ATP National Meeting, Photonics Manufacturing
San Jose, November 15-16, 1999

LED Photometric Standards

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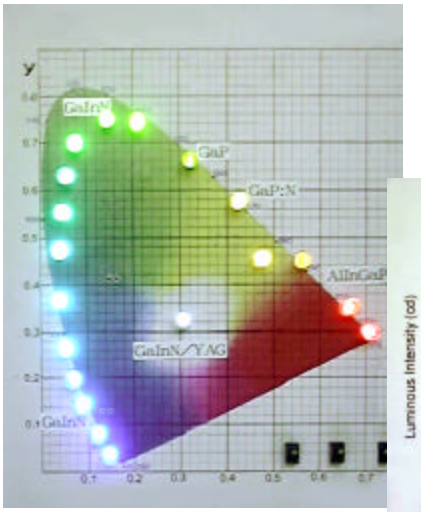
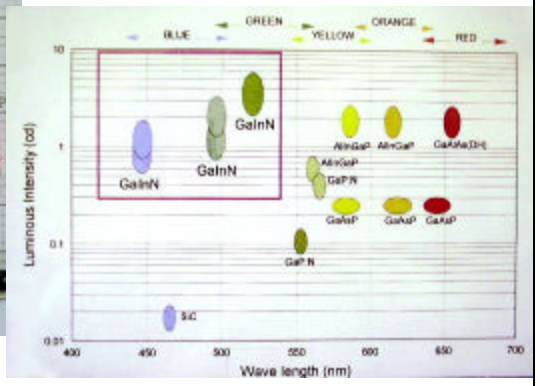
LEDs - State of the Art



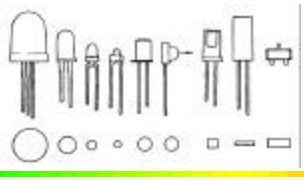


Products Display at CORM'99

Problems in Measurements

- Large discrepancies (as much as 50 %) of photometric measurements of LEDs (candela, lumen, watt) are currently reported among LED manufacturers and users.

- LEDs are unique light sources and are very different from traditional lamps in terms of physical size, flux level, spectrum, and spatial intensity distribution. Transfer of photometric scales from traditional luminous intensity standard lamps to varieties of LEDs is not a trivial task, and large uncertainties are currently involved.



Needs for Standards

To improve the accuracy of LED measurements, needs for varieties of standard LEDs and standardized measurement methods are addressed by CORM [1], CIE [2, 3], and other metrology communities.

However, standard LEDs are currently not available from NIST (and other national laboratories).

[1] CORM'99, Session II Measurement and Characterization of LEDs, Gaithersburg, May 4, 1999.
[2] CIE Workshop and Symposium on LED Measurements, Vienna, October 22-25, 1997.
[3] CIE Publication 127, Measurement of LEDs (1997)

Objectives of this Intramural Research

(FY99-FY01)

- Develop standard LEDs for luminous intensity (candela) and luminous flux (lumen) measurements, with a goal of the uncertainty of 2 % (k=2) for LEDs of all colors.
- Develop improved methods for luminous intensity, luminous flux, and color measurements of LEDs.
- Establish NIST standards and calibration services for the photometric and colorimetric quantities of LEDs.

"Luminous Intensity" Cannot be Measured

- Luminous intensity is a quantity for a point source.
- Many LEDs are not point sources. – Inverse square law does not hold well. The candela values vary depending on the measurement distance.

- CIE now recommends use of "Averaged LED Intensity" (CIE 127)

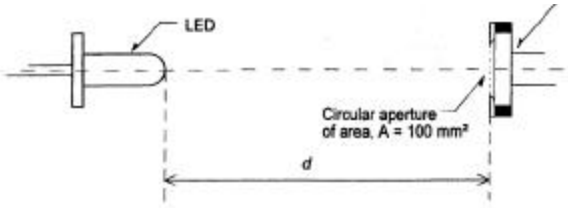
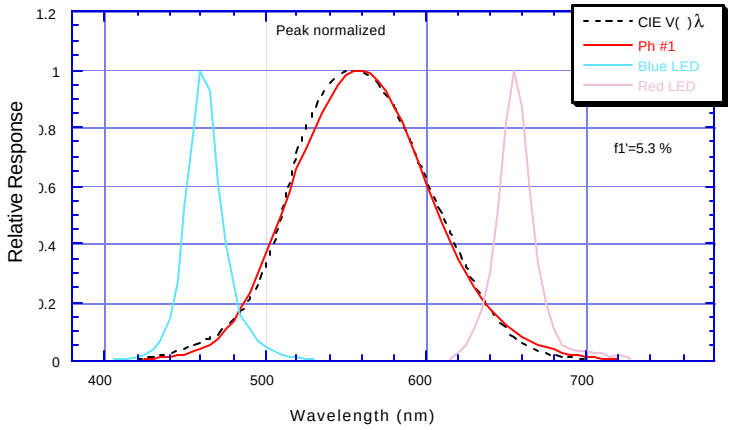


Fig. 5.3. Schematic diagram of CIE Standard Conditions for the measurement of Averaged LED Intensity. Distance d = 0,316 m for Condition A, d = 0,100 m for Condition B.

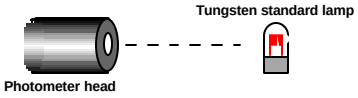
Spectral mismatch errors

Relative spectral response of a typical commercial photometer

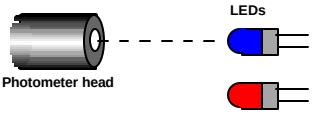


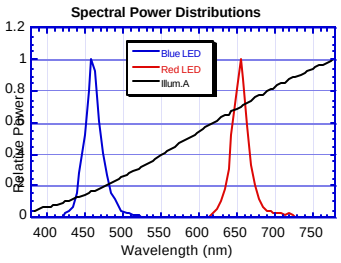
Spectral mismatch errors

If you calibrate the photometer:



When you measure:

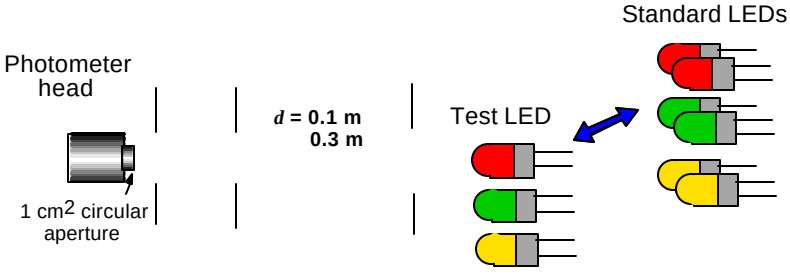




Error for the blue LED: - 20 %
Error for the red LED : +15 %

Luminous intensity measurement

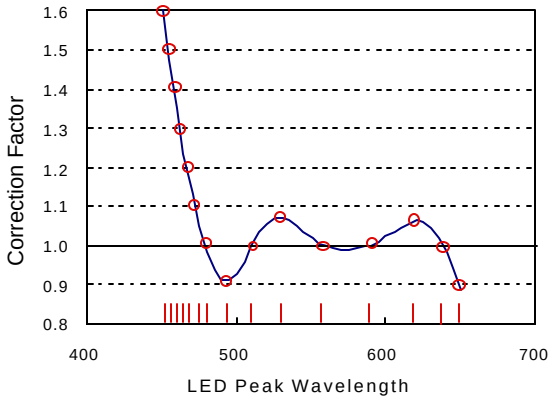
Subsitution Method (recommended by CIE)



LEDs of the same color are compared.
➡ No correction needed.

Spectral mismatch error function of the photometer for LEDs

(Gaussian model, 20 nm spectral width)

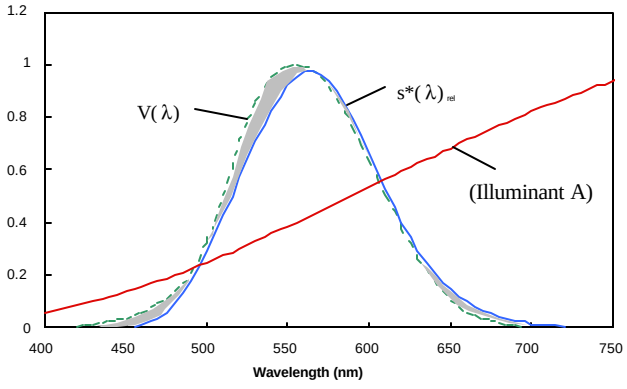


To keep the error within 5 %, 15 standard LEDs would be needed!

How to evaluate spectral mismatch of photometers – f_1'

$$f_1' = \frac{\int_0^\infty \left| s^*(\lambda)_{rel} - V(\lambda) \right| d\lambda}{\int_0^\infty V(\lambda)\, d\lambda} \quad \text{where} \quad s^*(\lambda)_{rel} = \frac{\int_0^\infty S(\lambda)_A\, V(\lambda)\, d\lambda}{\int_0^\infty S(\lambda)_A\, s(\lambda)_{rel}\, d\lambda}\, s(\lambda)_{rel}$$

(CIE 69)



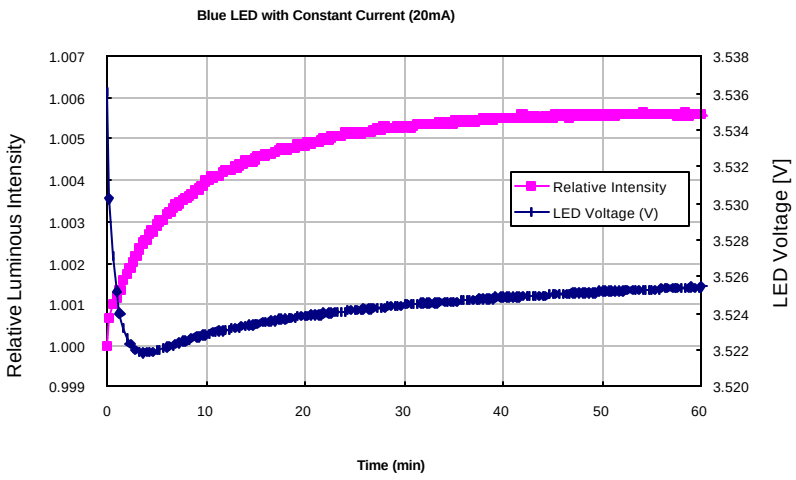
➡ **f_1' is not appropriate for LED measurements**

Work Plan
– Luminous Intensity Measurements–

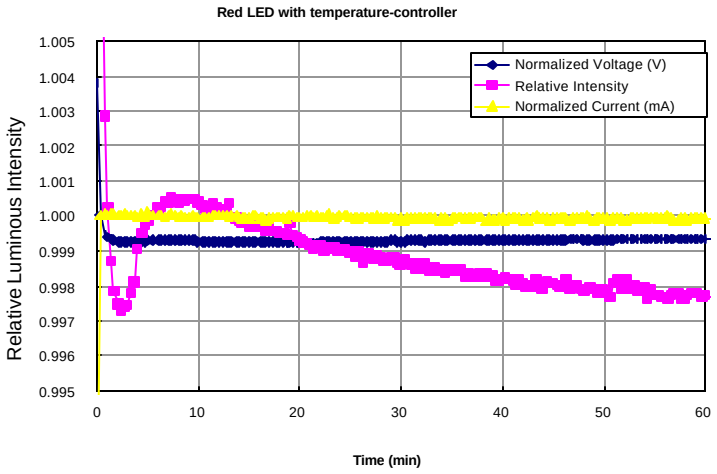
- Develop standard LEDs of various types (colors) and make them available from NIST (short-term solution).
- Investigate an alternative approach for measuring the intensities of LEDs (detector-based method.)
- Develop a better method for evaluating the V(λ) match of photometers for LED measurement.

Feasibility of Standard LEDs

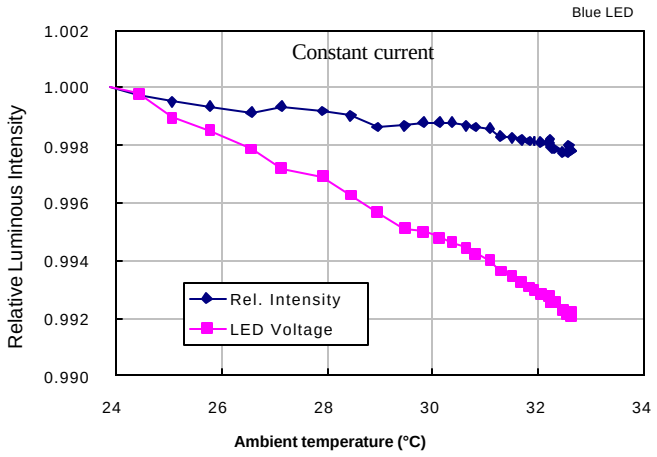
Stability



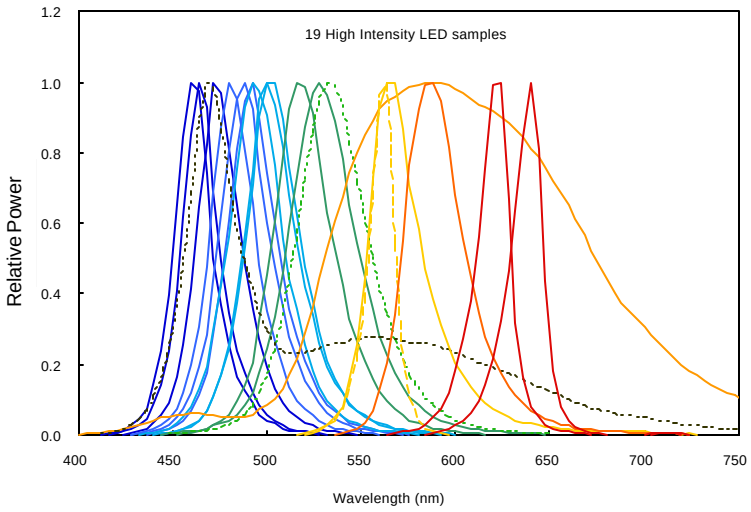
Stability of LEDs (2)



Temperature Dependence of LED Intensity



Spectral Distributions of LEDs

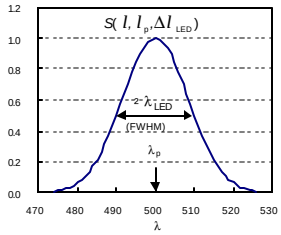


LED Model using Gaussian Function

$$S(\lambda, \lambda_p, \Delta\lambda_{LED}) = \exp\left[-2.7725\left(\frac{\lambda - \lambda_p}{\Delta\lambda_{LED}}\right)^2\right]$$

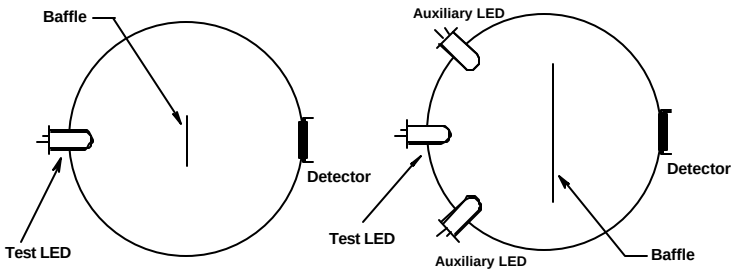
λ_p: peak wavelength

λ_{LED}: spectral width in FWHM

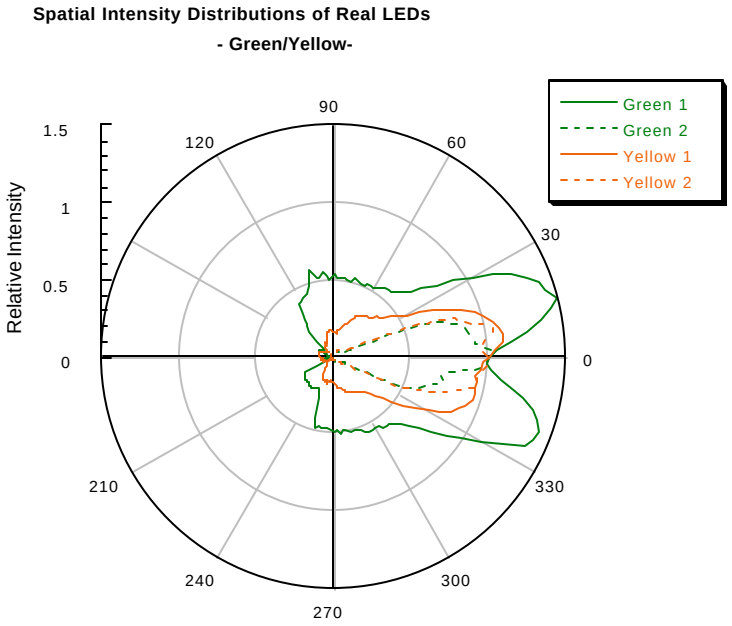


Luminous Flux measurements

Sphere Geometries recommended in CIE Pub.127
"LED Measurements"



Backward emission is excluded, but called "total Luminous flux". Side way emission is partially lost, causing large variations of results.



Work Plan
– Luminous Flux Measurements –

- Appropriate measurement quantities (forward flux (2π), total flux(4π), etc.) must be defined and standardized.
- Investigate the best integrating sphere geometries for LED luminous flux measurements.
- Build NIST facility for LED flux measurements.
- Develop standard LEDs for luminous flux and have NIST standards/calibration services available.

Color Measurement of LEDs

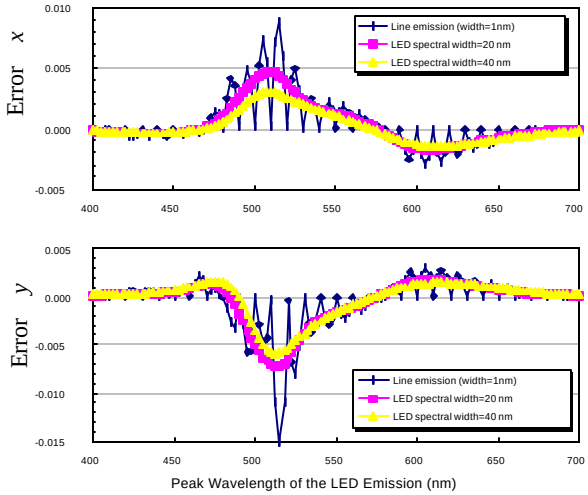
- Diode-array type spectroradiometers are widely used for color measurement of LEDs.
- Many of these instruments use bandwidth of 10 nm or 5 nm.
- Bandwidth of 1 nm or less is recommended for measurement of LED spectral distribution. (CIE 127)

➡ **A large gap between what is recommended and the reality.**

Simulation of a spectroradiometer

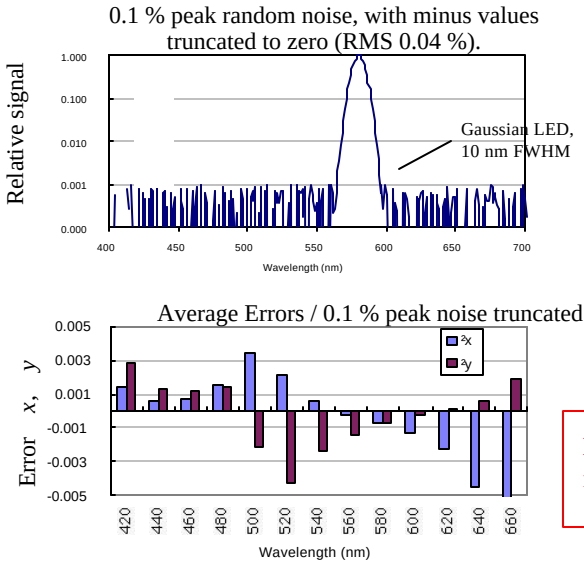
Chromaticity Errors Δx, Δy

Bandwidth = 10 nm, Scanning interval = 10 nm



Acceptable Bandwidth: ≤ 5 nm

Simulation of Truncated Random Noise



Do not truncate negative noise.

Work Plan
– Color Measurement of LEDs –

- Further investigate the uncertainties of commercial color measuring instruments for LEDs.
- Develop a NIST reference spectroradiometer system to measure the colors (chromaticity, dominant wavelength) of LEDs with the state-of-the-art accuracy.
- Establish NIST calibration services for standard LEDs for color.

Standardization Work

CIE (International Commission on Illumination)
Division 2 - Physical Measurement of Light and Radiation

TC2-45 Measurement of LEDs - Revision of CIE 127

TC2-46 CIE/ISO standards on LED intensity measurements

TC2-50 Measurement of the optical properties of LED clusters and arrays