

MEASUREMENT OF WEIGHTED LED RADIANCE RELATED TO PHOTOBIOLOGICAL SAFETY

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ABSTRACT

Optical radiation safety of light-emitting diode (LED) products is being addressed in the International Electrotechnical Commission (IEC) standard document 62471-2006. Measurement of weighted radiance of LEDs, used to assess the maximal exposure related to the photobiological safety, is very different from that of traditional luminance/radiance, and is not traceable yet to any national standard laboratories. We developed two measurement systems using a spectroradiometer and a CCD camera to obtain the weighted radiance of LED sources.

Keywords: LED, photobiological safety; measurement; blue light hazard; weighted radiance

1 INTRODUCTION

Optical radiation with biological significance covers the spectral range from 180 nm to 3000 nm. Most important human tissues related to the photobiological effect are skin and eyes. Over exposure of optical radiation in the spectral range from 300 nm to 1400 nm can cause photochemical and thermal injury to eye's retina. Optical radiation safety of LEDs was first addressed in the IEC standard document 60825-1 in 1993 for laser safety. However, LEDs were taken out from the scope of the laser safety standard IEC 60825-1 in Edition 2 in 2007 to avoid any confusion [1]. Currently, optical radiation safety of LEDs is addressed in the standard document S009/E:2002 for photobiological safety of lamps and lamp systems. This standard document was developed by the International Commission on Illumination (CIE) in 2002, and was adopted by the IEC as an international industrial standard IEC 62471/Ed.1 in 2006 [2]. Optical radiation safety of LEDs is also addressed in the standard documents for photobiological safety of lamps and lamp systems, EN 62471-2008 in European and GB/T 20145-2006 in China.

High-power white LEDs with attached optics have complex beam profiles. Typically

retina damage is the dominant hazard for these LED products. Due to the nature of human eyes, measurement of weighted radiance of LEDs, used to assess the maximal exposure related to the photobiological safety, is very different from that of traditional luminance/radiance, and is not yet traceable to any national standard laboratories.

2. PHOTOBIOLOGICAL RADIANCE RELATED TO EYE'S SAFETY

The differences of photobiological radiance in comparison to traditional radiance are that

- a.) it is weighted by a photobiological response, e. g., blue light hazard (BLH) spectral function,
- b.) field of view is related to exposure time,
- c.) incident aperture stop of the instrument has the same size of an eye's pupil,
- d.) there is accessible maximal exposure,
- e.) and the instrument is focused on the apparent source, not the true source.

The retinal hazard caused by optical radiation includes thermal burn and photochemically induced retinal injury. For a white LED based on a blue LED chip and yellow phosphor, the main hazard is the photochemical retinal injury caused by the high color temperature, high luminance small spot. The hazard functions for both thermal and photochemical hazard assessments and the photopic function, $V(\lambda)$, are entirely different. To assess LED hazard, it is required to measure spectral radiance in the spectral range from 300 nm to 1400 nm, which is wider than that of most of commercial spectroradiometers. It is also critical that the measurement geometry of the spectroradiometer mimics that of a human eye.

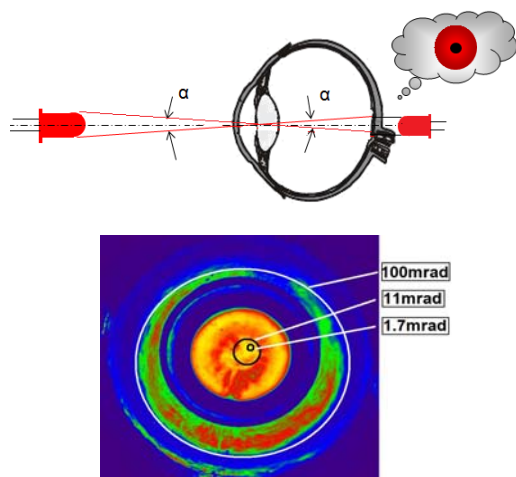


Figure 1. Nonuniformity of radiance of an LED within eye's angular subtenses

It is possible for a small light spot to be formed on the retina. The minimum spot size is 1.7 mrad subtense angle due to the limit of an eye's resolving power. A normal eye, however, when focuses on an object, moves slightly and randomly, resulting in a spread of the image of a point source over an area at the retina. The spread covers an angular subtense from 1.7 mrad to 100 mrad depending on exposure duration. As shown in Figure 1, radiance of an LED varies significantly, and it is difficult to evaluate the radiance level corresponding to an angular subtense ranging from 1.7 mrad to 100 mrad if an existing commercial instrument is used.

The measured radiance value of an LED also depends on the acceptance solid angle (and therefore the size of entrance aperture) of the instrument used, especially for a narrow beam LED [3]. To achieve consistent measurement results, the entrance aperture of an instrument is specified to be 7 mm diameter (the maximum size of an eye's pupil) in the safety classification, and the measurement distance from entrance aperture to the apparent source is 200 mm or a distance so that illuminance at the entrance aperture is 500 lx [2].

3. THE WEIGHTED RADIANCE MEASUREMENT SYSTEMS

A measurement system that mimics a human eye was set up (Figure 2), which includes a spectroradiometer, a scientific grade CCD camera, and a beam splitter that splits the measurement beam into the spectroradiometer and the CCD camera. An entrance aperture with 7 mm diameter was set at the front focal plane of the imaging lens, so that the field of view and the size of the entrance aperture are fixed no matter where the light source is. The measurement

area of the spectroradiometer and that of the CCD camera are overlapped exactly, thus the measured image by the CCD camera can be corrected by using the spectrum data measured by the spectroradiometer to determine the weighted radiance of the LED.

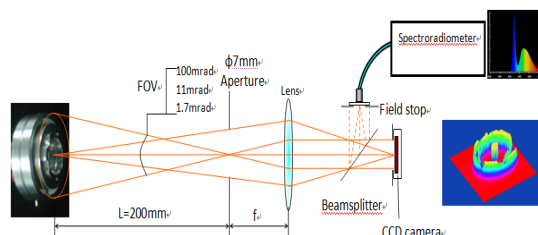


Figure 2. Principle of the measurement system.

The measurement FOV of the system can be set to from 1.5 mrad to 110 mrad in compliance to the CIE S009 / IEC 62471 standards. The maximum weighted radiance denoted as LB for blue, LR for red, and LIR for infrared, are determined based on the radiance distribution of the apparent source. A photograph of the measurement system at NIST is shown in Figure 3.

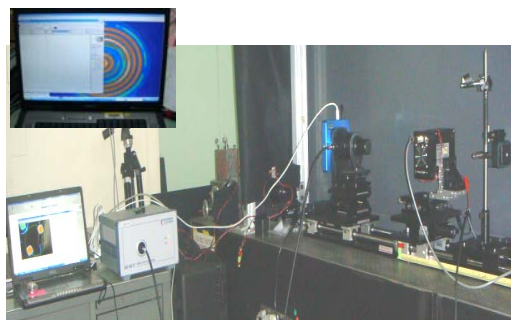


Figure 3. Photograph of the measurement system at NIST

The measurement system is calibrated for spectral radiance responsivity against a 1000 W spectral irradiance standard lamp by using a white reflectance standard, as shown in Figure 4.

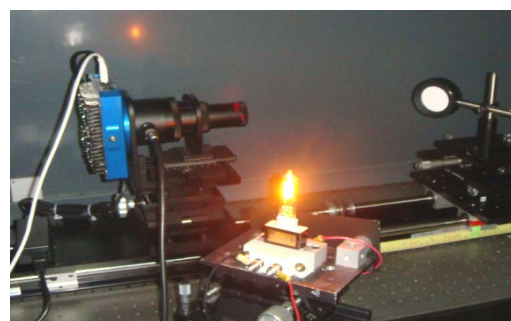


Figure 4. Photograph of the setup for calibration of the measurement system for spectral radiance responsivity.

For LEDs that are smaller than the specified measurement angular subtense, spatially averaged weighted radiance can be measured using the irradiance mode as shown in Figure 5. A 50 mm diameter sphere with a 7 mm aperture was placed at a specified position (at 200 mm from the LED source or at 500 lx location). The spectral irradiance is measured by using a spectroradiometer and is converted to the LED's weighted photobiological radiance.

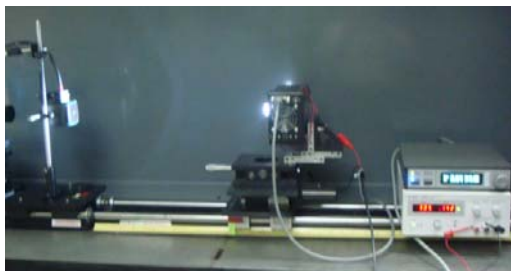


Figure 5. Photograph of the setup for the alternative irradiance-based method to measure spatially average radiance of LEDs

Three LEDs were measured for weighted blue radiance (LB) and infrared radiance (LIR) by using both the radiance-based method (using a CCD camera and a spectroradiometer) and the irradiance-based method. The angular subtense was either 34.8 mrad or 100 mrad. The measurement results are shown in Table 1. The results based on the two different methods agreed within a few percents, an implication that these two methods may be exchangeable.

Table 1. Comparison of measured weighted radiance by using the radiance-based method and the irradiance-based method.

LED Color and Measurement FOV	Radiance -based Method [W/m ² /sr]	Irradiance -based Method [W/m ² /sr]
White LED, L _B , 100 mrad	113	110
White LED, L _{IR} , 34.8 mrad	1.25	1.24
Blue LED, L _B , 100 mrad	262	260

CONCLUSIONS

Two methods were developed for measurement of weighted radiance of high-power LEDs related to photobiological safety. One is based on measurement of an LED's spatial distribution of radiance (using a

camera) and its spectra (using a spectroradiometer). This radiance-based method is suitable for measurement of LEDs with complex beam profiles or with a large size. The other is based on measuring spectral irradiance at the specified distance from an LED and then converting the measured spectral irradiance to the weighted radiance. This irradiance-based method can be used to measure small LED sources to obtain spatially averaged weighted radiance. The details and the measurement uncertainties of these two methods are being further investigated.

REFERENCES

- IEC 60825-1(Ed.2):2007, Safety of laser products - Part 1: Equipment classification, requirements and user's guide.
- IEC 62471:2006/CIES 009:2002. *Photobiological safety of lamps and lamp systems*
- Tongsheng M (2008). A Retinal Radiance Meter. CIE x033:2008 *CIE Expert Symposium on Advances in Photometry and Colorimetry*,
- Tongsheng M. (2007). The apparent sources determination for LEDs. CIE 178:2007 *CIE 26th Session, Beijing*

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