IEC 60747-5-11

Edition 1.0 2019-12

INTERNATIONAL STANDARD

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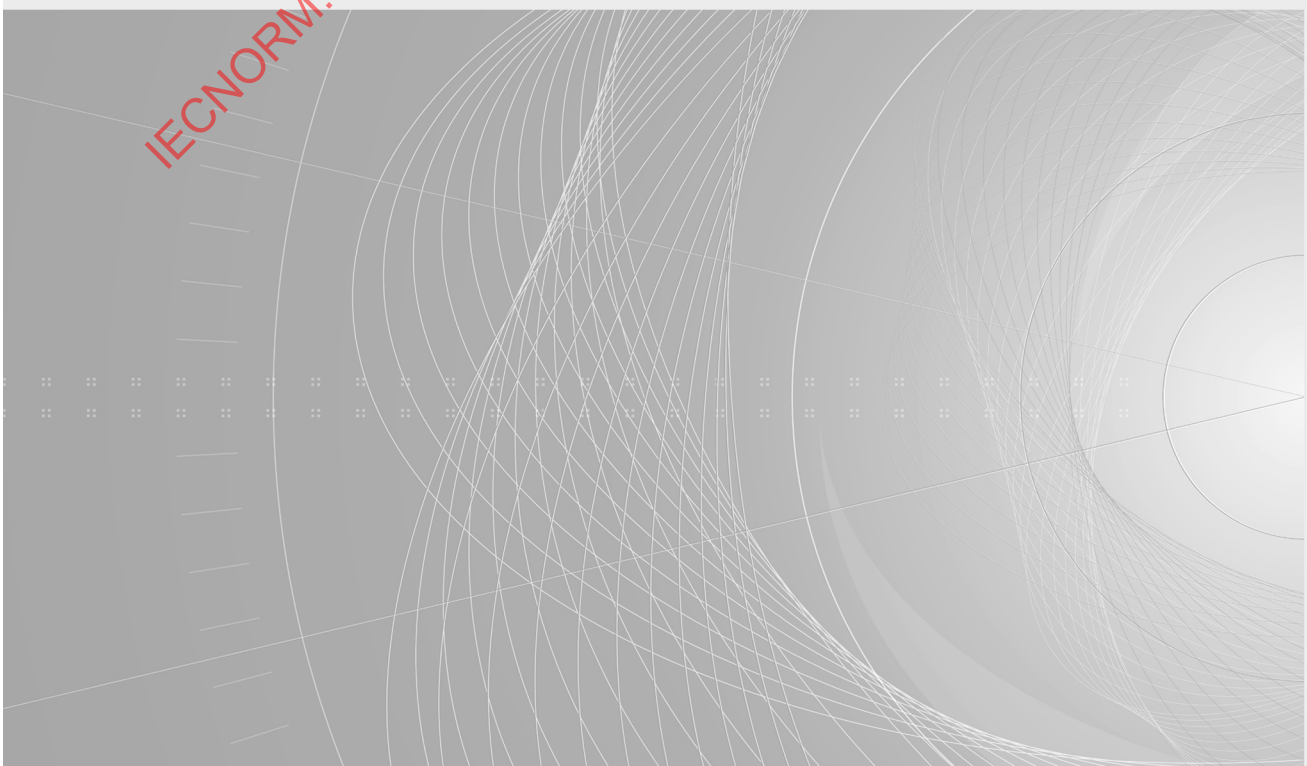
Semiconductor devices –
Part 5-11: Optoelectronic devices – Light emitting diodes – Test method of radiative and nonradiative currents of light emitting diodes



IEC 60747-5-11:2019-12(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 31.080.99

ISBN 978-2-8322-7657-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SEMICONDUCTOR DEVICES –

Part 5-11: Optoelectronic devices – Light emitting diodes – Test method of radiative and nonradiative currents of light emitting diodes

FOREWORD

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International Standard IEC 60747-5-11 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices.

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

CDV	Report on voting
47E/653/CDV	47E/678/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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SEMICONDUCTOR DEVICES –

Part 5-11: Optoelectronic devices – Light emitting diodes – Test method of radiative and nonradiative currents of light emitting diodes

1 Scope

This part of IEC 60747 specifies the measuring methods of radiative and nonradiative currents of single light emitting diode (LED) chips or packages without phosphor. White LEDs for lighting applications are out of the scope of this document. This document utilizes the internal quantum efficiency (IQE) as a function of current, whose measurement methods are discussed in other documents.

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 60747-5-6:2016, *Semiconductor devices – Part 5-6: Optoelectronic devices – Light emitting diodes*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

3.1.1
internal quantum efficiency
η_{IQE}
ratio of the number of photons emitted from the active region per unit time to the number of electrons injected into the LED per unit time

$$\eta_{IQE} = \frac{\Phi_{e,active} / h\bar{\nu}}{I_F / q}$$

where

$\Phi_{e,active}$ is the radiant power emitted from the active region
$h\bar{\nu}$ is the mean photon energy
I_F is the forward current
q is the elementary charge

[SOURCE: IEC 60747-5-8:2019, 3.2.4]

3.1.2
radiative current
I_{rad}
current that is consumed by the radiative recombination process in the LED

3.1.3
nonradiative current
I_{nonrad}
current that is consumed by the nonradiative processes in the LED

Note 1 to entry: The nonradiative processes in the LED include the nonradiative recombination in the active region and the carrier leakage outside the active region.

Note 2 to entry: The total forward current I_F supplied to the LED can be decomposed into radiative and nonradiative currents:

$$I_F = I_{rad} + I_{nonrad}.$$

Using the radiative and nonradiative currents, the IQE can be re-expressed as follows:

$$\eta_{IQE} = \frac{I_{rad}}{I_F} = \frac{I_{rad}}{I_{rad} + I_{nonrad}}.$$

Using the above relations, the radiative and nonradiative currents can be expressed as follows:

$$I_{rad} = \eta_{IQE} I_F;$$

$$I_{nonrad} = I_F - I_{rad} = (1 - \eta_{IQE}) I_F.$$

Electrical power consumed by the radiative process (P_{rad}) in the LED can be expressed as follows:

$$P_{rad} = I_{rad} V_F = \eta_{IQE} I_F V_F = \eta_{IQE} P$$

where P is the total electrical power dissipated by the LED: $P = I_F V_F$.

Electrical power consumed by the nonradiative processes ($P_{non\text{-}rad}$) in the LED can be expressed as follows:

$$P_{nonrad} = I_{nonrad} V_F = (1 - \eta_{IQE}) I_F V_F = (1 - \eta_{IQE}) P.$$

The power efficiency (η_{PE}) represents how much electrical power dissipated by the LED is converted to the radiant power (Φ_e):

$$\Phi_e = \eta_{PE} P.$$

Since $P = P_{rad} / \eta_{IQE}$ and $\eta_{PE} = \eta_{VE} \cdot \eta_{LEE} \cdot \eta_{IQE}$,

$$\Phi_e = \frac{\eta_{PE}}{\eta_{IQE}} P_{rad} = \frac{\eta_{VE} \cdot \eta_{LEE} \cdot \eta_{IQE}}{\eta_{IQE}} P_{rad} = \eta_{VE} \cdot \eta_{LEE} \cdot P_{rad}$$

or

$$\frac{\Phi_e}{P_{rad}} = \eta_{VE} \cdot \eta_{LEE}.$$

3.2 Abbreviated terms

LED light emitting diode

IQE internal quantum efficiency

4 Measuring methods

4.1 Basic requirements

4.1.1 Measuring conditions

a) Temperature

If not specified, measurements shall be made at an ambient temperature (T_a) of (25 ± 3) °C in a condition of free air.

b) Humidity

When the humidity condition is not specified, relative humidity shall be between 45 % RH and 85 % RH.

c) 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 can 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.

4.1.2 Measuring instruments and equipment

The measuring instruments and equipment shall be the same as listed in IEC 60747-5-6:2016, 6.1.2.

4.2 Radiative current (I_{rad}) measurement

4.2.1 Purpose

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

4.2.2 Measurement procedure

The measurement procedure is as follows.

a) Measure the IQE (η_{IQE}) and the forward voltage (V_F) at a specified forward current (I_F).

b) Calculate the radiative current by multiplying the IQE with the forward current, i.e.,

$$I_{rad} = \eta_{IQE} I_F$$

NOTE 1 The measurement of the forward voltage at a specified forward current is listed in IEC 60747-5-6:2016, 6.2.

NOTE 2 The measurement of the IQE at a specified current is listed in IEC 60747-5-9 and IEC 60747-5-10.

4.3 Nonradiative current (I_{nonrad}) measurement

4.3.1 Purpose

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

4.3.2 Measurement procedure

The measurement procedure is as follows.

Calculate the nonradiative current by using the following formula:

$$I_{nonrad} = I_F - I_{rad}\,.$$

4.4 Measurement sequence

Figure 1 summarizes the measurement sequence of the radiative and non-radiative currents when a specified forward current is applied. A test example is given in Annex A. Background information on the separated radiative and nonradiative currents are given in Annex B.

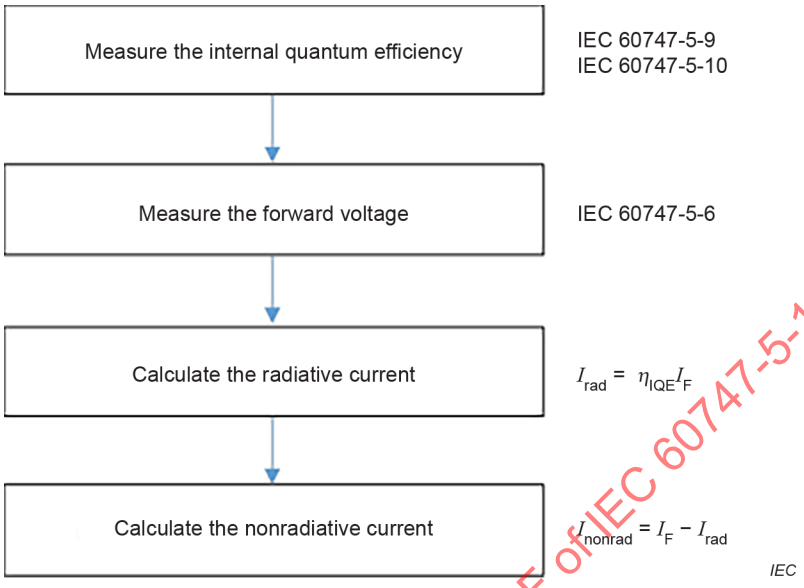

Figure 1 – Sequence of the radiative and nonradiative current measurements

5 Test report

The test report should include the items shown in Table A.1.

Annex A
(informative)

Test example

- Step 0: Test environmental specifications
  - sample: a flip-chip InGaN/GaN MQW LED grown on a c-plane sapphire substrate;
  - chip size: 800 μm × 800 μm;
  - peak wavelength: ~450 nm at T = 295 K;
  - humidity: 50 % RH;
  - current driving condition: pulsed current driving condition (pulse period: 1 ms, duty cycle: 1 %);
  - detector for radiant power measurement: Si photodiode;
  - equipment for electrical characteristics measurement: Keithley[1] semiconductor parameter analyser;
  - maximum driving current, I_{max} = 300 mA;
  - total number of data points, N = 65.
- Step 1: Acquire N data consisting of the IQE and forward voltage as a function of forward current as shown in Figure A.1.

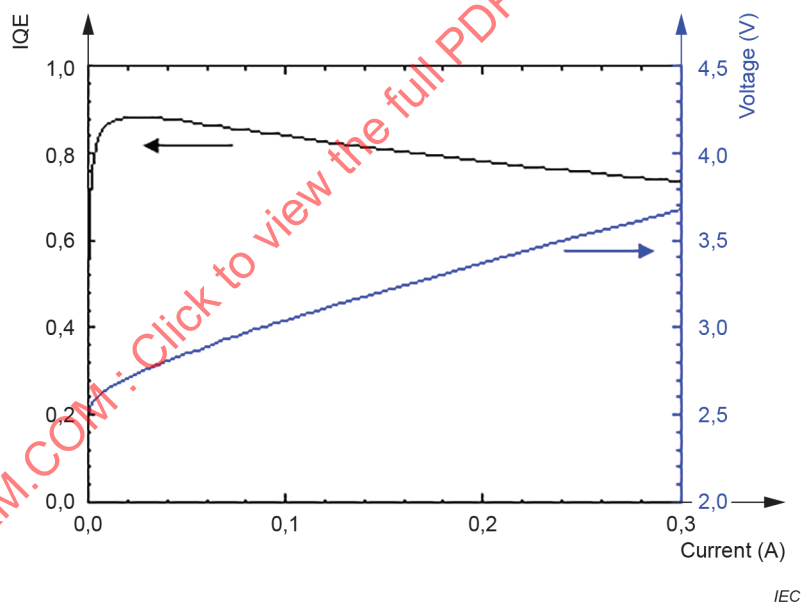

Figure A.1 – IQE and forward voltage as a function of forward current

- Step 2: Calculate the radiative current by multiplying the IQE with the forward current, i.e., $I_{rad} = \eta_{IQE} I_F$.

  The radiative current obtained this way is shown in Figure A.2.

[1] Keithley semi-conductor parameter analyser is the trade name of a product supplied by Tektronix. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

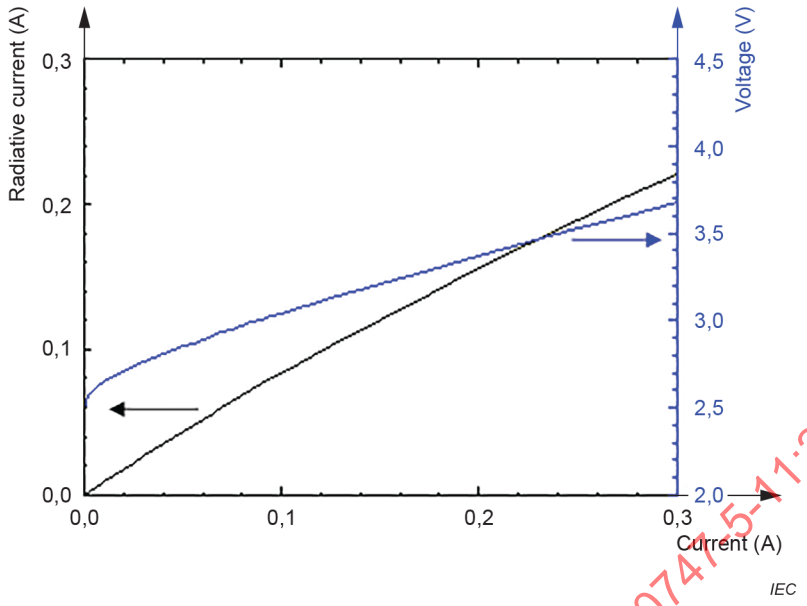

Figure A.2 – Radiative current and forward voltage as a function of forward current

- Step 3: Calculate the nonradiative current by using the following formula (Figure A.3):

$I_{\text{non-rad}} = I_{\text{F}} - I_{\text{rad}}$.

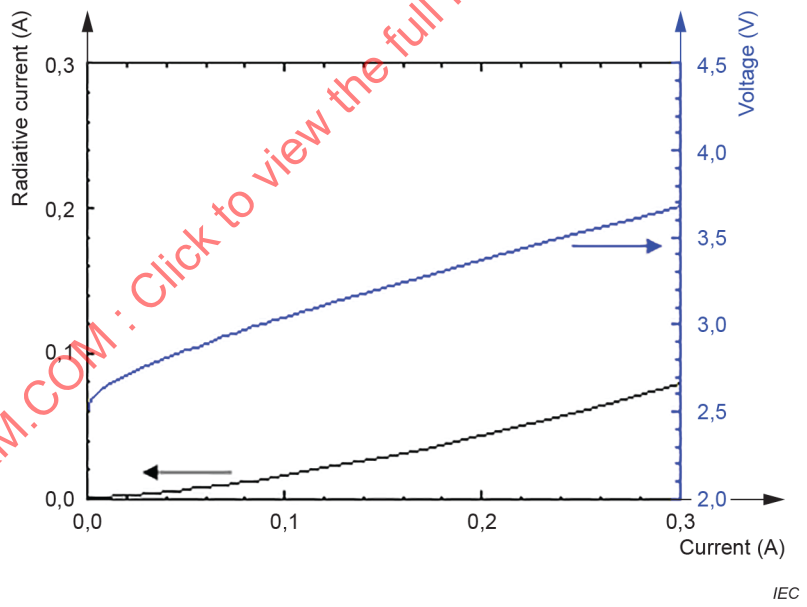

Figure A.3 – Nonradiative current and forward voltage as a function of forward current

The radiative and nonradiative current can also be plotted as a function of voltage as shown in Figure A.4.

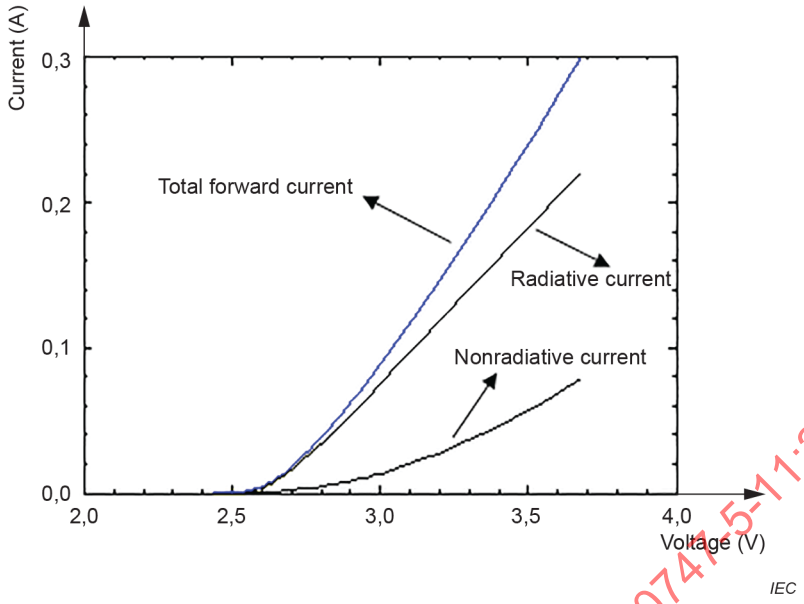

Figure A.4 – Total forward current, radiative current, and nonradiative current plotted as a function of forward voltage

Table A.1 – Summary of test report

Item	Unit	Value	Comment
LED maker	-		Specify the name of the company
Model name	-		Specify the model name
Chip size	[μm] × [μm]		
Package type	-		Ex. SMD
Peak wavelength	[nm]		
Maximum applied current (I_{max})	[mA]		
Data points N	-		
Pulse period	[ms]		
Duty	[%]		
Detector type	-		Ex. Si photodiode
Operating temperature	[K]		
Humidity	[% RH]		
Operating current	[mA]		
Internal quantum efficiency at operating current	[%]		
Radiative current at operating current	[mA]		
Nonradiative current at operating current	[mA]		

Annex B
(informative)

Background information

The current-voltage (I-V) characteristics of a pn diode is typically described by the Shockley equation as shown below:

$$I = I_0\left[\exp\left(\frac{qV_J}{n_{ideal}kT}\right)-1\right],$$

where I is the diode current, I_0 is the reverse-saturation current, q is the elementary charge, V_J is the voltage applied at the junction, n_{ideal} is the ideality factor, k is the Boltzmann constant, and T is the absolute temperature. The factor n_{ideal} typically represents the different recombination processes in the diode. In Si pn diodes, n_{ideal} varies between 1 and 2, depending on whether the dominant recombination process is the diffusion or the Shockley-Read-Hall (SRH) recombination via defects.

In LEDs, the recombination processes can be categorized as: radiative and nonradiative recombination processes. By separating the current consumed by the respective processes, one can obtain the radiative and nonradiative currents. There can be an additional nonradiative current resulting from the leakage flowing outside the active region such as the surface leakage. Taking all these components into account, the total current can be described by separate I-V equations as follows:

$$I_{rad} = I_{rad,0}\left[\exp\left(\frac{qV_J}{n_{ideal,R}kT}\right)-1\right];$$

$$I_{nonrad} = I_{nonrad,0}\left[\exp\left(\frac{qV_J}{n_{ideal,NR}kT}\right)-1\right]+I_{nonrad,leak}$$

for the radiative current I_{rad} and nonradiative current I_{nonrad}. Here, $I_{rad,0}$ and $I_{nonrad,0}$ represent the reverse-saturation current for the respective currents. $I_{nonrad,leak}$ represents the leakage current flowing outside the active region. One has to note that the ideality factors for the respective recombination currents, $n_{ideal,R}$ and $n_{ideal,NR}$, are different. For the radiative recombination current, it is known that the ideality factor is 1. For the nonradiative recombination current, the ideality factor can be between 1 and 2, depending on the nonradiative recombination process involved. By analysing the forward current in terms of radiative and nonradiative currents, one can obtain crucial information on the nonradiative recombination mechanisms in the device from the I_{nonrad}-V curve.

By having the information on the radiative and nonradiative currents, one can also obtain such information as the electrical power consumed by the radiative and nonradiative recombinations. The electrical power consumed by the radiative recombination is given by

$$P_{rad} = I_{rad}V_F,$$

where V_F is the forward voltage. On the other hand, the electrical power consumed by the nonradiative recombination is given by

$$P_{nonrad} = I_{nonrad}V_F,$$

which is converted to heat.