm and total radiant flux was 65,3 mW under condition (b).

The luminous intensity distribution was evaluated using $V(\lambda)$-matched photometer calibrated against the NMIJ luminous intensity standard scale. The photometric distance was 1.5 m. The luminous intensity distribution depicted in Figure 2 was almost equal to the Lambertian beam pattern. There was almost no difference between luminous intensity distributions of two operating conditions.

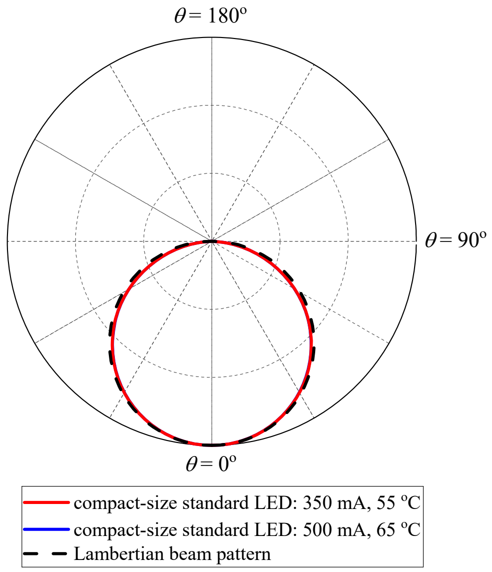

Figure 2 – Luminous intensity distribution of the compact-size standard LED under two operating conditions

The spectral characteristics were evaluated using LED goniophotometer system in NMIJ and array spectroradiometer calibrated against the NMIJ spectral irradiance standard scale. Figure 3 shows the spectra of the compact-size standard LED of two operating conditions. The spectrum shape of the compact-size standard LED was created considering the measurement uncertainties in spectral measurement: wavelength calibration uncertainty and slit function effect of the sphere-spectroradiometer (Nakazawa et al., 2017). Thus, as shown in Figure 3 the spectrum was smooth and had no sharp peaks or dips in order to reduce the spectral measurement uncertainty. In addition, the spectrum shape of the compact-size standard LED is almost the same as that of the 2π standard LED. Thus, the relative radiant intensity around 400 nm is intentionally large as well as that of the 2π standard LED, because of reducing the influence of low spectral responsivity of detectors below 450 nm.

The angular dependence of spectrum was also evaluated, and it was revealed that the spatial distribution of the relative spectrum is almost uniform independent of angles.

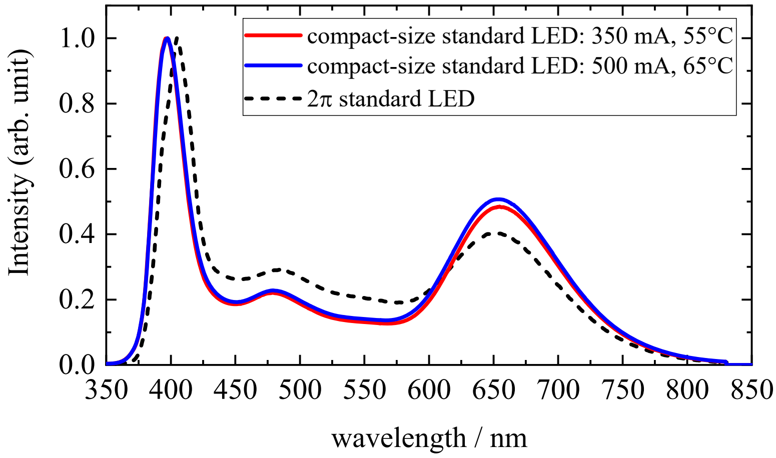

Figure 3 – Spectra of the compact-size standard LED under two operating conditions

3.2 Optical stability and reproducibility

The optical stability and reproducibility of the compact-size standard LED were evaluated after 500 hours aging processing. This aging time is longer than that of the 2π standard LED.

Figure 4 shows the short-term stability of radiant flux of the compact-size standard LED. As shown in Figure 4, stability of radiant flux of the compact-size standard LED is almost same as that of the 2π standard LED. It became almost constant after about 10 minutes operation. The short-term stability of radiant flux was about 0.01 % per hour. The compact-size standard LED and 2π standard LED was operated at rate of 10 mA·s^{-1} until operating current reaches the set value. Then, when the compact-size standard LED was operated at 500 mA, it took longer time for the current to reach the set value than 350 mA operation.

Note that periodical fluctuation of about 40 minutes founded in radiant flux data of compact-size standard LED was cause from room temperature fluctuation. That effect was not found in radiation flux data of 2π standard LED because the stability and reproducibility of 2π standard LED was evaluated in different room from that of compact-size standard LED.

The short-time stability of spectral radiant flux was below 0.05 % per hour in almost all wavelength from 380 nm to 780 nm.

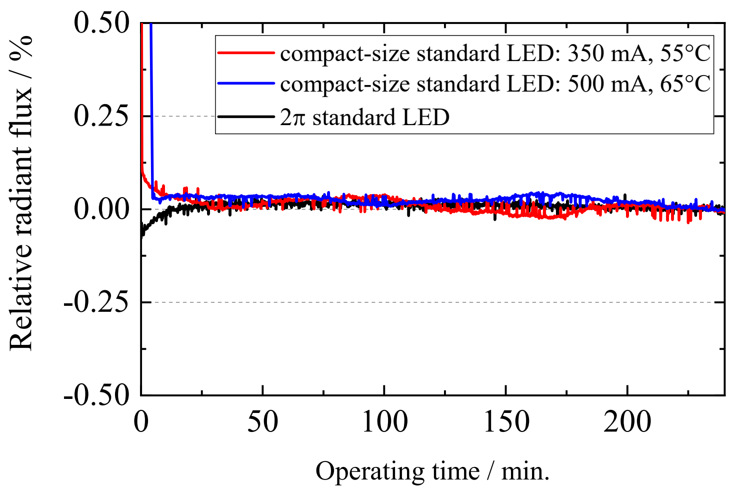

Figure 4 – Optical stability of radiant intensity of the compact-size standard LED under two operating conditions

The reproducibility of radiant flux and spectral radiant flux were evaluated in each of four independent 1-hour operations. As a result, reproducibility of the radiant flux was 0.02 % and that of the spectral radiant flux was within ±0.3 %.

The ambient temperature dependence of the compact-size standard LED operated two conditions are shown in Figure 5. The ambient temperature dependence of the compact-size standard LED was evaluated using thermostatic chamber at different three temperatures (18 °C, 23 °C, 28 °C). The ambient temperature dependence of the 2π standard LED and typical white LED without thermal control module are also plotted in Figure 5. As shown in Figure 5, the temperature variation coefficient of the radiant flux of the compact-size standard LED was less than 0.03 %·°C^{-1}. This ambient temperature dependence value is close to that of 2π standard LED, the ambient temperature dependence is less than 0.01 %·°C^{-1} and better than that of the typical white LED without thermal control module, that is about 0.1 %·°C^{-1}.

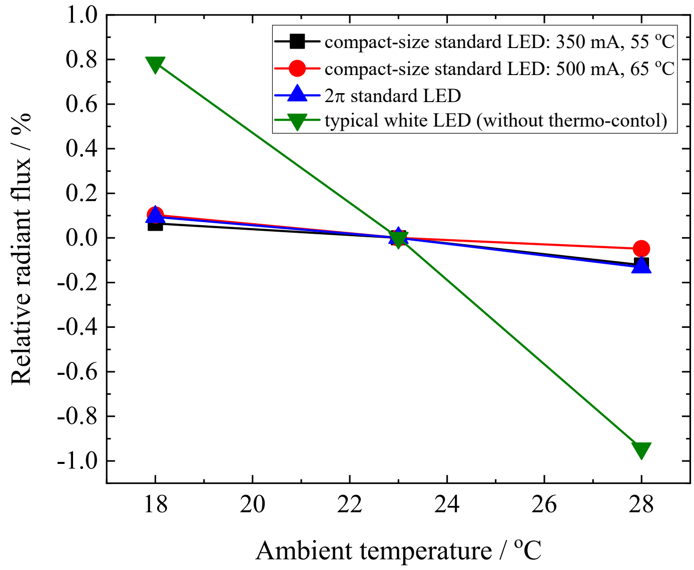

Figure 5 – Ambient temperature dependence of the compact-size standard LED under two operating conditions

4 Conclusion

The compact-size standard LED suitable for standard light source of TSRF measurement using small sphere-spectroradiometer had been developed. The diameter of the compact-size standard LED is ϕ25 mm and the size of the emitting area located at the centre is 3.2 mm square. A thermo-module that controls the temperature of the emitting area is installed inside the compact-size standard LED.

The spectra of the compact-size standard LED was smooth and had no sharp peaks or dips in order to reduce the spectral measurement uncertainty. The compact-size standard LED has sufficient spectral power over visible wavelength range by using UV-LED dies combined with four types of phosphors. The luminous intensity distribution of the compact-size standard LED was almost equal to the Lambertian beam pattern. The angular dependence of spectrum was revealed that the spatial distribution of the relative spectrum is almost uniform independent of angles.

Properties of the compact-size standard LED was evaluated under two operating conditions. Under both operating conditions, the results indicate that the compact-size standard LED was good properties about short-time stability, reproducibility, and ambient temperature dependence as a standard light source.

From the above evaluation results, we concluded that the compact-size standard LED is useful as a standard light source in the LED products measurement described by CIE 127 and CIE 255.

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