Measurement Challenges for Efficient Sustainable Lighting Technologies

Yoshi Ohno
President, International Commission on Illumination (CIE)
(National Institute of Standards and Technology, USA)

Other Delegates from CIE:
Kathryn Nield, General Secretary of CIE
Peter Blattner, President-Elect, Director of CIE Division 2
Tony Bergen, Secretary of CIE Division 2
OUTLINE

- Overview of CIE
- Solid State Lighting and measurement challenges
- Challenges in other aspects of SSL
- CIE’s work for future photometry
Overview of CIE

- Established in 1913
- **International scientific body** in the area of light and lighting, with ~1500 experts (scientists, standardization officers, lighting engineers, lighting designers, ...)
- **International standardizing body** in the area of light and lighting, recognized by ISO, IEC, and CIPM
- Participation from NMIs, test and measurement laboratories, universities, research institutes, industry,...
- **37 National Committees** and 3 associate National Committees – covering all continents
- ~ 120 **Technical Committees**
- More than 30 publications (technical reports, standards, technical notes) during the past 4 years
Structure of CIE

NCs of CIE
General Assembly

Board of Administration

Liaisons

Central Bureau
(Vienna, Austria)

ISO, IEC, CIPM, CEN, EURAMET, ...

Division 1
Vision and Colour

Division 2
Physical Measurement of Light and Radiation

Division 3
Interior Environment and Lighting Design

Division 4
Transportation and Exterior Applications

Division 6
Photobiology and Photo-chemistry

Division 8
Imaging Technology

TCs

JTCs

General Secretary, ....
## Overview of CIE

### Board of Administration 2015 – 2019

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<td>Kathryn Nield (Central Bureau)</td>
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MoU between CIE and CIPM

AGREEMENT BETWEEN THE
INTERNATIONAL COMMISSION ON ILLUMINATION
AND THE
INTERNATIONAL COMMITTEE FOR WEIGHTS AND MEASURES
2007

• Liaison from CIE to CCPR: Division 2 Director (P. Blattner)
• Liaison from CCPR to CIE: Y. Ohno
• CIPM is responsible for the units
• CIE is responsible for defining action spectra (including spectral luminous efficiency functions)
• Consult together on issues of quantities and units and metrology for optical radiation

CIE is also an observer in CCU
(K. Nield, P. Blattner)
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Light-Emitting Diodes (LED)

History of LED

1907 Electroluminescence (from SiC) was discovered by H. J. Round (UK).

1955 - 1961 Infrared LEDs developed

1962 Red LED invented by Nick Holonyak (USA)

1962 Yellow LED invented by George Craford (USA)

1994 Blue LED (InGaN) invented by S. Nakamura, H. Amano, and I. Akasaki (Japan). White LED possible

2014 Nobel Prize
Solid State Lighting (LED Lighting)

Incandescent  
10~15 lm/W  
(lumen / watt)

Fluorescent  
50~90 lm/W

Solid State  
(White LEDs)  
Potential  
300 lm/W

Evolution of Light Sources for Lighting

- High energy efficiency
- Long life
- Instant start
- Easy on/off control, dimming

Luminous Efficacy (lm/W)

Year

1850 1900 1950 2000

Theoretical limit  
Fluorescent, HID  
Incandescent  
carbon  
tungsten  
Fire  
Kerosene  
Gas Mantle  
Oil
Huge Energy Savings Potential

Lighting consumes ~20% of electricity
~8% of total energy
(statistics of USA)

Improvement of luminous efficacy of LED lighting products by 1% will save electrical energy of value 4 billion Euro /year globally.
White LED lm/W improvements

Needs for international harmonization of test methods and accreditation

DOE regulation on DOE regulations

LM-79 (US Test method)

Manufacturers & Testing labs

SSL Testing Lab Accreditation (NVLAP, ...)

Proficiency Testing for LM-79

Test reports

EN Test Method

Manufacturers & Testing labs

SSL Testing Lab Accreditation

PT for European Test Method

JIS Test Methods

Manufacturers & Testing labs

SSL Testing Lab Accreditation (CNAS)

PT for JIS Test Method

Chinese regulations

Chinese CQC and GB stds

Manufacturers & Testing labs

SSL Testing Lab Accreditation (IA-Japan)

PT for Chinese Test Method

Eco-design

Eco-label

Energy
Label

Energy
Label

Eco-mark

Eco-mark

26th CGPM, Nov. 2018, Versailles
Future Goal toward free trade and commerce for SSL products

- Energy Label
- DOE regulation on SSL
- International Test Method
- Manufacturers & Testing labs
- SSL Testing Lab Accreditation
- PT for Intn’l Test Method
- Test reports
- Mutually Recognized
- Shared
- International Test Method
- Manufacturers & Testing labs
- SSL Testing Lab Accreditation
- Proficiency Testing
- International Test Method
- Manufacturers & Testing labs
- SSL Testing Lab Accreditation (CNAS)
- Proficiency Testing
- International Test Method
- Manufacturers & Testing labs
- SSL Testing Lab Accreditation (IA-Japan)
- Proficiency Testing
- Chinese regulations
- Eco-design
- Eco-mark

26th CGPM, Nov. 2018, Versailles
CIE S 025:2015

- **International test method** for LED lamps, LED luminaires, and LED modules

- Developed by TC 2-71 (Ohno chair) with **40 members from 20 countries**. Took 4 years.

- Intended for use in SSL regulations and for **testing laboratory accreditation**.

- Joint work with CEN TC169 WG7, that produced a harmonized std:
  
  **EN 13032-4** Lighting Applications — Measurement and presentation of photometric data of lamps and luminaires — Part 4: LED lamps, modules and luminaires

- **Test method for European region.**
Capacity Building for the Industry

CIE Tutorial and Practical Workshop on LED Lamp and Luminaire Testing to CIE S 025
(1) PTB, Germany, Nov. 2015
(2) METAS, Switzerland, May 8-11, 2017
(3) VNISI, Moscow, Russia, Nov. 5-7, 2018

Measurement challenges for LEDs, LED lamps and LED luminaires

- **Variety of products** (components to lamps, luminaires)
- **Sensitive to temperature** (ambient temperature, air movement)
- **Large drift of output (~20%)** during stabilization
- **Dissimilar spectral distributions**
- **Sensitive to AC power supply characteristics** (impedance, harmonic distortion, power meter error)
- There are **many quantities** (total luminous flux, luminous efficacy, luminous intensity distribution, active power, colour quantities ... in regulations)
- **Uncertainty evaluation** is difficult for many industry laboratories (particularly for color quantities).
Worldwide Interlaboratory Comparison of Measurements of LED lamps (110 Labs)
(IEA 4E SSL Annex, IC 2013)

An example data

Ref. IC 2013 Final Report at http://ssl.iea-4e.org
Worldwide Interlaboratory Comparison of Measurements of LED lamps (110 Labs)
(IEA 4E SSL Annex, IC 2013)

Reported uncertainty (k=2) for chromaticity $y$

Ref. IC 2013 Final Report at http://ssl.iea-4e.org

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Other Recent Publications on LED measurement

**CIE 226:2017** Optical Measurement of High-Power LEDs
Measure LEDs at a given junction temperature.

**CIE 227:2017** High Speed Testing Methods for LEDs

**CIE S 025 SP-1** <approval stage>
Test Methods for OLED luminaires and OLED light sources
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Colour Quality of LED Lighting Sources

• Variety of Spectra
• New color quality design products

• Existing standard CIE Color Rendering Index does not meet the needs for SSL.

• CIE published a new metric: CIE 2017 Colour Fidelity Index (CIE 224:2017)

• Work in progress for further metrics.
Non-visual effects of light

Human visual system

5 Photoreceptors
- Cones (L, M, S)
- Rod (scotopic)
- ipRGC

(Intrinsically-Photosensitive Retinal Ganglion Cells)

Vision (image, colour)

Non-visual effects
- sleep-wake (circadian) regulation
- alertness / comfort
- eye fatigue

Action spectrum for melatonin suppression

"Healthful Lighting"
- What light is best for night (for good sleep)?
- What light is best for office work (productivity)?
- How much light is needed for healthful life?
Metrology for Non-visual effects of light

CIE Draft International Standard DIS 026: 2018
CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light

- Defines action spectra for ipRGC and other 4 photoreceptors, L,M,S-cones, and Rod.

- Defines quantities measured with these action spectra using SI units:

  - Examples of quantities:
    - Melanopic irradiance $E_{e,mel} = 65.7 \text{ mW/m}^2$
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CIE’s Work for Future Photometry

“CIE standard Illuminant for LED”

Photometric instruments

Current practice

Calibrated against:

Incandescent standard lamps

CIE I1uminant A

2856 K Planckian

CIE Source A

They measure:

LED products

Spectral mismatch errors

CIE’s Work for Future Photometry

“CIE standard Illuminant for LED”

Photometric instruments

Current practice

Calibrated against:

Incandescent standard lamps

CIE I1uminant A

2856 K Planckian

CIE Source A

They measure:

LED products

Spectral mismatch errors

CIE’s Work for Future Photometry

“CIE standard Illuminant for LED”

Photometric instruments

Current practice

Calibrated against:

Incandescent standard lamps

CIE I1uminant A

2856 K Planckian

CIE Source A

They measure:

LED products

Spectral mismatch errors
CIE’s Work for Future Photometry

“CIE Illuminant L”

Photometric instruments

Current practice

Calibrated against:

Incandescent standard lamps

CIE Illuminant A

2856 K Planckian

CIE Source A

They measure:

New Practice

LED products

Calibrated against:

Uncertainties reduced to ~ 1/4

“CIE Illuminant L”

“Source L”

CIE TC 2-90 LED Reference Spectrum for Photometer Calibration

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CIE’s Work for Future Photometry

Revision of
“Principles Governing Photometry” (BIPM, 1983), and
“Basis of Physical Photometry” (CIE 18.2-1983) (in approval stage)
developed by CIE-CCPR Joint TC (JTC-2)

Spectral Luminous Efficiency Function

\[ V_{\text{mes}}(\lambda) \] mesopic, based on CIE 191-2010

Very important for LED street/outdoor lighting applications.
Summary

- The revolution in lighting is on-going for huge energy savings globally. CIE supports SSL in metrology and scientific aspects.

- There are many other issues (flicker, glare, blue light hazard, connected lighting ..). Further new standards are needed for the evolving SSL.

- CIE has close cooperation with ISO, IEC, CCPR, IEA and many other organizations. We welcome new countries and other organizations to work together.
THANK YOU

Contact: ohno@nist.gov