JEDEC STANDARD

TERMS, DEFINITIONS AND UNITS GLOSSARY FOR LED THERMAL TESTING

JESD51-53A

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TERMS, DEFINITIONS AND UNITS GLOSSARY FOR LED THERMAL TESTING

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Foreword

In order to facilitate the communication of thermal and radiometric/photometric measurement and data information of power LEDs, a clear and well-defined language is necessary. This collection of terms and definitions will help to describe the thermal performance of LED packages and LED assemblies more accurately.

Introduction

This document has been prepared by the *JEDEC JC-15 Committee on Thermal Characterization* therefore it is focused on *thermal* characterization of LEDs – as special, packaged discrete semiconductor devices. It also provides reference to light measurement to the extent required for thermal characterization of LEDs. Thus, this document should be used in conjunction with the JESD51-50 through JESD51-52 series of standards. This document is also aimed at experts performing light output measurements of LEDs when during such measurements dedicated attention is paid to thermal issues as well. Therefore terms commonly used both in thermal testing and optical testing are collected here with common definitions coherent with the ones usual in the thermal and optical testing.

TERMS, DEFINITIONS AND UNITS GLOSSARY FOR LED THERMAL TESTING

(From JEDEC BoD Ballot JCB-22-24, formulated under the cognizance of the JC-15 Committee on Thermal Characterization Techniques for Semiconductor Packages.)

1 Scope

This document provides a unified collection of the commonly used terms and definitions in the area of LED thermal measurements. The terms and definitions provided herein extend beyond those used in the JESD51 family of documents, especially in JESD51-13, in order to include other often used terms and definitions in the area of light output measurements of LEDs. Definitions, symbols and notations regarding light output measurements used here are consistent with those defined in JESD77C.01 and with those defined by CIE (*International Commission on Illumination*), especially in the *International Lighting Vocubulary*, CIE S 017/E:2020 and in the CIE 127-2007 and CIE 225:2017 documents as well as in some other relevant standards of other standardization bodies from the solid-state lighting industry, e.g., ANSI/IESNA RP 16-05.

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 listed. 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 the Real Thermal Resistance and Impedance of Light-emitting Diodes with Exposed Cooling Surface.*

JESD51-52, *Guidelines for Combining CIE 127-2007 Total Flux Measurements with Thermal Measurements of LEDs with Exposed Cooling Surface.*

JESD51, *Methodology for the Thermal Measurement of Component Packages (Single Semiconductor Devices)*.

JESD51-1, *Integrated Circuit Thermal Measurement Method - Electrical Test Method.*

JESD51-12, *Guidelines for Reporting and Using Electronic Package Thermal Information.*

JESD51-13, *Glossary of Thermal Measurement Terms and Definitions.*

JESD51-14, *Transient Dual Interface Test Method for the Measurement of the Thermal Resistance Junction to Case of Semiconductor Devices with Heat Flow Through a Single Path.*

2 Normative References (cont'd)

JESD15-1, *Compact Thermal Model Overview.*

JESD15-3, *Two-Resistor Compact Thermal Model Guideline.*

JESD77C.01, *Terms, Definitions, and Letter Symbols for Discrete Semiconductor and Optoelectronic Devices.*

CIE S 017/E:2020: *International Lighting Vocabulary 2nd Edition (DOI: 10.25039/S017.2020)*

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

CIE 225:2017 Technical Report: *Optical Measurement of High-Power LEDs*, ISBN 978 3 902842 12 1 *(DOI: 10.25039/TR.225.2017)*

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

3 Terms, and Definitions

For the purpose of this document, the following terms and definitions apply.

AC LED: An LED designed to be driven by a sinusoidal alternating current (AC) power source, typically having an operational frequency and voltage equal to the frequency and voltage of the mains (50/60 Hz, 230/120 V).

anode: An electrode of an LED that, in the forward mode of operation, is connected to a positive potential with respect to the potential of the *cathode* electrode.

NOTE In the case of a single pn-junction diode, the anode electrode of the package is in ohmic contact with the p-doped side of the semiconductor pn-junction.

cathode: An electrode of an LED that, in the forward mode of operation, is connected to a negative potential with respect to the potential of the *anode* electrode.

NOTE In the case of a single pn-junction diode, the cathode electrode of the package is in ohmic contact with the n-doped side of the semiconductor pn-junction.

change of junction temperature (ΔT_J): The difference between two *steady-state* values of the temperature of that same *junction.*

NOTE ΔT_J is measured in Kelvins [K] or in degrees Celsius [°C].

DC LED: An LED device designed to be driven by a constant, steady forward current.

efficacy: See *luminous efficacy (of a source of light)*

3 Terms and Definitions (cont'd)

electrical power (supplied to an LED) (P_{el}): The product of the *forward voltage* and the *forward current.*

NOTE Electrical power is measured in watts [W].

emitted optical power (P_{opt}): Synonym for *total radiant flux.*

energy conversion efficiency: Synonym for *radiant efficiency.*

ensemble characteristic: Measured characteristic (such as *forward voltage*, *junction temperature*, *luminous flux, temperature sensitivity of forward voltage*) of an *LED ensemble*, considered as a single, average quantity as if it was measured as a single characteristic of an equivalent single pn-junction LED.

forward current (I_F): The current flowing from the p-type region to the n-type region.

NOTE 1 Forward current is measured in amps [A].

NOTE 2 In case of *LED ensembles* without any access to individual anodes and cathodes or their associated regions, the forward voltage is an *ensemble characteristic* of such a device.

forward voltage (V_F): A positive anode-to-cathode voltage.

NOTE 1 At high forward current, the value of the forward voltage varies typically between 2 V and 4 V for single pn-junction LEDs, depending on the color of the LED.

NOTE 2 In the case of constant *forward current*, the forward voltage almost linearly depends on the *junction temperature*.

NOTE 3 In the case of *LED ensembles* without any access to individual anodes and cathodes, the forward voltage is an *ensemble characteristic* of such a device.

NOTE 4 Forward voltage is measured in volts [V].

goniophotometer: A *photometer* system used to measure the spatial distribution (directional distribution) of light sources, luminaries, etc.

integrating sphere: A hollow sphere whose internal surface is a diffuse reflector that is as spectrally nonselective as possible.

NOTE 1 Two principal uses are to geometrically sum the spatial total flux emitted by a radiator and to eliminate the spatial and polarization inhomogeneities of radiation at the input to optical instruments (such as detectors).

NOTE 2 An integrating sphere is also known as an Ulbricht's sphere. It is equipped with ports to mount optical instruments (e.g., a detector) and the DUT.

junction: The operating portion of the active LED chip in a single-chip LED; practically it is a semiconductor pn-junction.

3 Terms and Definitions (cont'd)

junction temperature (T_J): The temperature of the operating portion of the active LED chip, which is assumed to be a uniform, single value.

NOTE 1 Its average value is considered to be an *ensemble characteristic* of an *LED ensemble* in which only single anode and cathode electrodes are provided to power the entire array of elementary LEDs.

NOTE 2 Junction temperature is measured in degrees Celsius [°C].

K factor; K-factor (K): The change in junction temperature divided by the change in a temperature-sensitive parameter (*TSP*) in the linear region of the TSP-temperature characteristic.

NOTE 1 The temperature-sensitive parameter (*TSP*) of semiconductor diodes is the *forward voltage*.

NOTE 2 The temperature-sensitive parameter (*TSP*) – the *forward voltage* – of today's high power LEDs often exhibits nonlinear temperature dependence in the junction temperature range relevant from LED operation point of view, therefore, instead of a single value of the K-factor, a junction temperature dependent *K-factor function* should be used.

K factor calibration: The measurement process that results in values of K factor or K-factor function for the semiconductor device under test.

K factor function: When an LED's forward voltage exhibits nonlinear dependence on the junction temperature, the exact temperature dependence is to be provided through the junction temperature dependent K-factor values obtained through the *K-factor calibration* process. The temperature dependence can be given by means of a higher order polynomial fitted to the measured temperature dependence.

LED: See *light-emitting diode*

LED ensemble: A multiple pn-junction single-chip device; a multichip single-package; or a single-assembly device.

light: Electromagnetic radiation in the visible range of the optical spectrum, typically with a wavelength between 380 nm and 770 nm.

NOTE See also IESNA RP 16-05.

light-emitting diode (LED): A pn-junction semiconductor device emitting optical radiation in the visible range of wavelength; it is either a single pn-junction single-chip device or an LED ensemble used as a point-like single light source.

NOTE As opposed to the definition of CIE 127:2007, the term is restricted to devices emitting visible light.

luminous efficacy (of a source of light) (η_v): The *total luminous flux* emitted divided by the total lamp power input.

NOTE 1 η_v is measured in lumens per watt [lm/W].

NOTE 2 See also CIE S 017/E:2020 ILV and IES RP-16-10

luminous flux (Φ_v): Synonym for *total luminous flux.*

3 Terms and Definitions (cont'd)

optical power (P_{opt}): Synonym for *total radiant flux.*

parameter stabilization: The operation of the DUT for a sufficient period of time such that the parameters to be tested are constant.

photometer: An optical detector with a spectral responsivity matched to the $V(\lambda)$ visibility function of photopic vision.

radiant efficiency (η_e): The emitted radiant power of an LED divided by the electrical power supplied to the LED.

NOTE Radiant efficiency is also known as energy conversion efficiency or wall-plug efficiency.

radiant flux (Φ_e): Synonym for *total radiant flux.*

radiant power (Φ_e): Synonym for *total radiant flux.*

radiometer: An optical detector with a uniform spectral responsivity.

standard LED: A seasoned, carefully selected, and stable LED whose current and temperature are stabilized in order to provide stable, repeatable light output and whose emitted flux values (*radiant flux* and *luminous flux*) are known and provided as certified values.

NOTE 1 A standard LED is used as a reference light-source standard for light-output measurements,

NOTE 2 Standard LEDs are usually traceable to a standard of a national testing laboratory such as the National Institute of Science and Technology (NIST).

stationary state: The state of an AC-driven LED in which its voltage, current, power, and junction temperature waveforms have stabilized their shape; i.e., the corresponding periodic time functions do not change.

steady-state: Describing conditions that are constant and stable.

temperature-sensitive parameter (TSP**)**: An electrical parameter of a semiconductor device that varies directly with junction temperature in a linear or very nearly linear fashion.

3 Terms and Definitions (cont'd)

temperature sensitivity of forward voltage (S_{VF}): The change of the *forward voltage* induced by a 1 °C *change of the junction temperature* in a forced-forward-current mode of operation.

NOTE 1 The temperature sensitivity of the forward voltage is the reciprocal of the constant *K factor* of pn-junctions.

NOTE 2 If the device under test is an *LED ensemble in which* the multiple pn-junctions are connected in series and there is no individual electrical access to single pn-junctions, this quantity is an *ensemble characteristic* of the device.

NOTE 3 The temperature sensitivity of forward voltage is measured in millivolts per kelvin [mV/K] or in millivolts per degree Celsius [mV/°C].

NOTE 4 In the case of LEDs, the temperature sensitivity of forward voltage may show large scattering among single LEDs manufactured in the same batch, and the value of this sensitivity may also change significantly with the number of operating hours of the LED.

NOTE 5 The temperature sensitivity of forward voltage as a single value can be defined only in the junction temperature range of an LED where the forward voltage shows linear temperature dependence. This temperature range might be narrower than the temperature range covered by the actual LED operation during test or application conditions.

total luminous flux (Φ_V): quantity derived from the *total radiant flux*, Φ_e, by evaluating the optical radiation according to its action upon the CIE standard photometric observer (see CIE DIS 017/E:2016).

NOTE 1 Definitions of JESD77C.01 and CIE S 017/E:2020 ILV are different. The above definition reflects the definition of the International Commission on Illumination (CIE): CIE S 017/E:2020 – as every reference where *luminous flux* is used in the JESD51-50 series of standards is based on CIE 127:2007 / CIE 225:2017 – CIE's technical reports on optical measurement of LEDs. JESD77C.01 defines the *(total) luminous flux* as "the time rate of flow of luminous energy" while CIE S 017/E:2020 ILV defines the luminous energy as "the time integral of the luminous flux".

NOTE 2 The action of the optical radiation upon the CIE standard observer is described by the $V(\lambda)$ visibility function of photopic vision.

NOTE 3 Φ_V can be measured by a *photometer* attached to an *integrating sphere*.

total radiant flux (Φ_e): The time rate of flow of *radiant* energy in all solid angles of space.

NOTE 1 Φ_e can be measured by a *radiometer* attached to an *integrating sphere*.

NOTE 2 The terms *emitted optical power, optical power, radiant flux, radiant power,* and total radiant flux usually have the same meaning although there may be different connotations. The two "optical power" terms are denoted by different symbols (P_{opt}), but all of the concepts are measured in watts [W]. While the adjective "total" specifically means "in all solid angles," that same meaning normally applies to the others unless otherwise specifically noted.

For terms and definitions not listed above, refer to JESD51-13 and ANSI/IESNA RP 16-05. The symbols most frequently used in the JESD51-50 series of documents are summarized in Table 1.

3 Terms and Definitions (cont'd)

Table 1 — Symbols Most Frequently Used in the JESD51-50 through JESD51-52 Series of Documents

Symbol	Unit of measure	Name, description
T_J	[°C]	**junction temperature** of the LED **(**see JESD51-1), denoted and referred to in CIE 127:2007 as T_C, the *chip temperature*. (In the temperature range of interest using [°C] is more common.) In CIE 225:2017 T_J is used to denote the junction temperature of LEDs.
ΔT_J	[°C] or [K]	**change of junction temperature (see** JESD51-50, JESD51-1). For temperature differences [°C] is commonly used.
$R_{\theta JX}$, R_{thJX}	[K/W]	**junction-to-specific environment thermal resistance (**see JESD51-50, JESD51-1) where x refers to the environment in question.
Ψ_{JX}	[K/W]	**junction-to-X thermal characterization parameter** (see JESD51-13).
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 JESD51-1, JESD51-14 and 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** as defined and referred to CIE S 017/E:2020as *total radiant flux* or *radiant power*, alternate notation to P_{opt}.
Φ_V	[lm]	**total luminous flux**
λ	[nm]	**wavelength of the emitted light**
$S(\lambda)$	[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 × value of the P_{opt} emitted optical power divided by the P_{el} supplied electrical power.
η_V	[lm/W]	**(luminous) efficacy**, the value of the LED's emitted total luminous flux Φ_V divided by the P_{el} supplied electrical power.
z	s	**logarithmic time**, the absolute value of this quantity is defined as $z = \log(t)$.
$Z_{\theta JX}$, 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.
TSP	n.a.	**temperature sensitive parameter,** in case of semiconductor diodes it is the V_F forward voltage.
S_{VF}	[mV/K]	**temperature sensitivity of the forward voltage**, measured at I_M measuring current (also called as sensor current).
K	[K/mV]	**K factor**, reciprocal of the S_{VF} temperature sensitivity of the forward voltage, identified at I_M measuring current (also called as sensor current).
I_H	[A]	value of the forward current of the LED applied as *heating current.*
V_H	[V]	value of the forward voltage of the LED when biased by the heating current.
I_M	[mA]	value of the forward current of the LED applied as *measuring current.*
t_{MD}	[s]	**measurement delay time**, time elapsed between the instance of switching the power applied to the LED under test and the instance of the first reading of the TSP not disturbed by electrical transients.
V_{Fi}	[V]	initial value of the forward voltage of the LED immediately after switching the power across the diode.
V_{Ff}	[V]	final value of the forward voltage of the LED when diode reached its final thermal steady-state after switching the power.

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