

INTERNATIONAL STANDARD



**Semiconductor devices –
Part 5-6: Optoelectronic devices – Light emitting diodes**



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IEC 60747-5-6

Edition 2.0 2021-07
REDLINE VERSION

INTERNATIONAL STANDARD



**Semiconductor devices –
Part 5-6: Optoelectronic devices – Light emitting diodes**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.080.99

ISBN 978-2-8322-1000-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES –

Part 5-6: Optoelectronic devices – Light emitting diodes

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 60747-5-6:2016. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 60747-5-6 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices. It is an International Standard.

This second edition cancels and replaces the first edition published in 2016. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) ultraviolet-emitting diodes (UV LED) and their related technical contents were added;
- b) power efficiency (η_{PE}) as part of electrical and optical characteristics were added;
- c) new measuring methods related to thermal resistance were added;
- d) hydrogen sulphide corrosion test was added to quality evaluation;
- e) some standards were added to the bibliography.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
47E/745/FDIS	47E/752/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 60747 series, published under the general title *Semiconductor devices*, can be found on the IEC website.

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SEMICONDUCTOR DEVICES –

Part 5-6: Optoelectronic devices – Light emitting diodes

1 Scope

This part of IEC 60747 specifies the terminology, the essential ratings and characteristics, the measuring methods and the quality evaluations of light emitting diodes (LEDs) for general industrial applications such as signals, controllers, sensors, etc.

LEDs for lighting applications are out of the scope of this part of IEC 60747.

LEDs are classified as follows:

- a) LED package;
- b) LED flat illuminator;
- c) LED numeric display and alpha-numeric display;
- d) LED dot-matrix display;
- e) ~~LED~~ (infrared-emitting diode (IR LED));
- f) ultraviolet-emitting diode (UV LED).

LEDs with a heat spreader or having a terminal geometry that performs the function of a heat spreader are within the scope of this part of IEC 60747.

An integration of LEDs and controlgears, integrated LED modules, semi-integrated LED modules, integrated LED lamps or semi-integrated LED lamps, are out of the scope of this part of IEC 60747.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60051 (all parts), *Direct acting indicating analogue electrical measuring instruments and their accessories*

IEC 60068-2-17, *Basic environmental testing procedures – Part 2-17: Tests – Test Q: Sealing*

IEC 60068-2-30, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60747-5-13, *Semiconductor devices – Part 5-13: Optoelectronic devices – Hydrogen sulphide corrosion test for LED packages*

IEC 60749-6, *Semiconductor devices – Mechanical and climatic test methods – Part 6: Storage at high temperature*

IEC 60749-10, *Semiconductor devices – Mechanical and climatic test methods – Part 10: Mechanical shock*

IEC 60749-12, *Semiconductor devices – Mechanical and climatic test methods – Part 12: Vibration, variable frequency*

IEC 60749-14, *Semiconductor devices – Mechanical and climatic test methods – Part 14: Robustness of terminations (lead integrity)*

IEC 60749-15, *Semiconductor devices – Mechanical and climatic test methods – Part 15: Resistance to soldering temperature for through-hole mounted devices*

IEC 60749-20, *Semiconductor devices – Mechanical and climatic test methods – Part 20: Resistance of plastic encapsulated SMDs to the combined effect of moisture and soldering heat*

IEC 60749-21, *Semiconductor devices – Mechanical and climatic test methods – Part 21: Solderability*

IEC 60749-24, *Semiconductor devices – Mechanical and climatic test methods – Part 24: Accelerated moisture resistance – Unbiased HAST*

IEC 60749-25, *Semiconductor devices – Mechanical and climatic test methods – Part 25: Temperature cycling*

IEC 60749-36, *Semiconductor devices – Mechanical and climatic test methods – Part 36: Acceleration, steady state*

ISO 2859-1, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

3 Terms, definitions and abbreviations

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1 General terms and definitions

3.1.1 integrating sphere

~~hollow sphere whose internal surface is a diffuse reflector, as non-selective as possible~~, the interior of which is formed from, or coated with, a diffusely-reflecting material that is as spectrally neutral and as spatially uniform as possible

Note 1 to entry: Owing to the internal reflections within the sphere, the illuminance on any part of the inside surface of the sphere for which the direct flux is hidden is theoretically proportional to the luminous flux entering the sphere or produced inside the sphere. The illuminance of the internal sphere wall can be measured via a small window.

Note 2 to entry: The window of an integrating sphere is often used in radiometric measurement systems to provide a source with good spatial uniformity and with an angular distribution of radiance or luminance that is close to Lambert's cosine law.

[SOURCE: ~~IEC 60050-845:1987, 845-05-24, modified~~ The term "Ulbricht sphere" and the note ~~have been removed.~~ IEC 60050-845:2020, 845-25-028]

3.1.2

diffuse reflector

reflector composed of a surface with diffuse reflection

3.1.3

diffuse reflection

~~diffusion~~ scattering by reflection in which, on the macroscopic scale, there is no regular reflection

[SOURCE: ~~IEC 60050-845:1987, 845-04-47~~ IEC 60050-845:2020, 845-24-054]

3.1.4

diffuse transmission

~~diffusion~~ scattering by transmission in which, on the macroscopic scale, there is no regular transmission

[SOURCE: ~~IEC 60050-845:1987, 845-04-48~~ IEC 60050-845:2020, 845-24-055]

3.1.5

diffuse reflectance

R_d ρ_d

~~ratio~~ quotient of the diffusely reflected part of the (whole) reflected flux, ~~to~~ and the incident flux

Note 1 to entry: ~~$R = R_r + R_d$~~ Reflectance, ρ , is the sum of regular reflectance, ρ_r , and diffuse reflectance, ρ_d : $\rho = \rho_r + \rho_d$

Note 2 to entry: ~~The results of the measurements of R_r and R_d depend on the instruments and the measuring techniques used.~~ The diffuse reflectance has unit one.

[SOURCE: ~~IEC 60050-845:1987, 845-04-62~~ IEC 60050-845:2020, 845-24-068]

3.1.6

diffuse transmittance

T_d τ_d

~~ratio~~ quotient of the diffusely transmitted part of the (whole) transmitted flux, ~~to~~ and the incident flux

Note 1 to entry: ~~$T = T_r + T_d$~~ Transmittance, τ , is the sum of regular transmittance, τ_r , and diffuse transmittance, τ_d : $\tau = \tau_r + \tau_d$.

Note 2 to entry: ~~The results of the measurements of T_r and T_d depend on the instruments and the measuring techniques used.~~ The diffuse transmittance has unit one.

[SOURCE: ~~IEC 60050-845:1987, 845-04-63~~ IEC 60050-845:2020, 845-24-069]

3.1.7

lambertian surface

ideal surface for which the radiation coming from that surface is distributed angularly according to Lambert's cosine law

Note 1 to entry: For a lambertian surface, $M = \pi L$, where M is the radiant exitance or luminous exitance, and L the radiance or luminance.

[SOURCE: ~~IEC 60050-845:1987, 845-04-57~~ IEC 60050-845:2020, 845-24-063]

3.1.8**spectral reflectance** $R(\lambda)$

~~ratio between the spectral radiant flux of wavelength λ that is reflected by an object and the spectral radiant flux of wavelength λ that is absorbed by the object~~

ratio of reflected radiant flux to incident radiant flux for a wavelength λ

Note 1 to entry: Spectral reflectance is also known as the "spectral reflection factor".

3.1.9**spectral transmittance** $T(\lambda)$

~~ratio between the spectral radiant flux of wavelength λ that is transmitted by an object and the spectral radiant flux of wavelength λ that is absorbed by the object~~

ratio of transmitted radiant flux to incident radiant flux for a wavelength λ

Note 1 to entry: Spectral transmittance is also known as the "spectral transmittance factor".

3.1.10**spectral distribution**

proportion of the quantum of radiation per unit wavelength included in the micro wavelength interval centre on wavelength λ , which is expressed as a function of wavelength λ

Note 1 to entry: Spectral distribution is also known as the "spectrum distribution".

3.1.11**spectral sensitivity** $S(\lambda)$

light sensitivity as a function of wavelength

Note 1 to entry: The response output of the optical receiver for the radiant ~~power~~ flux (or luminous flux) input of wavelength λ is expressed as a function of wavelength λ .

3.1.12**distribution temperature** T_D

temperature of the Planckian radiator whose relative spectral distribution $S(\lambda)$ is the same or nearly the same as that of the radiation considered in the spectral range of interest for which the following integral is minimized by adjustment of a and T :

$$\int_{\lambda_1}^{\lambda_2} \left[1 - \frac{S_t(\lambda)}{a S_b(\lambda, T)} \right]^2 d\lambda$$

where λ is the wavelength, $S_t(\lambda)$ is the relative spectral distribution of the radiation being considered, $S_b(\lambda, T)$ is the relative spectral distribution of the Planckian radiator at temperature T , and a is a scaling factor

Note 1 to entry: The scaling factor a is chosen to make the quotient $\frac{S_t(\lambda)}{S_b(\lambda, T)}$ equal to unity at a convenient wavelength which, in photometry and colorimetry is typically 560 nm.

$$S_b(\lambda, T) = \frac{P(\lambda, T)}{P(560\text{nm}, T)} \quad \text{with} \quad P(\lambda, T) = \lambda^{-5} \left(\frac{c_2}{e^{\lambda T}} - 1 \right)^{-1} \quad \text{where } c_2 \text{ is the second radiation constant.}$$

Note 2 to entry: Distribution temperature is a meaningful characteristic for radiators having a relative spectral distribution similar to that of a Planckian radiator, but only if calculated for an expanded wavelength range and for radiation whose spectral distribution of radiant flux is a continuous function of wavelength in that range.

Note 3 to entry: In photometry and colorimetry the wavelength range set by λ_1 and λ_2 is the visible spectral range, and in these cases the range from at least $\lambda_1 = 400$ nm to $\lambda_2 = 750$ nm is recommended.

Note 4 to entry: In practice, the integral is replaced by a summation. For incandescent lamps, equally spaced wavelength intervals of 10 nm will usually suffice. All values in the summation are treated with equal weight.

Note 5 to entry: The distribution temperature is expressed in kelvin (K).

Note 6 to entry: For further information, see CIE 114-1994, CIE Collection in Photometry and Radiometry – 114/4 Distribution Temperature and Ratio Temperature.

[SOURCE: ~~IEC 60050-845:1987, 845-04~~ IEC 60050-845:2020, 845-24-017]

3.1.13

infrared-emitting diode

IR LED

light emitting diode that emits infrared radiation

3.1.14

infrared radiation

optical radiation for which the wavelengths are longer than those for visible radiation

Note 1 to entry: For infrared radiation, the range between 780 nm and 1 mm is commonly subdivided into:

IR-A: 780 nm to 1400 nm, or 0,78 μ m to 1,4 μ m;

IR-B: 1,4 μ m to 3 μ m;

IR-C: 3 μ m to 1 mm.

Note 2 to entry: A precise border between "visible radiation" and "infrared radiation" cannot be defined because visual sensation at wavelengths greater than 780 nm can be experienced.

Note 3 to entry: In some applications the infrared spectrum has also been divided into "near," "middle," and "far" infrared; however, the borders necessarily vary with the application.

[SOURCE: IEC 60050-845:2020, 845-21-004, modified – The second preferred term (IR radiation) and the admitted term (IRR) have been removed.]

3.1.15

ultraviolet-emitting diode

UV LED

light emitting diode that emits ultraviolet radiation

3.1.16

ultraviolet radiation

optical radiation for which the wavelengths are shorter than those for visible radiation

Note 1 to entry: The range between 100 nm and 400 nm is commonly subdivided into:

UV-A: 315 nm to 400 nm;

UV-B: 280 nm to 315 nm;

UV-C: 100 nm to 280 nm.

Note 2 to entry: A precise border between ultraviolet radiation and visible radiation cannot be defined, because visual sensation at wavelengths shorter than 400 nm is noted for very bright sources.

Note 3 to entry: In some applications the ultraviolet spectrum has also been divided into "far," "vacuum," and "near" ultraviolet; however, the borders necessarily vary with the application (e.g. in meteorology, optical design, photochemistry, and thermal physics).

[SOURCE: IEC 60050-845:2020, 845-21-008, modified – The second preferred term (UV radiation) and the admitted term (UVR) have been removed.]

3.2 Terms and definitions relating to the measurement of the quantity of radiation

3.2.1

radiant energy

Q_e

~~time integral of the radiant flux Φ_e over a given duration Δt~~

energy emitted, transferred or received in the form of electromagnetic waves

Note 1 to entry: Radiant energy can be expressed by the time integral of radiant flux, Φ_e , over a given duration, Δt :

$$Q_e = \int_{\Delta t} \Phi_e dt$$

Note 2 to entry: Radiant energy is expressed as a function of wavelength, λ , as a function of frequency, ν , or as a function of wavenumber, σ .

Note 3 to entry: The corresponding photometric quantity is "luminous energy". The corresponding quantity for photons is "photon energy".

Note 4 to entry: The radiant energy is expressed in joule ($J = W \cdot s$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-27~~ IEC 60050-845:2020, 845-21-041]

3.2.2

radiant flux

Φ_e

~~power emitted, transmitted or received in the form of radiation~~

change in radiant energy with time

$$\Phi_e = \frac{dQ_e}{dt}$$

where Q_e is the radiant energy emitted, transferred or received, and t is time

Note 1 to entry: The corresponding photometric quantity is "luminous flux". The corresponding quantity for photons is "photon flux".

Note 2 to entry: The term "radiant flux" is the preferred term for most radiometric applications, with the notable exception of laser radiometry where the term "radiant power" is more commonly used.

Note 3 to entry: The radiant flux is expressed in watt (W).

[SOURCE: ~~IEC 60050-845:1987, 845-01-24, modified – The formula has been added.~~ IEC 60050-845:2020, 845-21-038, modified – The symbols P_e , Φ and P have been removed and the second preferred term "radiant power" has been removed.]

3.2.3

radiant intensity

I_e

~~quotient of the radiant flux $d\Phi_e$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle~~

density of radiant flux with respect to solid angle in a specified direction

$$I_e = \frac{d\Phi_e}{d\Omega}$$

where Φ_e is the radiant flux emitted in a specified direction, and Ω is the solid angle containing that direction

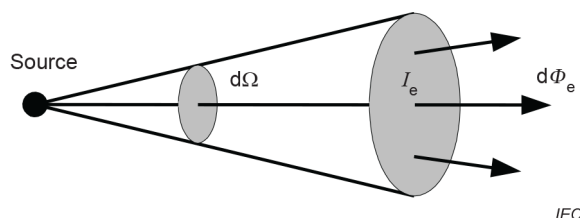


Figure 1 – Radiant intensity

~~Note 1 to entry: For a radiation source that is not regarded as a point radiation source, the limit value determined by the value (which is calculated by dividing the radiant power that is absorbed by a small area by the solid angle formed by the small area toward an arbitrary point on the radiation source) when the distance between the radiation source and the small area becomes longer, is used to calculate the radiant intensity.~~

~~Note 2 to entry: The unit used is: W/sr.~~

Note 1 to entry: The definition holds strictly only for a point source.

Note 2 to entry: The distribution of the radiant intensities as a function of the direction of emission, e.g. given by the polar angles (ϑ, φ) , is used to determine the radiant flux, Φ_e , within a certain solid angle, Ω , of a source:

$$\Phi_e = \int_{\Omega} I_e(\vartheta, \varphi) \sin \vartheta d\vartheta d\varphi.$$

Note 3 to entry: The corresponding photometric quantity is "luminous intensity". The corresponding quantity for photons is "photon intensity".

Note 4 to entry: The radiant intensity is expressed in watt per steradian ($\text{W} \cdot \text{sr}^{-1}$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-30~~ IEC 60050-845:2020, 845-21-044, modified – The symbol I has been removed and Figure 1 has been added.]

3.2.4 radiance

L_e

~~quantity defined by the formula $L_e = \frac{d\Phi_e}{dA \cdot \cos \theta \cdot d\Omega}$,~~

~~where~~

~~$d\Phi_e$ is the radiant flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction;~~

~~dA is the area of a section of that beam containing the given point;~~

~~θ is the angle between the normal to that section and the direction of the beam~~

density of radiant intensity with respect to projected area in a specified direction at a specified point on a real or imaginary surface

$$L_e = \frac{dI_e}{dA \cos \theta},$$

where I_e is radiant intensity, A is area, and θ is the angle between the normal to the surface at the specified point and the specified direction

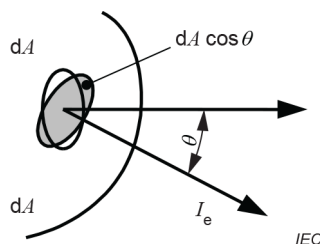


Figure 2 – Radiance

Note 1 to entry: ~~The unit used is: $W/(sr \cdot m^2)$.~~ The radiance is expressed in watt per square metre per steradian ($W \cdot m^{-2} \cdot sr^{-1}$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-34, modified — omitting the part about Notes~~ IEC 60050-845:2020, 845-21-049, modified – The symbol L has been removed, the angle symbol α has been replaced by θ , the notes have been removed, a new note has been added and Figure 2 has been added.]

3.2.5 radiant exitance

M_e

~~quotient of the radiant flux $d\Phi_e$ leaving an element of the surface containing the point, by the area dA of that element~~

$$M_e = \frac{d\Phi_e}{dA} = \int_{2\pi sr} L_e \cdot \cos\theta \cdot d\Omega \quad \text{(dA: small area)}$$

Note 1 to entry: ~~An equivalent definition could be given as follows: Integral, taken over the hemisphere visible from the given point, of the expression $L_e \cdot \cos\theta \cdot d\Omega$, where L_e is the radiance at the given point in the various directions of the emitted elementary beams of solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point.~~

Note 2 to entry: ~~The unit used is: W/m^2 .~~

density of exiting radiant flux with respect to area at a point on a real or imaginary surface

$$M_e = \frac{d\Phi_e}{dA}$$

where Φ_e is radiant flux and A is the area from which the radiant flux leaves

Note 1 to entry: For Planckian radiation, $M_e = \sigma T^4$ where σ is the Stefan-Boltzmann constant and T is thermodynamic temperature.

Note 2 to entry: The corresponding photometric quantity is "luminous exitance". The corresponding photon quantity is "photon exitance".

Note 3 to entry: The radiant exitance is expressed in watt per square metre ($W \cdot m^{-2}$).

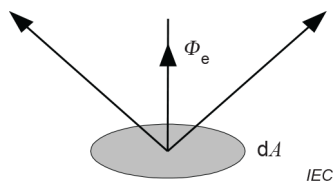


Figure 3 – Radiant exitance

[SOURCE: ~~IEC 60050-845:1987, 845-01-47~~ IEC 60050-845:2020, 845-21-080, modified – The symbol M has been removed and Figure 3 has been added.]

3.2.6 power efficiency

η_{PE}

ratio of the radiant flux (coupled to free space), Φ_e , to the electrical power consumed by the LED, $V_F I_F$, where V_F is the forward voltage and I_F is the forward current of the LED

$$\eta_{PE} = \frac{\Phi_e}{V_F I_F}$$

Note 1 to entry: Power efficiency is also known as the "wall-plug efficiency". Power efficiency is identical to the "radiant efficiency" when the power dissipated by any auxiliary equipment is excluded from the electrical power.

[SOURCE: IEC 60747-5-8:2019, 3.2.1, modified – The term "radiant power" has been replaced with "radiant flux".]

3.2.7 irradiance

E_e

~~quotient of the radiant flux $d\Phi_e$ incident on an element of the surface containing the point, by the area dA of that element~~

density of incident radiant flux with respect to area at a point on a real or imaginary surface

$$E_e = \frac{d\Phi_e}{dA}$$

where Φ_e is radiant flux and A is the area on which the radiant flux is incident

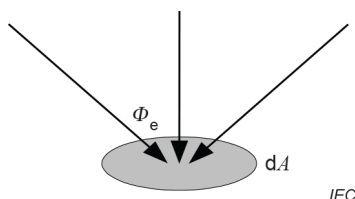


Figure 4 – Irradiance

~~Note 1 to entry:—An equivalent definition could be given as follows: Integral, taken over the hemisphere visible from the given point, of the expression $L_e \cos \theta d\Omega$, where L_e is the radiance at the given point in the various directions of the incident elementary beams solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point.~~

~~Note 2 to entry:—The unit used is: W/m^2 .~~

Note 1 to entry: The corresponding photometric quantity is "illuminance". The corresponding quantity for photons is "photon irradiance".

Note 2 to entry: The irradiance is expressed in watt per square metre ($\text{W}\cdot\text{m}^{-2}$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-37~~ IEC 60050-845:2020, 845-21-053, modified – The symbol E has been removed and Figure 4 has been added.]

3.3 Terms and definitions relating to the measurement of the photometric quantity

3.3.1

photometric standard lamp

lamp used for photometry that provides excellent stability and reproducibility and can indicate the photometric quantity

Note 1 to entry: There are two types of these lamps: luminous intensity standard lamps to which the luminous intensity value is added and luminous flux standard lamps to which the total flux value is added.

3.3.2

spectral luminous efficiency

$V(\lambda)$

relative spectral efficiency, which is defined as the standard value of spectral luminous efficiency for human eyes and whose maximum value is set to 1

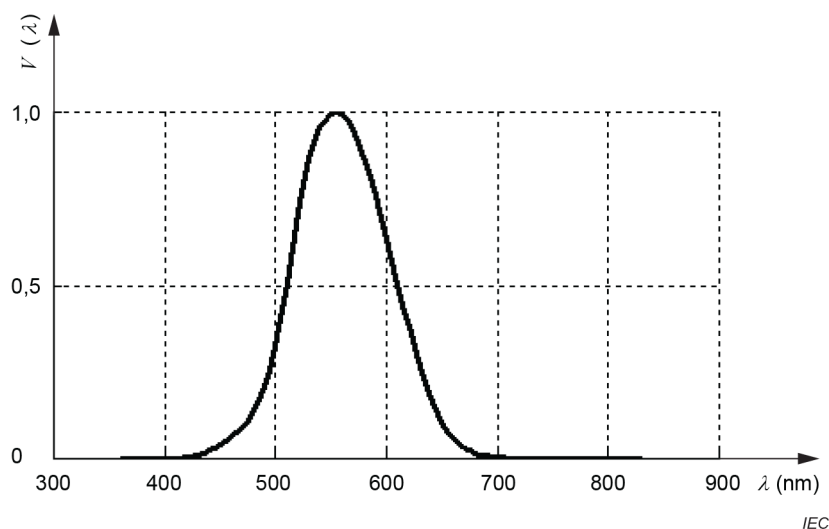


Figure 5 – Spectral luminous efficiency

Note 1 to entry: The spectral luminous efficiency for photopic vision was agreed at the CIE (International Commission on Illumination) in 1924 and adopted by the CIPM (*Comité International des Poids et Mesures* – International Committee for Weights and Measures in English) in 1933. The values for spectral luminous efficiency were originally given for the wavelength range 380 nm to 780 nm at 10 nm intervals. In 1972, new values were adopted by the CIPM for the wavelength range 360 nm to 830 nm at 1 nm intervals.

Note 2 to entry: Figure 5 and Table A.1 in Annex A show the graph and the numerical scheme for the spectral luminous efficiency, respectively.

3.3.3

maximum spectral luminous efficiency

K_m

maximum value that is expressed as the spectral concentration of the luminous flux in wavelength λ divided by the spectral concentration of the corresponding radiant ~~power~~ flux

Note 1 to entry: 683 lm/W ($\lambda = 555$ nm) is the value adopted by the CIPM.

3.3.4 luminous flux

Φ_v

~~quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer~~

~~Note 1 to entry: This definition was adopted by the CIE in 1948. The relation between luminous flux and radiant power is expressed by the following formula:~~

~~$$\text{For photopic vision } \Phi_v = K_m \int_0^\infty \frac{d\Phi_e(\lambda)}{d\lambda} \cdot V(\lambda) d\lambda$$~~

~~where~~

~~$\frac{d\Phi_e(\lambda)}{d\lambda}$ is the spectral distribution of the radiant flux and $V(\lambda)$ is the spectral luminous efficiency.~~

~~Note 2 to entry: The unit used is: lm.~~

change in luminous energy with time

$$\Phi_v = \frac{dQ_v}{dt}$$

where Q_v is the luminous energy emitted, transferred or received, and t is time

Note 1 to entry: Luminous flux is a quantity derived from the radiant flux, Φ_e , by evaluating the radiation according to its action upon the CIE standard photometric observer. Luminous flux can be derived from the spectral radiant flux distribution by

$$\Phi_v = K_m \int_0^\infty \Phi_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where K_m is maximum luminous efficacy, $\Phi_{e,\lambda}(\lambda)$ is spectral radiant flux, $V(\lambda)$ is spectral luminous efficiency and λ is wavelength.

Note 2 to entry: The distribution of the luminous intensities as a function of the direction of emission, e.g. given by the polar angles (ϑ , φ), is used to determine the luminous flux, Φ_v , within a certain solid angle, Ω , of a source:

$$\Phi_v = \iint_{\Omega} I_v(\vartheta, \varphi) \sin \vartheta d\vartheta d\varphi$$

Note 3 to entry: The corresponding radiometric quantity is "radiant flux". The corresponding quantity for photons is "photon flux".

Note 4 to entry: The luminous flux is expressed in lumen (lm).

~~[SOURCE: IEC 60050-845:1987, 845-01-25, modified — The note has been removed and part of the definition has been moved to notes to entry. IEC 60050-845:2020, 845-21-039, modified — The symbol Φ has been removed.]~~

3.3.5 quantity of light

Q_v

~~time integral of the luminous flux Φ_v over a given duration Δt~~

~~$$Q_v = \int_{\Delta t} \Phi_v dt$$~~

~~Note 1 to entry: The unit used is: lm·s (other unit: lm·h).~~

~~[SOURCE: IEC 60050-845:1987, 845-01-28]~~

3.3.5

luminous energy

Q_v

energy of electromagnetic waves weighted by the spectral luminous efficiency multiplied by maximum luminous efficacy of a specified photometric condition

Note 1 to entry: Luminous energy for photopic vision is expressed by

$$\Phi_v = K_m \int_0^{\infty} \Phi_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where $\Phi_{e,\lambda}(\lambda)$ is the spectral radiant energy at wavelength λ , $V(\lambda)$ is spectral luminous efficiency, and K_m is maximum luminous efficacy.

Note 2 to entry: The term "quantity of light" is no longer used.

Note 3 to entry: Luminous energy can be emitted, transferred or received.

Note 4 to entry: Luminous energy can be expressed by the time integral of the luminous flux, Φ_v , over a given duration, Δt :

$$Q_v = \int_{\Delta t} \Phi_v dt$$

Note 5 to entry: The corresponding radiometric quantity is "radiant energy". The corresponding quantity for photons is "photon energy".

Note 6 to entry: The luminous energy is expressed in lumen second (lm·s) or lumen hour (lm·h).

[SOURCE: IEC 60050-845:2020, 845-21-037, modified – The symbol Q has been removed.]

3.3.6

luminous intensity

I_v

~~quotient of the luminous flux $d\Phi_v$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle~~

~~$$I_v = \frac{d\Phi_v}{d\Omega} \text{ (d}\Omega \text{ solid angle)}$$~~

~~Note 1 to entry: The spatial definition of luminous intensity is shown in Figure 1; however, symbols I_θ and Φ_θ should be changed to I_v and Φ_v , respectively.~~

~~Note 2 to entry: For a light source that is not regarded as a point light source, the limit value determined by the value (which is calculated by dividing the luminous flux that is absorbed by a small area by the solid angle formed by the small area toward an arbitrary point on the light source) when the distance between the light source and the small area becomes longer, is used to calculate the luminous intensity.~~

~~Note 3 to entry: A luminous intensity of 1 cd is defined as $1/(60 \times 10^4)$ of the perpendicular-oriented luminous intensity on a 1-m^2 flat surface of a black-body whose temperature is equivalent to the freezing point of platinum under a pressure of $101,325\text{ N/m}^2$.~~

density of luminous flux with respect to solid angle in a specified direction

$$I_v = \frac{d\Phi_v}{d\Omega}$$

where Φ_v is the luminous flux emitted in a specified direction, and Ω is the solid angle containing that direction

Note 1 to entry: For practical realization of the quantity, the source is approximated by a point source.

Note 2 to entry: The distribution of the luminous intensities as a function of the direction of emission, e.g. given by the polar angles (ϑ, φ) , is used to determine the luminous flux, Φ_v , within a certain solid angle, Ω , of a source:

$$\Phi_v = \iint_{\Omega} I_v(\vartheta, \varphi) \sin \vartheta \, d\vartheta \, d\varphi.$$

Note 3 to entry: Luminous intensity can be derived from the spectral radiant intensity distribution by

$$I_v = K_m \int_0^{\infty} I_{e,\lambda}(\lambda) V(\lambda) \, d\lambda$$

where K_m is maximum luminous efficacy, $I_{e,\lambda}(\lambda)$ is the spectral radiant intensity at wavelength λ , and $V(\lambda)$ is spectral luminous efficiency.

Note 4 to entry: The corresponding radiometric quantity is "radiant intensity". The corresponding quantity for photons is "photon intensity".

Note 5 to entry: The luminous intensity is expressed in candela ($\text{cd} = \text{lm} \cdot \text{sr}^{-1}$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-31, modified – Two notes to entry have been added.~~ IEC 60050-845:2020, 845-21-045, modified – The symbol I has been removed.]

3.3.7 luminance

L_v

~~quantity defined by the formula~~

$$L_v = \frac{d\Phi_v}{dA \cdot \cos \theta \cdot d\Omega},$$

~~where~~

~~$d\Phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction;~~

~~dA is the area of a section of that beam containing the given point;~~

~~θ is the angle between the normal to that section and the direction of the beam~~

density of luminous intensity with respect to projected area in a specified direction at a specified point on a real or imaginary surface

$$L_v = \frac{dI_v}{dA \cos \theta},$$

where I_v is luminous intensity, A is area and θ is the angle between the normal to the surface at the specified point and the specified direction

Note 1 to entry: The spatial definition of luminance is shown in Figure 2; however, symbol I_e should be changed to I_v .

Note 2 to entry: ~~The unit used is: cd/m^2~~ The luminance is expressed in candela per square metre ($\text{cd} \cdot \text{m}^{-2} = \text{lm} \cdot \text{m}^{-2} \cdot \text{sr}^{-1}$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-35, modified – The note has been removed and a new Note has been added.~~ IEC 60050-845:2020, 845-21-050, modified – The symbol L has been removed, the angle symbol α has been replaced by θ , the notes have been removed except Note 8, that has become Note 2 and a new Note 1 has been added.]

3.3.8 luminous exitance

M_v

~~quotient of the luminous flux $d\Phi_v$ leaving an element of the surface containing the point, by the area dA of that element~~

~~$$M_v = \frac{d\Phi_v}{dA} = \int_{2\pi sr} L_v \cdot \cos \theta \cdot d\Omega \quad (dA: \text{small area})$$~~

~~Note 1 to entry: An equivalent definition could be given as follows: integral, taken over the hemisphere visible from the given point, of the expression $L_v \cdot \cos \theta \cdot d\Omega$, where L_v is the luminance at the given point in the various directions of the emitted elementary beams of solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point.~~

~~Note 2 to entry: The spatial definition of luminous exitance is shown in Figure 3; however, symbol ϕ_e should be changed to Φ_v .~~

density of exiting luminous flux with respect to area at a point on a real or imaginary surface

$$M_v = \frac{d\Phi_v}{dA}$$

where Φ_v is luminous flux and A is the area from which the luminous flux leaves

Note 1 to entry: Luminous exitance can be derived from the spectral radiant exitance distribution by

$$M_v = K_m \int_0^\infty M_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where K_m is maximum luminous efficacy, $M_{e,\lambda}(\lambda)$ is the spectral radiant exitance at wavelength λ and $V(\lambda)$ is spectral luminous efficiency.

Integral limits can be confined depending on the spectral responsivity of the detectors used as a sensor.

Note 2 to entry: The corresponding radiometric quantity is "radiant exitance". The corresponding quantity for photons is "photon exitance".

Note 3 to entry: The luminous exitance is expressed in lumen per square metre ($\text{lm} \cdot \text{m}^{-2}$).

[SOURCE: ~~IEC 60050-845:1987, 845-01-48, modified~~ — ~~Note 2 to entry has been added.~~ IEC 60050-845:2020, 845-21-081, modified – The symbol M has been removed.]

3.3.9 illuminance

E_v

~~quotient of the luminous flux $d\Phi_v$ incident on an element of the surface containing the point, by the area dA of that element~~

~~$$E_v = \frac{d\Phi_v}{dA} = \int_{2\pi sr} L_v \cdot \cos \theta \cdot d\Omega \quad (dA: \text{small area})$$~~

~~Note 1 to entry: An equivalent definition could be given as follows: integral, taken over the hemisphere visible from the given point, of the expression $L_v \cdot \cos \theta \cdot d\Omega$ where L_v is the luminance at the given point in the various directions of the incident elementary beams of solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point.~~

density of incident luminous flux with respect to area at a point on a real or imaginary surface

$$E_v = \frac{d\Phi_v}{dA}$$

where Φ_v is luminous flux and A is the area on which the luminous flux is incident

Note 1 to entry: Illuminance can be derived from the spectral irradiance distribution by

$$E_v = K_m \int_0^{\infty} E_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where K_m is maximum luminous efficacy, $E_{e,\lambda}(\lambda)$ is the spectral irradiance at wavelength λ and $V(\lambda)$ is spectral luminous efficiency.

Note 2 to entry: The corresponding radiometric quantity is "irradiance". The corresponding quantity for photons is "photon irradiance".

Note 3 to entry: The illuminance is expressed in lux ($\text{lx} = \text{lm} \cdot \text{m}^{-2}$).

Note 4 to entry: The spatial definition of illuminance is shown in Figure 4; however, symbol Φ_e should be changed to Φ_v .

[SOURCE: ~~IEC 60050-845:1987, 845-01-38, modified – Note 2 to entry has been added.~~ IEC 60050-845:2020, 845-21-060, modified – The symbol E has been removed and Note 4 has been added.]

3.4 Terms and definitions relating to the measurement of the thermal quantity

3.4.1 thermal resistance

quotient of the difference between the virtual temperature of the device and the temperature of a stated external reference point, by the steady-state power dissipation in the device

[SOURCE: IEC 60050-521:2002, 521-05-13]

3.4.2 electrical thermal resistance

$R_{\text{th}(j-X)\text{el}}$

quotient of the difference in the thermodynamic temperature between the junction temperature T_j and the reference point temperature T_X , by the electrical power dissipation P

$$R_{\text{th}(j-X)\text{el}} = \frac{T_j - T_X}{P}$$

Note 1 to entry: The electrical thermal resistance is expressed in kelvin per watt ($\text{K} \cdot \text{W}^{-1}$).

3.4.3 real thermal resistance

$R_{\text{th}(j-X)\text{real}}$

quotient of the difference in the thermodynamic temperature between the junction temperature T_j and the reference point temperature T_X , by the heating power dissipation (the heating power dissipation is the electrical power dissipation minus the radiant flux)

$$R_{\text{th}(j-X)\text{real}} = \frac{T_j - T_X}{P - \Phi_e}$$

Note 1 to entry: The real thermal resistance is expressed in kelvin per watt ($\text{K} \cdot \text{W}^{-1}$).

3.5 Abbreviations

PCB printed circuit board
AC alternating current

DC direct current

4 Absolute maximum ratings

Absolute maximum ratings are shown in Table 1. They are specified at the ambient temperature or the reference point temperature $T_X = (25 \pm 3) ^\circ\text{C}$, unless otherwise stated.

These ratings are applicable to ~~the five types of LED as described in Clause 4~~ the six types as follows:

- a) LED package;
- b) LED flat illuminator;
- c) LED numeric display and alpha-numeric display;
- d) LED dot-matrix display;
- e) ~~I-LED (infrared-emitting diode)~~ IR LED;
- f) UV LED.

Table 1 – Absolute maximum ratings

Item	Symbol	Conditions	Ratings	Unit	To be applicable for LEDs of type					
					a)	b)	c)	d)	e)	f)
Allowed forward current ^a	I_F	–		mA	○	○	○	○	○	○
Total allowed forward current ^b	I_F	–		mA	○	○	○	○	○	○
Forward current lapse rate ^b	ΔI_F	–		mA/°C	○	○	○	○	○	○
Allowed forward pulse current ^{a, e}	I_{FPM}	Pw = Duty =		A	○	○	○	○	○	○
Total allowed forward pulse current ^{b, e}	I_{FPM}	Pw = Duty =		A	○	○	○	○	○	○
Allowed forward pulse current lapse rate ^{b, e}	ΔI_{FPM}	Pw = Duty =		A	○	○	○	○	○	○
Reverse voltage	V_R			V	○	○		○	○	○
Electrostatic discharge ^{b, f}	ESD	HBM		V	○	○			○	○
Allowed power dissipation ^b	P_D	$T_j =$ or $T_X =$		mW	○	○	○	○	○	○
Operating temperature ^c	T_j or T_X	–	~	°C	○	○	○	○	○	○
Storage temperature ^d	T_{stg}	–	~	°C	○	○	○	○	○	○
Soldering temperature	T_{sol}	–		°C	○	○	○		○	○

a	These values are specified for each segment.
b	These items are specified when necessary.
c	The operating temperature is specified based on junction temperature T_j or reference point temperature T_X at X. Reference point X shall be selected according to the purpose. Reference point temperatures are described as T_c for case, T_s for soldering point and T_a for atmosphere.
d	The storage temperature is specified for ambient temperature.
e	Pw = pulse width.
f	HBM/ESD = human body model / electrostatic discharge test (IEC 60749-26).

5 Electrical and optical characteristics

Electrical and optical characteristics are shown in Table 2. They are specified at the ambient temperature or the reference point temperature $T_X = (25 \pm 3) ^\circ\text{C}$, unless otherwise stated.

These electrical and optical characteristics are applicable to ~~the five types of LED as described in Clause 1~~ the six types as follows:

- a) LED package;
- b) LED flat illuminator;
- c) LED numeric display and alpha-numeric display;
- d) LED dot-matrix display;
- e) ~~I-LED (infrared-emitting diode)~~ IR LED;
- f) UV LED.

Table 2 – Electrical and optical characteristics

Item	Symbol	Measuring method	Conditions	Characteristics			Unit	To be applicable for ^a					
				min.	typ.	max.		a)	b)	c)	d)	e)	f)
Forward voltage	V_F	see 6.2	$I_F = \dots \text{mA}$	–			V	○	○	○	○	○	○
Reverse current	I_R	see 6.5	$V_R = \dots \text{V}$	–	–		μA	○	○	○	○	○	○
Luminous flux ^b	Φ_v	see 6.10	$I_F = \dots \text{mA}$				lm	○	○	○	○		
Radiant flux ^c	Φ_e	see 6.11	$I_F = \dots \text{mA}$				mW					○	○
Luminous intensity ^{b, d}	I_v	see 6.12	$I_F = \dots \text{mA}$				mcd	○	○	○			
Radiant intensity ^{bc}	I_e	see 6.13	$I_F = \dots \text{mA}$				mW/sr					○	○
Luminance ^{ed}	L_v	see 6.14	$I_F = \dots \text{mA}$				cd/cm ²		○	○	○		
Peak emission wavelength ^e	λ_p	see 6.15	$I_F = \dots \text{mA}$				nm	○	○	○	○	○	○
Spectrum width of half value	$\Delta\lambda$	see 6.15	$I_F = \dots \text{mA}$	–		–	nm	○	○	○	○	○	○
Dominant emission wavelength ^e	λ_d	see 6.16	$I_F = \dots \text{mA}$				nm	○	○	○	○		
Chromaticity ^{ef}	x, y	see 6.16	$I_F = \dots \text{mA}$				–	○	○	○	○		
Cut-off frequency ^{d,e,f,g}	f_c	see 6.9	$I_F = \dots \text{mA}$ $I_p(f_0) = \dots \text{mA}$ $f_0 = \dots \text{MHz}$	–			MHz					○	○

Item	Symbol	Measuring method	Conditions	Characteristics			Unit	To be applicable for ^a					
				min.	typ.	max.		a)	b)	c)	d)	e)	f)
Thermal resistance _{d- f, h, i}	$R_{th(j-X)el}$	see 6.7	$P_D = \dots \text{ mW}$	–		–	K/W	○				○	○
	$R_{th(j-X)real}$	see 6.7	$P_D = \dots \text{ mW}$	–		–	K/W	○				○	○
Power efficiency _{f, j}	η_{PE}	IEC 60747-5-8	$I_F = \dots \text{ mA}$	–		–	–	○				○	○
Full width half maximum of an intensity ^k	$2\theta_{1/2}$	see 6.17	$I_F = \dots \text{ mA}$		–		°	○				○	○

^a These values are specified for each segment.

^b ~~Either radiant intensity or luminous flux is specified.~~

^c ~~Either luminance or luminous intensity is specified.~~

^b Either luminous intensity or luminous flux or both of them is specified.

^c Either radiant intensity or radiant flux or both of them is specified.

^d Either luminance or luminous intensity or both of them is specified.

^e Either peak emission wavelength or dominant emission wavelength or both of them is specified.

^{df} These items are specified when necessary.

^{eg} Either cut-off frequency or response time (rise time, fall time) is specified.

^{fh} Reference point X is selected according to the purpose.

Thermal resistances are described using reference points $R_{th(j-c)}$ for case, $R_{th(j-s)}$ for solder point and $R_{th(j-a)}$ for ambient.

ⁱ The following measurement condition should be described:

- measuring method (heating method or cooling method);
- the configuration, size and material of the PCB that the test LED is mounted on;
- the thickness and area of the pattern (copper) that is on the PCB;
- the size, material and fin of the attached heat sink (if appropriate).

^j It should be specified for LEDs with power consumption $\geq 0,5 \text{ W}$ and power efficiency $\geq 10 \%$.

^{gk} The radiation pattern of LEDs is shown with a figure.

6 Measuring method

6.1 Basic requirements

6.1.1 Measuring conditions

The measuring conditions are the following:

a) Temperature

~~If not specified,~~ Measurements shall be made at an ambient (T_a) or reference point temperature (T_X) of $(25 \pm 3) ^\circ\text{C}$ in a condition of ~~free air~~ natural convection unless otherwise specified.

b) Humidity

~~When humidity condition is not specified,~~ Relative humidity shall be between ~~45~~ 25 % and ~~85~~ 75 % unless otherwise specified.

c) Atmospheric condition

Atmospheric condition shall be between 86 kPa and 106 kPa unless otherwise specified.

d) Precaution

In some cases, measurements change because of heat generation in the test LED over time. In that case, it is necessary to decide on the measurement time, otherwise the measurement shall be performed after reaching thermal equilibrium.

Thermal equilibrium may be considered to have been achieved if doubling the time between the application of power and the measurement causes no change in the indicated result within the precision of the measurement instruments.

6.1.2 Measuring instruments and equipment**6.1.2.1 General**

The measuring instruments and equipment are specified in 6.1.2.2 to 6.1.2.7.

6.1.2.2 Power supplies

DC power-supply ripple shall be less than 3 %. In addition, the impedance value of the power supply shall not affect the measurement.

6.1.2.3 Instruments for electric characteristics and measuring instruments

When the accuracy is not specified, the instrument shall be as specified in IEC 60051 (all parts). A digital instrument and the measuring instrument shall have an accuracy either equalling or surpassing IEC 60051 (all parts), and the impedance shall be such that the influence on the measurement system can be ignored. ~~However, this is not the case in the following situations:~~

- ~~a) when no serious influence affects a measurement result;~~
- ~~b) when no serious influence affects a judgment of result.~~

NOTE Instead of the semiconductor electric characteristic measurement with the set of power supply and current source, the source monitor unit (SMU) that combines voltage/current source and digital measurement functions, or SMU system, has become the industry-wide standard. The measurement with SMU is suitable for high-accuracy measurements, such as in 6.5.

6.1.2.4 Standard light source

A light source for the photometry with high stability, high reproducibility and with an appropriate photometric value shall be used.

6.1.2.5 Measuring instruments for photometry

One of the following instruments shall be used:

- a) A ~~monochrometer~~monochromator-type instrument (a wavelength scanning type monochromatic light spectrophotometer):

A spectrophotometer that measures a spectrum by turning a diffraction grating, and taking light of a specific wavelength through a slit sequentially and selectively.

- b) A ~~polychromator~~polychromator-type instrument (many wavelength spectrophotometer):

A spectrophotometer which measures a spectrum with a detector at the same time using a one-dimensional photodiode array from the diffraction light out of a fixed diffraction grating.

- c) A filter-type instrument ($V(\lambda)$ spectrophotometer):

A photometer which has characteristics that are similar to spectral luminous efficiency, without using a spectrum optical system. This photometer comprises a photoelectric tube, a photomultiplier or a photoelectromotive force device whose sensitivity distribution on the light receiving side is flat and stable with a filter for visual sensitivity revision. In using this filter-type photometer, the measuring light shall be monochromatic, and the wavelength range of objective light should be within the wavelength range of the measuring instrument.

NOTE The filter-type photometer is not suitable for the photometry of the following products:

- product which has a light mixing method using excited light emission from the LED die and the fluorescent substance applied onto the LED die (phosphor based LEDs), or
- product of a many-wavelength light emission method equipped with different LEDs of a plurality of emission spectra.

6.1.2.6 Measuring instruments for radiometry

The measuring instruments for radiometry are the following:

- a) A ~~monochrometer~~ **monochromator** type instrument (a wavelength scanning type monochromatic light radiometer):

A spectroradiometer that measures a spectrum turning a diffraction grating, and taking light of a specific wavelength through a slit sequentially and selectively.

- b) A ~~polychrometer~~ **polychromator** type instrument (many wavelength radiometer):

A spectroradiometer which measures a spectrum with a detector at the same time using a one-dimensional photodiode array from the diffraction light out of a fixed diffraction grating.

- c) Optical power meter:

A radiometer consisting of a phototube, a photomultiplier or a photoelectromotive-force device. It provides a flat and stable response sensitivity characteristic in a wavelength range of measurement light, and is calibrated so as not to keep a weighting of the response sensitivity for the wavelength, without using a spectrum optical system. In using this radiometer, the measuring light shall be monochromatic, and the wavelength range of objective light should be within the wavelength range of the measuring instrument.

6.1.2.7 Devices used for the emission spectrum characteristic measurement

Devices with necessary wavelength bandwidth and resolution for the measurement of the LED under test shall be used.

6.1.3 Essential requirements

6.1.3.1 General

The essential requirements are given in 6.1.3.2 to 6.1.3.4.

6.1.3.2 Point with zero electric potential

The point with zero electric potential to apply the potential on each electrode of the LED under test shall be the cathode terminal.

6.1.3.3 Power supply

The power supply shall be the following:

- a) Applied voltage

The applied voltage to a certain electrode is the potential difference between the electrode and the point with zero electric potential.

- b) Supply voltage

The supply voltage is the voltage supplied to a circuit including the LED under test.

- c) Polarity

The polarity of all electric potential is specified by the polarity for the point with zero electric potential.

6.1.3.4 Shading

During the measurement, suitable shading shall be given so that the light from the outside or other emission does not affect the measurements.

6.1.4 General precautions

The general precautions are as follows:

a) Absolute maximum rating

Even a second, external stress shall not exceed this value to guarantee normal operation of the LED under test.

b) Transient behaviour

Even in a transient state, the voltage and current shall not exceed the value of the absolute maximum rating.

c) Consideration for the heating

In the event that the LED measurement needs to avoid a measurement error produced by heat generation in the LED under test during a measurement period, the measurement shall be performed in a pulse condition.

When absolutely necessary, indicate "Pulse measurement", and specify the pulse state.

d) Consideration for ultraviolet radiation

Provisions for the prevention and control of the risk of ultraviolet radiation.

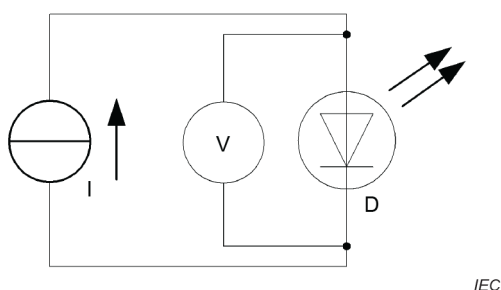
6.2 Forward voltage (V_F) measurement

6.2.1 Purpose

To measure the forward voltage of the LED when a specified forward current is applied.

6.2.2 Circuit diagram

The circuit diagram is shown in Figure 6.



Key

I constant current source

V voltmeter

D light emitting diode being measured

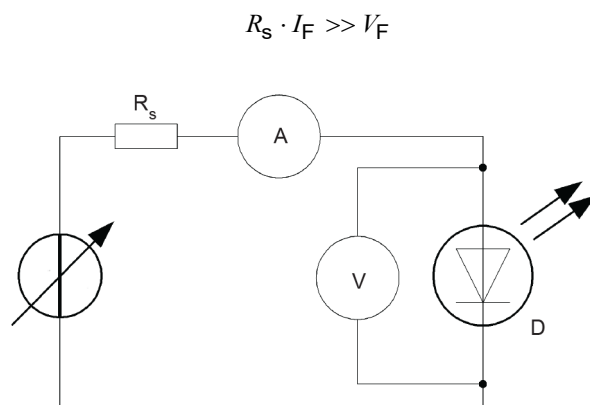
Figure 6 – Circuit diagram for V_F measurement

6.2.3 Requirements

A constant current source shall in principle be used for the measuring circuit.

If the forward current ~~needs to be~~ is set to the rated value using a constant voltage source and a current-limiting resistor, ~~design~~ the circuit diagram as shown in Figure 7 shall be applied.

In such a case, to avoid changes in the forward voltage resulting from accumulated heat in the test LED and corresponding changes in the set current, set the impedance for the drive side higher.



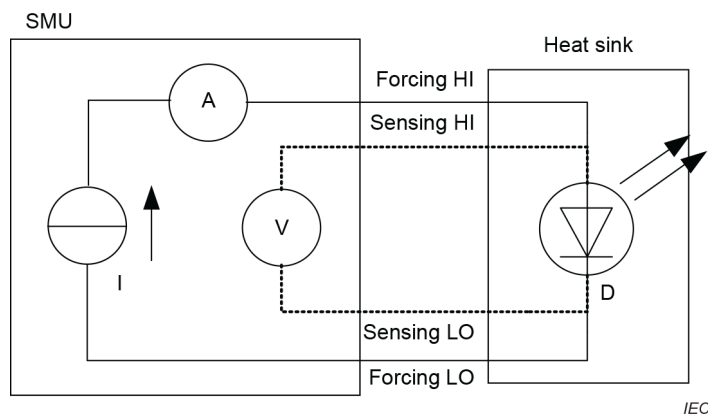
IEC

Key

- A ammeter
- V voltmeter
- R_s current limiting resistor
- D light emitting diode being measured

Figure 7 – Circuit diagram for V_F measurement with a constant voltage source and a current-limiting resistor

In the case of high driving power LED (high power LED, high-flux LED), the driving current rating is usually specified in a condition using a heat sink instead of free air condition. For the measurement, the LED shall be mounted on an appropriate heat sink, and be measured using Kelvin contact in order to reduce measurement errors resulting from contact resistance and wiring impedance. An example of measurement using SMU is shown in Figure 8.



IEC

Key

- SMU source measurement unit
- I constant current source
- A ammeter
- V voltmeter
- D light emitting diode being measured (high driving current LED)

Figure 8 – Circuit diagram for V_F measurement using an SMU

6.2.4 Measurement procedure

Forward voltage (V_F) is measured when the specified forward current (I_F) is applied to the test LED.

6.2.5 Precautions to be observed

See 6.1.

6.2.6 Specified conditions

The specified conditions are as follows:

- forward current and the driving conditions;
- ambient temperature (T_a), case temperature (T_c) or reference point temperature (T_X).

6.3 Reverse voltage (V_R) measurement

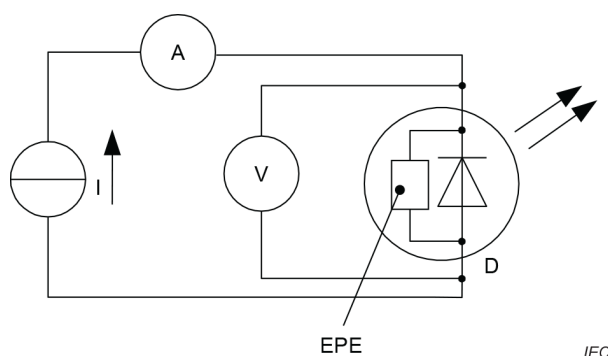
6.3.1 Purpose

To measure the reverse voltage of the LED when a specified reverse current is applied.

This measurement is performed for the reverse characteristics test in the case of LED mounting a parallel-connected Zener diode for electrostatic discharge protection. In measuring voltage at a rated current, thoughtless measurement of the reverse voltage for a general LED without any protection circuit should not be performed to avoid a stress voltage at breakdown voltage or above the absolute maximum rating of reverse voltage.

6.3.2 Circuit diagram

The circuit diagram is shown in Figure 9.



Key

I_R	constant current source
V	voltmeter
A	ammeter
D	light emitting diode being measured
EPE	electrostatic protection element

Figure 9 – Circuit diagram for V_R measurement

6.3.3 Measurement procedure

Reverse voltage (V_R) is measured when the specified reverse current (I_R) is applied to the test LED.

6.3.4 Precautions to be observed

See 6.1.

6.3.5 Specified conditions

The specified conditions are as follows:

- reverse current (I_R);
- ambient temperature (T_a), case temperature (T_c) or reference point temperature (T_X).

6.4 Differential resistance (r_f) measurement

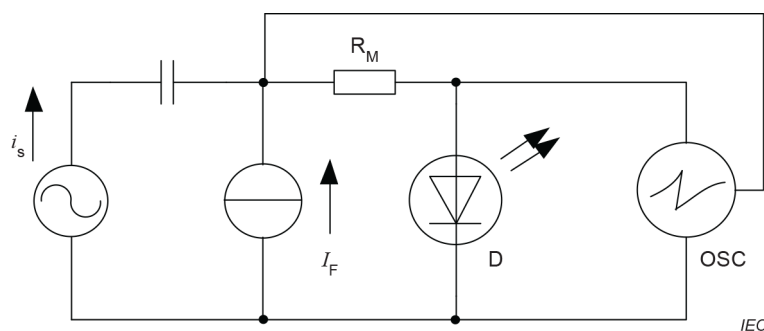
6.4.1 Purpose

To measure the differential resistance of the LED in specified measuring conditions.

NOTE Generally the series resistance of a LED is greater than that of a general rectifier diode. This measurement is performed to determine required driving voltage and to design the driving circuit for a power LED or a high flux LED driven by high current.

6.4.2 Circuit diagram

The circuit diagram is shown in Figure 10.



Key

R_M	current detect resistor
i_s	superimposed AC
I_F	forward DC
OSC	oscilloscope
D	light emitting diode being measured

Figure 10 – Circuit diagram for r_f measurement

6.4.3 Requirements

In principle, the differential resistance shall be measured in such a manner that the AC is superimposed on the specified DC.

NOTE If the region in which the forward characteristic curve of the LED can be substantially regarded as a straight line near the specified current, the measurement can also be performed by calculating the resistance value based on the gradient of the current and voltage values between two points near the region.

6.4.4 Measurement procedure

The specified forward DC and AC to be superimposed are applied to the test LED.

After measurement of forward current and forward voltage waveforms of the LED with a calibrated oscilloscope, the differential resistance is calculated using their amplitude by the following formula:

$$r_f = \frac{\Delta V_F}{\Delta I_F}$$

where

ΔV_F is the amplitude of forward voltage waveform;

ΔI_F is the amplitude of forward current waveform.

6.4.5 Precautions to be observed

The precautions to be observed are as follows:

- a) The frequency of AC to be superimposed should be around 10 kHz so that it will not affect the measurement.
- b) The forward current including AC should be as high as possible within the rated value.
- c) For details other than those provided in a) and b) above, see 6.1.

6.4.6 Specified conditions

The specified conditions are as follows:

- the value of forward current and the amplitude of AC to be superimposed, or the amplitude modulation factor $(M = (\max|i_s|) / I_F)$;
- ambient temperature (T_a), case temperature (T_c) or reference point temperature (T_x).

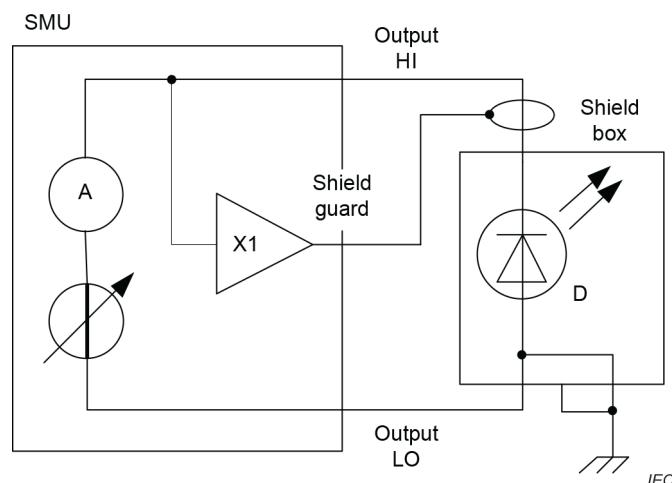
6.5 Reverse current (I_R) measurement

6.5.1 Purpose

To measure the reverse current of the LED at a specified reverse voltage.

6.5.2 Circuit diagram

Figure 11 is an example using the SMU.

**Key**

SMU	source measurement unit
A	ammeter
X1	buffer amplifier
D	light emitting diode being measured

Figure 11 – Circuit diagram for I_R measurement**6.5.3 Provisions**

Since the reverse current is extremely small within the rated applied voltage, the measurement becomes the "minute current measurement". It is desirable to have a shield to eliminate foreign noise, prevent leaks at cables and the connecting terminals, and prevent any electrostatic discharge. If the SMU has a current limiter function, it is desirable to set the current limiter to prevent the test LED from being destroyed.

6.5.4 Measurement procedure

The reverse current (I_R) is measured when specified reverse voltage (V_R) is applied to the test LED.

6.5.5 Precautions to be observed

See 6.1.

6.5.6 Specified conditions

The specified conditions are as follows:

- reverse voltage (V_R);
- ambient temperature (T_a), case temperature (T_c) or reference point temperature (T_x).

6.6 Measurement of capacitance between terminals (C_t)**6.6.1 General**

Two measuring methods are specified:

- measurement using LCR meter;
- measurement using AC bridge.

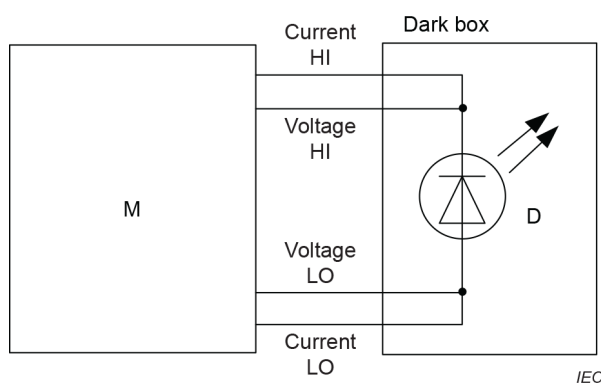
6.6.2 Measurement using LCR meter

6.6.2.1 Purpose

To measure the capacitance between terminals of the LED when the specified reverse voltage is applied (including zero bias voltage).

6.6.2.2 Circuit diagram

The circuit diagram is shown in Figure 12.



Key

D light emitting diode being measured

M LCR meter (or impedance analyzer) using a self-balancing bridge system

Figure 12 – Circuit diagram for C_t measurement

6.6.2.3 Requirements

The self-balancing bridge system represents a system in which the impedance is calculated using the phase information of the signal source and comparison of the voltage of the AC signal source with the value of the voltage that is converted from the current flowing along the test sample.

6.6.2.4 Measurement procedure

The capacitance between the terminals (C_t) is measured when the specific DC bias voltage is applied to the test LED.

6.6.2.5 Precautions to be observed

See 6.1.

6.6.2.6 Specified conditions

The specified conditions are as follows:

- DC bias voltage;
- frequency to be measured (f) – usually 1 MHz is used;
- ambient temperature (T_a), case temperature (T_c) or reference point temperature (T_X).

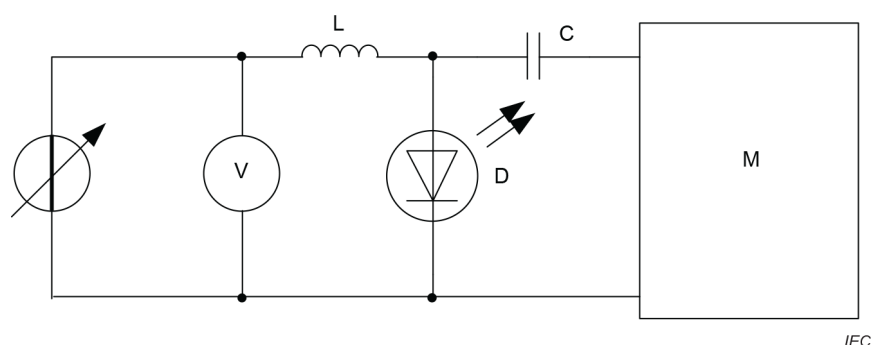
6.6.3 Measurement using AC bridge

6.6.3.1 Purpose

To measure the capacitance between the terminals of the LED when the specified reverse voltage is applied other than for a zero-bias voltage.

6.6.3.2 Circuit diagram

The circuit diagram is shown in Figure 13.



Key

- D light emitting diode being measured
- M AC bridge
- L inductor
- C capacitor

Figure 13 – Circuit diagram for C_t measurement

6.6.3.3 Requirements

The bias circuit for the test LED shall satisfy the following condition in order to maintain the accuracy of the measurement and the measuring signal voltage shall be a signal that is sufficiently smaller than the bias voltage.

$$C \gg C_X \gg \frac{1}{(2\pi f)^2 L}$$

where

C_X is the capacitance of the test LED;

f is the measuring frequency.

6.6.3.4 Measurement procedure

The capacitance between terminals (C_t) is measured when the specific DC bias voltage is applied to the test LED.

6.6.3.5 Precautions to be observed

See 6.1.

6.6.3.6 Specified conditions

The specified conditions are as follows:

- DC bias voltage;
- measuring frequency (f) – usually 1 MHz is used;
- ambient temperature (T_a), case temperature (T_c) or reference point temperature (T_X).

6.7 Measurement of junction temperature (T_j) and thermal resistance

($R_{th(j-X)el}$, $R_{th(j-X)real}$)

6.7.1 Purpose

To measure the junction temperature and the thermal resistance under ~~established~~ specified conditions.

6.7.2 Measurement principle

~~While specified total power dissipation (P) is applied to the LED keeping the specified condition of heat radiation and ambient temperature, the junction temperature (T_j) and the reference point temperature (T_X) at reference point X are measured. Thermal resistance $R_{th(j-X)}$ is calculated from the following formula.~~

$$R_{th(j-X)} = \frac{T_j - T_X}{P}$$

~~The reference point shall be chosen according to the purpose and the reference point temperature (T_X) will equal, for example, that of the ambient temperature (T_a), the case temperature (T_c) or the soldering position temperature (T_s).~~

~~T_j is estimated by using the temperature dependence of the forward voltage (V_F) as a temperature sensitive parameter. The temperature dependence of forward voltage is obtained by the measurement of forward voltage (V_F) at different points of ambient temperature. The rise of junction temperature is estimated by the change in forward voltage (V_F) induced by total power dissipation (P).~~

~~The thermal resistance is classified into "saturated thermal resistance" and "transient thermal resistance" as follows depending on time duration (t_p) of total power dissipation (P).~~

~~a) Saturated thermal resistance~~

~~The thermal resistance under the condition in which the total power dissipation (P) is continuously applied until the thermal equilibrium is reached.~~

~~b) Transient thermal resistance~~

~~The thermal resistance when power dissipation is applied for a short period of time. The value of thermal resistance depends on time duration (t_p) of power.~~

While specified electrical power dissipation (P) is applied to the device being measured, the electrical thermal resistance $R_{th(j-X)el}$ is calculated by using the junction temperature (T_j) and the reference point temperature (T_X) as follows.

$$R_{th(j-X)el} = \frac{T_j - T_X}{P}$$

Change in the forward voltage (V_F) induced by electrical power dissipation (P) causes the rise of T_j . T_j is derived from the temperature dependence of the forward voltage (V_F) as a temperature sensitive parameter. The temperature dependence of the forward voltage is obtained by measuring the forward voltage (V_F) at different ambient temperatures.

The real thermal resistance $R_{th(j-X)real}$ is calculated by using the heating power dissipation that is the subtraction of the radiant flux from the electrical power dissipation. It can be derived from the optical energy conversion efficiency (power efficiency η_{PE}) as follows.

$$R_{\text{th(j-X)real}} = \frac{T_j - T_X}{P(1 - \eta_{\text{PE}})}$$

However, it should be noted that power efficiency η_{PE} is a temperature dependent parameter.

To calculate the actual junction temperature more accurately, η_{PE} shall be determined under actual usage conditions by considering its temperature dependence.

η_{PE} shall be derived separately according to the temperature at the reference point X and the driving current.

Figure 14 shows an example of the temperature dependence of η_{PE} .

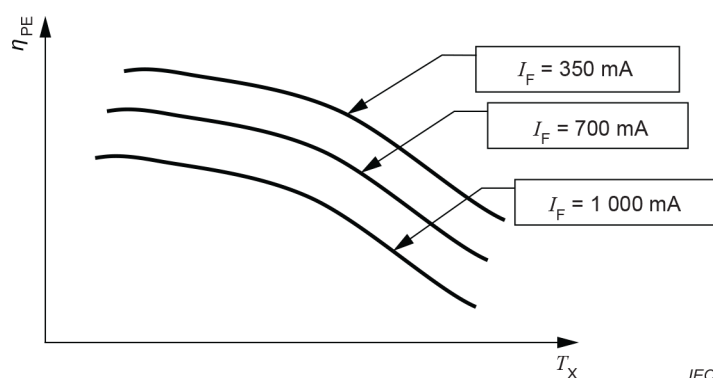


Figure 14 – An example of the temperature dependence of η_{PE}

Reference point X shall be on the heat flow path of the substrate mounted LED, and the temperature shall be measured when the LED is lit.

For example, for a 2-terminal LED device, the reference point X should be a terminal side with higher heat flow, namely the soldering point of the terminal on which the LED die is mounted.

However, when it is difficult to locate the reference point X in such an area, the reference point shall be set at the location where the heat flow rate is as large as possible.

The measured thermal resistance of a LED with appropriate heat sink shows a dependence on the heating time duration (t_p) as shown in Figure 15.

Figure 15 shows an example that two saturation regions are observed.

The first saturated region indicates the state in which the case (or the soldering point) has almost warmed up, while the last saturated region indicates the process until the whole test sample has reached the steady state.

That is, the two saturation regions above correspond to the junction-to-case thermal resistance $R_{\text{th(j-c)}}$ or the junction-to-soldering point thermal resistance $R_{\text{th(j-s)}}$ and the junction-to-ambient thermal resistance $R_{\text{th(j-a)}}$, respectively.

Figure 16 shows the cumulative thermal capacitance versus cumulative thermal resistance characteristics (generally referred to as the "structural function") determined by mathematically converting the data given in Figure 15.

In the structural function, Figure 16, the part with large inclination such as the one between B and C corresponds to one of the structural layers of the tested LED package which have low thermal resistance and high thermal capacitance values. On the other hand, the part with low inclination in the structural function such as the one between A and B corresponds to one of the structural layers of the tested LED package which have high thermal resistance and low thermal capacitance values.

This means that the point where the inclination changes in the structural function reveals the difference in the structure. By using this property, the thermal resistance and the thermal capacitance can be estimated separately for each structural layer of the LED package.

Therefore, it is recommended to use the cumulative thermal capacitance versus cumulative thermal resistance characteristics (structural function) for the thermal design of a pulse-driven systems.

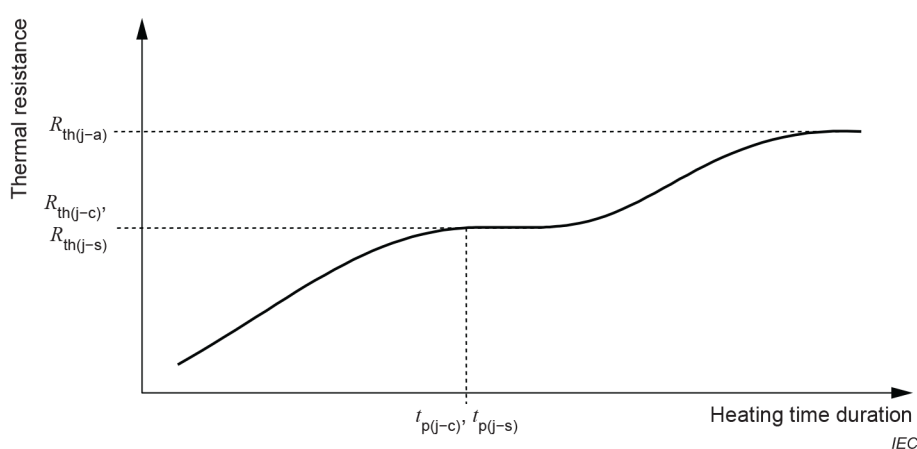


Figure 15 – Heating time duration dependence of the measured thermal resistance

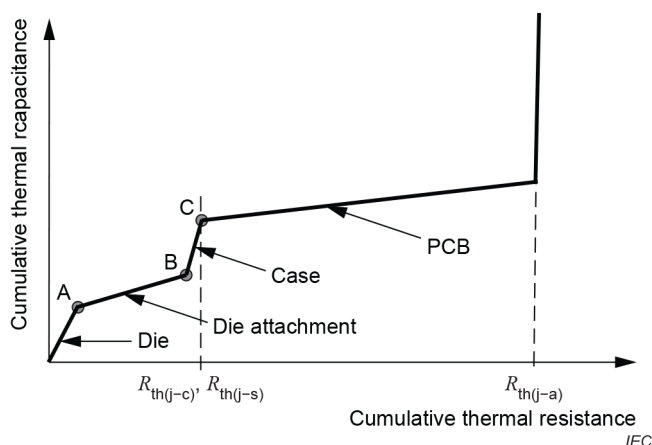


Figure 16 – Cumulative thermal capacitance versus cumulative thermal resistance characteristics (structural function)

6.7.3 Measurement procedure

6.7.3.1 Preparation

The test LED shall be mounted on PCB and/or thermally managed. Measuring atmosphere around the test LED shall be natural convection.

If the LED is to be enclosed in a box to prevent effect from external heat and wind, the box size and material shall be selected appropriately according to the degree of heat. If the measuring

is not performed in a dark environment, influence of the photoelectric effect on the measurement accuracy shall be checked in advance.

6.7.3.2 Measurement of temperature coefficient of forward voltage (V_F)

~~The relationship between the forward voltage (V_F) and junction temperature (T_j) is obtained as the temperature coefficient by the following procedure.~~

~~At first, the LED is held in a variable temperature oven and left until it is considered to be at equilibrium as T_j becomes equal to the oven temperature. Then the forward voltage (V_F) is measured at a small measuring current (I_M) so that the temperature rise by the measurement is negligible.~~

~~Subsequently, several points of the forward voltage are measured sequentially corresponding to the varied oven temperature as a temperature dependent characteristic of the forward voltage.~~

Temperature coefficient of the forward voltage (V_F) shall be measured by using the following procedure.

The LED being measured is held in a variable temperature oven. Then wait until reaching at thermal equilibrium as T_j becomes equal to the oven temperature. Then measure the forward voltage (V_F) at a small forward current (I_M). The forward current shall be small enough so that the junction temperature rise is negligible. Generally, approximately 1 mA per die should be applied for the measurement.

Subsequently, repeat the above procedure sequentially at different oven temperatures to get the temperature dependent characteristic of the forward voltage. Derive the temperature coefficient of the forward voltage from the measurement result.

NOTE In the case of LED with resistor, even though the measured temperature coefficient includes the temperature dependence of the resistor, the measured value is still considered to be the temperature coefficient of the LED.

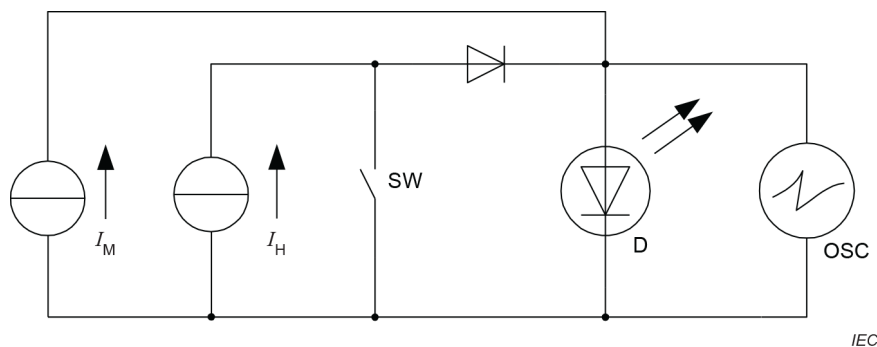
6.7.3.3 Measurement of change in forward voltage (V_F) induced by power dissipation (P)

~~The change in forward voltage (V_F) induced by the power dissipation (P) given on the LED is measured by the circuit shown in Figure 14 as an example.~~

There are two methods for the measurement of the change in the forward voltage (V_F) induced by the power dissipation (P) given on the LED. One is heating method (dynamic mode) and the other is cooling method (static mode). Both methods can be applicable for calculating the thermal resistance of the LED, but it shall be stated in the specification table that which method is used for the derivation of the thermal resistance.

Both methods use the measuring circuit shown in Figure 17. However, the two methods differ from each other in terms of how the electrical power dissipation (P) is applied and when the forward voltage (V_F) is measured after heating.

In these methods of measurement, the transient thermal resistance can be measured more quickly using the static mode, and the junction temperature may be slightly lower using the dynamic mode.



Key

I_M	measuring current
I_H	heating current
SW	switch
D	light emitting diode being measured
OSC	oscilloscope

Figure 17 – Circuit diagram for measurement of change in V_F

a) Heating method (dynamic mode)

Turn the SW on.

Apply a small measuring current (I_M) only to the LED where the junction temperature rise is negligible, and measure the forward voltage before heating (V_{F1}).

Turn the SW off for applying the heating current (I_H) superimposed on I_M at the same time.

The heating current is applied for power dissipation during a specified "heating time duration (t_p)".

Then, turn the SW on. In this situation, only the small measuring current (I_M) is applied to the LED.

Measure the forward voltage again (V_{F2}) just after the SW on.

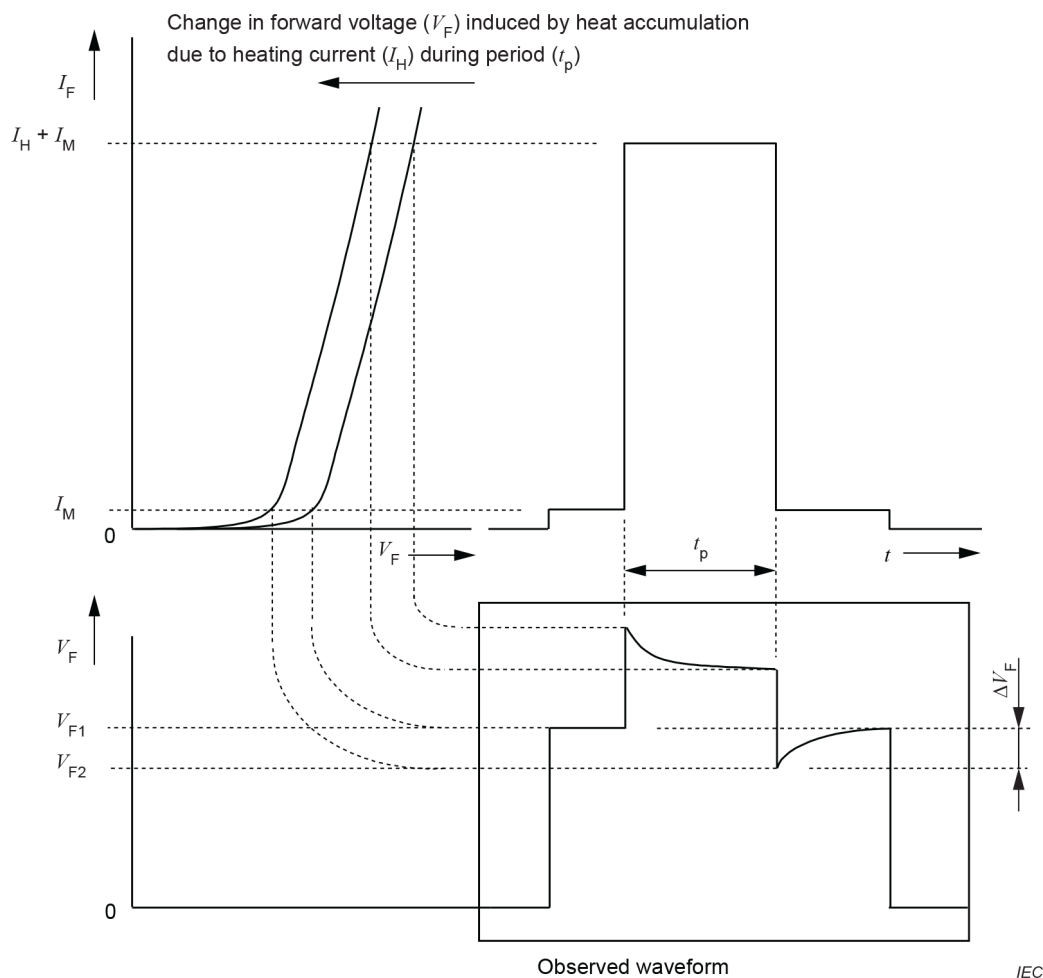


Figure 18 – Change in V_F during the measurement

The measured forward voltage V_{F2} just after the end of power dissipation is lower than the forward voltage V_{F1} before heating due to heat accumulation produced by power dissipation. However, V_{F2} will return to value V_{F1} afterwards.

The forward voltage change observed by a oscilloscope are shown in Figure 18.

The measurement timing of V_{F2} just after the end of heating shall be short enough in comparison with the thermal time constant of the test LED. However, since a transient ringing noise is superimposed onto the observed waveform due to the cut-off of the heating current (I_H), V_{F2} sampling is done after a certain delay time to avoid the influence of the ringing noise. The junction temperature T_j that is determined by using the dynamic mode is corresponds to specific delay time has passed, not immediately after the heating is off. Accordingly, junction temperature T_j may be slightly lower for some types of LED.

b) Cooling method (static mode)

Turn the SW off.

Heating current and a small measuring current are applied to the LED for a sufficiently long time until the system reaches the equilibrium state.

After heating current is off, namely just after turning the SW is on, measure the time variation in V_F .

In this situation, only the small measuring current (I_M) is applied to the LED.

Figure 19 shows an example of the measured time variation in V_F .

Since the forward voltage V_F that is observed immediately after the heating current (I_H) is off inevitably contains the transient vibration waveform, an accurate V_F value cannot be determined from the observed waveform.

An accurate V_F can be calculated by extrapolating the cooling behaviour which is linear to the square root of time as shown in Figure 20.

The junction temperature T_j is determined from the derived values by performing a conversion in accordance with 6.7.3.2. Details on this approach are provided in the JEDEC standards (JESD51-14).

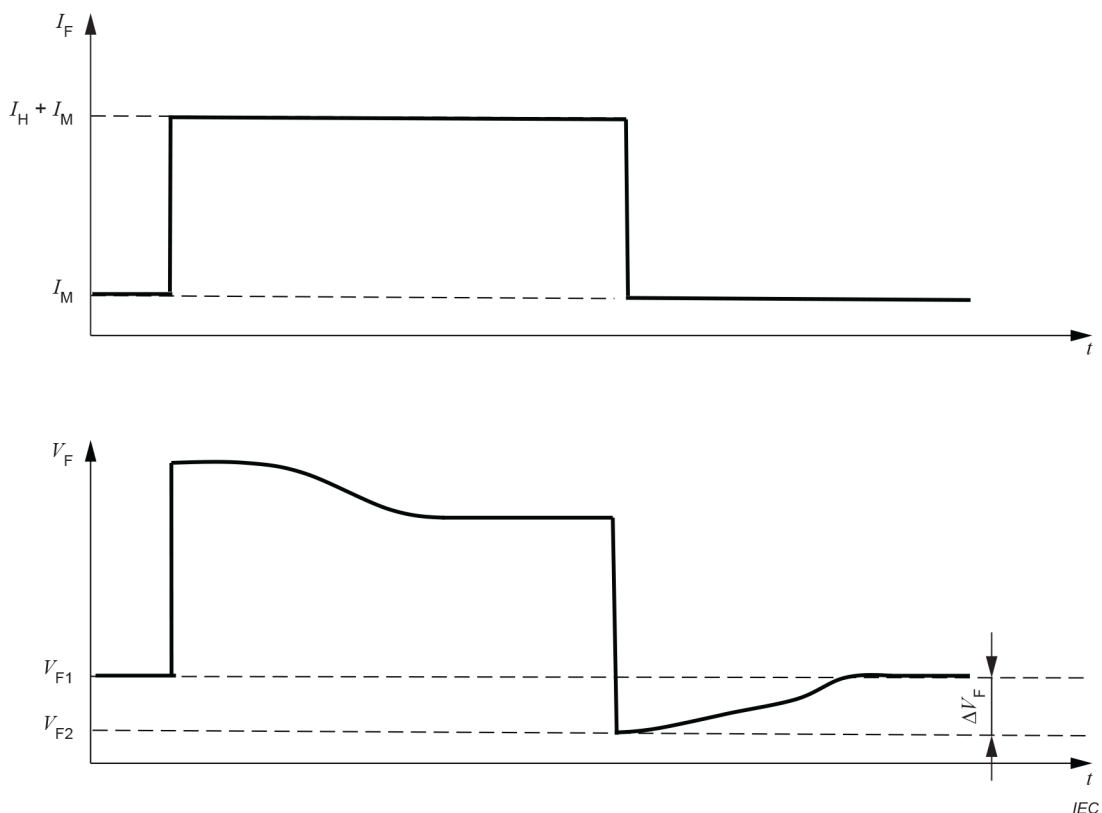


Figure 19 – Example of the time variation in V_F

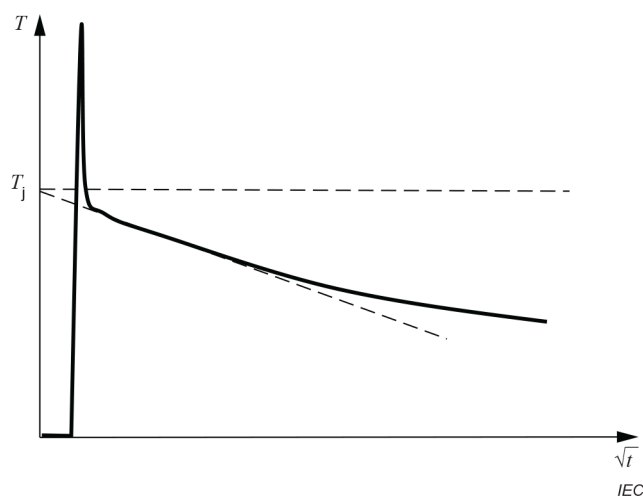


Figure 20 – Transient vibration waveform immediately after the heating is off

~~6.7.3.3 Thermal resistance measurement~~

~~6.7.3.3.1 Transient thermal resistance measurement~~

~~The switch is closed beforehand.~~

~~Only a small measuring current (I_M) is applied to the LED where the junction temperature rise is negligible, and the forward voltage (V_{F1}) before heating is measured with a calibrated DC oscilloscope.~~

~~When the switch is open, a heating current (I_H) is superimposed at the same time.~~

~~The heating current is applied for power dissipation during a specified “power dissipating time (t_p)”.~~

~~The switch is then closed.~~

~~Forward voltage (V_{F2}) just after the time of the return to only the “measurement current (I_M)” is measured again with the calibrated DC oscilloscope.~~

~~6.7.3.3.2 Saturated thermal resistance measurement~~

~~Close the switch beforehand.~~

~~Only a small measuring current (I_M) is applied to the LED where the junction temperature rise is negligible, and the forward voltage (V_{F1}) before heating is measured with the calibrated DC oscilloscope.~~

~~When the switch is open, the heating current (I_H) is superimposed at the same time.~~

~~The heating current is applied for power dissipation for a long time until the system reaches the equilibrium state.~~

~~Forward voltage (V_{F2}) just after the time of the return to only the “measurement current (I_M)” is measured again with the calibrated DC oscilloscope.~~

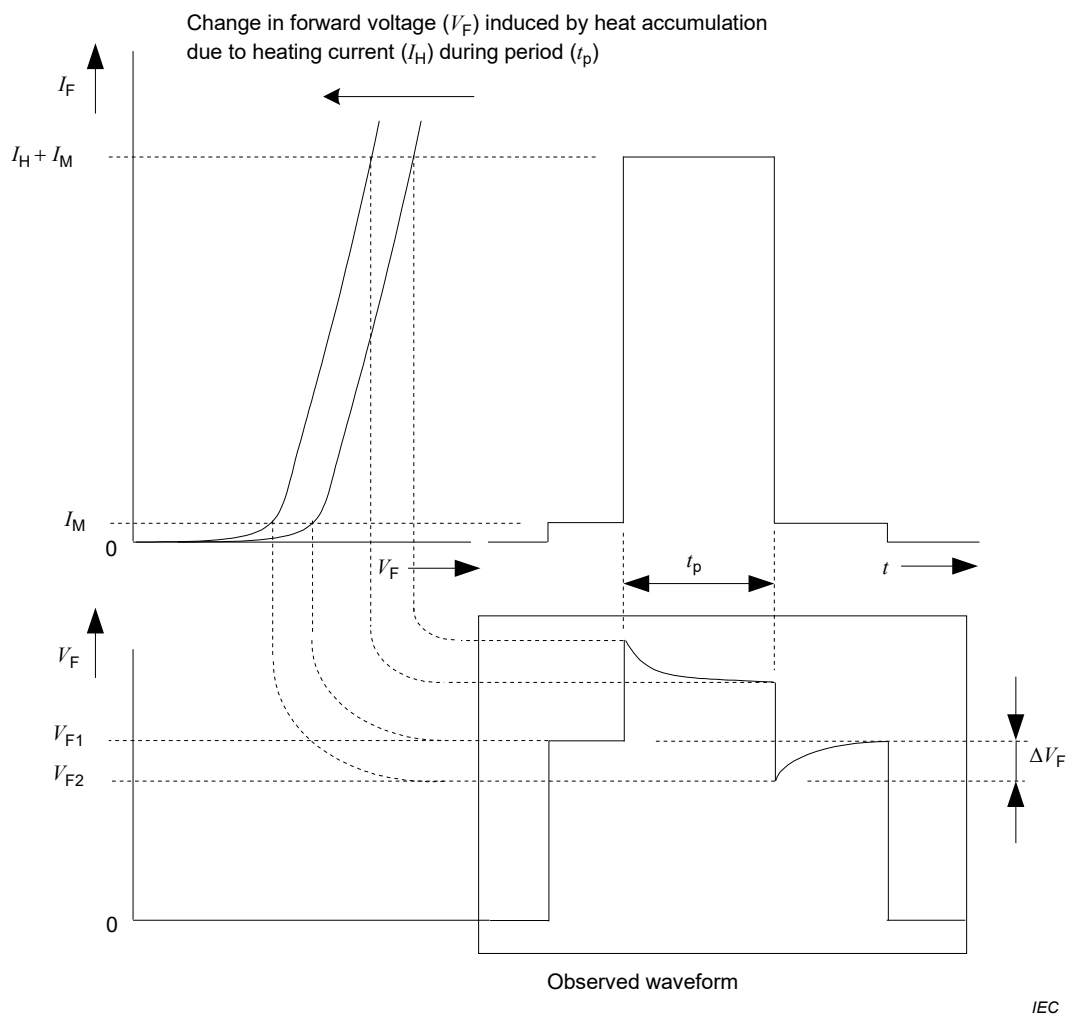


Figure 15 – Waveform of change in V_F

The measured forward voltage V_{F2} just after the end of power dissipation is lower than the forward voltage V_{F1} before heating due to heat accumulation that is produced by power dissipation. However, V_{F2} will return to value V_{F1} before the heating with cooling of junction temperature afterwards.

The forward voltage change and waveform observed by the DC oscilloscope are shown in Figure 15.

The measurement timing of V_{F2} just after the end of heating needs to be short enough in comparison with the thermal time constant of the test LED. However, since a transient ringing noise is superimposed onto the observed waveform due to the cut-off of the heating current (I_H), V_{F2} sampling is done after a certain delay time to avoid the influence of the ringing noise.

6.7.3.4 Measurement of the temperature at the reference point T_X

The temperature should be measured using a proper thermocouple.

For a measurement conducted using a thermocouple, its type (material) and wire size shall be carefully selected in order to prevent the measurement point from being cooled down by the thermocouple.

6.7.3.5 Calculation of thermal resistance

The thermal resistance from the junction to a certain reference point X, $R_{th(j-X)}$, is calculated using the following formula:

$$R_{th(j-X)} = \frac{T_j - T_X}{P} \approx \frac{\Delta V_F / b}{I_H \cdot V_F} (I_M \ll I_H)$$

where

T_j — is the junction temperature;

T_X — is the reference point temperature;

P — is the total power dissipation;

b — is the temperature coefficient of the forward voltage;

$\Delta V_F = |V_{F1} - V_{F2}|$.

Transient thermal resistance $R_{th(j-X)}$ of an LED which has an appropriate heat sink varies with the heating time (t_p) as shown in Figure 16.

Two saturated regions are observed in this example.

The first saturated region indicates the state in which the LED die has almost warmed up, while the last region indicates the process until the case (or the soldering point) has reached the steady state.

The two saturated regions reflect the junction to case thermal resistance $R_{th(j-c)}$ (or the junction to soldering point thermal resistance $R_{th(j-s)}$) and the junction to ambient thermal resistance $R_{th(j-a)}$, respectively.

Because the thermal resistance from the reference point is determined by t_p , the value of t_p shall be chosen in accordance with the purpose.

The thermal resistance of LEDs that the rated driving current establishes assuming use of the heat sink should be clearly specified by $R_{th(j-c)}$ or $R_{th(j-s)}$.

For measurement of the LED which has an appropriate heat sink, transient thermal resistance $R_{th(j-c)}$ (or $R_{th(j-s)}$) is measured by choosing $t_{p(j-c)}$ (or $t_{p(j-s)}$) as the value of t_p which is considered to be a thermal time constant until the case (or the soldering point) as shown in Figure 16.

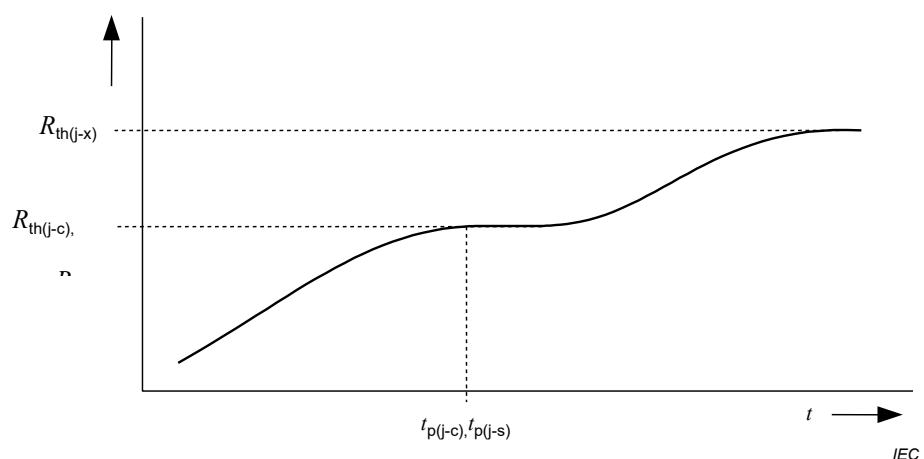


Figure 16 – Transient change in thermal resistance (double-logarithmic plots)

The thermal resistance from the junction to a certain reference point X, $R_{th(j-X)}$, shall be calculated using the following formula. The power efficiency η_{PE} should be measured at the same time when the thermal resistance is measured.

$$R_{th(j-X)el} \equiv \frac{T_j - T_X}{P} \approx \frac{\Delta V_F / b}{I_H \cdot V_F} (I_M \ll I_H)$$

$$R_{th(j-X)real} \equiv \frac{T_j - T_X}{P(1 - \eta_{PE})} \approx \frac{\Delta V_F / b}{I_H V_F (1 - \eta_{PE})} (I_M \ll I_H)$$

where

T_j junction temperature

T_X temperature at reference point X

P electrical power dissipation

ΔV_F $V_{F1} - V_{F2}$

b temperature coefficient for forward voltage

η_{PE} power efficiency

NOTE There are other ways to calculate the thermal resistance from the junction to the reference point.

This is a method in which the separate point in the structural function of a LED, which has different heat flow paths after the reference point, is regarded as the thermal resistance from the junction to the reference point.

In the JEDEC standards (JESD51-14), this approach is recommended as a method for calculating the thermal resistance from the junction of a semiconductor device to the rear surface of its package.

Since the precondition for this approach is that the heat flow paths before the separate point are identical, so this path is one-dimensional.

JESD51-14 explains that with a heat sink is attached to make the heat flow path one-dimensional, the heat flow path beyond the rear surface of the package can be changed by applying grease selectively.

According to JESD51-14, this separate point for the Structural function corresponds to the thermal resistance from the junction to the rear surface of the package.

This idea can be applied to a LED as follows. For example, taking a soldering point on the LED as a reference point, the LED is mounted on two types of PCB that have differently designed soldering pads, which allows the separate point to be determined. The two types of PCB can be one with a different pad size or one with a different copper thickness.