Final Publishable JRP Summary for ENG62 MESaIL
Metrology for Efficient and Safe Innovative Lighting

Overview

Solid-state lighting (SSL) refers to a type of lighting that uses semiconductor light-emitting diodes (LEDs) as sources of illumination rather than electrical filaments, plasma (used in arc lamps such as fluorescent lamps), or gas. The second generation of SSL products is now being developed and includes organic light-emitting diodes (OLEDs), polymer light-emitting diodes (PLED) and nano-structured and flexible LEDs. They have the potential to revolutionise the efficiency, appearance and quality of lighting. This project developed measurement solutions and an advanced metrological framework for novel second generation SSL products, covering light output and efficiency, as well as safety and lifetime aspects. A new set of metrics were developed through physiological studies to investigate safety and comfort aspects of lighting and user perception. This will enable the reliable measurement of SSL performance and encourage the use of these forms of lighting and improve energy efficiency, reduce energy bills and enable consumers to make informed decisions regarding lighting products.

Need for the project

The objective of the European 2020 Strategy is to reduce the Union's primary energy consumption by 20% by 2020. Innovative SSL could contribute to these savings by increasing energy efficiency and assuring longer product lifetime.

The first generation of SSL products, based on LED technology, initially had lower light quality and variable performance, but the gradual maturing of SSL technology has led to a steady improvement in product quality and lighting efficiency, and an established metrology framework. The second generation of SSL products, such as OLEDs/OLED arrays, pulsed SSL and nano-structured and flexible LEDs have different characteristics in terms of the spectrum emitted, shape, colour and brightness. This means that they need either more accurate measurements and standards, or completely new metrological standards.

To improve user confidence in manufacturer's claims for this technology, and to encourage its use, an extensive program is required including new research, measurement capabilities and standards that will allow unambiguous data on SSL to be determined. Existing guidelines work well for incandescent lighting sources and first generation LEDs, but do not provide unambiguous results for efficacy, light intensity distribution, lifetime and colour rendering for the latest SSL.

This project will advance the measurement framework for SSL through: 1) development of missing measurement methods and equipment, 2) delivery of traceability for pulsed SSL and lifetime assessment, 3) quality improvement by developing safety metrics and 4) ensuring scientific excellence via collaboration with academic research. The project will also create impact via close collaboration with stakeholders (industry, test laboratories and standardisation bodies) and aims to help speed up the standardisation process related to SSL by providing technical inputs to written standards at International (CIE) and European (CEN) levels.

Since metrology for SSL covers a wide set of parameters; related to optical output, electrical aspects, reliability, perception and safety, a broad expertise is indispensable. Therefore, the cooperation of NMIs and academic partners with complementary knowledge and facilities will ensure this project is successful in strengthening the metrological framework for SSL and building confidence in this new technology.

EMRP European Metrology Research Programme ▸ Programme of EURAMET

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Scientific and technical objectives

This project aims to deliver an advanced metrological framework for novel SSL by providing transfer standards applicable at NMI and test laboratory level, to develop measurement solutions for large area and pulsed SSL, to provide metrics and equipment accounting for safety and comfort aspects of novel SSL, and to assure longer lifetime and provide its traceability.

The technical objectives are to:

1. Develop sets of optical and electrical reference standards to calibrate as well as to characterise the setups used in testing laboratories and to verify their capability to perform particular measurements of novel SSL
2. Improve measurement methods and decrease uncertainty in photometrical parameters of OLED measurements, electrical power measurements of AC-operated (developing an impedance stabilisation network) and pulsed SSLs. Study the feasibility of using standard measurement equipment for 3D complex goniometric measurements of large area and complex SSL (3D nano- structured)
3. Deliver a full set of metrics for safety and comfort aspects of novel SSL through development of measurement solutions and by performing physiological studies on (a) flicker/stroboscopic effect, (b) blue hazard, (c) well-being/comfort experience and (d) lighting quality perception.
4. Develop measurement solutions and establish traceability for lifetime and reliability testing of SSL products. Investigate various aging mechanisms involved in material degradation of novel SSL devices.

Results & Conclusions

Optical and electrical reference standards

An integrating sphere measurement setup is the system usually used to compare lamps with similar properties. However, in many cases the properties of the device under test differ from the transfer standard used which may cause significant errors, e.g. if an LED-based lamp is calibrated in an integrating sphere which was calibrated with a halogen lamp.

In this project, a novel Multiple Transfer Standard device (MTS) was introduced which was designed not only to transfer a single calibration value but also to enable the characterisation of the compete test setups. The MTS is a temperature stabilised cube, where 5 of its 6 surfaces are covered with printed circuit boards (PCBs), each assembled with 5 stable LEDs of different colours. Every single LED can be addressed separately by wireless connection to set the amount of electrical current and its modulation mode. In addition, the MTS can also be equipped with geometrical accessories to mimic a spherical globe, a linear tube or a panel type of source. Five MTS devices were built and characterised by project partners. SSL devices used for the project's comparisons/campaigns were fully characterised. A series of characterisation and measurement campaigns, between the NMIs and test laboratories of the respective countries, based on the MTS were completed. The results showed that the MTS allows testing laboratories to calibrate measurement setups, and also get additional information to estimate uncertainties.

In addition, an electrical Multiple Transfer Standard device (e-MTS) was designed and built. The device can simulate up to 8 different SSL lamps and 1 incandescent lamp. Using the e-MTS to simulate the voltage and current of SSL products the project was able to validate electrical measurement setups of test laboratories.

A LED-based mosaic test standard device consisting of an 8 x 8 LED array was developed for use as test standard for Imaging Luminance Measuring Devices (ILMD). The quality indices of the ILMD were extensively analysed in this project.

The objective was fully achieved and the novel optical and electrical reference standards and devices developed in this project can improve the measurement setups of stakeholders.

Improve measurement methods

For the new generation of SSL products, for instance, OLED, pulsed SSLs and complex SSL (3D nano-structured), photometric and electrical measurement methods need to be improved.

In a previous EMRP project ENG05 LIGHTING it was found that electrical measurements of SSL products from different laboratories showed large discrepancies. The Impedance Stabilisation Network (ISN) developed in this project is a unique device which provided equalised impedance in laboratories to improve electrical measurements of SSL products with different AC sources. Two inter-laboratory comparisons on electrical measurement parameters were carried out and the behaviour of the ISN and a selected group of SSL artefacts were measured with different source-lamp configurations. Encouraging results showed the potential of the ISN to improve the repeatability of electrical measurements of SSL products. This will avoid any ambiguity in product performance data.

The accuracy of using a variety of spectroradiometers to measure modulated light was studied. It was found that most handheld instruments, with or without a flicker mode, were sensitive to all modulation parameters and provided lower than expected power measurements, mainly due to wrong default parameter setting of the instruments. Therefore, the integration time or response time needed to be set correctly with respect to the modulation period to provide stable and consistent measurement results between continuous waves and modulated waves.

Several OLEDs and SSL devices were measured in different integrated spheres and goniophotometers. The effects caused by edge-emission, spectral self-absorption and fluorescence were evaluated and were rather small for most of the SSL devices tested. It is more important to take the edge-emission into account in design of luminaires, because despite the low luminous level, it can be visually perceived and often has very different spectral contribution (such as blue or green tint) compared to the white main emitting surface.

The feasibility of using standard measurement equipment for 3D complex goniometric measurements of large area and complex SSL (3D nano-structured) was studied. The measurement setup was extended by manipulators with probe tips, enabling on-wafer measurements by ILMDs and a near-field goniophotometer. The project successfully completed near-field goniometer measurements of the prototype extended measurement set-up.

In addition, the short-pulse testing method used in industry to evaluate light output performance of the LEDs during production was validated by this project. The short-pulse method is very efficient in the case where a well-defined electrical current pulse is applied and the stabilisation time of the device is “a priori” accurately determined. No colour shift is observed. The largest contributors to the measurement uncertainty were identified by the project.

The objective was fully achieved and new measurement methods for new generation of SSL products developed in this project will improve the measurement setups of stakeholders.

Metrics for safety and comfort aspects

Guidelines for evaluating an SSL lighted environment considering the blue light hazard were prepared. The Spectral Power Distribution (SPD) of different white LEDs (blue and violet LED) was measured. It was found that the hazard factor of looking into SSL devices with violet LED technology increases as much as 30 % for people with an intraocular lens (the lens that replaces the natural lens in cataract operations) compared to those with healthy eyes. There was no such issue for the SSL devices with blue LED technology.

A subjective experiment of short-term effects of time-modulated lighting was carried out at LNE with 30 people. Various test signals were used for 3 visual tasks (reading, searching words, and connecting dots) and the observation of a pendulum with fast oscillations for stroboscopic effect visibility. Results showed that waveform shape and frequency impact the perceived comfort but the most surprising result was that people have a preference for lower frequencies. RISE studied the effects of mixed time-modulation by means of a desk lamp and a ceiling lamp on comfort, visual attention, and reaction time. Multichannel drivers were programmed to generate the different waveforms and flicker frequencies.

Based on these results, it was concluded that comfort and visual task performance are missing from the existing flicker metrics (IES, CIE, IEEE) and it is recommended to reconsider flicker metrics for comfort and performance. To study the effect of light mediated by eyes on circadian rhythms and non-visual functions, an accurate instrument with autonomous operation, capable of measuring the level and spectral content of light reaching the cornea during day and night time has been developed in this project. A protocol to use it for the assessment of non-visual effects has been prepared.

In addition, a pilot study was carried out to investigate a method to evaluate non-visual effects of variable lighting in workplaces using both self-assessed and physical data. The method was successful and provided interesting results based on the measured physical data; i.e. the resting pulse rate was lowered and the sleep quality improved for the test subjects during the weeks of dynamic office lighting.

Lifetime and reliability testing

The reliability and lifetime standards for LED-based SSL products were assessed. Research work covered the major failure mechanisms and reliability issues that are commonly found in SSL systems, including luminous flux lost over time, colour shift, solder fatigue, phosphor degradation, driver failure, accelerated testing and system reliability modelling. A new approach for evaluating reliability was developed by the project, which had innovative accelerated testing methods, a newly developed reliability and lifetime prediction model, as well as a new methodology to couple different failure models. These approaches can now enable manufacturers to analyse the degradation mechanisms, improve lifetime estimation accuracy and reduce testing time.

Two prototypes of packaged core-shell LEDs (with and without high-refractive index encapsulation) with improved processing were measured. Electro-optical test measurements were carried out using a commercial remote phosphor converter. The qualitative electro-optical properties, emission directionality and the dependence on temperature cycles of single devices were investigated.

Natural ageing measurements and accelerated ageing measurements from a variety of novel SSL products were performed by 4 project partners. Accelerated ageing was performed using damp-heat stress and UV exposure methods.

It was noticed that natural ageing of the inorganic LED artefacts resulted in small changes in average luminous flux. The colorimetric quantities were stable with correlated colour temperature changes less than 31 K. In contrast, it was observed that accelerated ageing with damp/heat severely affected the yellow phosphors, changing spectral shape or decreasing efficiency of emission and slightly affecting the blue LED emission. Furthermore, the results showed that the damp/heat stress at 85°C/85 %HR does not represent natural ageing with an acceleration factor.

Actual and potential impact

Dissemination of results

The project outputs have been shared widely with the metrology, instrumentation and industrial communities. 23 papers reflecting the achievement of the project were presented at a variety of prestigious conferences and in journals. Two joint-CIE Tutorial and Practical workshops disseminated the project outputs and encouraged liaison between the stakeholders and the industrial, standards and research communities. Three training courses were also organised during the project for stakeholders with support by the European National Committees of CIE.

Input to standards and tests

CIE is the most important partner for standardisation and pre-normative work in the international field of light and lighting. CIE is organised through different technical committees, and this project is relevant to Divisions 2, 4 and 6.The project made major contributions to the CIE through a CIE Tutorial and Practical Workshop. The consortium members were also invited to present their results to CIE and relevant CIE TC members followed the presentations and communicated with the project partners.

In addition, the project provided input during the preparation of the draft documentary European standard EN 13032-4:2015 Light and lighting – Measurement and presentation of photometric data - Part 4: LED lamps, modules and luminaries. The project has helped with the development of related standards at the European level.

Actual impact

The aims of this project were fully achieved. Novel devices and new methods for the generation of SSL products developed in this project can now improve the measurement setups of stakeholders. Metrics for safety and comfort aspects will protect customers better, and research on lifetime and reliability testing will help manufacturers in their production.

The new LED-based calibration source MTS allows testing laboratories to calibrate measurement setups, and to gain additional information about the sensitivity necessary to estimate uncertainties. The potential users of MTSs participated in the projects joint-CIE Training and Stakeholders Workshop. Project partner, Osram has shown a great interest in taking over further development of the MTS device as it offers key features for their end users including ease of use and affordability.

The project's optical head for measuring luminous flux reaching the eye has the potential to be the subject of a patent application. Further commercial exploitation is possible, as is the case with the e-MTS and ISN developed in this project.

The MTS, the ISN and the uncertainty evaluation tool for the electrical parameters measurements developed in this project showed their effectiveness and will be adopted in CIE Training courses in the future. Stakeholders, such as test laboratory of Technical Universtity of Denmark, have also shown interest in the e- MTS and ISN developed in this project when they were presented in the project's final stakeholder meeting. A commercialising plan is under discussions between VTT, VSL and METAS.

Finally, the traceability of the high speed short-pulse testing method used in LED production was validated by the project. This result has prompted interest from end users from testing labs and industry in the USA following the presentation of the results at an Annual IES Conference.

Potential impact

This project set out to develop an advanced metrological framework for novel SSL, and some of the physical standards are now already in use. This will enable the reliable measurement of SSL performance in the broadest sense, including basic light output and efficacy, light distribution, light quality, light perception, safety aspects and life-time aspects. The project has had the expected impact across the entire SSL value chain; providing developers, designers, producers, distributors and end-users with the tools they need to improve, predict and specify SSL performance based on reliable measurements. The LED manufacturing industry could also benefit from this work by improving their methods, updating their instrumentation and evaluating their setups following recommendations and conclusion from the study. For end-users, the improved energy efficiency will help to reduce energy bills, and the availability of reliable data on light output, energy consumption, safety/health aspects and lifetime will allow informed and objective decisions.

List of Publications

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