JEDEC STANDARD

Guidelines for Combining CIE 127-2007 Total Flux Measurements with Thermal Measurements of LEDs with Exposed Cooling Surface

JESD51-52

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JEDEC SOLID STATE TECHNOLOGY ASSOCIATION

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GUIDELINES FOR COMBINING CIE 127-2007 TOTAL FLUX MEASUREMENTS WITH THERMAL MEASUREMENTS OF LEDS WITH EXPOSED COOLING SURFACE

CONTENTS

GUIDELINES FOR COMBINING CIE 127-2007 TOTAL FLUX MEASUREMENTS WITH THERMAL MEASUREMENTS OF LEDS WITH EXPOSED COOLING SURFACE

Foreword

This document has been prepared by the JEDEC JC-15 Committee on Thermal Characterization. It provides guidelines on the implementation of the light output measurement of power LEDs when used in combination with thermal characterization.

Introduction

This document is intended to be used in conjunction with the JESD51-50 series of standards, especially with JESD51-51 (*Implementation of the Electrical Test Method for the Measurement of Real Thermal Resistance and Impedance of Light-emitting Diodes with Exposed Cooling Surface*) document. This present document focuses on the measurement of the *total radiant flux* of LEDs in combination with the measurement of LEDs's thermal characteristics: guidelines on the implementation of the recommendations of the CIE 127-2007 document are provided.

Terms and definitions of the JESD51-53 (*Terms, Definitions and Units Glossary for LED Thermal Testing*) document are used here in a way consistent with the relevant definitions of CIE – the *International Committee of Illumination,* given in CIE S 017/E:2011 ILV, CIE 127:2007, CIE 84:1989, and other standards used in the solid-state lighting industry, e.g., ANSI/IESNA RP-16-10.

The reason why these guidelines are provided is that the physics determining LEDs's light output characteristics is rather complex, which requires special care both in thermal characterization and during light output measurements. The need for measurement guidelines for LEDs has arisen when light-emitting diodes with high power and high energy conversion efficiency emerged.

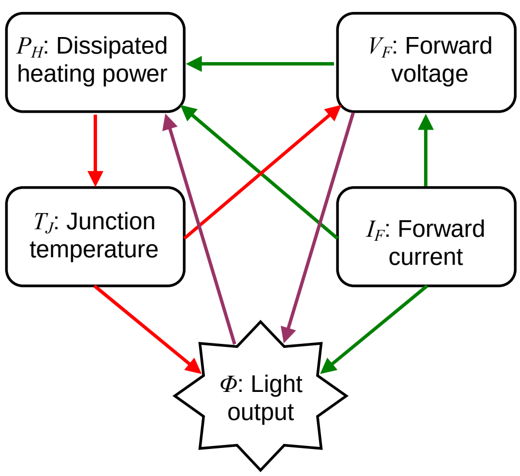


Figure 1 — The mutual dependence of LEDs's light output and different (macroscopic) quantities characteristic to LEDs's operating conditions

Introduction (cont'd)

This complexity in the physics – as illustrated in Figure 1– becomes manifest in the following:

- Light output of LEDs is primarily determined by the recombination processes taking place in the pn-junction. The higher the ratio of the radiative recombination with respect to the non-radiative recombination, the more photons are generated, hence the electrical energy to light conversion efficiency of the LEDs is higher.
- This ratio is determined by the operating conditions of the LED: the junction temperature and the applied forward current. This efficiency is not a single number because it depends both on the LED's junction temperature and forward current (as shown in Figure 2).
- The power dissipated at the active region of an LED is thus determined by the difference between the supplied total electrical energy ($V_F \cdot I_F$) and the total energy emitted as optical radiation (Φ_e – emitted total radiant flux, also denoted as P_{opt}):

$$P_H = V_F \cdot I_F - \Phi_e \quad (1)$$

  This power together with the thermal resistance of the LED determines the junction temperature.

- For the end-users of the LEDs, the manifestation of this complex and temperature dependent physics of LEDs's operation is the change of the properties of the emitted light: drop in the emitted luminous flux, shift of peak wavelength of the spectrum, and the change of the spectral power distribution of the emitted light (such as shown in Figure 3) resulting also in the chnage of other characteristics of the emitted light.

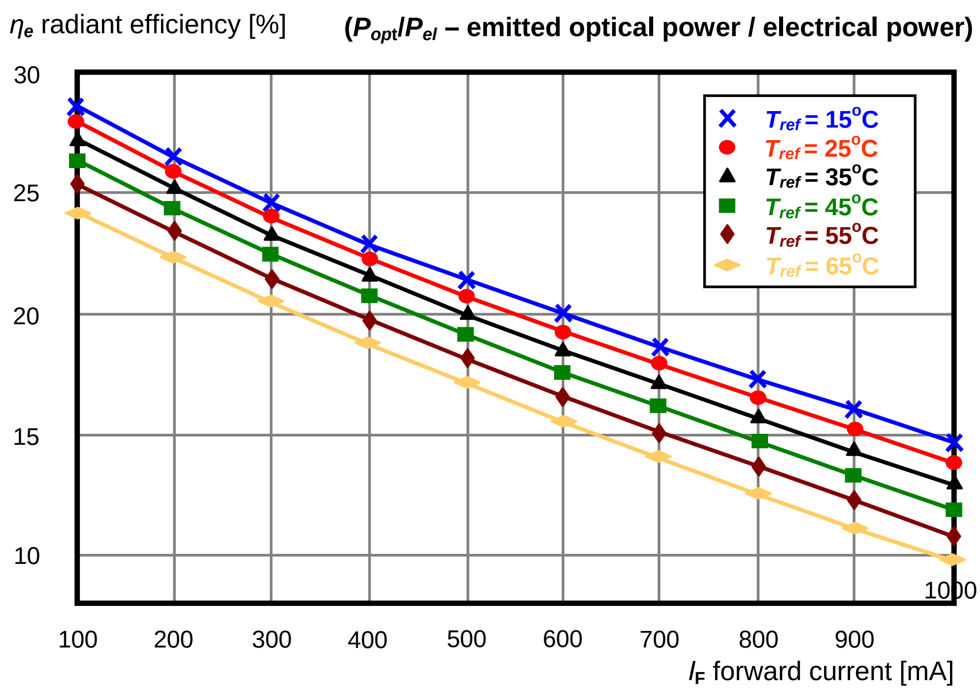


Figure 2 — Temperature and forward current dependence of the energy conversion efficiency (also known as radiant efficiency) of a power LED

Introduction (cont'd)

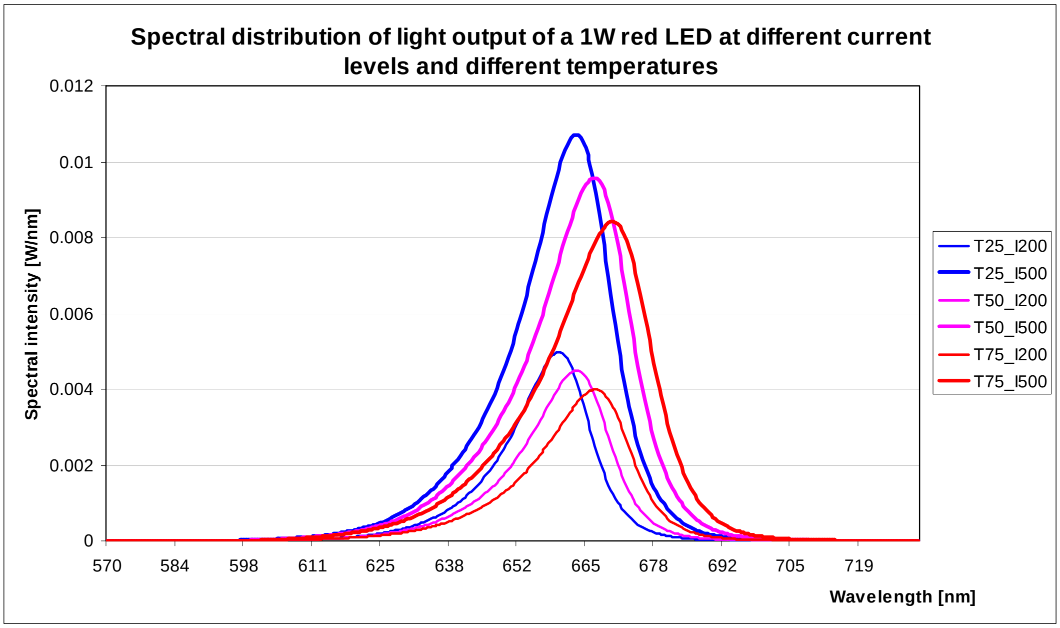


Figure 3 — Temperature dependence of spectral distribution of the light output a red LED at different current levels

GUIDELINES FOR COMBINING CIE 127-2007 TOTAL FLUX MEASUREMENTS WITH THERMAL MEASUREMENTS OF LEDS WITH EXPOSED COOLING SURFACE

(From JEDEC Board Ballot JCB-12-09, formulated under the cognizance of the JC-15 Committee on Thermal Characterization.)

1 Scope

These guidelines specify testing procedures and conditions for power light-emitting diodes (power LEDs) and/or high brightness light-emitting diodes (HB LEDs) – in the following referred to as LEDs – which are typically used in the operating regime of the forward current of 100mA and above, and emit visible light[1)]. The application of these guidelines is recommended for packaged LEDs

1. with a total electrical power consumption above 0.5 W,
2. which have energy conversion efficiency above 5%,
3. that are measured and considered as a *single light source*.

This document is restricted to LEDs which have an exposed cooling surface. Guidelines provided here refer to *laboratory measurements*. Issues of high speed bulk measurements of LEDs (such as in-line testing aimed for, e.g., binning) are dealt with by other standardization bodies such as the relevant technical committees of CIE. Recommendations given in this document are valid for *LEDs powered by DC forward current* only. Measurement issues of AC power driven LEDs will be dealt with in future documents.

2 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this guideline. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

JESD51-50, *Overview of Methodologies for the Thermal Measurement of Single- and Multi-Chip, Single- and Multi-PN-Junction Light-Emitting Diodes (LEDs).*

JESD51-51, *Implementation of the Electrical Test Method for the Measurement of Real Thermal Resistance and Impedance of Light-emitting Diodes with Exposed Cooling Surface.*

JESD51-53, *Terms, Definitions and Units Glossary for LED Thermal Testing.*

CIE S 017/E:2011 ILV, *International Lighting Vocabulary.*

[1)] Strictly speaking, the term LED should only be applied to those diodes which emit visible light. Those, which emit infra red or UV radiation, should be referred to as IR LEDs or UV LEDs and are not dealt with in this document.

2 Normative references (cont'd)

CIE 127:2007, Technical Report, *Measurement of LEDs*, ISBN 978 3 901 906 58 9.

CIE 84:1989, Technical Report, *The measurement of luminous flux,* ISBN 978 3 900734 21 3.

ANSI/IESNA IES Nomenclature Committee, IES RP-16-10, *Nomenclature and Definitions of for Illuminating Engineering*, ISBN 978-0-87995-208-2

3 Terms, definitions, and notations

In this document the notations used in JESD51-50, which is the overview document for the JESD51-51 through JESD51-53 series of standards, and in JESD51-51 are applied. Generic terms and quantities related to light output measurement are used as defined in the *International Lighting Vocabulary*, CIE S 017/E:2011; LED specific terms of photometry and radiometry given in CIE 127:2007 are also used. The most important terms and notations referred to in the series of LED thermal testing documents are listed in Table 1. For terms and definitions not listed below refer to JESD51-53.

Table 1 — Symbols used in this document

Symbol	Unit of measure	Name, description
T_J	[^{o}C]	**junction temperature** of the LED as defined in JESD51-50 and JESD51-51, denoted and referred to in CIE 127:2007 as T_C, the *chip temperature*. (In the temperature range of interest using [^{o}C] is more common.)
ΔT_J	[^{o}C] or [K]	**change of junction temperature** (see JESD51-50). For temperature differences [^{o}C] is commonly used.
V_F	[V]	**junction forward voltage**
I_F	[A]	**junction forward current**
P_H	[W]	**heat dissipated at the junction of the LED** (see JESD51-50), also denoted as P_H and referred to as heating power in JESD51-51.
P_{opt}	[W]	**emitted optical power of the LED** referred to as total *radiant flux* and denoted as Φ_e in CIE S 017/E, 2011 ILV. It is also called total *radiant power*.
P_{el}	[W]	**electrical power supplied to the LED** which is equal to the product of the forward voltage and the forward current: $P_{el} = V_F \cdot I_F$. This quantity is denoted as P in CIE 127:2007.
Φ_e	[W]	**emitted optical power of the LED**, alternate notation to P_{opt} as defined and referred to in CIE S 017/E, 2011 ILV as total *radiant flux* or *radiant power* .
Φ_V	[lm]	**total luminous flux**
λ	[nm]	**wavelength of the emitted light**
S(λ)	[W/nm]	**spectral power distribution** indicating the radiant power of the emitted light at a given wavelength.
η_e, WPE	[%]	**radiant efficiency** or *energy conversion efficiency* or *wall plug efficiency* of the LED: 100 × the value of the P_{opt} emitted optical power divided by the P_{el} supplied electrical power. Throughout this document WPE is defined for a single LED device.
η_V	[lm/W]	**efficacy**, the LED's total luminous flux Φ_V divided by the P_{el} supplied electrical power.
$Z_{\theta JX}$, Z_{thJX}	[K/W]	**junction-to-specific environment thermal impedance**, the temporal change of junction temperature with respect to temperature of environment X, normalized to 1W heating power and scaled in z logarithmic time.
I_M	[mA]	value of the forward current of the LED applied as *measuring current.*
I_H	[mA]	value of the forward current of the LED applied as *heating current.*

3 Terms, Definitions, and notations (cont'd)

The everyday term (high) *power LED* is somewhat ambiguous, since there is a tendency to package multiple single pn-junction LED chips into a single package (sharing the same cooling assembly and optics) or have multiple elementary pn-junctions on a single chip form an LED device. Also, in many cases, multiple packaged LEDs are assembled to a substrate (usually a high thermal conductivity board such as a metal core PCB or MCPCB in short) to form one single device. In this document, the phrase "LED" means a device used as a single light source with a generic *anode* and *cathode* electrical contact.

All measured characteristics (e.g., thermal resistance, temperature sensitivity of the overall forward voltage, radiant flux, luminous flux, color, etc.) of array type single light source LED devices are ensemble characteristics *of the array. In such cases the array is considered a single chip equivalent device which possesses the measured ensemble characteristics of the array device.*

In the subsequent sections under term LED (or power LED) or LED device, it is meant either as an individually available single LED of any LED array arrangement or an equivalent LED of an LED array where elements of the array are not accessible individually, (this equivalent LED being characterized by its ensemble characteristics). Either configuration would have an exposed cooling surface which is to be heat-sunk during normal operation. Regarding the term LED see also definition 6.8.5.1 of LED packages and definition 6.8.5.2 of the LED arrays in ANSI/IESNA RP 16-05 Addendum A. The scope of this document does not include any other solid-state lighting device defined in ANSI/IESNA RP 16-05 Addendum A.

4 Recommended test environment for LEDs

As a reference environment for thermal and light output measurement of LEDs, *temperature controlled cold-plates are recommended*. Such a cold-plate can be either liquid-cooled or cooled by a thermoelectric cooler, TEC. Accurate means of measuring the cold-plate temperature during test is recommended.

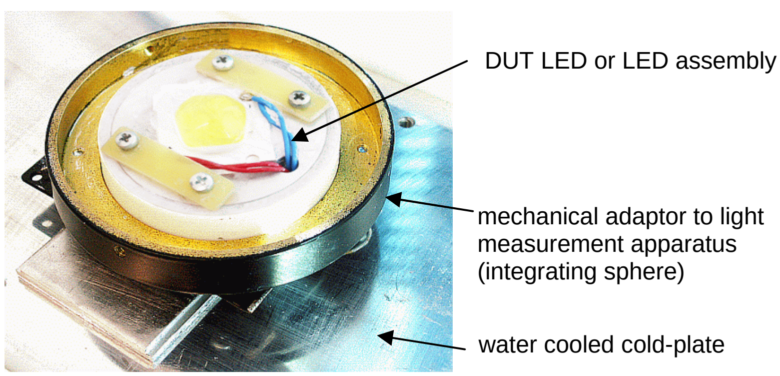


Figure 4 — Example of a test fixture used as a cold plate environment for thermal testing and used as a DUT fixture for light output measurements of an LED

4 Recommended test environment for LEDs (cont'd)

For the determination of the actual heating power of LEDs, the emitted optical power (radiant flux) needs to be measured. *In order to maintain the consistency of measured data, it is recommended that, during light output measurements, the LED be placed in exactly the same thermal environment as it was attached to during the thermal test, and the same reference temperature shall also be applied as the one used during thermal testing.* Furthermore, the physical assembly of the LED and test environment must remain mechanically intact between the light output measurements and the thermal test.

In a practical realization, such a cold-plate used during thermal tests, can also be attached to an apparatus (e.g., an integrating sphere equipped with appropriate photo detector and reference light source as described in CIE 127:2007) which is used to measure the light output of LEDs. Figure 4 shows an example for such a solution.

4.1 General recommendations for measuring the light output

Measuring the light output of LEDs in connection with thermal testing should be performed according to the recommendations of the CIE 127:2007 with the following additions:

- *Light output measurement techniques specified for laboratory testing shall be used*.
- Light output measurements need to be carried out with *DC current supply and under steady-state thermal conditions*.
- The *total radiant flux of the test LED has to be measured* for the purpose of consideration in heating power calculation (see JESD51-51, 5.1.5, equation (19)) of the thermal resistance/impedance measurements for the same forward current and junction temperature pairs which take place during thermal testing. In addition to the measurement of the radiant flux, photometric and colorimetric quantities and spectral properties can be also identified.
- *The thermal environment of the LED under test during light output measurements should be the same as the one used in thermal testing*. The recommended test environment is a liquid cooled or a Peltier-cooled, temperature controlled cold-plate (see clause 4). Test fixtures like the one shown in Figure 4 are suggested.
- The light output measurement apparatus should be calibrated against current and temperature stabilized reference light source also known as standard LEDs (see CIE127:2007, 2.2.2). *Standard LEDs providing radiant flux in the same order of magnitude as the expected radiant flux of test LEDs shall be used*. Moreover, the relative spectral distribution of the reference standards should be as close to the relative spectral distribution of test LEDs as possible. In other words, the *strict substitution method* described in CIE 127:2007, 6.2.3.1 shall be used.
- *Measurement of the total radiant flux shall be preferably carried out using an integrating sphere* (aimed at measuring visible light) based on the pattern of the measurement of the luminous flux defined in CIE 127:2007, chapter 6, with the following considerations:
  - Since power LEDs do not have backward light emission, collecting light is sufficient from 2π steradian solid angle. Therefore, to allow proper cooling of the test LED through an actively cooled, temperature controlled cold plate, *the geometry shown in Figure 9b of CIE 127:2007, 6.2.2.1 shall be used*. The arrangement suggested for use in combination with thermal measurements of LEDs is also shown in Figure 5.

4 Recommended test environment for LEDs (cont'd)

4.1 General recommendations for measuring the light output (cont'd)

- o As opposed to provisions of CIE 127:2007, 6.2.2.1, instead of a $V(\lambda)$ function-matched photometric detector, *a radiometric detector shall be used*, that is, a detector with flat spectral response in the visible range of light. Errors resulting from the deviations of the detector from the ideal flat characteristics shall be taken care of by the application of the *strict substitution method* as described above or by using a *color correction* method (see CIE 127:2007, 5.2 and 6.2.3.2).
- o If the above described radiometric detector is not available, a spectroradiometer calibrated to the measurement of the absolute total spectral radiant flux may also be used (see CIE 127:2007, 6.2.3.3 and 7.4.2.1). The radiant flux shall be calculated as

$$\Phi_e = \int_{380nm}^{780nm} S(\lambda) d\lambda \qquad (2)$$

- o Instead of using an integrating sphere, goniophotometric techniques can be applied for the measurement of the total radiant flux if proper correction for the angular dependence of the emitted spectral power is made and if it is assured that the environmental temperature of LED under test is known and remains constant.
- o *The calibration principle described in CIE 127:2007, 6.2.3 shall be followed* for the measurement of the radiant power, therefore such standard LEDs which have certificate values for radiant power, are required. Self-absorption correction of the test LED has to be performed following the recommendations of CIE 84:1989. This has to be performed only once for one type of LED by allowing easier measurements and providing better opportunities for combining thermal and radiometric measurements of LEDs in a single LED testing station. The measurement control software should care about using the right calibration files, depending on the color of the LED being tested.

- For light output measurements performed in connection with thermal test, *4-wire (Kelvin) electrical connections* need to be established as shown in Figure 6.

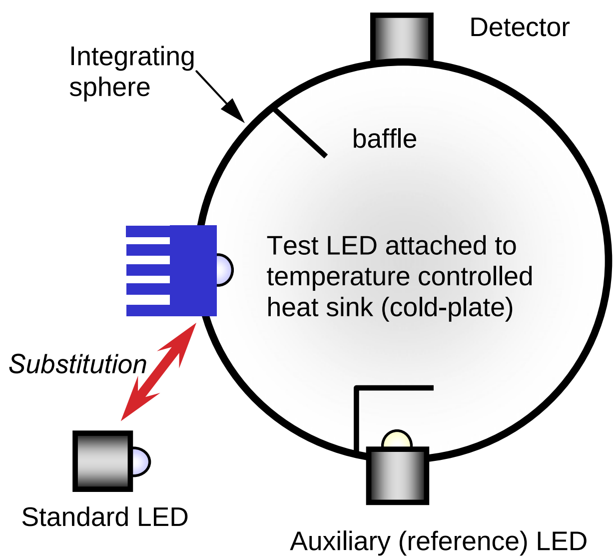


Figure 5 — Suggested integrating sphere setup for total radiant flux measurement of LEDs to be used in combination with thermal measurements

4 Recommended test environment for LEDs (cont'd)

4.1 General recommendations for measuring the light output (cont'd)

The light output measurement system outlined above can be completed with any other type of detector which provides photometry / colorimetry data of interest.

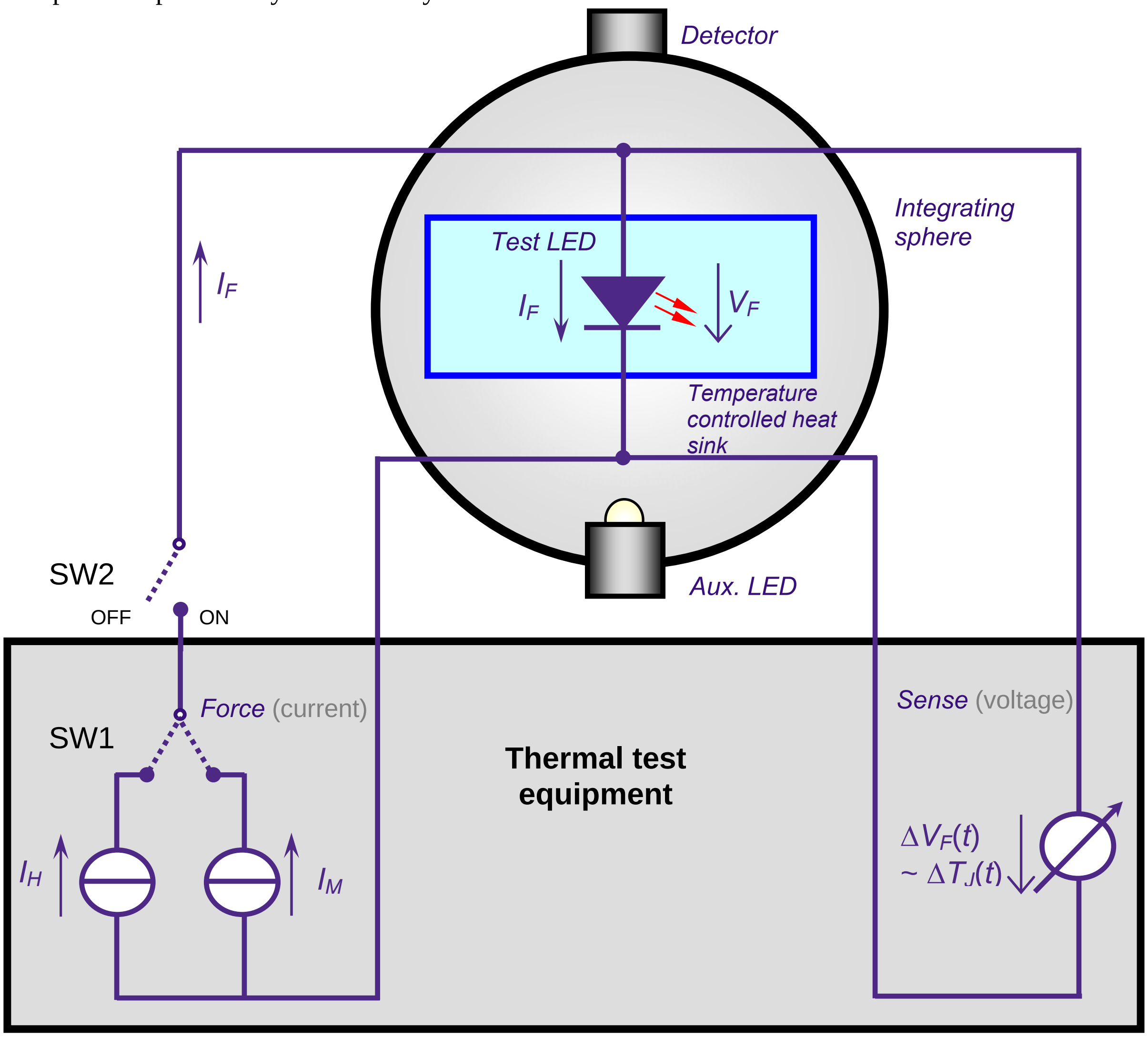


Figure 6 — Schematic diagram of a combined thermal and radiometric LED testing station

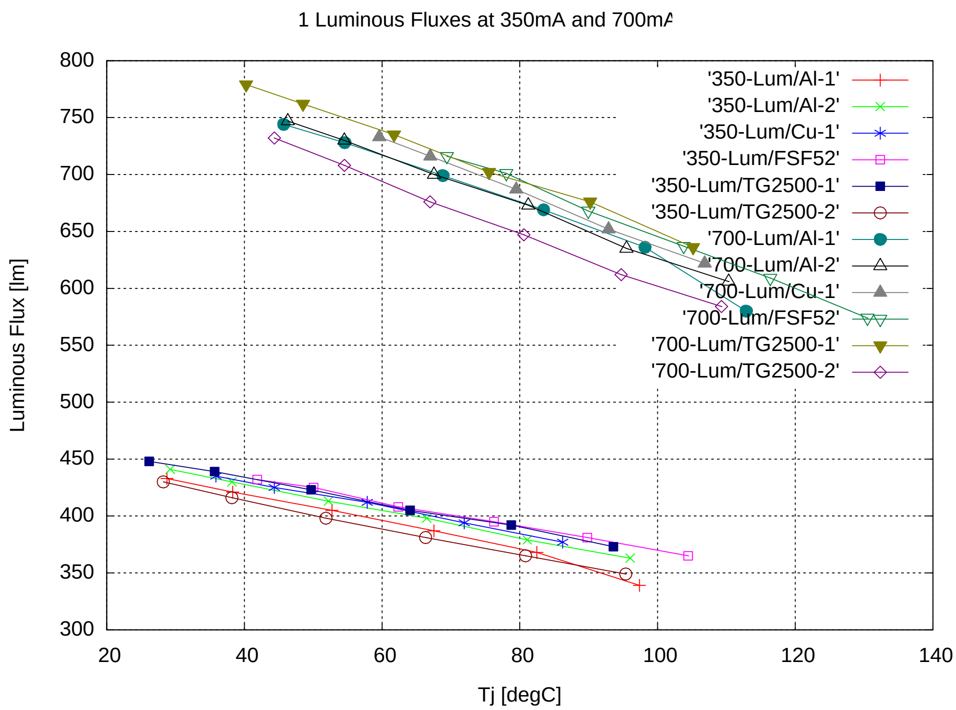
4.2 Combined thermal and radiometric LED testing station

In order to assure consistency between thermal and light output measurements, application of a combined thermal and radiometric LED testing station is preferred – see Figure 6. In such a setup, the DC current for the light output measurements is provided from the thermal testing apparatus (thermal test equipment) when it is switched to provide I_H, heating current, (switch SW1 set to the I_H position). The electrical scheme of the combined setup needs another switch (SW2) with which the forward current of the test LED can be completely switched off – allowing the dark photocurrent offset compensation and the self-absorption compensation in the light measurement system. In this later case, the test LED must be turned off and the reference LED or auxiliary LED is turned on.

4 Recommended test environment for LEDs (cont'd)

4.2 Combined thermal and radiometric LED testing station (cont'd)

The control of the heat sink temperature is also an essential part of the combined LED testing station.



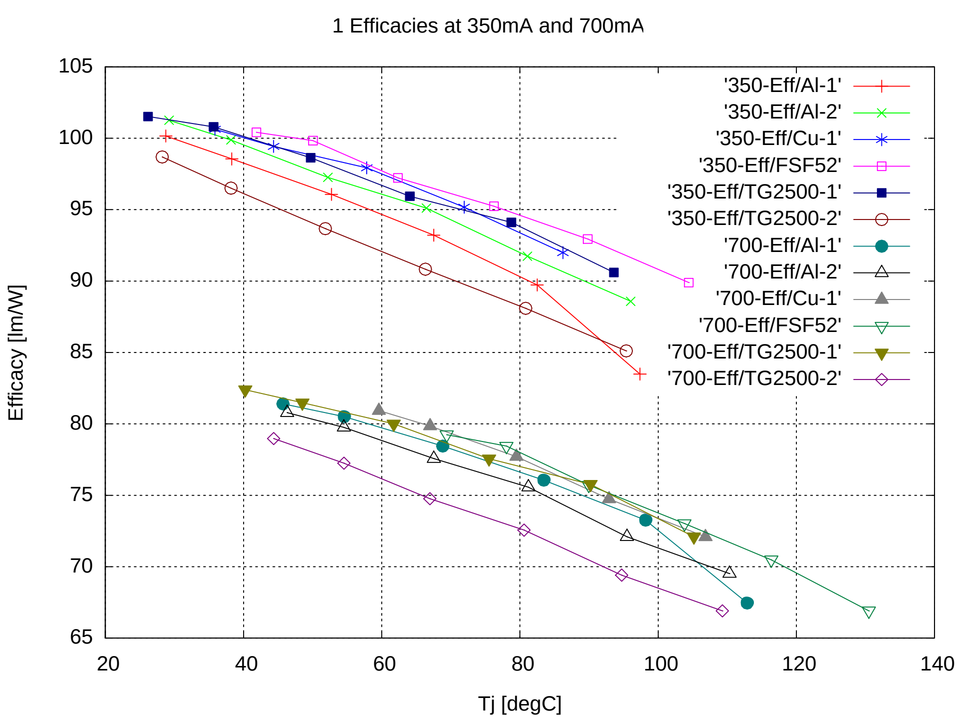


Figure 7 — Measured luminous flux and efficacy values for 7 samples of 4-chip 10 W white LEDs

5 Data reporting

With the control of the heat-sink temperature and using equation (22) of JESD51-51, the light output properties can be identified as functions of junction temperature and forward current. (Another method for estimating the junction temperature during light output measurements is also described in Ref. 1.) Such properties may include luminous flux, efficacy, correlated color temperature (for white LEDs) etc. Examples of such results (all shown as a function of LED's junction temperature calculated using JESD51-51, equation (22)) are presented in Figure 7.

Light output metrics must be reported together with the applied forward current and the identified junction temperature.

It is preferred that LEDs's data sheets always include typical data of $\Phi_e(I_F, T_J)$, radiant flux values, $\eta_e(I_F, T_J)$, energy conversion efficiency values, and $\Phi_V(I_F, T_J)$, luminous flux values, $\eta_V(I_F, T_J)$, efficacy values, preferably in the form of plotted diagrams and numerical tables.

For data reporting on thermal test results of LEDs, provisions of JESD51-50 apply. As recommended by JESD51-50, the measured thermal metrics must be reported together with details of the actual test environment, including the reference temperature. The $R_{\theta JX\text{-}real}$, real thermal resistance, ($Z_{\theta JX\text{-}real}$, thermal impedance) must always be reported.

The $R_{\theta JX\text{-}el}$, thermal resistance value, ("electrical-only" thermal resistance) can be optionally reported with a clear indication that the emitted optical power was *not considered*. If the $R_{\theta JX\text{-}el}$, thermal resistance is reported, on top of the details of the test environment and the reference temperature, the heating current and the corresponding forward voltage value to which the $R_{\theta JX\text{-}el}$ value is related, must also be reported. The same applies if thermal characterization parameters (without considering the emitted optical power) are reported.

6 Bibliography

1. Zong, Y. and Y. Ohno, "New practical method for measurement of high-power LEDs", *Proceedings of the CIE Expert Symposium 2008 on Advances in Photometry and Colorimetry,* CIE x033:2008, July 2008, pp. 102-106.

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