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ABSTRACT BOOKLET

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001

MULTIPLE TRANSFER STANDARD FOR CHARACTERISATION OF SPHERE TEST SETUPS

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Abstract

The new international CIE standard CIE S025/E:2015 "*Test methods for LED Lamps, LED Luminaires and LED Modules*", which is also published with nearly the same content as European standard EN 13032-4 "*Light and lighting – Measurement and presentation of photometric data of lamps and luminaires – Part4: LED lamps, modules and luminaires*", is a standard for test laboratories to define environmental and operational conditions for test measurement of LED sources. Different to other internationally test standards used before, this standard now commit test laboratories to evaluate uncertainty contributions for measurements and to assign an uncertainty budged to their measurement result.

Although the annexes of these standards show some information about how to assign measurement uncertainties and what uncertainty components are most important, typical test laboratories will have severe problems to determine appropriate values for their measurements. The main reason is that the operator of the test setup in a test house has in many cases only restricted information about electrical, spectral, angular dependent and frequency dependent parameters of the device under test (DUT) and the interaction between these parameters and their measurement setup.

The question how it will be possible to assist testing laboratories when implementing the CIE S025 was picked up by the European project "Metrology for Efficient and Safe Innovative Lighting" (ENG62 MESaIL), which is funded by the EU in the framework of the European Metrology Research Programme (EMRP). The project is aiming to develop a special Multiple Transfer Standard (MTS), which is capable to operate in different modes, where the spectral, geometrical and temporal properties of the modes will be chosen such that they can be used to work out information about the sensitivity of the measurement setup of the test laboratory with respect to specific DUT characteristics. To support this, a set of unique capabilities of the MTS are realised. To provide information about:

- **the spectral dependencies**, the MTS is equipped with different coloured LEDs (e.g. blue, green, red, warm white, cold white LEDs)
- **the dependencies on light distribution**, the MTS can independently light downwards, left, right, backward and forward.
- **temporal dependencies**, the MTS can be operated at various DC (constant light output) and AC (variable time dependent light output) conditions.
- **the dependencies on the geometry of the light source**, the MTS can be applied with different light guiding elements.

Moreover, to provide information about **the dependencies on the impedance of the load (DUT),** a special device will be developed next to MTS which is capable to provide different impedance conditions.

The basic idea behind this concept is that an MTS will be calibrated by an NMI or an accredited calibration laboratory for every single mode of operation. This means, for instance, that the sphere calibration factor of an ideal integrating sphere, determined with the MTS operating in one of the light emitting modes, should be equally reproduced independently of a mode set during calibration. A typical non-ideal sphere however, if calibrated using one of the calibrated modes, will show up different calibration factors for different modes. The type and magnitude of the deviation will already give some hints about the sensitivity of this integrating sphere facility. More comprehensive information about expected uncertainties will be able to be determined by the detailed comparison of measured DUT data and measured MTS data, and MTS calibration data.

The aim of the paper is to contribute to the CIE Expert Symposium by showing the current status of the development of the MTS. First measurements in the PTB's 2.5 meter integrating sphere have proven the thermal stability of the latest developed design. In addition, first measurement results of the light distribution of the MTS based on measurements carried out with the Robot-Goniophotometer of PTB will be shown and future steps regarding the implementation of MTS-concept will be explained.

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AUXILIARY CORRECTION IN GONIOPHOTOMETRY, SIMULATION AND MEASUREMENT

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This paper outlines some challenges and solutions to axillary correction of goniophotometric measurements. Goniophotometric measurements are susceptible to temporal changes in the light output of the device under test (DUT), due to the extended duration of the measurement. We will seek to quantify the effect, using a simple model simulation as well as by applying a wireless sensor platform to goniophotometric measurements in various goniophotometric setups. However, it introduces a source of error when a sensor is placed in the near field of the DUT. Therefore, we will look into using temperature or other measurements as a less disruptive method of applying this correction.

Most LED based luminaries are subject to significant thermal effects when in operation. For DUTs without active stabilization this will result in a gradual decrease in light output from the start of operation, until a certain level of thermal equilibrium is reached. The thermal resistance, which gives rise to this effect, is also often dependent on the orientation of the DUT. The usual way to deal with the thermal stabilization is wait while the DUT stabilizes thermally to a certain level of light output variation before measurement commences, as defined in the CIE standard S025 (CIE, 2015). However, for DUTs with integrated controls, such as constant lumen output controls (CLOs), a level of stability will be reached immediately, but the DUT might give unpredictable variation in the light output due to overshooting and settling time in the CLO system. A third source of error is low quality driver electronics that can cause random jumps or gradients in the drive current to the light sources in the DUT.

To account for these effects one can apply auxiliary correction (Krochmann, 1991). This is a method where the light output of the DUT is measured in one or a few constant directions relative to the DUT. Hereby the primary measurement can be corrected by a certain amount. However, such an auxiliary measurement constitutes a number of challenges: The axillary sensor constitute a challenge, since by definition it must be placed in an angle with sufficient illumination from the DUT. For goniophotometers where the DUT is moving the sensor must be mounted on or very near the DUT to facilitate sensor movements to be the same as for the DUT. Minimization of the shadowing effect requires an unobtrusive sensor and mount. For setups where the DUT is stationary one or more axillary sensors can be placed at a distance far from the DUT, causing no shadowing for the main measurement. However, here the issue is that the goniophotometer rig, mirror or other mechanical or optical parts will cause varying shadowing or stray light on the axillary sensor.

We will investigate if direct auxiliary measurement of the light can in some instances be avoided by indirect measurement of for instance temperature or orientation.

For most goniophotometric setups, an easily applicable auxiliary method is to monitor the value obtained from the intersection of the measurement planes, sometimes referred to as the zero-passes or pole values. However, this method is limited by the angular uncertainty of the sensor as it passes the pole. For light intensity distributions with sharp gradients near the pole, this uncertainty might cause the pole values to vary too much. We will investigate this effect by simulation, using different model distributions.

For this purpose a goniophotometric measurement can be simulated with a relatively simple model. The DUT is given a certain light intensity distribution. Examples of distributions could be a Lambert radiator, a point source or various narrow beam sources. The distribution can then be set to vary with various parameters, for instance time, angle etc., with the simplest variation being a scaling of the distribution. The measurement is then simulated by reading

singular angular values of the modified distribution at different time steps. Then resulting distributions and integrated values of the measurements can be compared for different configurations.

We will also compare the simulated results with data from several goniophotometric measurements monitored by a wireless auxiliary sensor platform. We have constructed the sensor platform to be fitted on larger DUTs. The dimensions of the enclosure are 6cm x 15cm x 23cm, with possibility to attach sensor probes. The sensor platform can be used for monitoring irradiance in two specific directions, relatively to the DUT i.e. independent of the orientation of the DUT. Additionally the platform can monitor temperature with two probes, acceleration in three directions, and relative humidity.

This work could potentially have applications both in measurement and uncertainty estimation for goniophotometric auxiliary correction. Furthermore, in cases where a direct measurement of light for auxiliary correction is unwanted due to shadowing, it could be used to monitor and/or correct the signal using other quantities that are correlated to the light output.

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003

AUXILIARY PHOTOMETER METHOD FOR GONIOPHOTOMETRIC MEASUREMENTS ACCORDING TO CIE S025

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Being the first internationally agreed measurement standard for LED devices, CIE S025 will have a great impact on the measurements performed worldwide. By specifying the requirements for electrical, photometric and colorimetric measurements, the standard gives guidelines to generate reliable and accurate results. To ensure that the given recommendations will be implemented by a vast majority of users, the standard was developed to allow measurement equipment that obtain correct results and is affordable at the same time. In the popular case of using a turning-luminaire goniometer for goniophotometric far-field measurements, the so-called auxiliary photometer correction method complies with CIE S025 and puts minimal requirements on the user concerning budget and test room dimensions.

In most of the cases, the passive heat sink of Solid State Lighting (SSL) sources is designed for the operating orientation used in the application. The convective air flow through the cooling fins assures the intended cooling rate and with that the anticipated temperature of the LEDs. A disturbed convective air flow might change the optical properties of the luminaire. Such a perturbation might be induced by operating the device in a position different from the manufacturers intended burning position with respect to gravity. The influence of the operating position is highly dependent on the luminaire type. A comparison of the results with the turning-luminaire to measurements of the test specimen in its designed burning position has been performed. The data shows how pronounced the influence of the operating position is when using state of the art SSL devices. Furthermore it sets the basis for validating an applied correction.

CIE S025 in principle allows goniometric measurements to be performed in an orientation other than the designed burning position. To meet the requirements of the standard, a suitable correction has to be applied. One possible implementation of the requested correction is the auxiliary photometer method. The basis of this correction method is the monitoring of the relative optical output of the test specimen in a fixed direction in space while the test specimen changes its orientation with respect to gravity. An auxiliary photometer head whose orientation and distance to the light source is maintained during the movement can provide such monitoring data. Weighted with a reference, the value measured in each different operating position serves as a correction factor for the measurement. The reference value is measured with the light source in the designed operating position after it is thermally stabilized.

The paper demonstrates an implementation of the auxiliary photometer method on a commercial turning-luminaire goniospectroradiometer. Emphasis is placed on the practical implementation of the correction method and on the validation of the corrected data for different types of light sources. A comparison of the results to measurements of the test specimen in its designed burning position has been performed. Based on the measurement results with consideration of the influence of the burning position, a recommendation for the most convenient norm compliant measurement procedure for different light sources will be given.

004

PHOTOMETRIC CHARACTERIZATION OF EXTENDED SOURCES BY SUBSOURCE GONIOSPECTRORADIOMETRY

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The present scientific and technological progress in cameras for low-uncertainty photometric measurements allows near-field characterization of sources as an alternative to the conventional far-field procedures. One of the problems of this technique is the large amount of data obtained from the acquired images, which need to be used for calculating the relevant photometric quantities of the source. The near-field approach allows the inherent near-field systematic errors in photometric measurements to be avoided. The cost of this advantage is the need of a more complex measurement system, endowed with an imaging device. This instrument introduces new uncertainty sources, being the stray light (2 %) the prevalent one in the measurement of luminance.

We developed and presented in this work a complete procedure to reduce the near-field data by characterizing the spectral and angular distribution of small areas of the source, which we will call “subsources” hereafter. They are defined by the field-of-view areas of the camera pixels when frontally directed to the source. The sum of these subsources forms the complete source to be measured. Our proposal is to derive the angular distributions of the luminance of these subsources from camera acquisitions. It allows simple expressions for the luminance of the subsources to be obtained, all of them differing just in a small set of parameters.

The obtained luminance equation allows any photometric quantity of the complete source to be calculated in a very modest lapse of time, which is a clear advantage with respect to ray-tracing methods for real time visualization applications. This luminance equation is also an important starting point to identify the relevant uncertainty sources in a near-field measurement. To test this procedure, we have used the near-field goniospectroradiometer developed at IO-CSIC, which allows also spectral, angular and spatial photometric measurement to be carried out. This near-field goniospectroradiometer is composed of two perpendicularly-arranged motorized rotation stages, which allow polar and azimuthal rotations to be realized. A 12-bits CCD camera with a 50 mm objective lens is used as near-field detector. A liquid crystal tunable filter is located in front of the camera to obtain spectral resolution. Its spectral range is between 400 nm and 720 nm, with a bandwidth of 7 nm.

A set of OLEDs from different sizes, shapes and manufactures are used as test sources. Their large size is adequate to reveal clearly the systematic effect due to the far-field conditions.

The subsource procedure here proposed was applied to the measures of this set of OLEDs. For some of them, angular parameters (obtained by fitting) and spectral parameters (obtained by principal component analysis) will be explicitly shown. The results obtained by this procedure will be compared with the ones obtained using conventional far-field goniophotometry at short distances, and they explain the systematic errors introduced by measuring in these conditions.

005

MODELLING SPECTRAL MEASUREMENTS OF LEDS

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Array-spectroradiometers or double grating monochromators are commonly used to measure the spectral power distribution emitted by light sources such as coloured or white LEDs. From the spectral power distribution a couple of integral values can be derived which are used to characterize the light source. Examples are the centroid wavelength, colour coordinates or the correlated colour temperature [1]. The integral values, together with their associated uncertainties, are then often used to compare different light sources or to assess the compliance of the light source with certain specifications.

Following the *Guide to the expression of uncertainty in measurement* (GUM) [2], “the result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate”. Application of the GUM requires a model function, which describes the relationship between the input quantities and the resulting measurand. For the measurement of spectral power distributions usually no simple explicit model function for the measurand exists. E.g., accounting for effects like bandpass broadening [3] or incorrect wavelength calibration typically requires signal-processing techniques that cannot easily be transferred into a simple model function. The spectral power distribution is specified in terms of a multivariate vector, where the number of elements is given by the number of pixels of the utilized CCD array or the number of wavelength values. Hence the associated covariance matrix is represented by a corresponding square matrix where the diagonal elements denote the squared uncertainty of each element of the spectral power distribution and where the off-diagonal elements characterize correlation effects.

In order to gain insight into complex measurement processes virtual computer experiments can be employed by simulating the measurement process in terms of a computer algorithm [4]. In this work this approach is employed to spectral power distribution measurements of LEDs. To this end a computer model of a spectral power distribution measurement has been implemented taking a number of influencing effects into account: dark signal, dark signal non uniformity, straylight-, bandpass, and interpolation effects and influences from an imperfect calibration of the wavelength and intensity scale of the measurement device [3,5,6,7,8,9,10]. Within the virtual computer experiment all influencing effects can be controlled, e.g. by specifying their values in accordance with a real spectroradiometer, and their impact on the result of the virtual experiment can be studied. In addition the virtual computer experiment can be utilized to derive the covariance matrix associated to the spectral power distribution. The covariance matrix of the spectral power distribution then also enables the calculation of the covariance associated to integral values derived from the spectral power distribution.

Similarities and differences of the proposed virtual experiment approach, when compared to the GUM methodology, will be discussed. The application of the proposed approach is demonstrated in terms of measurements of spectral power distributions of LEDs using two different measurement devices. Based on the covariance matrix of the spectral power distribution as well as on the covariances of derived integral values the agreement of LED measurements using different measurement setups is assessed.

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006

AC POWERED SSL LAMPS LOAD INPUT IMPEDANCE CHARACTERISITION IN TIME DOMAIN

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LEDs (Light Emitting Diodes), also known as Solid State Lighting (SSL), are replacing traditional light sources in nearly every imaginable lighting application.

Unlike traditional light sources, SSL lamps are non-linear loads. Designed with different topology, some time, when compatibility issue rises among dimmer, driver and transformer, customer has likely experienced confusion, frustration, and even disappointment in using SSL products.

Further, a lamp contains a converter operates over a frequency range from 30 kHz to over 100 kHz. A small magnetic transformer forms part of the circuit to provide galvanic isolation and to reduce the dimension of the lamp. At the same time, the SSL lamps become a dominant electromagnetic interference (EMI) source. Power line EMI filter is inevitable in product design. The EMI filter should not be designed too optimistic or too conservative.

One approach to solve these challenges is to obtain the knowledge of load impedance of SSL products before installation or during installation. Besides, accurate load impedance under its operating condition can help users understand the electrical circuits better and avoid potential problems like saturation or resonance. There is emerging need of accomplishing a “power on” operating condition load impedance measurement with safe and easy to install equipments.

In this paper, a three-probe method is proposed to measure the load impedance of SSL products. The measurement is done in time domain. A multitone signal consisting of 150 tones from 1 kHz to 150 kHz is injected through an injection probe and the generated currents in loop circuit are measured in time domain using receiver probe and monitor probe in every 1 ms. Unlike previous method implemented using VNA or spectrum analyzer in frequency domain, only the “averaged” load impedance is measured, this method can measure the variation of the load input impedance during the period of one cycle of an AC signal (20 ms for 50 Hz power system).

It can be observed in the measurement result, that the measured impedance varies with the turn on and turn off of the rectifiers. With this knowledge, the filter requirement will be all right in design.

The proposed three-probe method in this work is able to measure load impedances at 2 k – 150 kHz at “power on” condition and the vector calculations can lead to accurate results which the previous method cannot realize at this frequency range. Besides, simple measurement instruments and mathematic deduction make this method easy to be implemented wherever the measurement is needed.

007

PHOTOGRAMMETRICAL METHODS USED IN IMAGING PHOTOMETRY

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Abstract

During the last years cameras for the determination of the luminance distribution of objects became increasingly important. The PTB as Germany's national metrology institute will need to be able to calibrate these cameras in a traceable way and associate a measurement uncertainty, which is currently not feasible. In comparison to conventional luminance measuring devices, which use a single photometer as sensor element, the usage of an image sensor as photometer matrix raises the complexity of the measurement process. Many different location- and angle-dependent, spectral and temporal properties of luminance standard and camera (image sensor, V_λ-filter, objective) superpose mutually. To calculate the measurement uncertainty it is required to vary each input quantity of the measurement model and determine the induced change of the measurand.

For the calibration of single photometers the luminance standard can be approximated by an ideal homogenous Lambertian source. This is not applicable for measurement cameras anymore. The approach introduced in this presentation is based on the discrimination of the location- and angular-dependent properties of camera and luminance standard. The first step to accomplish this is the calibration of the relative position and orientation (pose) between camera, luminance standard and positioning system. After this measurements with variable but known camera poses in respect to the luminance standard can be done to separate their inhomogeneities.

The calibration setup uses a positioning system with three translational and two rotational degrees of freedom. With this the camera is movable freely in front of the luminance standard. The pose of the camera is defined by the position of their entrance pupil (which acts as the theoretical centre for the central projection) and the relative position of the image sensor to this projection centre. The exact position of this projection centre is usually not known because it is dependant of the focus setting. The geometrical calibration procedure needs to determine relative offset pose of the cameras projection centre to the stage of the positioning system and the luminance standard. This is done by methods of close-range photogrammetry. For this the camera itself is used as measurement device for geometrical measurements. It observes homologous features from different positions and directions. The theoretical 3D positions of these observed features are mapped by a camera model to a virtual image plane and compared to their real observations. This leads to an over-determined non-linear equation system whose solution gives the unknown parameters (positions of the feature-points, camera offset, inner/outer orientation of the camera).

The homologous features are realized by circular targets with ring codes, placed on a plate, which is to put in front of the luminance standard in a repeatable way. The constant offset between this target plate and the reference plane of the luminance standard gives the link to the global coordinate system. The equation system is solved by bundle-adjustment. This method gives a high flexibility to adjust it to different configurations (objectives, field of view, known parameters) and can be extended to handle optical aberrations in future.

After the geometrical calibration the relative offset of camera and stage can be compensated and rotations around an arbitrary virtual pivot are possible, e.g. around the projection centre or a point on the reference plane of the luminance standard. Now it is possible to define an absolute relation of image pixel and observed point on the luminance standard by spatial intersection or resection. With this a series of images are taken by rotating around the centre point of the luminance standard or the projection centre of the camera. For the evaluation of

the measured intensities the evaluation area can be chosen in a way that the local direction of the viewing line is kept constant either at the luminance standard or inside the camera.

This leads to the distribution of the vignetting of the camera. In the next step the local variations of luminance standard and camera are separated by taking several lateral shifted images processed by principal component analysis (PCA). This separates eigen-images attributed to the camera or the standard. From this a transfer function of the image is derived, which can be applied to newly taken images to compensate the influence of the camera.

The presentation will give an overview over the photogrammetrical methods used for the geometrical calibration and explain the measurement steps for the discrimination of location- and angle-dependent properties of camera an luminance standard. Some preliminary results will be presented.

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IMPACT OF THE PHOTOMETRIC DATA OF LUMINAIRES TO THE LIGHTING DESIGN CALCULATIONS WITH RESPECT TO THE GONIOPHOTOMETRY

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By means of goniophotometry are measured luminous intensity distribution curves (LIDC) of luminaires which they are further provided to the lighting designers for the calculation of photometric parameters by photometric data e.g. LDT, IES etc. That files are edited by testing laboratory to provide all photometric information about luminaire. At the present two important standards about testing of LED products were completed beside the already issued and approved document LM-79 where goniophotometry of luminaires was declared and are complementary to the older standards of testing luminaires. In laboratories are used goniophotometers of various far field types of goniophotometers according to CIE 121:1996 The Photometry and Goniophotometry of Luminaires which currently is under revision at CIE level. At the measurement of some types of goniophotometers occur some problems which should be properly treated by testing laboratory. For example when goniophotometer with rotating luminaire is used the corrections by using of auxiliary photometer should be applied because during the measurement the work position of the luminaire changes with every rotation of the goniophotometer. There are present doubts how large the error is, compared to goniophotometric system where Earth's gravitational field is not changing. Other still more and more laboratories have started use the new approach of the near-field goniophotometry based on image photometers where relation between luminance and luminous intensity unit is used for determination of LIDC of luminaire respective light source. This technology is not still fully implemented into the international standards owing to lack of validation process. In the international standards for testing of LED products e.g. CIE International Standard CIE S025:2014 harmonised with EN standard 13032 part 4 it is mentioned that system should fulfil performance as much as far-field goniophotometer. Even more some laboratories assume symmetries of luminaires according to various planes to save the measurement time. Therefore goniophotometric measurements are very important for lighting designers who use results from these measurements to lighting desings purposes by performing calculations in the various software tools. Furthermore the lighting designers very often do not know how to treat with provided photometric data due to the fact impact of the uncertainty of measurement of LIDCs of luminaires is at the present big unknown. Metrologists involved in the field of goniophotometry still try to find the way how to express the uncertainty of LIDC measurement by one number. Until now it could not be found agreement among the community what expression should be used. As it was mentioned goniophotometry is close connected with lighting designs of lighting systems. Therefore it can be possible influence of uncertainty measurement of LIDC of luminaires on photometric parameters which are important for lighting designers. Simultaneously it can solve problem to improve of knowledge of lighting designers or customers who concerns about LIDC of luminaires. The paper concerns problems connected with goniophotometry of luminaires by various methods with different goniophotometers in connection with lighting calculations at the design level of various lighting systems. Even more the expression of uncertainty measurement of LIDC is analysed to lighting design calculation of lighting systems and it analyses the impact of this parameter assign to the result of measurement to the lighting designs. The research work which has already been done can serve as background for future work how to express and treat influence of uncertainty measurement of LIDC of luminaires in connection to practical treatment and interest from side of lighting designers. Furthermore based on the results can be stated procedure how to treat photometric measurements of luminaires i.e. uncertainty of measurement will not serve as invisible or not important number on the test reports of testing laboratories which measurements were performed. After that either accredited or not accredited photometric laboratory will not vaste anymore with time on uncertainty evaluation of measurement at the LIDC measurements of luminaires. At the end of the paper is introduced analysis which can serve for new treatment about uncertainties at the photometric measurements and can also

find solution for other parameters which are measured with their uncertainties as their influence on parameters to be interesting for lighting engineering field. They could in the future much easier to predict possible errors influenced by these measurements and finally it can be determined responsibility owing to improper design. Thus lighting designers can do better lighting designs what can avoid possible inconveniences which sometimes occur in the practice. Avoiding these problems can save lot of money which can be possibly lost as result of improper design.

009

DEVELOPING A NEW DETECTOR FOR THE REALIZATION OF THE SI BASE UNIT "CANDELA"

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Introduction

The current realization of the SI base unit for luminous intensity "Candela" at PTB is based on a network of photometers and incandescent lamps [1]. When realizing the "Candela" the photometric responsivity of the photometers is traceable to the national primary standard for optical power, a cryogenic radiometer. The uncertainty level for optical power calibrations with the cryogenic radiometer is of 10^{-5}. Via this traceability chain an uncertainty of $2{,}5 \cdot 10^{-3}$ $(k = 2)$ is achieved for the realization of the luminous intensity for the photometers with an incandescent lamp and even higher for luminaires with different spectral distributions. In contrast to the realization, the groups of incandescent lamps used for maintaining the unit can be operated at a reproducibility of $2 \cdot 10^{-4}$ [2], including the expected aging.

To detect deviations in the maintenance with the lamps and reduce the uncertainty in the realization a new detector is being build. This new detector, a so called $V(\lambda)$ trap detector, can be calibrated directly for optical power at the primary standard and can be used with a filter for realizing the luminous intensity. Additionally the temperature of a high-temperature blackbody radiator can be measured using the same detector to determine spectral distributions of the incandescent lamps. This yields in a much shorter traceability chain without transfer steps and the uncertainties resulting from each transfer.

First steps with the new detector

The $V(\lambda)$ trap detector will consist of a six element transmission trap detector, specially designed filters with precision apertures and a CCD-camera. Using a detector with six Si-Photodiodes offers several advantages in comparison to a single photodiode. By scanning the active area of the detector with a laser beam the spatial uniformity of responsivity was measured. The trap detector was measured to have a spatial uniformity at a level of 10^{-4} which is a big improvement in comparison to a single photodiode. By using the diodes in a transmission configuration there is less light backscattered to the filter and apertures, if the diodes are underfilled. The illumination condition on the photodiodes can be checked by using the CCD-camera, which measures the transmitted light passing trap detector. With this spatially resolved detection of the transmitted light, the transfer from power to irradiance can be achieved with lower uncertainty. Additionally the uncertainty contribution of the spatial uniformity of responsivity can be reduced by knowing the illumination conditions. When the detector is used in irradiance mode, meaning the front aperture is overfilled, the camera can be used to ensure the underfilling of the photodiodes. By underfilling the photodiodes no light will be reflected from the edges of the diodes as straylight within the trap detector. The polarization dependency of the detector can be greatly reduced by carefully choosing the alignment of the diodes ([3], [4]). This was already observed during the spatial uniformity characterization and will be investigated in further characterizations.

For matching the spectral responsivity of the detector to the luminous efficiency function $V(\lambda)$ a specially designed filter will be used. The calibration of the filter and the detector will be done with the laser setup TULIP[5] at PTB. Especially when using laser radiation for calibration interference oscillation has to be taken into account. This oscillation adds to the uncertainty of the spectral responsivity of the detector and therefore should be minimized. Several filters with different designs were characterized for their angular dependent transmission to observe the occurring oscillation. The measurements show greatly reduced amplitudes of the oscillation when using glass wedges attached to the filter glass. For comparison a $V(\lambda)$-filter consisting of

parallel glass filters was measured showing a higher interference amplitude than the wedged filters. The glass wedges will therefore be included in the filter design.

Summary and perspective

First characterizing measurements on components of the new detector have been done, already showing significant improvements of the investigated properties like spatial uniformity of responsivity of the trap detector and interference oscillation occurring at the filter. Further characterizations for example polarization dependency of the responsivity will be done. The measured data will also be used for validation of a theoretical model that is developed in parallel. By comparing the measured and the simulated data the detector components can be optimized for a reduced measurement uncertainty. With this approach, by reducing the uncertainty contributions of each detector component and by shortening the traceability chain the resulting overall uncertainty is expected to reach a level of $5 \cdot 10^{-4}$. This will not only benefit the realization and dissemination of the luminous intensity, but also of all derived photometric units.

Acknowledgment

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010

3D GAN LEDS – TECHNOLOGIES AND ANALYTICS

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Abstract

3D GaN structures attract a lot of attention since they are expected to open up new routes to high efficiency semiconductor devices like solid state-based high power light engines. Whereas several groups worldwide are involved in 3D GaN research, the Institute of Semiconductor Technology at TU Braunschweig focusses on the special case of 3D GaN structures with a core-shell geometry. This core-shell design offers a dramatically enhanced active area per chip, since the active area is scaling with the height of the 3D structures. Aspect ratios of above 20 can easily be achieved, enabling operating conditions under lower current densities. By this, the droop problem could be possibly avoided, thus enhancing the output of photons per chip area and increasing the luminous density.

Regarding the sample preparation, the InGaN/GaN LED core-shell structures presented in this contribution are grown by Metal Organic Vapor Phase Epitaxy (MOVPE) employing selective area growth (SAG). The systematically arranged arrays of these 3D LEDs - each with a diameter about 1µm in arrays with a few µm pitch - are manufactured on a sapphire substrate which has been passivated before MOVPE growth by a SiO_2 mask layer deposited via plasma enhanced chemical vapor deposition (PECVD) or physical vapor deposition. The pattern of holes is arranged in a hexagonal array by photolithography and transferred into the 30 nm SiO_2 layer by reactive ion etching with inductive coupled plasma (RIE-ICP) using SF_6 and O_2 [1]. The structures under investigation have aspect ratios of up to 20. They occur with (000-1) orientation and show semipolar planes, the c-facet on top and they have a symmetric hexagonal shape with m-plane sidewalls [1],[2]. After growth of the GaN:Si core, the InGaN/GaN MQW and p-type GaN:Mg shell is grown on the surfaces of the core-structures using layer growth conditions. On these templates the LED pillars are grown in a MOVPE system with a close coupled showerhead in the following growth sequence: after a thorough nitridation step, GaN:Si with a dominant vertical growth rate is grown, forming the n-type core. In a further step, this core is overgrown by a fivefold InGaN/GaN MQW stack and finally a GaN:Mg p-type shell. Details about the growth conditions for this core-shell selective area growth (SAG) are described elsewhere [1]. In order to activate the Mg acceptors of p-type GaN:Mg, the samples are annealed successively at 900 °C and 600 °C under a nitrogen atmosphere prior to electrical characterization.

The optical, electrical and morphological properties of the 3D GaN structures have been characterized by different techniques. Since the optical transitions of the InGaN and GaN are mainly related to near band edge (NBE) recombination, recombination from QW states and defect related yellow luminescence (YL), optical properties of the InGaN/GaN structures have been obtained by spatially resolved CL emission in distinct spectra bands (NBE, QW, YL) at room temperature (RT). Electron beam induced current (EBIC) measurements have been carried out inside a SEM by electrically contacting the structure with tungsten probe tips and micro-manipulators to reveal the electrical properties of the p-n-junction of the diodes. Electroluminescence measurements have been carried out inside an SEM as well as in an optical microscope setup combined with a probe station. Details on the electro-optical characterization of 3D GaN LED structures can be found in [3]. Morphological investigations were done by bright field transmission electron microscopy (TEM) on thinned lamellas, which have been prepared by a Dual-Beam FIB-SEM using a focused ion beam induced deposition (IBID) of platinum, milling and thinning. Secondary electron (SE) images are obtained in both SEMs and the FIB-SEM.

By the above described methods we achieved insight into 3D optical and electrical properties, especially by cleaving these pillar-like structures. This allows for direct comparison with the structural informations obtained by TEM investigations of lamellas prepared from structures of the same sample type. The TEM measurements revealed that the InGaN/GaN MQW and the p-type GaN are on the one hand grown as a stack of layers on all surfaces of the structure, on the other hand the thickness clearly varies on the sidewall and top facets. These variations as well as a difference in Indium incorporation due to anisotropic growth rates and diffusion effects during growth are thought to be the origin of an inhomogeneous wavelength distribution of the QW emission observed by spatially resolved CL on single structures. The core-shell geometry of the pn-junction has been successfully proven by EBIC measurements. Complete core-shell pillars were investigated using a p-n-p contact configuration and current crowding inside the p-type shell was also explained by EBIC.

By electroluminescence measurements on single 3D structures inside an ensemble emission patterns were observed, which shows that the light extraction is related to the geometry of the pattern. The experimental results have been supported by modeling the light paths within these 3D GaN arrays as well as within single structures with high aspect ratios. This investigation gives insight to the origin of the observed emission pattern and its directionality.

In this contribution, processing technologies for the synthesis of 3D semiconductors as described above as well as alternative approaches for 3D GaN LED manufacturing employed at the Institute of Semiconductor Technology will be presented. Recent results on the electro-optical characterization of single structures within ensembles of 3D GaN structures will also be shown. The institute is involved in the European ENG62 MESaIL-project and its part is to deliver 3D LED samples for further investigations towards retraceable characterization techniques for 3D LEDs. This talk introduces the device processing steps for the MESaIL-project. Finally, further device related solutions, e.g. the processing of white 3D LEDs will be demonstrated.

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FEASIBILITY OF SOLDER CRACK INITIATION IDENTIFICATION USING IN-SITU HIGH PRECISION ELECTRICAL RESISTANCE MONITORING

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Abstract

The reliability of solder interconnects becomes increasingly important in LED lighting product and many other electronic packages. In order to evaluate the reliability in an adequate way, accelerated tests are the most appropriate route. However, the accelerated test of solder joints for applications with a long expected lifetime such as solid state lighting is generally very time consuming and cost ineffective. One of the main reasons is that most of the current tests are based on Test-to-Failure methodology, which ignores the damage evolution before the final catastrophic failure (deformation energy accumulation, crack initiation and its propagation) during testing. It is well known that the time of crack propagation in many packages such as Ball Grid Arrays (BGA) is often relatively short and can be negligible compared to the total time to failure. However, as for solder joint in LED assembly, the propagation time generally is much longer due to Land Grid Array (LGA) that has been commonly adopted. Therefore, if the crack initiation point can be identified clearly, it seems feasible to shorten the reliability testing time by early termination of the test. Moreover, crack initiation in solder joint is the consequence of deformation energy accumulation. In that sense, a parameter that responds fairly in a different way to deformation as to cracking would be very desirable as it would allow damage and crack evolution measurements which could lead to a system capable of detecting imminent system failure.

There are several techniques or approaches that are capable of detecting cracks in solder joints, such as dye and pry inspection, micro-sectioning inspection, tomographic scan, strain gauge with backface strain technique and high resolution X-ray imaging. However, those techniques or approaches are less suitable in case of many individual solder joints in-situ and in parallel, and therefore for in-situ crack initiation identification. Online electrical resistance measurement seems to have the potential to overcome the limitations. Our previous work shows that it is possible to detect the viscoplastic deformation prior to crack and the crack propagation in the solder joint with our high precision electrical resistance measurement setup. However, for the experimental conditions used so far deformation and cracking have the same effect on solder electrical resistance making it difficult to distinguish the crack initiation.

In this study, a test approach based on high precision electrical measurement that has the potential to in-situ identify the solder fatigue crack initiation is presented. A series of individual SAC 305 (96.5%Sn-3%Ag-0.5%Cu) solder joints were tested in a double lap shear (DLS) test. The electrical resistance of each solder joint was monitored during the test involving the use of conventional 4-point resistance measurement structure with specially configured electrodes. It is found that in one of the joint viscoplastic deformation has a negative effect on resistance, whereas crack propagation has a positive effect, which makes it convenient to identify the crack initiation point as the minimum in a resistance-test cycle curve. This finding agrees with FEA simulation results. Thus, the intention of this paper is to show that with proper configuration of electrodes, accurate in-situ crack initiation identification in multiple solder joints tested in parallel can be achieved.

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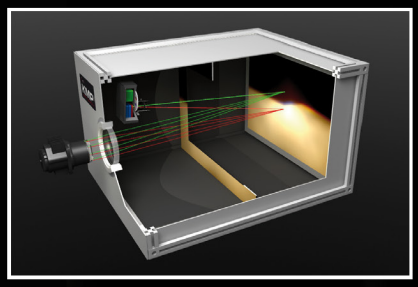

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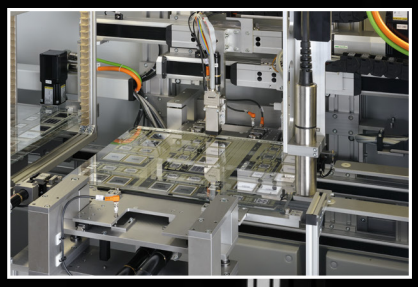

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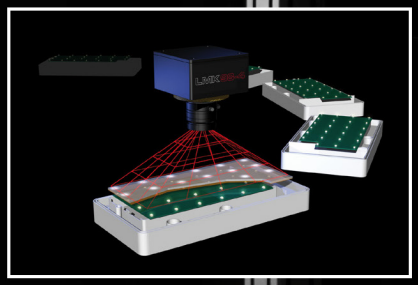

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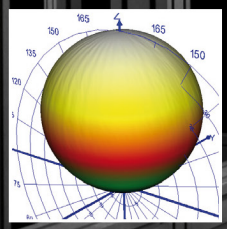

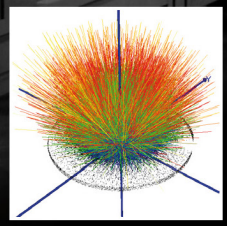

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