

JEDEC STANDARD

Implementation Of The Electrical Test Method For The Measurement Of Real Thermal Resistance And Impedance Of Light-Emitting Diodes With Exposed Cooling Surface

JESD51-51A

(Revision of JESD51-51, April 2012)

OCTOBER 2022

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION



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Published by
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IMPLEMENTATION OF THE ELECTRICAL TEST METHOD FOR THE MEASUREMENT OF REAL THERMAL RESISTANCE AND IMPEDANCE OF LIGHT-EMITTING DIODES WITH EXPOSED COOLING SURFACE

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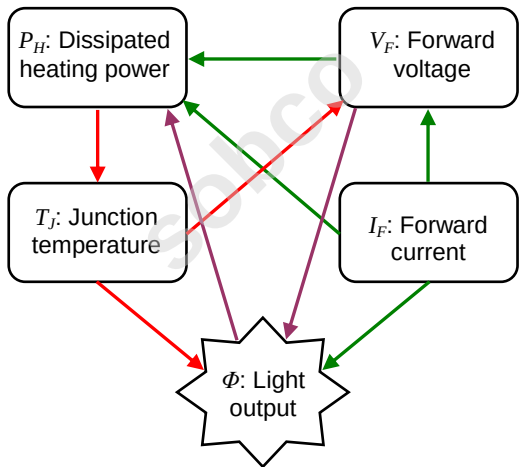
Foreword

This document has been prepared by the JEDEC JC-15 Committee on Thermal Characterization. It specifies the details and provisions of physically meaningful thermal characterization of power LEDs.

Introduction

The purpose of this document is to specify, how LEDs' thermal metrics and other thermally-related data are best identified by physical measurements using well established testing procedures defined for thermal testing of packaged semiconductor devices (published and maintained by JEDEC) and defined for characterization of light sources (published and maintained by CIE – the International Commission on Illumination).

This document focuses on **thermal** characterization of LEDs – as special, packaged discrete semiconductor devices. However, whenever needed, reference to light measurement is also made where terms, definitions and symbols specified and used in the relevant document of the *International Commission on Illumination* (CIE), (CIE 127:2007, CIE 225:2017, CIE S 017/E:2020) will be used or referred to.

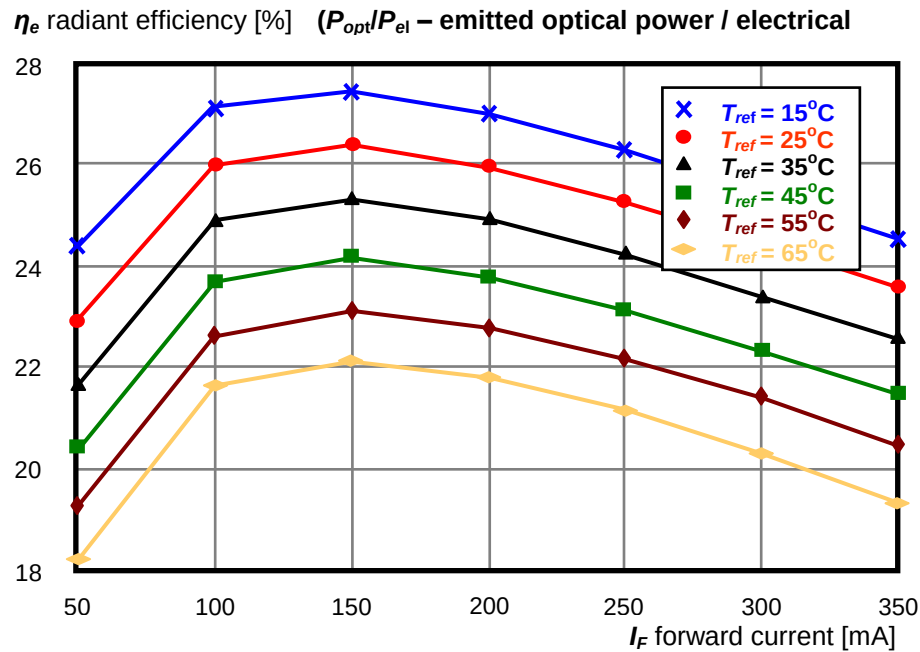


NOTE Different (macroscopic) quantities characteristic to the LEDs' operating conditions are shown.

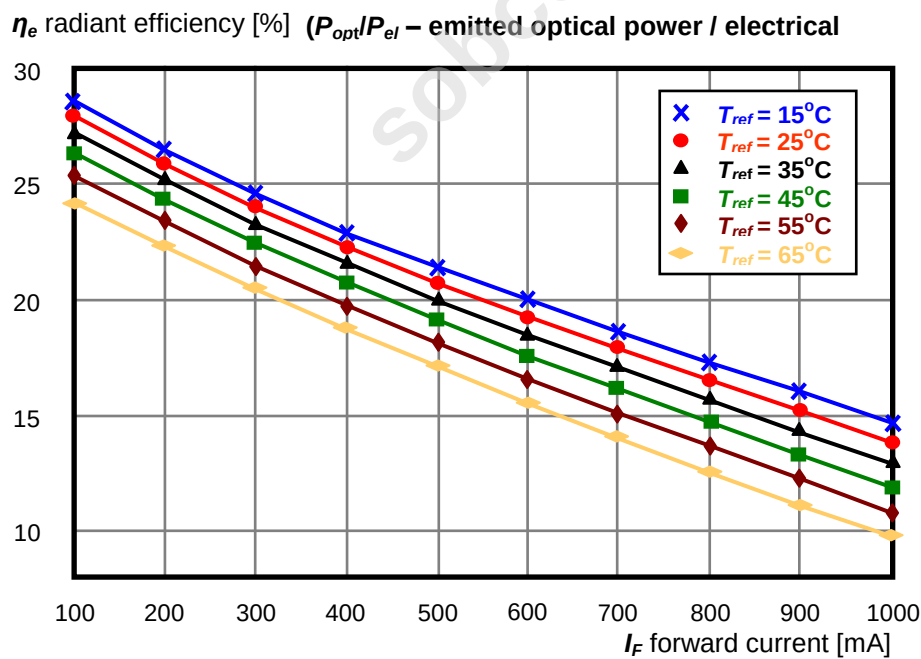
Figure I.1 — The Mutual Dependence of LEDs' Light Output

LED specific aspects of thermal testing procedures are defined in a generic way which means, that whenever possible, no distinction is made between steady-state and dynamic (transient) thermal measurements. Thus, this document belongs to the JESD51-50 through JESD51-53 series of standards. The overview of these standards is provided in the JESD51-50 document, (*Overview of Methodologies for the Thermal Measurement of Single- and Multi-Chip, Single- and Multi-PN-Junction Light-Emitting Diodes (LEDs)*). This document should also be used in conjunction with the JESD51 series of standards, especially with JESD51-1 (*Integrated Circuit Thermal Measurement Method - Electrical Test Method*) and JESD51-14 standard about junction-to-case thermal resistance measurement (*Transient Dual Interface Test Method for the Measurement of Thermal Resistance Junction-to-Case of Semiconductor Devices with Heat Flow through a Single Path*).

Introduction (cont'd)



a)



b)

NOTE Temperature and forward current dependence of the energy conversion efficiency (also known as radiant efficiency) of two different power LEDs

Figure I.2 — Temperature and Forward Current Dependence of the Energy Conversion Efficiency

Introduction (cont'd)

The reason why these guidelines are provided specifically for LEDs is that the physics determining their thermal behavior is more complex than in case of conventional semiconductor devices which are not aimed at emitting any kind of electro-magnetic radiation like visible light.

Thermal characterization of LEDs is a special case of thermal characterization of semiconductor diodes. The need for measurement guidelines for LEDs has arisen when light-emitting diodes with high power and high energy conversion efficiency emerged.

This complexity in the physics, as illustrated by Figure I.1, becomes manifest in the following:

- The electric to light energy conversion efficiency is determined by the operating conditions of the LED: the junction temperature and the applied forward current. This efficiency is not a single number since it depends both on the LED's junction temperature and forward current as shown in Figure 2a) and Figure 2b).
- The power dissipated at the active region of a LED is thus determined by the difference of 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. In some cases it is recommended to add another loss term, P_{loss} , that describes extra losses such as light absorption in the lens (ideally it is negligible) and energy loss in the phosphor (in case of white LEDs). In practical cases these hardly can be measured separately, therefore are not accounted for.

IMPLEMENTATION OF THE ELECTRICAL TEST METHOD FOR THE MEASUREMENT OF REAL THERMAL RESISTANCE AND IMPEDANCE OF LIGHT-EMITTING DIODES WITH EXPOSED COOLING SURFACE

(From JEDEC BoD Ballot JCB-22-23, formulated under the cognizance of the JC-15 Committee on Thermal Characterization Techniques for Semiconductor Packages.)

1 Scope

This document specifies thermal testing procedures 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 light¹⁾. The application of these measurement guidelines is recommended for packaged LEDs:

- with a total electrical power consumption above 0.5 W,
- which have energy conversion efficiency above 5%, and
- that are powered by steady DC power (typically with forced constant forward current), regardless whether the LED device inside the package is realized as single chip or multi chip device.

Further details of the definition of term *LED* or *LED device* used in this document are given in 0. This document does not deal with laser diodes.

When speaking about thermal testing, one can distinguish between laboratory testing and bulk testing. The scope of this document is laboratory testing of power LEDs.

Recommendations given in this document are valid for both steady-state and dynamic (transient) thermal measurements of LEDs, both relying on JEDEC JESD51-, *Electrical test method*. For steady-state thermal metrics both the *static* and *dynamic* test methods defined in JESD51-1 can be used.

Regarding the *heating power*, this document is aimed as an LED specific extension of the JEDEC JESD51-14, *Transient Dual Interface Test Method for the Measurement of Thermal Resistance Junction-to-Case of Semiconductor Devices with Heat Flow through a Single Path* document, applicable for DC driven LEDs only. Further LED specific additions to JESD51-14 may also be published in the future which would deal with practical aspects of the differences between power LED packages and other power semiconductor device packages.

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.

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.

2 Normative References (cont'd)

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

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 Thermal Resistance Junction-to-Case of Semiconductor Devices with Heat Flow through a Single Path*.

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

JESD51-52, *Guidelines for Combining CIE 127:2007 / CIE 225:2017 Total Flux Measurements with Thermal Measurements of LEDs with Exposed Cooling Surface*.

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)

MIL-STD-750D METHOD 3101.3, *Thermal Impedance (Response) Testing of Diodes*.

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

ANSI/IESNA IES-LM-80, *Approved Method for Measuring Lumen Maintenance of LED Light Sources*, ISBN 978-0-87995-227-3.

3 Terms and Definitions, Notations

3.1 Symbols and Terms

In this document the notations employed in the JESD51, JESD51-1, JESD51-12, JESD51-13 and JESD51-14 are used. Generic terms and quantities related to light output measurement are used as defined in the *International Lighting Vocabulary*, CIE S 017/E:2020; LED specific terms of photometry and radiometry given in the CIE 127:2007 and CIE 225:2017 documents are used. The most important terms and notations referred to in this document are listed in Table 1. Comprehensive descriptions of terms, definitions and units used in conjunction with LEDs are provided in JESD51-53, *Terms, Definitions and Units Glossary for LED Thermal Testing* document. For terms and definitions not listed there refer to JESD51-13, CIE S 017/E:2020 and ANSI/IESNA RP-16-10 documents.

Table 1 — Symbols Used in this Document

Symbol	Unit of measure	Name, description
T_J	[°C]	junction temperature (see JESD51-1) of the LED, denoted and referred to as T_C , the <i>chip temperature</i> , in CIE 127:2007. (In the temperature range of interest, the usage of [°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 JESD51-1, JESD51-50). For temperature differences [°C] is commonly used.
$R_{\theta JX}, R_{thJX}$	[K/W]	junction-to-specific environment thermal resistance (see JESD51-1, JESD51-50) where x refers to the environment in question.
θ_{JX}	[K/W]	alternate symbol to $R_{\theta JX}$ (see JESD51-1, JESD51-50).
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 (see JESD51-1, JESD51-14 and MIL-STD-750D METHOD 3101.3) .
P_{opt}	[W]	emitted optical power of the LED referred to as <i>total radiant flux</i> and denoted as Φ_e in CIE S 017/E:2011 ILV. It is also called <i>radiant power</i> .
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 as <i>total radiant flux or radiant power</i> (see CIE S 017/E:2020).
η_e , WPE	[%]	radiant efficiency or <i>energy conversion efficiency</i> or <i>wall plug efficiency</i> of the LED: $100 \times$ 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 (short hand for <i>luminous efficacy</i> of a source as per CIE S 017/E:2020) 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.

Table 1 — Symbols Used in this Document (cont'd)

Symbol	Unit of measure	Name, description
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 <i>heating current</i> .
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 <i>measuring current</i> .
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.

3.2 Definition of LEDs

The everyday term (high) *power LED* is somewhat ambiguous, since there is a tendency that multiple single pn-junction LED chips are packaged into a single package (sharing the same cooling assembly and optics) or 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 many cases these devices – internally formed as arrays of elementary light-emitting diodes – have only limited number of electrical connections to the outside world: this way the electrical circuitry for most high power LED arrays does not allow for connection to an individual diode. With only two electrical contacts, the thermal measurement must treat the entire array as a single diode. The implication of this reality is that the junction temperature measurement results actually in a weighted average of multiple junction temperatures and there is also limited ability to relate the measured temperature to a spatial location within the array. Figure 1 illustrates the different possible electrical configurations – as an example – for a 3×3 physical arrangement of single light-emitting diodes.

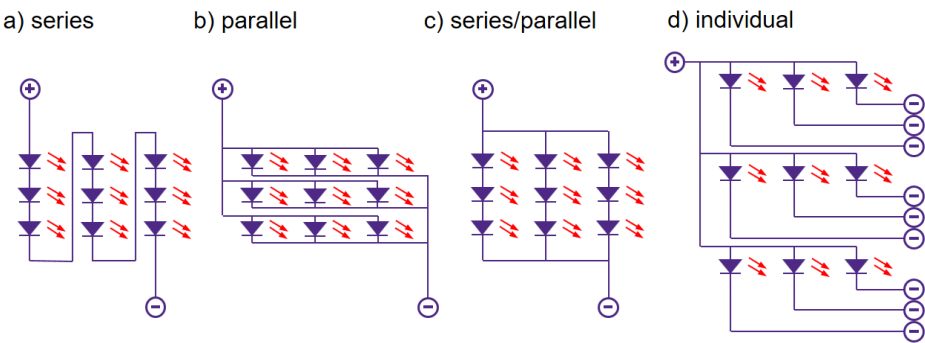


Figure 1 — Different LED Array Configurations