MEASUREMENT OF THE PHOTOMETRIC CHARACTERISTICS OF LEDs

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Proposed and implemented a method for measuring LEDs, which is based on self-calibration of the LED goniophotometer facility by using a trap-detector. Designed and manufactured automated goniophotometer, which provides a measurement of high power LEDs at a specified junction temperature. Designed and experimentally researched the photometer with a photometric sphere based diffuser, which meets all requirements of CIE for photometric measurements of LEDs.

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FOREWORD

The rapid development of light-emitting diodes (LEDs) revealed the problem of the lack of accurate and reliable methods for measuring the photometric characteristics of LEDs. Their unusual photometric parameters, such as spectrum radiation, spatial luminous intensity distribution, and others, have led to the fact that existing methods and measurement means that were developed for incandescent lamps have become unusable for LEDs. Trying to compare the results of photometric measurements in various National Metrology Institutes revealed a difference in measurement results up to several tens of percent. In the framework of international cooperation by the International Commission on Illumination (CIE), general guidelines were developed for measuring LEDs – CIE 127-2007 "Photometry LEDs" [1]. These recommendations contain only a general concept which results in each country solving the problem of measuring photometric characteristics of LEDs by developing their own techniques.

It is also important to have appropriate measurement means that are traceable to the national standards, the comparisons of which on an international scale, provides the required accuracy of measurements and unity of the measured results throughout the world. Therefore, an important and urgent task is to create methods and means for measurement of LEDs that would on the one hand meet the requirements of the CIE, and on the other, are traceable to the national standards, providing the required accuracy and traceability of measurement results.

1. GONIOPHOTOMETER LGF-C-42

It is still the unanswered question – which characteristics should have a reference means for measurement of LEDs? In the world measurement practice, the greatest success on this issue was reached by the National Institute of Standards and Technology (NIST) (US) and Physical-Technical Institute (PTB) (Germany). In the NIST, as a standard means for measuring the average LED intensity, reference photometers were used with aperture area of 100 mm^2. Measurement of luminous flux of LEDs is performed using NIST 2.5 m absolute integrating sphere, based on the absolute measurement method [2].

In PTB the measurements of LEDs are made on specially designed goniophotometer which are also used to measure luminous flux of LEDs [3].

To measure the luminous flux of LEDs, (the most important parameter for light sources) the integrating sphere method is attractive enough because of the speed, however, to perform precision measurements it is necessary to use the luminous flux standard. Goniophotometry is an absolute method for measurement of total luminous flux and does not require luminous flux standards. A photometer scans over an imaginary spherical surface around the test LED and measures the illuminance distribution. The measured illuminance is then integrated over the entire spherical surface to calculate the total luminous flux. Goniophotometry tends to be more accurate at measuring varieties of light sources but is more time-consuming than sphere photometry. The creation of a measuring device based on goniophotometric method for measuring luminous flux of LED is most appropriate.

For these purposes, LED Goniophotometer Facility LGF-C-42 was designed and created, to measure the photometric characteristics of LEDs (Fig. 1). The required software was also developed.

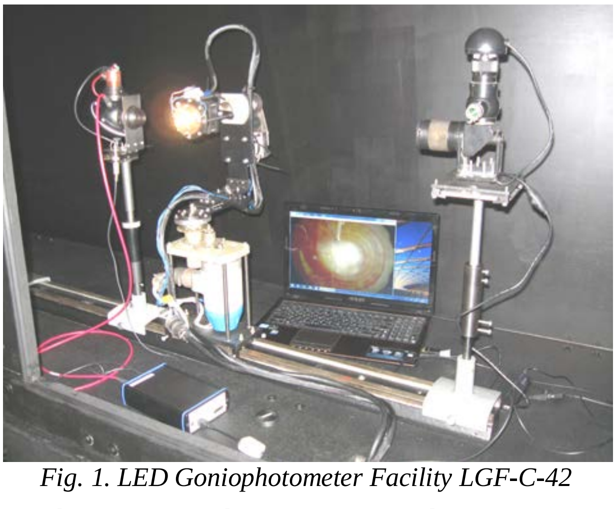

Fig. 1. LED Goniophotometer Facility LGF-C-42

The rotating mechanism was created using two stepper motors and reducers. The Goniophotometer resolution to change planes C-equal 0.00014º, the resolution to change γ-angles equal 0.08º, which is sufficient for most measurements.

The test LED was mounted on the mounting plate of the thermostat via printed circuit boards "Star" or the like. The required temperature level can be set and maintained using a Peltier element. In the lateral plane of the mounting plate, temperature sensor DS18B20 was installed, to provide feedback between the thermostat control unit and the computer on which the program for management and monitoring temperature was run. Using the thermostat, measurement of photometric characteristics of high-power LEDs at specified constant junction temperature was performed in accordance to a method developed by NIST [4].

2. SPHERE-PHOTOMETER

For photometers that are used to measure average LED intensity, there is a requirement of sensitivity uniformity within the aperture [1]. This requirement is caused by the presence of certain types of LED narrow beam distribution or non-uniform spatial distribution of intensity, that create non-uniform distribution of light within the surface of aperture opening.

Usually non-uniformity of the sensitivity within the photometer sensitive area is 0.1% or less when using photometric sphere as the diffuser. This gives 3-5 times better uniformity of the sensitivity than silicon photodiodes highest quality [5].

In view of the above, the advantages of the photometric sphere as diffuser becomes apparent, therefore the photometer was designed and manufactured to use such a photometric sphere (Fig. 2, Table 1).

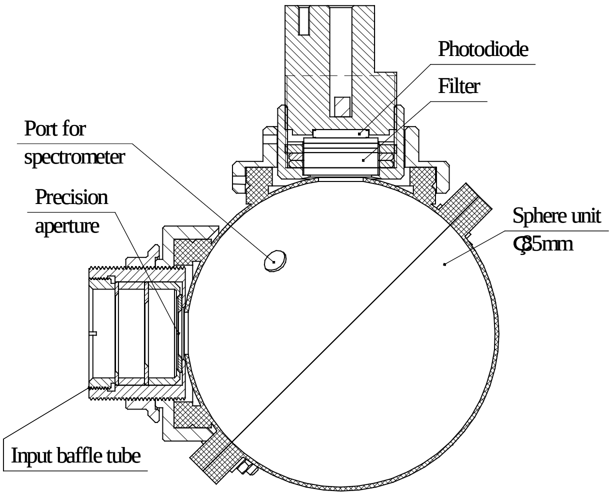

Fig. 2. Sphere-photometer

The detector used in the photometer was the photodiode Hamamatsu S1337-1010BQ. Since the S1337 series photodiodes are not corrected to the CIE V(λ) function, a filter based on a set of colored optical glasses was calculated and manufactured. Given the influence of the sphere coating (paint OPRC from OptoPolymer), f_1' was calculated equal to 5.86%, and measured – 5.83%. This result is more dependent on the quality of colored glasses, so in future it can be improved.

For amplification of the output signal from the photometer a transimpedance amplifier was designed based on the operational amplifier AD549JHZ. As the feedback resistance, precision 100 MOhm resistor was used.

To automate the measurement process on the goniophotometer facility LGF-C-42, appropriate software was created (Fig. 3) that allows automatic (according to the preset settings) measurement of the spatial light intensity distribution of the test LED. During measurement, the operator can monitor the process and measurement results in the software's main window.

Table 1

Characteristics of the created sphere-photometer

Characteristics	Designation	Value
V(λ) match	f_1’	5.825%
Cosine response	f_2	0.0089%
Linearity error	f_3	0.07%
Temperature coefficient	A	0.012%/°C
Fatigue	f_5	0.146%
Modulated radiation	f_7	0.1%
Effect of nonuniform illumination of the acceptance area of a photometer head	f_9	0.41%

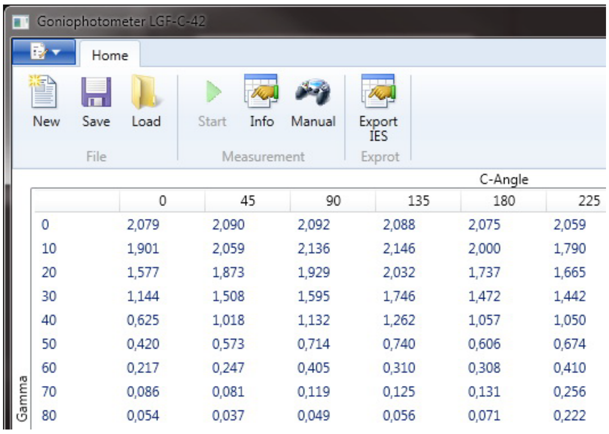

Fig. 3. Goniophotometer LGF-C-42 software

After measurement ends, the results can be saved in *.xml spreadsheet format or as IES-file. The latter allows use of measuring results in programs for lighting simulation, such as Photopia, Zemax or TracePro.

3. SPHERE-PHOTOMETER CALIBRATION

For the traceability of the results to the state primary standards it was decided to use the standard detector method, which is more versatile than the method of standard light source. This method has the following advantages: the unit of the measured value remains on the photometer, which is more stable over time and it has a long service life and requires smaller service costs.

The issue of transmission scale from the standard detector to the test detector, down to comparing the reaction of the test detector and the standard detector measured at each wavelength of the desired spectral range and spectral characteristics determine the ratio of photocurrent / power of radiation incident on the test detector, i.e. its spectral characteristics A/W sensitivity [6].

To transfer the scale from the standard detector to the test detector a spectral comparator facility was designed (Fig. 4), which uses the substitution method with monitor-detector.

As a reference detector the designed trap-detector [7] was used, which consists of three silicon photodiodes Hamamatsu S1337-1010BQ. The trap-detector allows reproduction of the scale of radiation power in range from 10^{-9} to 10^{-2} W in the visible range. Margin of main relative measurement error is ± 0.2%.

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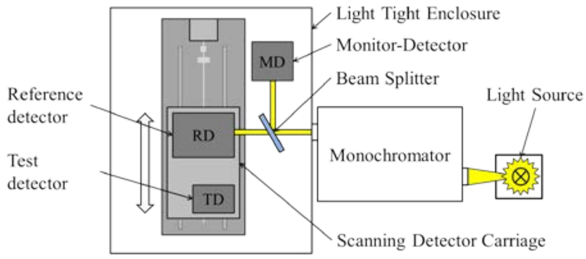

Fig. 4. Spectral comparator facility

As a test detector, photometric head with silicon photodiode Hamamatsu S1337-1010BR and precision aperture were used. After calibration, this photometer is used as a working standard for calibration of photometers in other measurement devices.

With spectral power responsivity of the working standard, it's easy to find the integral value of the luminous flux that was measured during calibration. Thus, knowing the exact value of the aperture acceptance area, it is possible to calculate the integral value of illuminance on the aperture acceptance area of the working standard.

Calibration of the photometer of LGF-C-42 is made by the working standard detector using the method of substitution. For calibration of the test detector, it is set alternately with the working standard detector at equal distance from the standard illuminant type A.

Equation of the illuminance responsivity of the sphere-photometer LGF-C-42 is shown below:

$$S_{LGF} = \frac{\frac{U_{LGF}}{R_{LGF}} \cdot l_{LGF}^2 \cdot S_s \cdot \cos(\alpha_s)}{\frac{U_s}{R_s} \cdot l_s^2 \cdot \cos(\alpha_{LGF})}, \qquad (1)$$

where U_{LGF} – voltage on exit of LGF-C-42 transimpendance amplifier; R_{LGF} – feedback resistance of LGF-C-42 transimpendance amplifier; l_{LGF} – distance between standard illuminant type A and the aperture acceptance area of LGF-C-42 photometer; α_{LGF} – angle of deviation from the optical axis of LGF-C-42; U_s – voltage on exit of working standard detector transimpendance amplifier; R_s – feedback resistance of working standard detector transimpendance amplifier; l_s – distance between standard illuminant type A and the aperture acceptance area of working standard detector; α_s – angle of deviation from the optical axis of working standard detector; S_s – illuminance responsivity of the working standard detector.

The illuminance responsivity of the sphere-photometer LGF-C-42 equals $1.804451 \cdot 10^{-10}$ [A/lx]. The uncertainty budget for calibration is presented in Table 2.

Table 2

Uncertainty budget for sphere-photometer calibration

Uncertainty component	Relative standard uncertainty (type B), %
Voltage on exit of LGF-C-42 transimpendance amplifier	0.005
Feedback resistance of LGF-C-42 transimpendance amplifier	0.085
Distance between light source and the aperture of LGF-C-42 photometer	0.191
Angle of deviation from the optical axis of LGF-C-42	0.001
Voltage on exit of working standard detector transimpendance amplifier	0.005
Feedback resistance of working standard detector transimpendance amplifier	0.042
Distance between light source and the aperture acceptance area of working standard detector	0.191
Angle of deviation from the optical axis of working standard detector	0.001
Illuminance responsivity of the working standard detector	0.203
Cosine response	0.005
Linearity error	0.040
Temperature coefficient (for T_{amb} =18°C)	0.048
Fatigue	0.084
Modulated radiation	0.058
Effect of nonuniform illumination of the acceptance area of a photometer head	0.237
Relative expanded uncertainty of calibration U (k=2)	0.88

4. LEDs MEASUREMENTS

Measurement of high-power LEDs, including (if necessary) averaged luminous intensity performed at a goniometer zero position in which the mechanical axis of the test LED is aligned to the photometric axis of sphere-photometer. The equation used for measurement of luminous intensity on goniophotometer LGF-C-42 is obtained by:

$$I_{LED} = \frac{U - U_0}{R_{LGF} \cdot S_{LGF}} \cdot \frac{F^* \cdot r^2}{\cos(\alpha)}, \qquad (2)$$

where U and U_0 – measured and dark signal respectively; R_{LGF} – feedback resistance of LGF-C-42 transimpendance amplifier; S_{LGF} – illuminance responsivity of the sphere-photometer LGF-C-42; F^* – spectral mismatch correction factor; r – distance between LED and the aperture acceptance area of LGF-C-42 photometer; α – deviation angle from the optical axis of LGF-C-42.

Spectral mismatch correction factor F^* calculated for each test LED as given by

$$F^* = \frac{\int S(\lambda) \cdot V(\lambda) d\lambda}{\int S(\lambda) \cdot s_{rel}(\lambda) d\lambda} \cdot \frac{\int S_A(\lambda) \cdot s_{rel}(\lambda) d\lambda}{\int S_A(\lambda) \cdot V(\lambda) d\lambda}, \qquad (3)$$

where $S(\lambda)$ – the relative spectral distribution of the test LED; $S_A(\lambda)$ – the relative spectral distribution of the CIE standard illuminant type A; $V(\lambda)$ – the CIE spectral luminous efficiency function of the photopic vision; $s_{rel}(\lambda)$ – the relative spectral responsivity of the photometer head.

Table 3

Uncertainty budget for luminous intensity measurements of high-power LED

Uncertainty component	Type	Probability distribution	Standard uncertainty of an input quantity	Relative sensitivity coefficient	Relative standard uncertainty, %
Measured signal	B	Rectangular	0.00015	-0.36229	0.005
Dark signal	B	Rectangular	$3.5\cdot10^{-6}$	-0.36229	0.0001
Feedback resistance of amplifier	B	Normal	84394.26	$-1\cdot10^{-8}$	0.0845
Calibration of sphere-photometer	B	Normal	$7.9\cdot10^{-13}$	$-5.5\cdot10^{-9}$	0.44
Spectral mismatch correction factor	B	Normal	0.007	0.98814	0.6928
Distance measurement	B	Rectangular	0.00087	3.04535	0.2641
Combined relative standard uncertainty, %					0.87
Expanded uncertainty U (k = 2), %					1.73

For the measurement of luminous flux on goniophotometer LGF-C-42 the same steps of preparatory work must be performed as for luminous intensity measurements. The only difference is that LED intensity is measured in all directions. To calculate the luminous flux the measurement equation used is:

$$\Phi_v = 2\pi r^2 \sum_{\theta=0}^{\pi} E(\theta,\varphi)(\cos\theta_1 - \cos\theta_2), \quad (4)$$

where r – distance between LED and photometer [m]; E – illuminance on sphere-photometer aperture [lx]; θ, φ – coordinates of luminous intensity direction in spherical coordinates system.

Since most of the factors that affect the measurement of luminous flux of LEDs are identical with the corresponding effects in measuring the luminous intensity, the latter is used without changes. Additionally consideration is only needed for the scanning step and influence of changing the ambient light that depend on the position of the LED (see Tables 3, 4).

Table 4

Uncertainty budget for luminous flux measurements of high-power LED

Uncertainty component	Type	Probability distribution	Relative standard uncertainty, %
Uncertainty of luminous intensity measurements	B	Normal	0.87
Scanning step and luminous flux calculation	B	Rectangular	0.06
Stray light influence	B	Rectangular	0.12
Combined relative standard uncertainty, %			0.88
Expanded uncertainty U (k = 2), %			1.78

CONCLUSIONS

As a result of this work a goniophotometer facility for measuring photometric characteristics of high-power LEDs was designed created and experimentally researched. This facility meets all requirements described in CIE 127-2007 and also meets global trends of these type of measurements. The goniophotometer facility allows measuring high-power LEDs at desired junction temperature using the method developed by NIST. All measuring processes are controlled from a PC by using specially developed software.

The proposed, created and experimentally researched unique sphere-photometer also satisfies the requirements of CIE with regards to measurement photometry of LEDs, and combines the functions of the input optics for photometer and for the spectrometer. The Sphere-photometer calibration was achieved by using developed self-calibrated trap-detector, that provides traceability of measurement results to the primary standards of Ukraine.

REFERENCES

1. *Measurement of LEDs:* CIE 127-2007. 2007, 38 p.
2. C. Cameron Miller, Yuqin Zong, Yoshihiro Ohno. LED photometric calibrations at the National Institute of Standards and Technology and future measurement needs of LEDs // *Fourth Intern. Conf. on Solid State Lighting: Proc. of SPIE. Bellingham,* WA. 2004, v. 5530, p. 69-79.
3. G. Zauter, M. Lindemann, Y. Ohno, A. Sperling. Photometry of LEDs // *Svetotekhnyka.* 2004, № 3, p. 5-11 (in Russian).
4. Y. Zong, Y. Ohno. New practical method for measurement of high-power LEDs // *CIE Expert Symp. 2008 on Advances in Photometry and Colorimetry / CIE x033:2008.* Turin, 2008.

5. Optical Radiometry. Experimental Methods in the Physical Sciences / Ed. by A.C. Parr, R.U. Datla, and J.L. Gardner. 2005, v. 41, San Diego: Academic Press, 586 p.
6. T.C. Larason. Spectroradiometric Detector Measurements: Ultraviolet, Visible, and Near-Infrared Detectors for Spectral Power // *NIST Special Publication 250-41.* Gaithersburg: NIST, 2008, 120 p.
7. L.A. Nazarenko, A.S. Litvinenko, D.P. Zubkov, et al. The reference trap-detector // *Lighting engineering and power engineering*. 2011, № 2, p. 34-38.

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ИЗМЕРЕНИЕ ФОТОМЕТРИЧЕСКИХ ХАРАКТЕРИСТИК СВЕТОДИОДОВ

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Предложен и реализован метод измерения светодиодов, который заключается в самокалибровке гониофотометрической установки для измерения светодиодов с помощью трап-детектора. Разработан и изготовлен автоматизированный гониофотометр, который обеспечивает измерение мощных светодиодов при заданной температуре p-n-перехода. Разработан и экспериментально исследован фотометр с фотометрической сферой в качестве диффузора, который отвечает всем требованиям МКО для фотометрических измерений светодиодов.

ВИМІРЮВАННЯ ФОТОМЕТРИЧНИХ ХАРАКТЕРИСТИК СВІТЛОДІОДІВ

Л.А. Назаренко, Д.П. Зубков

Запропоновано та реалізовано метод вимірювання світлодіодів, який полягає в самокалібруванні гоніофотометричної установки для вимірювання світлодіодів за допомогою трап-детектора. Розроблено та виготовлено автоматизований гоніофотометр, який забезпечує вимірювання потужних світлодіодів при заданій температурі p-n-переходу. Розроблено та експериментально досліджено фотометр з фотометричною кулею в якості дифузора, який відповідає всім вимогам МКО для фотометричних вимірювань світлодіодів.