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INTERNATIONAL STANDARD

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Semiconductor devices – Part 5-10: Optoelectronic devices – Light emitting diodes – Test method of the internal quantum efficiency based on the room-temperature reference point

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SEMICONDUCTOR DEVICES –

Part 5-10: Optoelectronic devices – Light emitting diodes – Test method of the internal quantum efficiency based on the room-temperature reference point

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International Standard IEC 60747-5-10 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/652/CDV	47E/677/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- withdrawn,
- replaced by a revised edition, or
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SEMICONDUCTOR DEVICES –

Part 5-10: Optoelectronic devices – Light emitting diodes – Test method of the internal quantum efficiency based on the room-temperature reference point

1 Scope

This part of IEC 60747 specifies the measuring method of the internal quantum efficiency (IQE) 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 only the relative external quantum efficiency (EQE) measured at an operating room temperature. In order to identify the reference IQE, an operating current corresponding to the injection efficiency of 100 % is found and the radiative efficiency is determined by the infinitesimal change of the relative EQE at that point. The IQE as a function of current is then calculated from the relative ratio of the EQEs to the value at the reference point, which is called room-temperature reference-point method (RTRM).

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

$$\eta_{\mathrm{IQE}} = \frac{\Phi_{\mathrm{e,active}} / h\overline{\nu}}{I_{\mathrm{F}} / q}$$

where

$\Phi_{\mathrm{e,active}}$ is the radiant power emitted from the active region

$h\overline{\nu}$ is the mean photon energy

I_{F} is the forward current

q is the elementary charge

Note 1 to entry: It is in general a function of ambient temperature (T_a) and forward current (I_F).

[SOURCE: IEC 60747-5-8:2019, 3.2.4, modified – The note has been added.]

3.1.2
external quantum efficiency
η_{EQE}
ratio of the number of photons emitted into the free space per unit time to the number of electrons injected into the LED per unit time

$$\eta_{EQE} = \frac{\Phi_e / h\bar{v}}{I_F / q}$$

where

Φ_e is the radiant power

Note 1 to entry: It is in general a function of ambient temperature (T_a) and forward current (I_F).

[SOURCE: IEC 60747-5-8:2019, 3.2.3, modified – The note has been added.]

3.1.3
light extraction efficiency
η_{LEE}
ratio of the number of photons emitted into the free space to the number of photons emitted from the active region

$$\eta_{LEE} = \frac{\Phi_e}{\Phi_{e,active}}$$

Note 1 to entry: It is in general independent of forward current (I_F) at certain ambient temperature (T_a).

[SOURCE: IEC 60747-5-8:2019, 3.2.5, modified – The note has been added.]

3.1.4
injection efficiency
η_{IE}
ratio of the number of electrons injected into the active region per unit time to the number of electrons injected into the LED per unit time

$$\eta_{IE} = \frac{I_{F,active}}{I_F}$$

where

$I_{F,active}$ is the portion of the forward current injected into the active region

[SOURCE: IEC 60747-5-8:2019, 3.2.6]

3.1.5
radiative efficiency
η_{RE}
ratio of the number of photons emitted from the active region per unit time to the number of electrons injected into the active region per unit time

$$\eta_{RE} = \frac{\Phi_{e,active} / h\bar{v}}{I_{F,active} / q}$$

[SOURCE: IEC 60747-5-8:2019, 3.2.7, modified – The note has been removed.]

3.1.6
peak EQE point
set of operating conditions of the forward current and radiant power at which the external quantum efficiency (EQE) is the maximum for a given temperature

Note 1 to entry: The forward current and radiant power at the peak EQE point are denoted as I_{peak} and Φ_{peak}, respectively.

3.1.7
normalized variables of X and Y
converted quantities of current and radiant power, defined as:

$$X = \sqrt{\Phi_e(I_F) / \Phi_e(I_{peak})}$$

$$Y = I_F / I_{peak}$$ f

3.1.8
coefficients of a_1 and a_2
coefficients of the quadratic equation of Y in X, i.e., $Y = a_1 X + a_2 X^2$

Note 1 to entry: a_1 and a_2 change slowly enough according to the forward current as compared to X and Y, but should be treated as a function of the forward current in the data analysis.

3.1.9
reference point
operating point at which a_2 is the minimum

Note 1 to entry: a_2, X, and Y at the reference point are represented by $a_{2,ref}$, X_{ref}, and Y_{ref}, respectively. The forward current at the reference point is denoted as $I_{F,ref}$.

3.2 Abbreviated terms

EQE external quantum efficiency

IQE internal quantum efficiency

LED light emitting diode

RTRM room-temperature reference-point method

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 Purpose

To measure the internal quantum efficiency (IQE) at an operating temperature of the LED without any parameter assumptions under established conditions. The method utilizes just the experimental curve of radiant power (Φ_e) as a function of forward current (I_F) measured at an ambient temperature (T_a).

4.3 Measurement

4.3.1 Measurement setup

All of the tests should be performed under well-certified and defined conditions to avoid any external disturbances. Basic measurement setup schematics are the same as listed in IEC 60747-5-6.

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

The measurement of the radiant power at a specified current is listed in IEC 60747-5-6:2016, 6.11.

The measurement of the emission spectrum distributions, peak wavelength (λ_p), and spectral half bandwidth of the LED are listed in IEC 60747-5-6:2016, 6.15.

The measurement of the pulse current is listed in IEC 60747-5-6:2016, 6.8.

4.3.2 Measurement principle

First, the measurement procedure seeks to find the IQE at the reference point η_{IQE} where the injection efficiency (η_{IE}) is supposed to be 100 % and the radiative efficiency (η_{RE}) is calculated from the infinitesimal change of the relative external quantum efficiency (η_{EQE}). Once the IQE at the reference point is exactly found, the IQE at any other point is calculated by the relative ratio of EQE values to the one at the reference point, i.e., $\eta_{IQE}(I_F) = [\eta_{EQE}(I_F)/\eta_{EQE}(I_{F,ref})] \cdot \eta_{IQE}(I_{F,ref})$.

The injection efficiency becomes the maximum when a_2 becomes the minimum. However, the uncertainty of the injection efficiency being exactly 100 % and its criterion should be established in the future.

4.3.3 Measurement sequence

The IQE measurement should proceed according to the following ten sequential steps as shown in Figure 1. A test example is given in Annex A.

- Step 0: Test environmental specifications

  All of the tests should be performed under well-certified and defined conditions to avoid any external disturbances. An example of the test's environmental specifications is listed in Annex A. The specifications should include such parameters as the humidity, the current driving condition, and the detector for radiant power measurement.

- Step 1: Acquire N data consisting of radiant power and current

  Radiant power is measured as a function of current from 0 to I_{max}, and a set of N data consisting of the radiant power (Φ_e) and forward current is obtained. The radiant power does not have to be the absolute value. It is recommended to divide by at least 100 in the current range from 0 to I_{peak}. It is also recommended to divide the current range from I_{peak} to I_{max} by 100 or more.

- Step 2: Draw a relative external quantum efficiency (EQE) curve

  The relative EQE is obtained by dividing the radiant power by the forward current, i.e. $\eta_{IQE}(I_F) = \Phi_e(I_F)/\ I_F$.

- Step 3: Find the peak point in the relative EQE curve

  Find a set of operating conditions of the forward current (I_{peak}) and radiant power (Φ_{peak}) at which the relative EQE is the maximum.

- Step 4: Convert the radiant power and current to the normalized variables of X and Y

  Find the normalized variables of X and Y from the following definitions of $X(I_F) = \sqrt{\Phi_e(I_F)/\Phi_e(I_{peak})}$ and $Y(I_F) = I_F/I_{peak}$.

- Step 5: Find the coefficients of a_1 and a_2

  Find a set of $\{a_{1,i}\}$ and $\{a_{2,i}\}$ by solving the following two simultaneous equations with the two nearest experimental data (X_i, Y_i) and (X_{i+1}, Y_{i+1}).

$$\begin{aligned} Y_i &= a_{1,i} X_i + a_{2,i} X_i^2 \\ Y_{i+1} &= a_{1,i} X_{i+1} + a_{2,i} X_{i+1}^2 \end{aligned} .$$

- Step 6: Find a reference point in a_2 versus X curve

  When a_2 is represented by a function of X, an operating point at which a_2 is the minimum is selected as a reference point. I_F, a_1, a_2, X, and Y at the reference point are represented by $I_{F,ref}$, $a_{1,ref}$, $a_{2,ref}$, X_{ref}, and Y_{ref}, respectively.

- Step 7: Calculate the internal quantum efficiency (IQE) at a reference point

  Using $a_{1,ref}$, $a_{2,ref}$ and X_{ref} at the reference point, calculate the IQE from the following formula:

$$\eta_{IQE,ref} = \frac{a_{2,ref} X_{ref}^2}{a_{1,ref} X_{ref} + a_{2,ref} X_{ref}^2} .$$

- Step 8: Find the IQE at an arbitrary current (I_F)

  Determine the IQE at any current using the EQE curve at an arbitrary current and the internal quantum efficiency at the reference point as follows:

$$\eta_{IQE}(I_F) = \eta_{IQE}(I_{ref}) \frac{\eta_{EQE}(I_F)}{\eta_{EQE}(I_{ref})} .$$

- Step 9: Create the test report

  Fill in the test report given in Annex A.