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INTERNATIONAL STANDARD

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Semiconductor devices –
Part 5-9: Optoelectronic devices – Light emitting diodes – Test method of the internal quantum efficiency based on the temperature-dependent electroluminescence

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International Standard IEC 60747-5-9 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/651/CDV	47E/676/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

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SEMICONDUCTOR DEVICES –

Part 5-9: Optoelectronic devices – Light emitting diodes – Test method of the internal quantum efficiency based on the temperature-dependent electroluminescence

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 the relative external quantum efficiencies (EQEs) measured at cryogenic temperatures and at an operating temperature, which is called temperature-dependent electroluminescence (TDEL). In order to identify the reference IQE of 100 %, the maximum values of the peak EQE are found by varying the environmental temperature and current.

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
radiant power
Φ_e
power emitted, transmitted or received in the form of radiation

Note 1 to entry: The unit used is: W. Radiant power is also known as the "radiant flux".

[SOURCE: IEC 60747-5-8:2019, 3.1.1]

3.1.2
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

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.]

3.1.3
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

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

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.]

3.1.4
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

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

[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 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
cryogenic temperature
temperature range below 200 K

3.1.8
critical cryogenic temperature
T_c
cryogenic temperature at which the peak EQE shows the maximum value

3.2 Abbreviated terms

EQE	external quantum efficiency
IE	injection efficiency
IQE	internal quantum efficiency
LED	light emitting diode
RE	radiant efficiency
TDEL	temperature-dependent electroluminescence

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. When the chip is cooled down in a cryostat, the temperature in the cryostat should be noted.

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

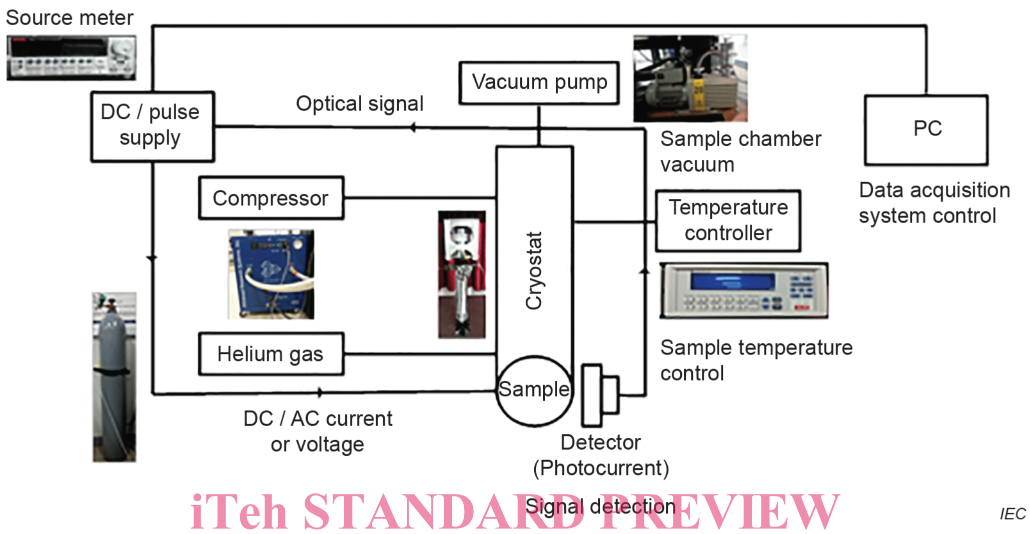
To measure the IQE at an operating temperature of the LED chips and packages, the method needs a radiant power as a function of the forward current at various temperatures from the room temperature to the cryogenic temperature. The IQE is determined by analysing the relative EQE converted from the radiant power.

4.3 Measurement

4.3.1 Measurement setup

4.3.1.1 General

All of the tests should be performed under well-certified and defined conditions to avoid any external disturbances. The basic measurement setup schematics are depicted in Figure 1.



Key

PC: personal computer

Figure 1 – Example of the measurement setup with the FDEL

4.3.1.2 Cryostat

The cryostat changes the temperature from the operating temperature to the cryogenic temperature. The lowest cryogenic temperature should be less than or equal to 25 K. A T_c of 25 K is typically recommended. In some cases, when the criteria for saturation properties are not satisfied (steps 5 and 6 in Figure 5), a T_c of 10 K is recommended.

4.3.2 Measurement principle

4.3.2.1 Effect of temperature on radiant power

Figure 2 is a schematic diagram of the radiant power as a function of current at various temperatures. As the temperature decreases, the radiant power increases.

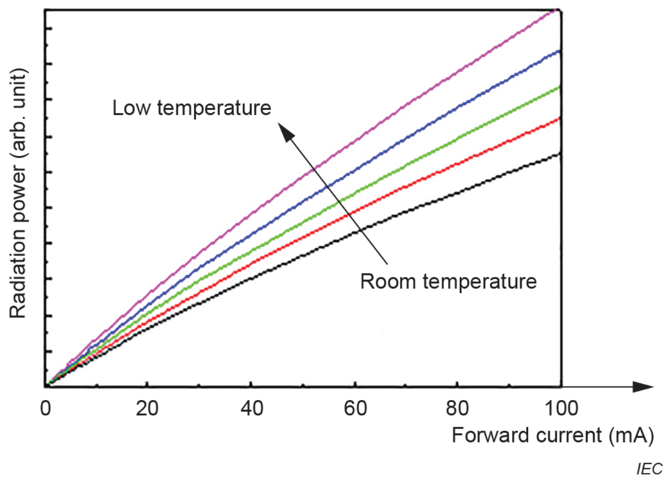


Figure 2 – Schematic diagram of radiant power as a function of forward current at various temperatures

4.3.2.2 Conversion of radiant power to relative EQE

The relative EQE is defined as the ratio of the radiant power to the forward current.

4.3.2.3 Criterion of the measurement validity

In general, the peak value of the relative EQE of a LED chip starts to increase as the temperature is decreased from the room temperature. The behaviour of the peak relative EQE can be split into two categories with decreasing temperature: one is the case where the peak value continuously increases or eventually saturates with the decreasing temperature, i.e., T_c, the temperature at which the maximum relative EQE value is observed, is the lowest cryogenic temperature used. The other is the case where the peak relative EQE reaches a maximum and decreases as the temperature is decreased further, i.e., T_c is higher than the lowest cryogenic temperature used. In order to find a reference point in the relative EQE data that can be assumed as an IQE of 100 %, both the injection efficiency (IE) and the radiant efficiency (RE) shall be 100 %.

Examples of the generally observed categories are explained as follows:

a) Category 1: T_c is the lowest cryogenic temperature used

The peak value of the relative EQE continuously increases with the decreasing temperature as seen in Figure 3a). In Figure 3a), T_c = 25 K. Normalize all the relative EQE data by the maximum value of the relative EQE obtained at T_c and express them in %. Check:

i) whether or not the rate of change of the normalized peak EQE is less than or equal to 0,10 %/K between the lowest and the next lowest cryogenic temperatures;

ii) whether or not the change of the normalized EQE obtained at T_c remains within 1 % for currents twice and half the current level for the peak EQE point.

Criterion i) is to ensure that the RE is 100 % and criterion ii) is to ensure that the IE is also 100 %. Only when both criteria are satisfied, can the IQE of 100 % be assumed at the peak EQE point.

NOTE 1 The assumption that the IQE is 100 % at the peak EQE point implies that the defects, which act as nonradiative recombination centres, fully freeze out and no longer play the role at T_c. At the same time, the constancy of the peak EQE against the current implies that all the carriers are injected into the same place of the active region.