Publishable Summary for 15SIB07 PhotoLED
Future Photometry Based on Solid-State Lighting Products

Overview

The aim of this project is to address the obsolescence of traditional incandescent standard lamp technology used in photometric calibrations and the need to support the introduction and uptake of new solid-state lighting (SSL) products. The project will develop and validate the basis for a new photometric system based on white light-emitting diodes (LEDs), by developing new LED-based calibration sources and measurement techniques supporting the specific properties of the new light sources and detector technology, including illuminance measurement of the new LED calibration sources without optical *V*(*λ*)-filters in calibrations of photometers and measurement facilities used for determining the energy efficiency of new SSL products coming to market.

Need

Classical photometry relies heavily on the use of incandescent standard lamps and *V*(*λ*)-filtered photometers as transfer standards in calibrations of luminous intensity, luminous flux and photometer illuminance responsivity. Photometric measurement methods and illuminants, i.e. spectral data of different types of light sources, used in colorimetric analysis of lighting were established long before SSL products became available. As the spectral responsivities of *V*(*λ*)-filtered photometers differ from the *V*(*λ*) curve defined by the International Commission on Illumination (CIE), all photometers are typically calibrated using incandescent standard lamps with spectral power distributions (SPDs) close to the CIE Standard Illuminant A that describes typical incandescent lighting with correlated colour temperature of 2856 K.

During the last few years the phasing out of incandescent lamps has changed the lighting market, test laboratories and other, so that users of photometric instruments no longer measure incandescent lighting, but more often SSL products based on white LEDs. However, all typical photometric equipment are still calibrated using incandescent light spectrum that causes spectral errors in measurements of SSL due to the optical *V*(*λ*) filters used in photometers, and the differences between the SPDs of two types of light sources. In addition, the incandescent standard lamps used in calibrations are disappearing from the market, so there is an urgent need to develop new illuminants and calibration spectra with agreed SPDs for colorimetry and photometry, including new standard lamps for photometric calibrations that are based on a technology that is widely available and spectrally compatible with measurements of SSL products.

Luminous flux (lm) and active electrical power consumption (W) of new SSL products coming to market are measured by test laboratories to determine the luminous efficacy (lm/W) and energy class of the products. The luminous flux is often measured using an integrating sphere photometer that allows quick and convenient testing of SSL products compared to mechanically more demanding and time consuming measurements with goniophotometers. Typically the highest sources of uncertainty in measurement of luminous flux of SSL products using an integrating sphere are due to the spectral and angular errors that originate from the measurement system and the differences between incandescent calibration lamps and SSL products under test, and in many cases cannot be easily corrected for. New LED-based standard lamps with well-defined spectra and a new quicker method for determining angular corrections for SSL products in measurements with integrating spheres need to be developed for photometric calibrations to reduce uncertainties and enable more reliable testing and classification of new SSL products coming to market.

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Objectives

The overall aim of the project is to develop and validate the performance of an LED-based photometric system with new transfer standard lamps and supporting measurement techniques that will complement the classical photometric system based around tungsten filament lamps. The specific technical objectives of the project are:

1. **To develop LED-based illuminants and calibration spectra that can complement or replace the CIE Standard Illuminant A** in photometric calibrations and in analysis of colorimetric parameters and to evaluate the consequences of the defined new spectra.
2. **To develop new LED-based photometric standard lamps for dissemination and maintenance of the units of luminous intensity, illuminance and luminous flux triggered by the ban on incandescent lamps.** The new LED-based standard lamps will be optimised for compatibility with existing calibration facilities, spectral properties close to the defined LED calibration spectra, well-defined angular uniformity, long lifetime and temporal stability of electrical (DC- or AC-operation), photometric and colorimetric characteristics to enable low uncertainties in measurements of their photometric and radiometric properties.
3. **To develop new photometers and photometric measurement methods that enable illuminance measurement of the new LED-based standard lamps with uncertainties as low as 0.2 % (*k* = 2)** in the primary realisation of photometric units, or in calibrations of photometer illuminance or luminous flux responsivities at NMIs, accompanied by high-end spectral irradiance measurement of the new standard lamps with uncertainties as low as 0.4 %.
4. **To reduce the uncertainties of luminous flux and luminous efficacy measurement of solid-state lighting (SSL) 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 a test laboratory.
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.

Progress beyond the state of the art

For the new LED-based photometric system, new LED illuminants, i.e. defined SPDs of specific types of lighting that provide the basis for comparing images or colours recorded under different lighting conditions, will be defined that describe typical SSL products. From the LED illuminants, a well-chosen subset of SPDs will be selected as LED calibration spectra that will form the basis for development of the new physical LED-based standard lamps to complement the existing incandescent standard lamps in photometric calibrations. Recent studies have shown that the spectral errors in measurements of SSL products can be reduced by a factor of three on average in testing of SSL products and in field measurements of SSL by utilising LED-based standard lamps in calibrations of photometer illuminance responsivity. Due to the limited spectral bandwidth of white LEDs (approximately 380 – 850 nm), the illuminance of an LED-based standard lamp can be measured with novel detector technology without an optical $V(\lambda)$ filter. Instead, the photometric weighting can be made numerically with accurate measurement of the LED spectrum during calibration of photometric instruments for measurements of SSL.

LED-based photometry based on modern technology will provide an alternative to the classical photometric methods used at NMIs and at test laboratories. The new standard lamps based on white LEDs will enable the units of luminous intensity, illuminance and luminous flux to be transferred from NMIs to industrial test laboratories and allow calibration of photometers and testing of SSL products with lower uncertainty due to spectral properties compatible with typical SSL products. In addition to providing new LED-based transfer standard lamps and measurement methods for general photometric calibrations, a new revolutionary fish-eye-camera method for measuring the angular intensity distribution of SSL products quickly and reliably without a large goniophotometer will be developed for the use in the integrating spheres of test laboratories. By utilising these new methods, it is expected that test laboratories will be able to drastically reduce the spectral and angular errors, and measure luminous efficacy of SSL products with uncertainties as low as 1 %.

Results

LED illuminants and calibration spectra

During autumn 2016, this project collected a total of 1300 spectral power distributions of white LED products from partners and stakeholders. The spectral data were analysed and those based on blue LEDs and phosphors were binned according to their Correlated colour temperatures (CCTs) into 8 different bins between 2700 K and 6500 K. In addition, 4 special shapes including (red, green, blue) RGB and ultraviolet LEDs + phosphors were chosen to be used in possible colorimetric applications. Discussions with CIE Division 1 are ongoing to with the aim of having some of the studied spectra published by CIE as illuminants for use in colorimetry. The white LED spectra identified are being further analysed to obtain a suitable subset of LED calibration spectra that could complement the CIE Standard Illuminant A in photometric calibrations. The LED calibration spectra will be selected using statistical methods by minimising the spectral errors in measurements of SSL products with typical photometers and luxmeters, while ensuring compatibility with all typical photometric and colorimetric applications.

LED-based photometric standard lamps

Using the LED calibration spectra as the basis, new photometric transfer standard lamps for luminous intensity and luminous flux will be developed. For this purpose, the mechanical, electrical and optical specifications of the new standard lamps have been investigated. The next step is to finalise the selection of the LED calibration spectra, after which white LEDs with spectral properties close to the defined LED calibration spectra will be acquired together with the industrial partners of the project. The new standard lamps will be fully characterised and evaluated in two different comparisons to demonstrate their applicability in future international photometry key comparisons as direct replacements for obsolete incandescent standard lamps.

New photometers and photometric measurement methods

New reference photometers based on the predictable quantum-efficient detector (PQED) of SIB57 NEWSTAR are being developed to be operated without optical $V(\lambda)$ filters, accompanied with specially characterised spectroradiometers, to allow illuminance measurement of the new LED-based standard lamps with uncertainties as low as 0.2 % (k = 2). The design plan of the new photometers has been completed and the selection of suitable materials for the new precision apertures is ongoing. The method will allow calibration of standard photometers directly against the room-temperature PQED, the new primary standard of optical power used at NMIs.

Reducing uncertainties of luminous flux and luminous efficacy of SSL products

The new LED-based standard lamps will allow the units of luminous intensity and luminous flux to be transferred from NMIs to test laboratories for the calibration of photometers and other systems, such as integrating spheres that are used for measuring luminous flux and efficacy of new SSL products. Due to the new LED technology used in the transfer standard lamps, spectral errors in the testing will be reduced to 1/3 on average, compared to using incandescent standard lamps for the calibration of the system responsivity. Furthermore, the quick and convenient fish-eye camera method targeted specially for test laboratories will allow the angular intensity distribution of SSL products to be measured inside an integrating sphere, enabing the spatial non-uniformity correction to be used also in laboratories that do not have goniophotometers. Suitable camera modules for the fisheye camera method have been investigated and test measurements with an integrating sphere for a group of SSL products with different angular spreads have been carried out. The preliminary results show that the method works and will allow measurement of angular properties of light sources during luminous flux measurement with integrating spheres. The analysis method is being fine tuned and will be validated with different integrating spheres and goniophotometers of the project partners.

Impact

The first Stakeholder Workshop of the project PhotoLED to gather input from CIE and industry for the development of LED calibration spectra and standard lamps was held on 11 May 2017 at METAS, Switzerland. The workshop was arranged during the CIE Tutorial and Practical Workshop on LED Lamp and Luminaire Testing to CIE S025 with a total of 36 participants from test laboratories, instruments manufacturers and people working in CIE TCs.

Impact on industrial and other user communities

This project is envisaged to change the way how the lighting industry will utilise photometry in the future. The project will demonstrate that the classical tungsten filament standard lamps can be replaced by standard lamps based on SSL technology that will offer much smaller spectral errors in measurements of SSL products, reduced signal noise, better stability, robustness and lifetime, for maintaining photometric scales in laboratories and shipping of the lamps between NMIs and test laboratories.

Achieving lower uncertainties in photometric measurements of SSL products will benefit the lighting industry and consumers. Manufacturers of SSL products will be better able to rely on the measurement results from test laboratories, thus speeding up product development and enabling better judgement of the performance of new products coming to market. With the development of a coherent and efficient European metrological infrastructure based on LED-based photometric standards, new measuring instruments and supporting measurement methods, as well as written standards, the benefits of SSL products such as energy efficiency, will be assured and market penetration will be increased. There will be direct economic benefits for stakeholders from the direct customer, through to test laboratories and finally industry.

Impact on the metrology and scientific communities
This project will not only contribute to solve the metrological problems caused by phasing out of incandescent standard lamps, but will also lead to an improved scientific and technical system of photometry for the measurement of LEDs and other SSL products for the benefit of the society and which better reflects the characteristics and requirements of these type of lighting products.

Impact on relevant standards
This project will speed up the work towards LED-based calibration spectra or standard illuminants in technical committees (TCs) of the CIE. The development of the new LED illuminants and LED calibration spectra have been carried out with close connections to CIE since the start of the project, including both Division 1 and 2 in the discussions.

Longer-term economic, social and environmental impacts
The results of the project will enable more reliable classification of energy efficiency of lighting products based on SSL technology. When new technologies reach the market, the consumer will have better confidence in the stated performance of the products, i.e. the values printed on the box, thus enabling them to make more informed choices. A sound metrological framework is the backbone of all accurate measurements. Low uncertainties obtained by high quality measurements increase the confidence in the products and enable better differentiation between the qualities of various products. Achieving lower uncertainties in the testing of SSL products will also result in less waste and reduced costs for manufacturers due to fewer SSL products being erroneously rejected from entering the market due to the use of large guard bands in determining the energy classes of products.

List of publications

Peer-reviewed papers have not yet been published at this early stage of the project.

Project start date and duration:	01 September 2016, 36 months	
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