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International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

TECHNICAL REPORT

Optical Measurement of High-Power LEDs

CIE 225:2017

UDC: 535.24
535.65
535.243

Descriptor: Photometry
Colorimetry
Spectrophotometry

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organization devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in about 40 countries.

The objectives of the CIE are:

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organizations concerned with matters related to the science, technology, standardization and art in the fields of light and lighting.

The work of the CIE is carried out by Technical Committees, organized in seven Divisions. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.
A plenary session is held every four years at which the work of the Divisions and Technical Committees is reported and reviewed, and plans are made for the future. The CIE is recognized as the authority on all aspects of light and lighting. As such it occupies an important position among international organizations.

LA COMMISSION INTERNATIONALE DE L'ECLAIRAGE

La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant environ 40 pays.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par Comités Techniques, organisés en sept Divisions. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.
Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in rund 40 Ländern.

Die Ziele der CIE sind:

1. Ein internationales Forum für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Messtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird durch Technische Komitees geleistet, die in sieben Divisionen organisiert sind. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind auf der ganzen Welt anerkannt.
Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen berichtet und überprüft werden, sowie neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Technical Committee 2-63 of Division 2 "Physical Measurement of Light and Radiation" and has been approved by the Board of Administration as well as by Division 2 of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 2-63 de la Division 2 "Mesures Physiques de la Lumière et des Radiations" et a été approuvé par le Bureau et Division 2 de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

Dieser Technische Bericht ist vom Technischen Komitee CIE 2-63 der Division 2 "Physikalische Messungen von Licht und Strahlung" ausgearbeitet und vom Vorstand sowie Division 2 der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist.

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The following members of TC 2-63 “Optical Measurement of High-Power LEDs” took part in the preparation of this Technical Report. The committee comes under Division 2 “Physical Measurement of Light and Radiation”.

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OPTICAL MEASUREMENT OF HIGH-POWER LEDS

Summary

Measurement results for light emitting diodes (LEDs) strongly depend on their thermal conditions. In order to achieve reproducible results with small uncertainties it is critical to accurately set and control the junction temperature of an LED during the time of optical measurement. This technical report describes the methods and procedures for measurement of high-power LEDs (HP-LEDs) under DC operation to acquire photometric, radiometric, and colorimetric quantities at a specified junction temperature.

MESURES OPTIQUES DE DELS HAUTE PUISSANCE

Résumé

Les résultats de mesures optiques de diodes électroluminescentes (LEDs) dépendent fortement de leur environnement thermique. Pour obtenir des résultats reproductibles avec de faibles incertitudes, il est critique d'ajuster et de contrôler précisément la température de jonction de la LED au cours de la mesure optique. Ce document technique décrit les méthodes et les procédures de mesures pour l'acquisition des données photométriques, radiométriques et colorimétriques de LEDs haute puissance (HP-LEDs), en mode DC (continu) et à une température de jonction spécifiée.

OPTISCHE MESSUNGEN AN HOCHLEISTUNGS-LEDS

Zusammenfassung

Messergebnisse für lichtemittierende Dioden (LEDs) hängen stark von den technischen Bedingungen ab. Um reproduzierbare Ergebnisse mit geringen Unsicherheiten zu erhalten, ist es entscheidend, die Sperrschichttemperatur der LED während der Dauer der optischen Messung exakt festzulegen und zu kontrollieren. Dieser technische Bericht beschreibt die Methoden und Prozeduren für die Messung von Hochleistungs-LEDs unter Gleichspannungsbetrieb, um photometrische, radiometrische und farbmetrische Größen bei einer festgelegten Sperrschichttemperatur zu erlangen.

1 Introduction

High-power light emitting diodes (HP-LEDs, see 3.1), most of which are white HP-LEDs for lighting applications, are now widely used in all types of solid-state lighting products. The technical report CIE 127:2007 (CIE 2007) has addressed many issues with regard to the optical measurement of LEDs in general, but it does not cover HP-LEDs. Optical measurement of HP-LEDs has been difficult because they are highly sensitive to their thermal conditions, in particular, their junction temperatures that vary significantly with operating conditions. LED manufacturers commonly measure HP-LEDs using a milliseconds-long single pulse or microseconds-long multiple pulse train without mounting the HP-LEDs on a heat sink, and it is assumed that the pulse is short enough so that the junction temperature, T_J, is close to the ambient temperature (typically 25 °C) (CIE 2017). Therefore, published HP-LED specifications normally refer to $T_J = 25$ °C. However, HP-LEDs in lighting applications are commonly operated in DC mode and at much higher temperatures (ranging from $T_J = 50$ °C to over $T_J = 120$ °C), where their photometric, radiometric, and colorimetric values deviate significantly. To meet the specifications of a lighting product, HP-LED users need to know the performance of an HP-LED at a known, hot condition.

To set or monitor the thermal condition of an HP-LED, “case temperature”, “pin temperature”, “board temperature”, “solder-point temperature”, or “heat sink temperature” is often used. Such a thermal reference is useful to ensure that the operating temperature of an HP-LED does not exceed the allowed maximum temperature or to reproduce the same thermal condition for a particular HP-LED. However, the reference is not always available and the measurement results of different HP-LEDs of the same type or the results of a different type of HP-LEDs cannot be directly compared. Also, an accurate measurement of temperature at such a reference point is often difficult because there is always an unknown thermal contact resistance between the reference point and the temperature sensor. Furthermore, the above reference temperature terms are vendor-specific.

On the other hand, the performance of an HP-LED is strongly correlated to its junction temperature, thus it is the ideal thermal reference for acquiring reproducible measurements and can be universally used for all types of HP-LEDs no matter how different the LED packages are. The junction temperature of an HP-LED can be measured. One example of such work (that also deals with measuring real thermal resistance) is described in (JEDEC 2010), (JEDEC 2012), and (Keppens et al. 2011).

The optical measurement method described in this report is straightforward (Zong and Ohno 2008). It uses the junction temperature of an HP-LED as the measurement reference condition. An HP-LED under test is directly set and controlled to a specified constant junction temperature and is operated in DC mode, therefore, all conventional optical instruments (such as sphere photometers, sphere-spectroradiometers, goniophotometers, goniocolorimeters, and gonio-spectroradiometers, etc.) designed for measurement of traditional light sources in the lighting industry can be used for measurement of HP-LEDs. In addition, the DC method is superior in terms of measurement uncertainties (even though it is slow) compared to the pulse methods which also use junction temperature as the thermal reference condition. For example, when a single pulse method is used, the measurement error due to the significant rise of junction temperature during a milliseconds-long single pulse (see Annex B) may be large, while the DC method completely eliminates such a measurement error (see Clause 4). Also, when a phosphor-converted white HP-LED is measured using a single-pulse method or a pulse-train method the measurement error resulting from the “cold” phosphor may by large. This is because under such a pulse-mode operation, the phosphor temperature of an HP-LED is close to its junction temperature, which is significantly lower (e.g. tens of degrees Celsius) (Yan et al. 2011) (Hwang et al. 2010) than the real temperature of “hot” phosphor when the HP-LED is operated in DC mode at the same junction temperature. While when the phosphor-converted white HP-LED is measured using the DC method, the HP-LED operates in the same way as it does in a typical lighting product, which completely eliminates the measurement error resulting from the “cold” phosphor. In principle, the above two measurement errors associated with the pulse methods can be analysed and corrected. However, such work is not

trivial. Alternatively, such measurement errors can be corrected by comparing the measurement result obtained using the pulse method with that obtained using the DC method.

This report describes setting and operating HP-LEDs at a specified junction temperature, various measurement setups, and measurement of photometric quantities (luminous intensity and total luminous flux), radiometric quantities (radiant intensity and total radiant flux), and colorimetric quantities.

The report aims to provide a guide for optical measurement of HP-LEDs for calibration and testing laboratories with emphasis on simplicity, excellent reproducibility, and small measurement uncertainties.

2 Scope

This technical report deals with methods used by calibration and testing laboratories for the measurement of optical quantities (including photometric, radiometric, and colorimetric quantities) of HP-LEDs, with focus on small uncertainties. The document covers measurement of HP-LEDs under DC operation only with the thermal condition referring to their junction temperatures. It does not cover those pulse methods with focus on measurement speed for testing facilities that perform fast measurement of a large number of LEDs (e.g. testing facilities used in LED production lines). Such methods are described in the CIE Technical Report “High-Speed Testing Methods for LEDs” (CIE 2017).

This document covers all single-diode HP-LEDs (including large-die HP-LEDs where the junction temperature may be different across the die). It also covers multiple-diode HP-LEDs (where multiple diodes are electrically connected in series or parallel, or both in series and parallel) as long as the total forward voltage is accessible, which include single-die, multiple-diode HP-LEDs, such as high-voltage LEDs (HV-LEDs) where many micro LEDs are integrated onto a single substrate, and multiple-die, multiple-diode HP-LEDs, such as chip-on-board (COB) HP-LEDs where multiple LED dies or surface-mounted device (SMD) LEDs are packaged onto a single metal-core printed circuit board (MCPCB) or a ceramic board. In the case of a large-die HP-LED or multiple-diode HP-LED the junction temperature used as the thermal reference is the average junction temperature. For phosphor-converted white HP-LEDs it covers both the contact phosphor type where phosphor is coated directly on the LED die and the remote phosphor type where phosphor is thermally insulated from the LED die.

This document does not cover AC-driven LEDs, organic light emitting diodes (OLEDs), LED modules, LED light engines, LED lamps, and LED luminaires. Those LED products are covered in other CIE publications, partly still in preparation. In particular:

- Characterization of AC-driven LEDs is described in the report of CIE TC 2-76 "Characterization of AC-driven LED Products for SSL Applications", currently still in preparation.
- LED products that comprise multiple dies or packages, and where the forward voltage is not accessible, are within the scope of the report of CIE TC 2-50 "Measurement of the Optical Properties of LED Modules and Light Engines", currently still in preparation.
- Organic LEDs (OLEDs) are covered by the report of CIE TC 2-68 "Optical Measurement Methods for OLEDs used for Lighting", currently still in preparation.
- The international standard CIE S 025/E:2015 deals with LED lamps, LED luminaires and LED modules (CIE 2015b).