Development, implementation and validation of a high-power LED-based radiation source for goniometric spectral radiance factor measurements

Irina Santourian[1], Sven Teichert[1], Kai-Olaf Hauer[1], Tatjana Quast[1], and Alfred Schirmacher[1]

[1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig und Berlin, Germany
Corresponding e-mail address: Irina.Santourian@ptb.de

To improve the accuracy in spectral radiance factor measurements with the robot-based gonioreflectometer at PTB the suitability of LEDs as additional radiation sources in the short-wavelength visible spectral range was investigated. An LED sphere radiation source (LED-SR) was constructed. Its performance with respect to the spectral range and coverage, the temporal stability, and the homogeneity of the radiation field is presented. Comparative measurements of the spectral radiance factor between the currently used radiation source and the LED-SR were performed and the results indicate that the LED-SR is an appropriate radiation source for goniometric spectral radiance factor measurements at the border between the visible and the UVA spectral range.

INTRODUCTION

LEDs have the potential to be used in a variety of applications due to their long lifetime, efficiency and the available high radiation power. Also, recent advances in LED technology are leading to an increase in accessible spectral ranges and open even more application areas.

For the currently used sphere radiation source, equipped with an internal 400 W quartz-tungsten halogen lamp, the achievable measurement uncertainty of the setup at wavelengths around 400 nm is dominated by statistic effects according to the decreasing available output power. By using LEDs a considerably higher sample irradiance in the short wavelength range is achievable which was the main reason to investigate the use of LEDs as an additional radiation source for the gonioreflec-tometer.

GONIOREFLECTOMETER AT PTB

The gonioreflectometer at PTB is the national standard for the determination of the absolute spectral radiance factor $\beta(\lambda)$ of diffusely reflecting materials in a variety of bidirectional measurement geometries [1]. It consists of a large rotation stage carrying the mentioned sphere radiation source. This source can thus be rotated around the sample, which is placed on a five-axes robot in the centre of the apparatus. This setup enables, in combination with a fixed detection path, highly precise measurements of the spectral radiance factor with almost arbitrary bidirectional geometries. It is well described in several publications [1-3].

LED SPHERE RADIATION SOURCE

The currently used sphere radiator creates a highly homogeneous and Lambertian beam profile on the sample which is required by the measuring principle. Based on this principle an LED sphere radiation source was constructed to improve the available radiant power in the short wavelength spectral range (preliminary studies described in [4]). As sphere wall coating sintered PTFE was used for the LED-SR instead of a standard barium sulphate coating because of its higher diffuse reflection in this spectral range. As primary source a board with 21 surface-mounted device LEDs covering the spectral range from 365 nm to 410 nm was designed by using LEDs with three different peak wavelengths. To obtain a temperature independent temporal stability an active temperature regulation with thermoelectric cooling was added. This new LED-SR maintains the advantages of the existing system and provides a higher radiation power level in the design spectral range.

RESULTS

Prior to implementation in the gonioreflectometer setup the LED-SR was characterized for the spectral coverage, the temporal stability, and the homogeneity of the emitted radiation field. As expected by design, the LED-SR has a fairly smooth spectrum consisting of a composition of the three peaks of the LEDs used (peaks at 365 nm, 385 nm, 405 nm) for the designed LED board. Below 430 nm the LED-SR delivers a significantly higher signal compared to the currently used source. Moreover, the LED-SR also meets all other requirements, e.g.

the homogeneity of the radiation beam is about ± 1 % and thus comparable to the halogen-lamp based radiator [2]. Based on the high-precision actively regulated temperature control a photocurrent change of only 1 % in 286 h operation time of the LED-SR is achieved and allows measurements with high precision.

For validation the LED-SR was implemented in the gonioreflectometer to perform comparative measurements with the currently used radiator. A silicon diode (Hamamatsu S1337-66 BR) was used for detection in the entire spectral range. The absolute spectral radiance factor $\beta(\lambda)$ of a white and red ceramic, representing a high and a low reflectance, were measured for geometry 45°:0° with both sources. For each sample the resulting relative uncertainty (k = 1) of the mean spectral radiance factor for seven (white) respectively ten repetitions (red ceramic) measured with both radiators are given in Fig. 1.

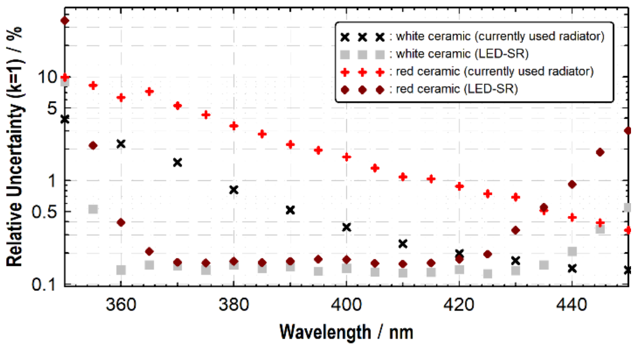

Figure 1. Relative uncertainty (k = 1) of the average absolute spectral radiance factor for a white and red matte ceramic sample measured with the currently used sphere radiator and the LED-SR in 45°:0° geometry.

The measurement uncertainty was determined by considering various systematic and statistical effects. In case of the white ceramic measured with the standard source statistical uncertainties begin to dominate the total uncertainty below 430 nm and result in a rise towards shorter wavelengths. In ordinary calibrations this would have to be compensated by a higher number of repetitions or by switching to a more sensitive detector type. The uncertainty resulting from the LED-SR however stays constant and only rises below 360 nm when the available power decreases. Therefore, one can conclude that the statistical contributions are very small for this source in its design wavelength range. This is underlined by the results for the low-reflective red sample, which are only slightly higher than for the white standard. The break-even point is at 435 nm for the measurements on the red sample.

It is therefore shown that the application of the LED-SR results in a considerable improvement with respect to the achievable measurement uncertainty.

CONCLUSION

A newly developed LED sphere radiation source equipped with a high-power LED board and an active temperature regulation was developed. The basic properties such as spectral range, temporal stability and homogeneity of the radiation field were characterized and fulfill the necessary requirements for applying this radiation source at the gonioreflectometer to determine the spectral radiance factor. Validation measurements show that achievable measurement uncertainties in the spectral range between 360 nm and 430 nm can be reduced significantly. The results demonstrate that the LED-SR is an appropriate radiation source for measurements at the border between visible and UVA wavelengths and that the main objectives such as the reduction of the measuring time and reducing measurement uncertainties were achieved.

ACKNOWLEDGMENTS

The authors thank the members of the mechanical workshop Jörn Hauffe, Morten John, Marcel Janik and Henry Ganz for the construction of several parts of the LED sphere radiation source. Also, we thank Rouven Krake and Stefan Pendsa for the electrical layout of the LED board and the TEC unit. We gratefully acknowledge the support of the Braunschweig International Graduate School of Metrology B-IGSM.

REFERENCES

1. D. Hünerhoff, U. Grusemann, and A. Höpe, New robot-based gonioreflectometer for measuring spectral diffuse reflection, Metrologia, BIPM and IOP Publishing Ltd, Vol. 43, No. 2, pp. 1-10, March 2006.
2. K. Hauer and A. Höpe, High-grade uniform light source for radiometric and photometric applications, MAPAN, Springer Science+Business Media S.A., Vol. 24, No. 3, pp. 175-182, September 2009.
3. C. Strothkämper et al., Multilateral spectral radiance factor scale comparison, Applied Optics, OSA Publishing, Vol. 56, No.7, pp. 1996-2006, March 2017.
4. I. Santourian, S. Teichert, K.-O. Hauer, A. Schirmacher, Investigation of the suitability of high-power LEDs for the use as radiation source for PTB's gonioreflectometer, TU Ilmenau, Lux junior 2019, pp. 43-50, 2019.