Optical Testing of Solid State Lighting

Dr. Peter S. Weitzman

Senior Vice President

Labsphere, Inc.

Labsphere Company Information

- Founded in 1979
- A subsidiary of Halma p.l.c. since 2007
- Acquired SphereOptics in January 2010
- 105 employees
- 8,000 m^2 facility in New Hampshire, USA
- 350 m^2 facility in Shanghai, China
- ISO 9001:2000 Certified

World experts in optical radiation measurement applications

Chris Durell

Vikrant Mahajan

Angelo Arecchi

Jonathan Scheuch

Greg McKee

Nadine Cariou

Joe Jablonski

Raymond Yu

Leadership and membership in the major US and Global standard setting organizations

- IES
- CORM
- CIE

Industries Served

- Lighting/LED
- Aerospace
- Automotive
- Biomedical Optics
- Display
- Electronic Imaging
- Fiber Optics
- Laser/Laser Diode
- Medical imaging
- Optics
- Optoelectronics
- Remote Sensing
- Solar Cell Testing

Shanghai Lanfei Optical Co. Ltd. (Labsphere China)

- 350 m^2
- Coating service
- Make Spheres up to 3m
- Mechanical assembly
- Electronic assembly
- Light Measurement systems integration
- Calibration services
- Repair Services

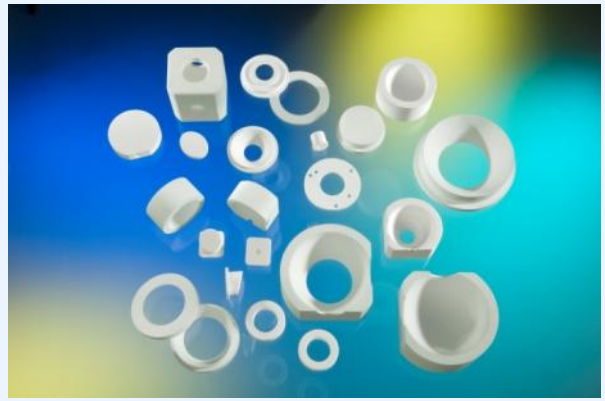
Reflectance Materials & Coatings

Labsphere makes the “whitest” white materials and coatings commercially available.

Our machineableSpectralon material reflects up to 99% of light in the UV through NIR range

Our spray-on coating Spectraflect reflects up to 98% of light

Ideal for backlighting and diffuse illumination applications



Diffuse Reflectance Applications

- Integrating Spheres
- Illumination Chambers
- Collection Chambers
- Reflectance Chambers
- Backlight Reflectors
- Laser Pump Chambers
- Reflectance Standards
- Reflectance Targets

Above: Spectraflect coated items for OEM customers

Below: Custom fabrication of Spectralon for a customer

Global Presence

ENERGY STAR Program Requirements for SSL Luminaires

Required standards for

• **Test method and measurement**	IESNA LM-79
• **Chromaticity specification**	ANSI C78.377
• **Test method for lifetime of LEDs.**	IESNA LM-80
• **Laboratory accreditation for measurement**	NVLAP EELP-SSL
• **Terminology**	ANSI/IESNA RP-16

IESNA LM-79 Approved Method for Electrical and Photometric Measurements of SSL Products

- Test method used for DOE SSL Energy Star
- Covers LED luminaires and integrated LED lamps.

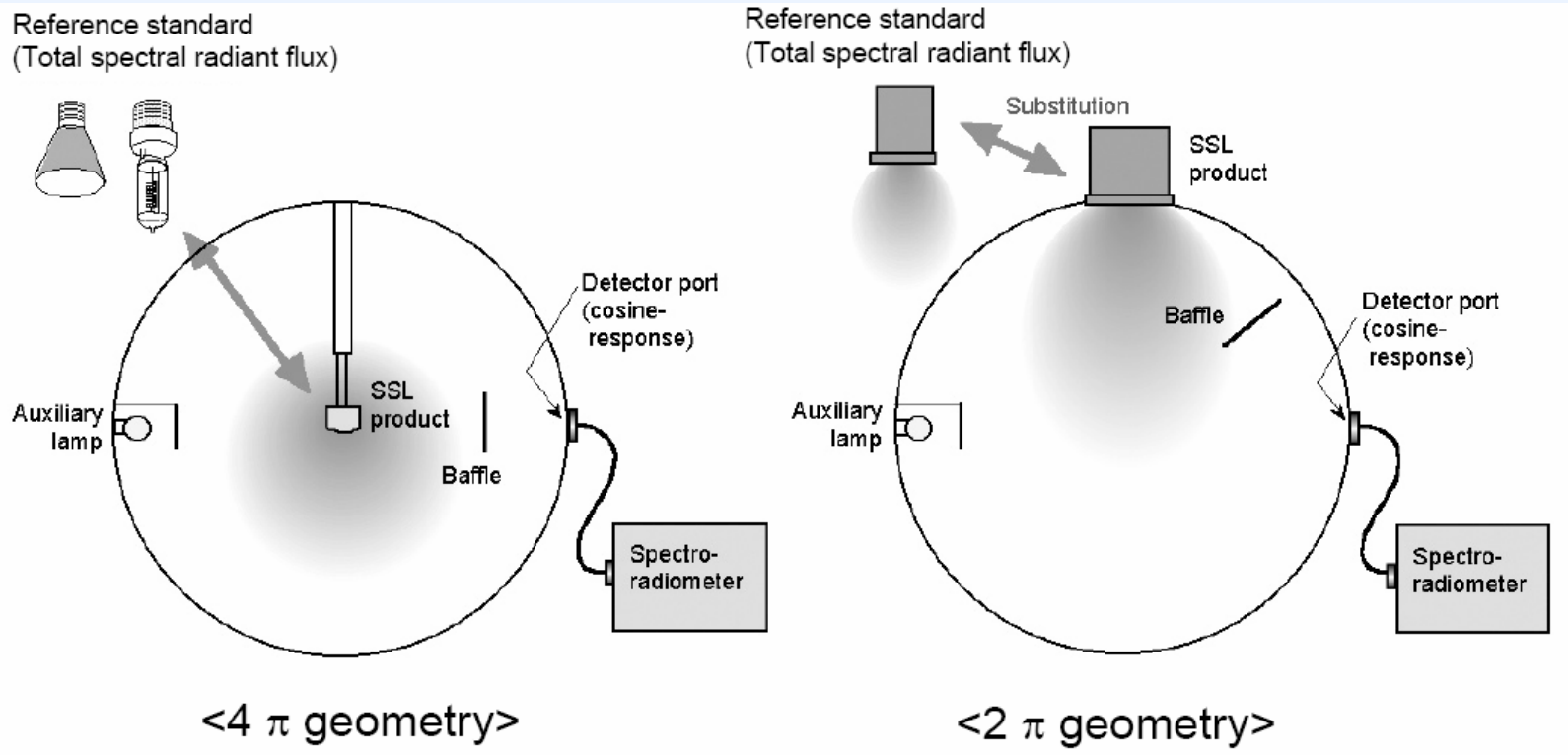
- Covers measurements of
  - Total luminous flux (lumen)
  - Luminous efficacy (lm/W)
  - Chromaticity, CCT, CRI (4 π integrated)
  - Luminous intensity distributions
- Methods using
  - Sphere-spectroradiometer
  - Sphere-photometer
  - Goniophotometer

Sphere and Goniometer

- Integrating Sphere to Measure Flux – total output

- Goniometer to measure angular distribution

Sphere –Spectrometer System



Sphere –Spectrometer System

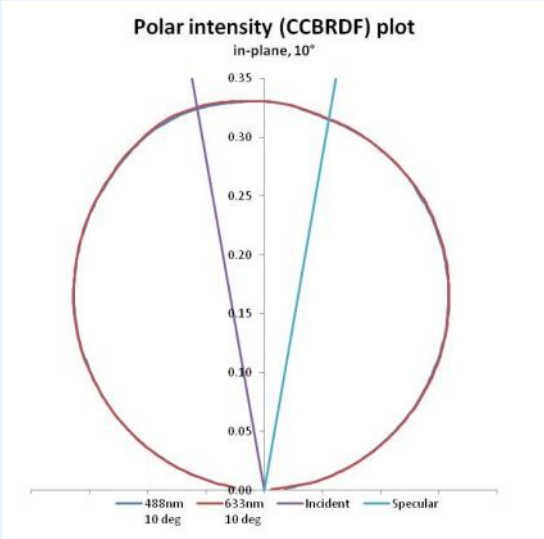
Size

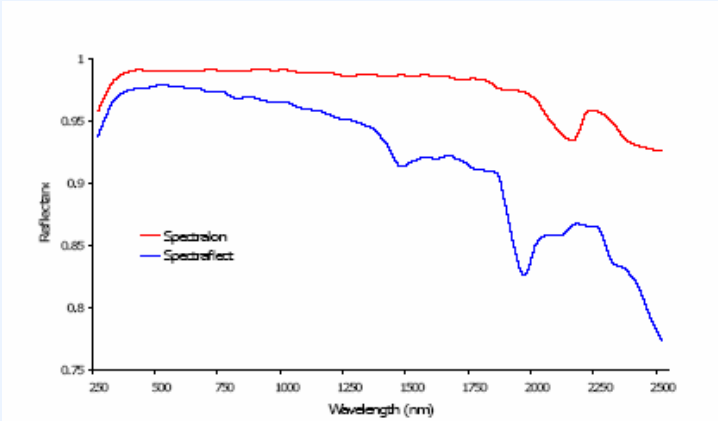
- 4pi
  - 1m or larger for compact lamps
  - 1.5m to 3m for larger lamps
  - Less than 2% of total area of sphere wall i.e. 30cm diameter for in a 2m sphere
  - 2/3 diameter for linear lamps
- 2pi: 1/3 diameter of sphere

Sphere –Spectrometer System

Interior Coating

- Highly diffuse
- 90 to 98%
- Higher reflectance:
  - Higher signal
  - Smaller spatial uniformity errors
  - Less sensitivity to source intensity distribution variations
  - Compensates for decrease of average reflectance





Sphere –Spectrometer System

Spectrometers

- Shall have a minimum spectral range of 380 to 780nm
- The detector port shall be a flat diffuser or satellite sphere near cosine receiver

Spectrometers

Cost ranges from $5,000 to $30,000 – what is the difference

Spectrometer	Photopic range in 10" sphere (lumens)	Int time needed to measure 50 lm lamp in 10"sphere (ms)	Int time range (sec)	Stray light	% noise on 100% line
CDS 610	0.124 - 2470	49	0.001 - 5	1.66%	0.20%
CDS 2100	0.003 - 1424	228	0.008 - 900	1.87%	0.05%
CDS-3020	0.010 - 15901	16	0.010 - 20	0.97%	0.18%

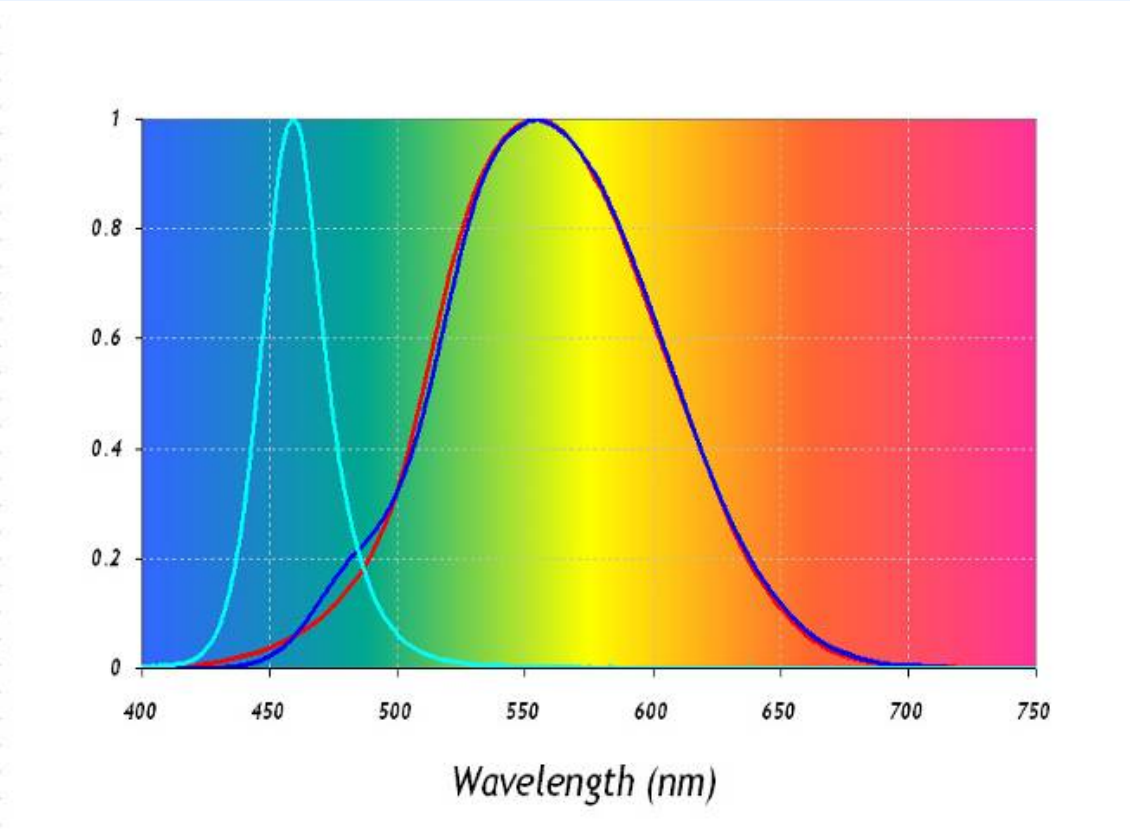
- 1. Low range defines as 20% of saturation at the longest usable integration time.
- 2. High range is defined as 80% saturation at the shortest integration time.
- 3. Stray light is defined as the average reported transmission from 360-470nm for a 500nm cut on filter illuminated by a 3000K QTH.
- 4. Noise is the %standard deviation on a 100% line when measuring a QTH lamp

Wavelength Accuracy Results

Wavelength Accuracy			
λ (nm)	cds-610	cds-2100	cds-3020
365.21	-0.13	-0.04	-0.12
404.86	-0.38	0.02	-0.2
435.84	-0.26	0.03	0.01
491.60	-0.08	0.33	0.14
546.07	0.02	0.3	-0.06
585.45	0.01	0.05	0.06
659.90	0.23	0.17	0.08
724.69	0.05	-0.08	-0.31
811.21	0.41	0.23	-0.27
912.30	0.25	0.25	-0.09

Not much difference between different classes of spectrometers

Why use spectrometers?



- Filter based photometers usually have small errors relative to the V(l) curve, particularly in the blue region of the spectrum
- Spectral information is required to study the phosphor/emitter inter-reactions in white LEDs
- Characterization of monochromatic LEDs needs to be done spectrally

Sphere –Spectrometer System

Lamp Standards

$$L_T = \frac{S_T}{S_R} L_R = \frac{S_T}{S_R} L_{R0} \left(\frac{V_R}{r_R J_{R0}} \right)^{M_I} (1 - \alpha \cdot \Delta t)$$

NVLAP Lab Code 200951-0

NO. DM-02010-
REV

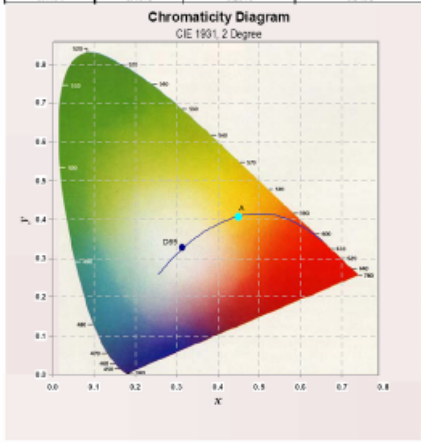
FFS-100-400/1000 CALIBRATION CERTIFICATE

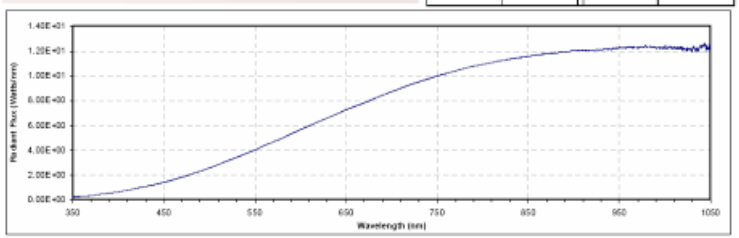
DATE OF REPORT 9/18/2009
PAGE 2 OF 2

Table II Spectral Flux Calibration Report

Radiant Flux (mW)	Luminous Flux (lumens)	Correlated Color Temp. (deg. K)	Color Rendering Index Avg. (RA)
5.780	321	2839	99
Chromaticity coord x	Chromaticity coord y	Chromaticity coord u	Chromaticity coord v
0.4494	0.4078	0.2370	0.3498

wavelength (nm)	Spectral Flux (mW/nm)	wavelength (nm)	Spectral Flux (mW/nm)
350	2.36E-01	710	9.00E+00
360	2.39E-01	720	9.28E+00
370	3.43E-01	730	9.52E+00
380	4.51E-01	740	9.70E+00
390	5.38E-01	750	1.00E+01
400	6.39E-01	760	1.02E+01
410	7.78E-01	770	1.04E+01
420	9.22E-01	780	1.06E+01
430	1.07E+00	790	1.08E+01
440	1.22E+00	800	1.09E+01
450	1.42E+00	810	1.11E+01
460	1.61E+00	820	1.12E+01
470	1.83E+00	830	1.14E+01
480	2.07E+00	840	1.15E+01
490	2.32E+00	850	1.16E+01
500	2.57E+00	860	1.17E+01
510	2.85E+00	870	1.18E+01
520	3.14E+00	880	1.19E+01
530	3.43E+00	890	1.19E+01
540	3.73E+00	900	1.20E+01
550	4.03E+00	910	1.21E+01
560	4.38E+00	920	1.21E+01
570	4.67E+00	930	1.21E+01
580	4.96E+00	940	1.21E+01
590	5.34E+00	950	1.21E+01
600	5.68E+00	960	1.21E+01
610	5.96E+00	970	1.22E+01
620	6.32E+00	980	1.24E+01
630	6.63E+00	990	1.22E+01
640	6.93E+00	1000	1.24E+01
650	7.20E+00	1010	1.24E+01
660	7.50E+00	1020	1.23E+01
670	7.82E+00	1030	1.22E+01
680	8.14E+00	1040	1.24E+01
690	8.45E+00	1050	1.24E+01
700	8.75E+00		

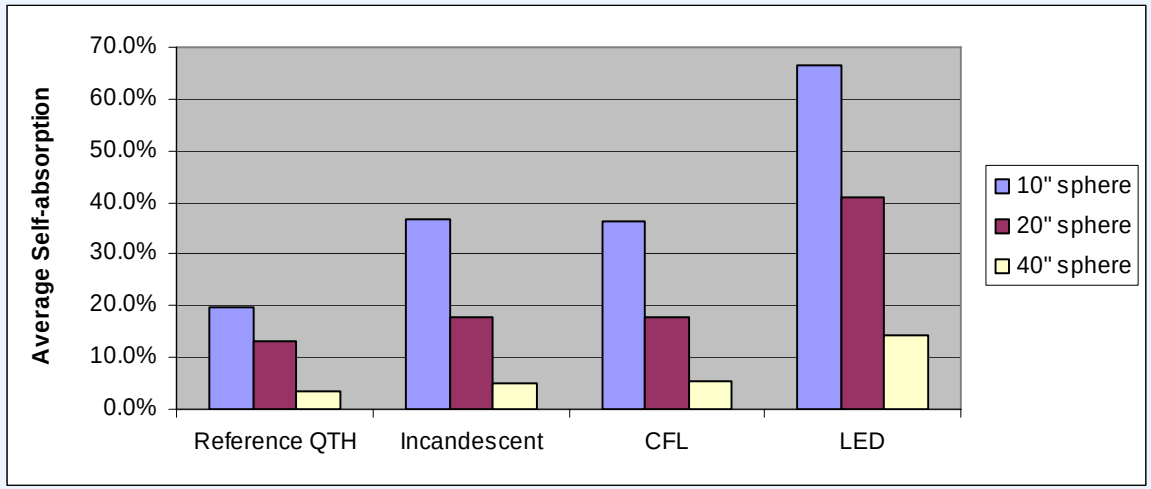




Sphere –Spectrometer System

Self Absorption Correction

- Tungsten contiguous broad bands
- Stable



The LED lamp in 10”, 20”, and 40” sphere

Sphere –Spectrometer System

Principle Measurement and Self absorption correction

$$\phi_{test}(\lambda) = \phi_{ref} \frac{y_{test}(\lambda)}{y_{ref}(\lambda)} \frac{1}{\alpha(\lambda)}$$

$$\alpha(\lambda) = \frac{y_{aux,test}(\lambda)}{y_{aux,ref}(\lambda)}$$

Sphere –Spectrometer System

Luminous Efficacy

$$\eta_v = \frac{\phi_{test}}{P_{test}} \left[\qquad \right]$$

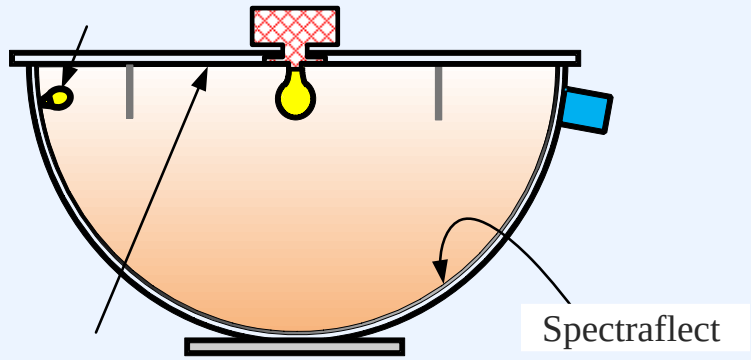
Stabilization

- Operate long enough to reach stabilization and thermal equilibrium (typically 30 minutes to 2 hrs)
- Recommendation
  - 3 readings of light output and power
  - 30 minutes
  - Every 15 minutes
  - Less than 0.5%

Ambient Conditions

- Air temperature: 25C +/- 1C
- Air flow: kept to a minimum

HalfMoon Spectrometer Systems



HalfMoon
labsphere Photal OTSUKA ELECTRONICS

Advantages of HalfMoon over Full Sphere

- More accurate for 2pi measurements
  - Reduced absorption correction for electronics
- Smaller footprint, easier to do top-down measurements
- More sensitive, ~2X signal to spectrometer for same light source

Comparison – Integrating Sphere vs HalfMoon

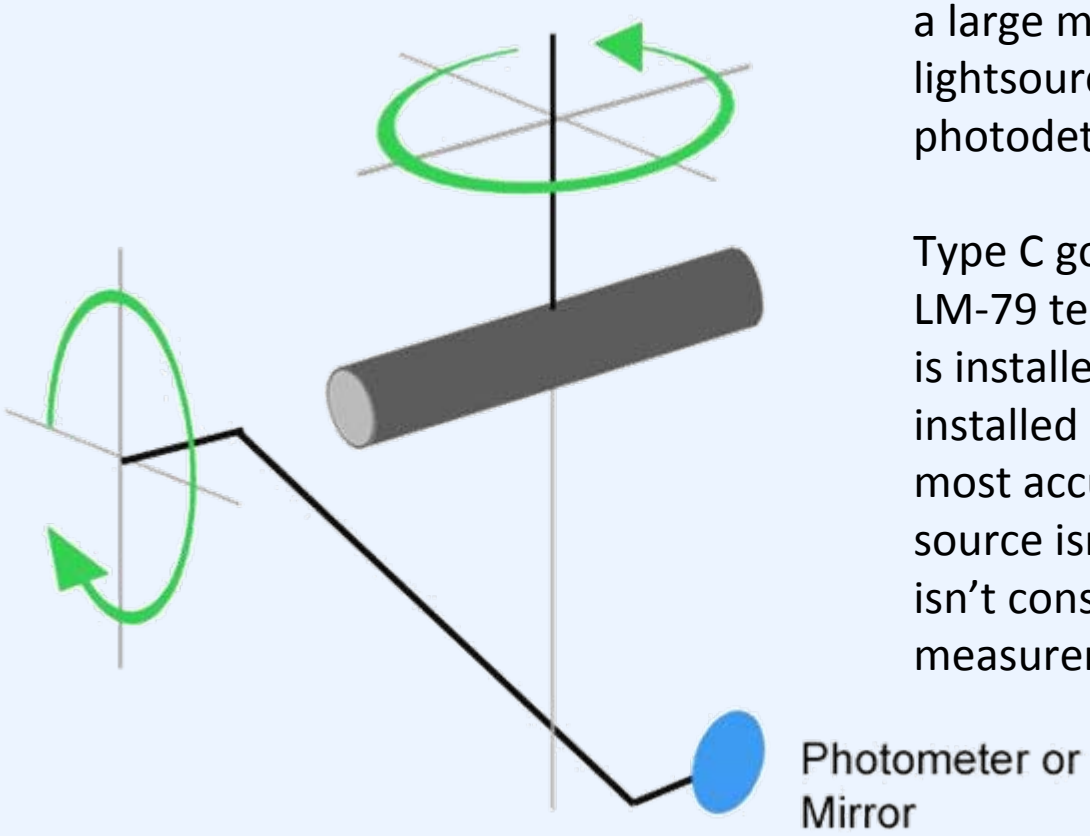
Sample		Exp	Φ	Φv	Chromaticity coordinates		CCT			
		sec	mW	lm	x	y	K	Ra	Dom W	Lamp Type
Krypton Lamp	IS	0.3	283	44.1	0.4500	0.4080	2825	100	-	Clear lamp
	IH	0.2	284	44.3	0.4500	0.4080	2823	100	-	
White LED	IS	8.0	5.46	1.58	0.3170	0.3140	6359	85	-	5mm Clear
	IH	5.0	5.52	1.59	0.3160	0.3120	6475	85	-	
White LED	IS	6.0	7.14	1.99	0.3060	0.3090	7167	85	-	5mm Diffuse
	IH	4.0	7.15	1.99	0.3050	0.3080	7217	85	-	
Blue LED	IS	1.8	0.24	0.152	-	-	-	-	475.5	5mm Clear
	IH	1.9	0.25	0.151	-	-	-	-	475.4	
Green LED	IS	5.8	2.72	0.162	-	-	-	-	524.6	5mm Clear
	IH	5.9	2.76	0.161	-	-	-	-	524.5	
Red LED	IS	2.9	0.54	0.698	-	-	-	-	623.7	5mm Clear
	IH	2.9	0.53	0.698	-	-	-	-	623.8	
Before correction	IS	1.1	39.5	11.5	0.3150	0.3150	6490	84	-	Diffuse Backlight
	IH	0.6	41.2	12.0	0.3130	0.3130	6628	84	-	
After correction	IS	1.1	42.1	12.2	0.3140	0.3140	6560	84	-	
	IH	0.6	41.7	12.1	0.3130	0.3120	6641	84	-	

GONIOMETRIC MEASUREMENTS

"Goniophotometers shall be the type that maintains the burning position unchanged with respect to gravity; therefore, only Type C Goniophotometers are allowable."

- Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products, IES LM-79-08

Type C Goni



In the swinging mirror configuration, the lightsource is fixed in its intended position, and a large mirror on an arm is rotated around the lightsource, reflecting the output to a photodetector.

Type C goniophotometers are required for LM-79 testing, because the lightsource is installed in the same way it will be installed in the field. This provides the most accurate readings, as the light source isn't tilted, and thus the heat profile isn't constantly changing throughout the measurement cycle.

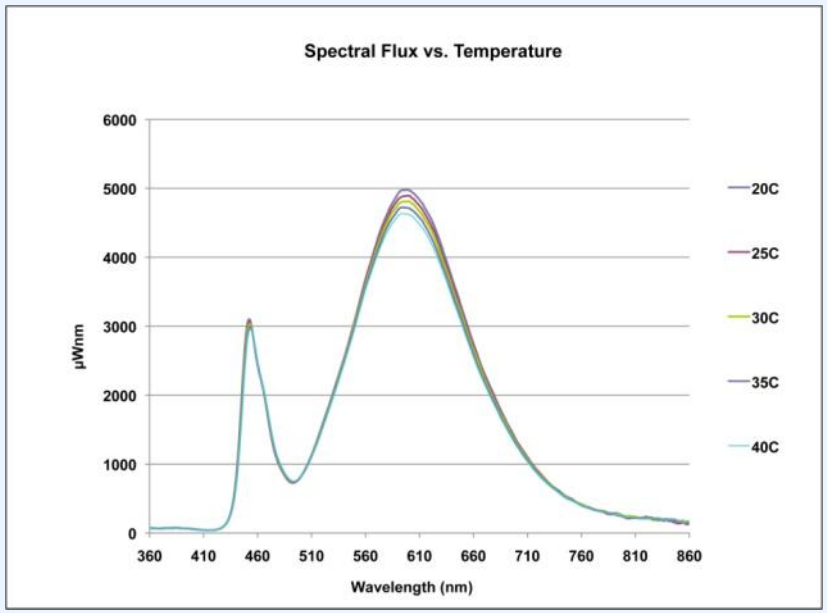
Definition according to IES LM-75-01

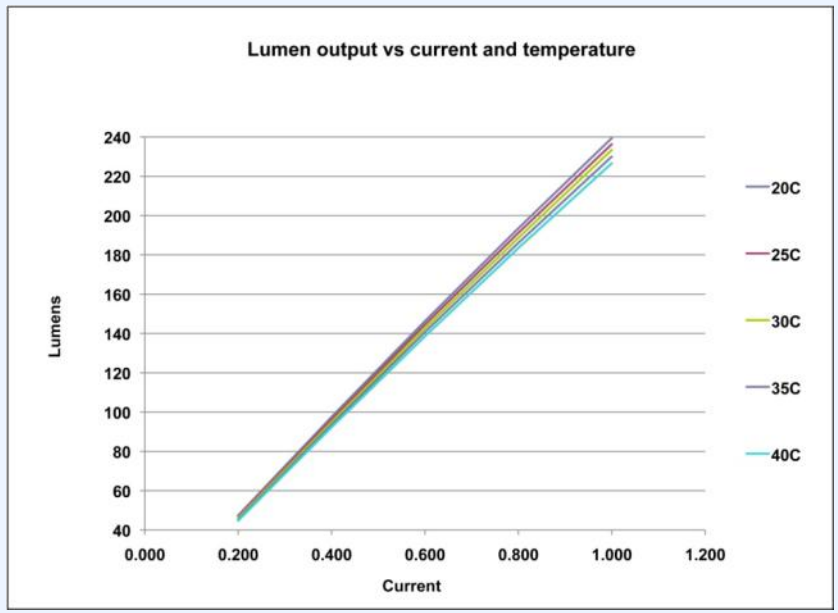
UL Lighting Science - Type C Goni

Thermal LED Considerations

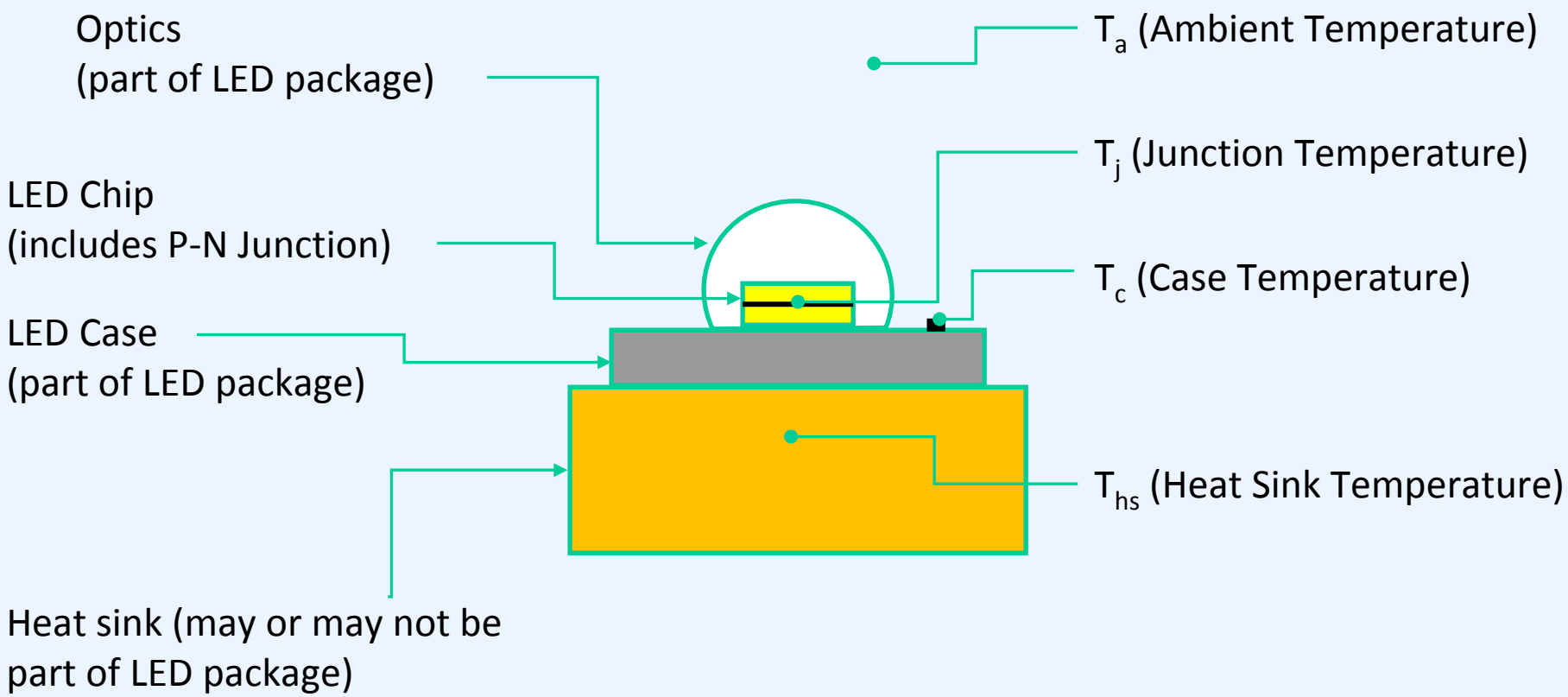
LED FLUX = f(I, Tj)

- LED (**L**ight **E**mitting **D**iode) is a semiconductor device that emits light when electric current passes through it.
- Flux emitted by LED is dependent on the drive current and is <u>also</u> dependent on LED junction temperature.

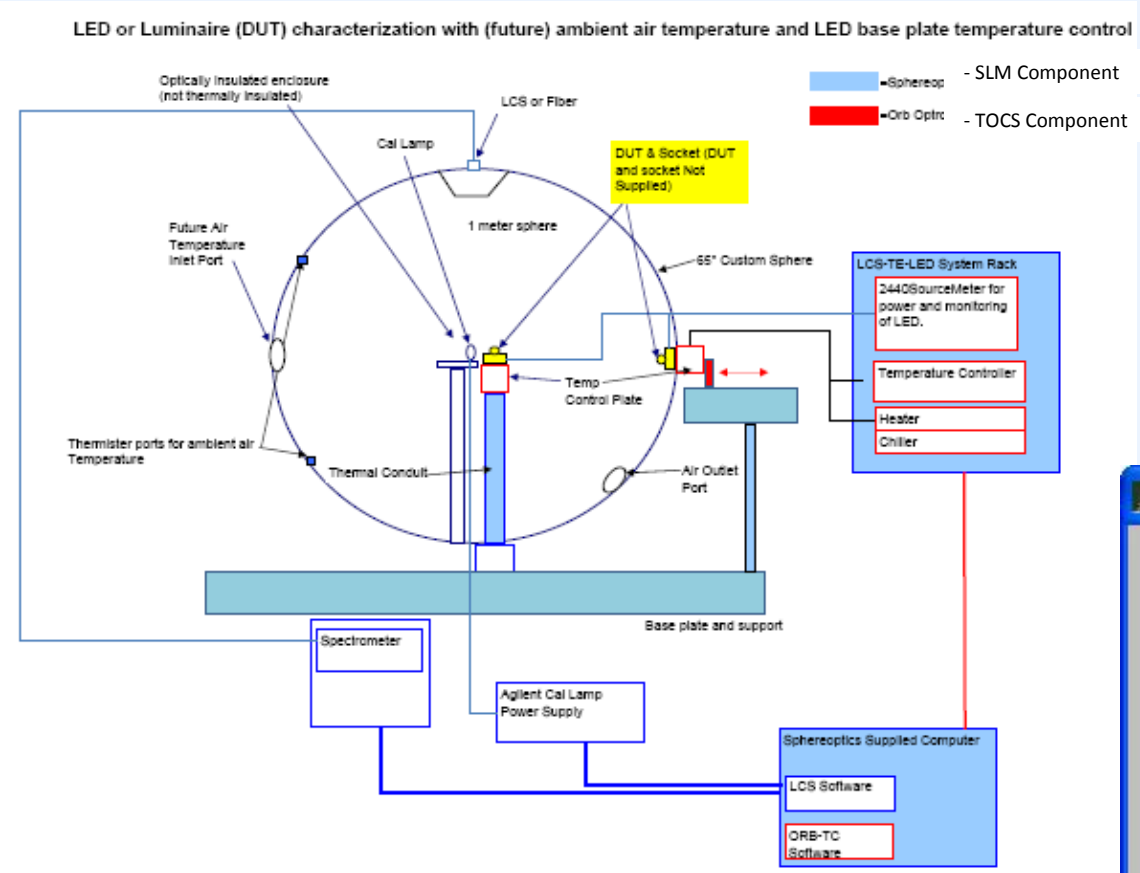




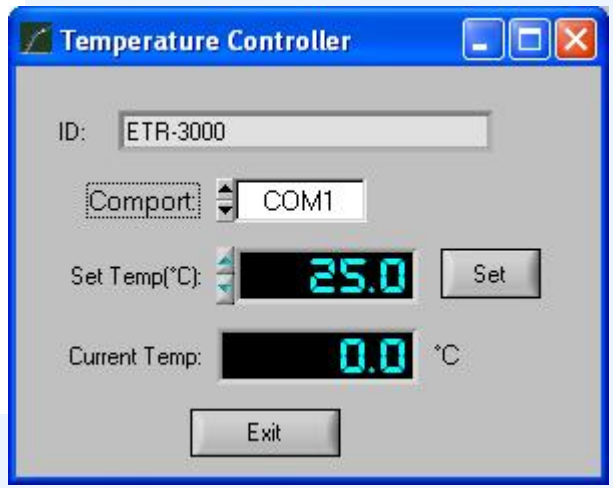
LED Temperature Terms



Thermal – Optical – Electical



- **Complete System** can be formed around a sphere or goniometer
- Ambient Air Temperature Control also Possible



Labsphere TOCS LED Characterization System

Lifetime Testing (LM-80)

- LUMEN MAINTENANCE LIFE
  - Elapsed operating time over which the LED light source will maintain the percentage of its initial light output:

    L_{70}(hours) = time to 70% of lumen maintenance
- TEST GUIDELINES
  - Test minimum of 6000hrs (minimum increment of every 1000hrs).
  - Test conducted at ambient temp (25C +/-2C)
  - Burn devices at minimum 3 case temperatures (T_s): 55C, 85C and third temp selected by manufacturer
    - Hold T_s to +/-2C of during life testing
    - Hold near DUT ambient air to +/-5C of T_s during life testing
  - Testing in <65% RH
  - Thermocouple needs to be <+/-1.1C or +/-0.4% (whichever if greater)accurate for Case Temperature during test.

Refer to IESNA LM-80 for detailed test methodology.

IES LM-79 revision

- Upcoming major revision to the most important testing standard for Solid State Lighting

- LM-79describes the procedures to be followed and precautions to be observed in performing reproducible measurements of total luminous flux, electrical power, luminous intensity distribution, and chromaticity of solid-state lighting (SSL) products for illumination purposes, under standard conditions. This approved method covers LED-based SSL products with control electronics and heat sinks incorporated, that is, those devices that require only AC mains power or a DC voltage power supply to operate. This approved method covers LED luminaires, LED light engines, and integrated LED lamps.
- LM-79 does not cover SSL products that require external operating circuits or external heat sinks (e.g., LED chips, LED packages, and LED modules). This document covers SSL products in a form of luminaires (fixtures Incorporating light sources) as well as integrated LED lamps. This document does not cover fixtures designed for SSL products sold without a light source. This document describes test methods for individual SSL products, and does not cover the determination of the performance rating of products, in which individual variations among the products should be considered.

LM-79 revision cont.

- Air Movement
  - The incidence of air movements on the surface of a SSL product under test may substantially alter electrical and photometric values. Air flow around the SSL product being tested should be such that normal convective air flow induced by device under test is not affected.
- Power Supply Characteristics
  - Waveshape of AC power supply
    - The AC power supply, while operating the SSL product, shall have a sinusoidal voltage waveshape at the prescribed frequency (typically 60 Hz or 50 Hz) such that the RMS summation of the harmonic components does not exceed 3 percent of the fundamental during operation of the test item. When applying AC power, the AC power supply shall be set to initiate power at zero degree phase. Some driver circuits can have a large in-rush current if power is applied at 90 degree phase.
  - Voltage Regulation
    - The voltage of an AC power supply (RMS voltage) or DC power supply (instantaneous voltage) applied to the device under test shall be regulated to, within ±0.2 percent under load.

LM-79 revision cont.

- Operating Orientation
  - The SSL product under test shall be evaluated in the operating orientation recommended by the manufacturer for an intended use of the SSL product. Stabilization and photometric measurements of SSL products shall be done in such operating orientation. The orientation of the SSL product as mounted for measurement shall be reported with the results. This statement is related to 9.3.1 Type of Goniometer.
- Uncertainties
  - The calibration uncertainties of the instruments for AC voltage and current shall be ≤ 0.2 percent. The calibration uncertainty of the AC power meter shall be ≤ 0.5 percent and that for DC voltage and current shall be ≤ 0.1 percent.

LM-79 revision cont.

- Test Methods for Total Luminous Flux Measurement
  - Integrating sphere concerns lamps with feedback – smaller sphere and reflectance of sphere can affect the operation of the lamp. In addition, the auxiliary lamp cannot be left on during the measurement and subtracted from the results lamps with remote phosphor – smaller sphere the auxiliary lamp can cause an issue with the self-absorption measurement. In addition, blue light intended to be used in the general illumination can be reabsorbed and emitted at a different Wavelength.
  - Allow the Halfmoon configuration and other alternate methods.

IES activities around Standards for OLEDs

- A Survey was taken among 11 companies to determine the interested and needs of OLED testing
- Results:
- Are OLED needs covered by existing standards?
  - Unanimous 'No'
- Is there consensus if OLEDs should be tested like luminaire or LED?
  - No consensus
  - Some responded no temp effects, others responded significant temp effects
- Do OLED Display standards cover OLED Lighting Need?
  - No
  - Different Metrics/Objectives
- Conclusions
  - Testing standards are needed
  - IEC is working on some standards, expected in 2-3 years, scope not covering all needs o CIE is working on some standards, with pre-work completed by OLED100.eu project
  - Emerging technology results in different technical assessments as to the challenge/approach to the measurement needs
  - Difficult getting responses and broad participation
- A Working group will be formed

Summary

- There is a great deal of complexity around the measurement of the performance of solid state lighting devices
- International teams are working hard to standardize the testing methodologies so that good products are delivered to global markets