Title: Future photometry based on solid-state lighting products

Abstract

Solid-state lighting (SSL) products have become popular in general lighting, gradually replacing incandescent lamps. The luminous flux and efficacy of new SSL products coming to market are characterised by test laboratories. Utilising incandescent standard lamps in calibrations of $V(\lambda)$-filtered photometers causes unwanted spectral errors in the characterisation of SSL products, and in measurements of SSL lighting. New SSL-based standard lamps and supporting detector technology need to be developed for photometric calibrations of SSL products at national metrology institutes, and convenient and reliable traceability for calibrations of SSL products at test laboratories is required to pave the way to lower uncertainties.

Keywords

Solid-state lighting (SSL), light-emitting diode (LED), luminous efficacy, photometer, $V(\lambda)$-filter, spectral error, Predictable Quantum Efficient Detector (PQED), standard lamp, phase out incandescent, test laboratory

Background to the Metrological Challenges

The phasing out of incandescent lamps requires the development of new types of standard lamps for future photometric calibrations. Division 2 of the International Commission on Illumination (CIE) is about to approve a new reportership that will investigate the advantages and disadvantages of moving towards the use of standard illuminants based on light emitting diodes (LEDs) for detector calibrations, taking into account the ability of LED manufacturers to realise the illuminants and the impact on national metrology institutes (NMIs), testing laboratories and others in the photometric measurement community. A major benefit of the new LED-based illuminant would be the reduced spectral mismatch error of photometers used for measuring SSL products in comparison to illuminant A type sources (i.e. incandescent lamps). In addition, the Consultative Committee for Photometry and Radiometry (CCPR) Working Group on Key Comparisons (WG-KC) has assigned a task group to perform a pilot study on the use of white LED sources as transfer standards for comparison of photometric quantities.

Determining the luminous efficacy (lm/W) of a new SSL product coming to market requires measurement of its luminous flux (lm) and active electrical power consumption (W) in a test laboratory. For the luminous flux measurement, integrating spheres or goniophotometers are used in combination with $V(\lambda)$-filtered photometers and spectroradiometers. Two major sources of uncertainty in the measurement of luminous flux of an SSL product are due to the luminous responsivity calibration of the photometer and the spectral mismatch correction. The luminous responsivity is typically calibrated using an incandescent luminous flux standard lamp with traceability to an NMI. NMIs and some test laboratories are able to correct for the spectral mismatch error, but its magnitude can be several percent if the correction cannot be applied. Spectral correction requires measurement of the relative spectral responsivity of the photometer, and the spectra of the reference source and the SSL product under test. In addition, large differences in the angular spread of SSL products, for example between spot and omnidirectional lamps, may cause increased uncertainties due to the reflectance inhomogeneity of integrating spheres. Analysis of the spatial nonuniformity correction requires scanning of the reflectance profile of the sphere and measuring the relative angular intensity distribution of the SSL product with a goniophotometer or with another suitable method.

The Interlaboratory Comparison (IC 2013) conducted by the International Energy Agency (IEA) 4E SSL Annex with more than hundred laboratories measuring SSL products indicated an agreement within ±5 % between the luminous efficacy values measured by most of the participants [1]. The measurement of the electrical power consumption of AC-operated SSL products can be a significant source of uncertainty in luminous efficacy measurement. The measurement of the RMS current, total harmonic distortion (THD) and power factor (PF) of SSL products can be heavily influenced by the limited bandwidth of the power meter,

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

but also by the characteristics of the output impedance of the AC voltage source and the AC/DC-converter of the SSL product. The higher uncertainties of some test laboratories are partly explained by the fact that not all laboratories can correct for the effects that originate from the electrical and optical differences between the incandescent calibration source and the SSL product under test.

One of the largest sources of uncertainty in illuminance and luminous flux responsivity calibrations of photometers utilising $V(\lambda)$-filters originates from the measurement of relative spectral responsivity of the photometer. Illuminance measurement without a $V(\lambda)$-filter using the Predictable Quantum Efficient Detector (PQED) is another possibility [2]. The photometric weighting is then carried out numerically, which requires special care in the measurement of the relative spectrum of the LED.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP protocol.

The JRP shall focus on the development of new reference standards and measurement methods for photometric calibrations of solid-state lighting products with reduced uncertainties.

The specific objectives are

1. To develop new types of standard lamps for luminous intensity, photometer illuminance responsivity and luminous flux calibrations triggered by the ban on incandescent lamps. Specific needs are long term stability of electrical, photometric and colorimetric characteristics, robustness, DC-operation and/or stable AC/DC-converters, well-defined spectral and angular properties, and compatibility with existing calibration facilities.
2. To evaluate the consequences of defined spectra of new candidate standard illuminants and to develop accurate measurement methods for the relative spectrum of the new standard lamps.
3. To develop photometers that allow illuminance measurement of the new standard lamps with uncertainties as low as 0.2 % (k = 2).
4. To reduce the uncertainty of luminous efficacy measurements of solid-state lighting products at national metrology institutes to 0.5 % (k = 2) and to demonstrate that uncertainties as low as 1 % (k = 2) can be achieved in test laboratories.
5. To facilitate the uptake of the measurement methods developed by the project by the measurement supply chain, ensuring traceability of measurement results to the end users (test laboratories, lighting manufacturers) and contribute to the development of standards by the international standardisation committees (CIE) concerning solid state lighting.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the iMERA-Plus project T1.J2.3 qu-Candela and EMRP projects SIB57 NEWSTAR, ENG05 Lighting and ENG62 MESaIL and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 21 % of the total EU Contribution to the project. Any deviation from this must be justified.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the "end user" community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the solid state lighting sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)".

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] Y. Ohno, K. Nara, E. Revtova, W. Zhang, T. Zama, C. Miller, Solid State Lighting Annex 2013 Interlaboratory Comparison Final Report, International Energy Agency, 89 p (2014). http://ssl.iea-4e.org
[2] T. Dönsberg et. al., "New source and detector technology for the realization of photometric units," Metrologia 51, S276-S281 (2014).