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INTERNATIONAL STANDARD

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Semiconductor devices –
Part 5-16: Optoelectronic devices – Light emitting diodes – Test method of the flat-band voltage of GaN-based light emitting diodes based on the photocurrent spectroscopy

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IEC 60747-5-16 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices. It is an International Standard.

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

Draft	Report on voting
47E/788/CDV	47E/797/RVC

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/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.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under 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- withdrawn,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
- amended.

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SEMICONDUCTOR DEVICES –

Part 5-16: Optoelectronic devices – Light emitting diodes – Test method of the flat-band voltage of GaN-based light emitting diodes based on the photocurrent spectroscopy

1 Scope

This part of IEC 60747 specifies the measuring method of flat-band voltage of single GaN-based light emitting diode (LED) die or package without phosphor, based on the photocurrent (PC) spectroscopy. White LEDs for lighting applications 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 60747-5-6:2021, *Semiconductor devices – Part 5-6: Optoelectronic devices – Light emitting diodes*

IEC 60747-5-15:2022, *Semiconductor devices – Part 5-15: Optoelectronic devices – Light emitting diodes – Test method of the flat-band voltage based on the electroreflectance spectroscopy*

3 Terms, definitions and abbreviated terms

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

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

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

3.1 Terms and definitions

3.1.1
spectral radiant flux
$\Phi_{e,\lambda}(\lambda)$

radiant flux per unit wavelength interval at a given wavelength (λ)

Note 1 to entry: Spectral radiant flux is typically denoted by Φ_λ, which is equivalent to $d\Phi/d\lambda$, and is usually expressed in units of watts per nm.

[SOURCE: IEC 62607-3-1:2014 [1][1], 3.20, modified – A symbol has been added.]

[1] Numbers in square brackets refer to the Bibliography.

3.1.2
spectral photocurrent
$I_{\text{ph},\lambda}(\lambda)$

photocurrent per unit wavelength interval at a given wavelength (λ)

Note 1 to entry: Spectral photocurrent is expressed in amperes per nm.

3.1.3
PC signal
spectral photocurrent divided by the spectral radiant flux of the radiation source, which is expressed as a function of wavelength λ, i.e., $I_{\text{ph},\lambda}(\lambda)/\Phi_{e,\lambda}(\lambda)$

3.1.4
differential PC signal
difference between the adjacent PC signals divided by the wavelength step

3.1.5
peak slope
absolute value of the extremum in the differential PC signal

3.1.6
quantum well
potential well which enables quantum confinement of particles in one dimension

[SOURCE: IEC 60050-511:2018 [2], 511-02-09, modified – The note to entry has been removed.]

3.1.7
flat-band voltage
V_{FB}
voltage at which the mean electric field across the wells can be considered to be zero

[SOURCE: IEC 60747-5-15:2022, 3.1.2]

3.2 Abbreviated terms

LED light emitting diode

PC photocurrent

ER electroreflectance

4 Measuring methods

4.1 Basic requirements

4.1.1 Measuring conditions

a) Temperature

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

b) Humidity

When humidity condition is not specified, relative humidity shall be between 25 % RH and 75 % 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 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.

4.1.2 Measuring instruments and equipment

Measuring instruments and equipment shall be the same as listed in 6.1.2 of IEC 60747-5-6:2021.

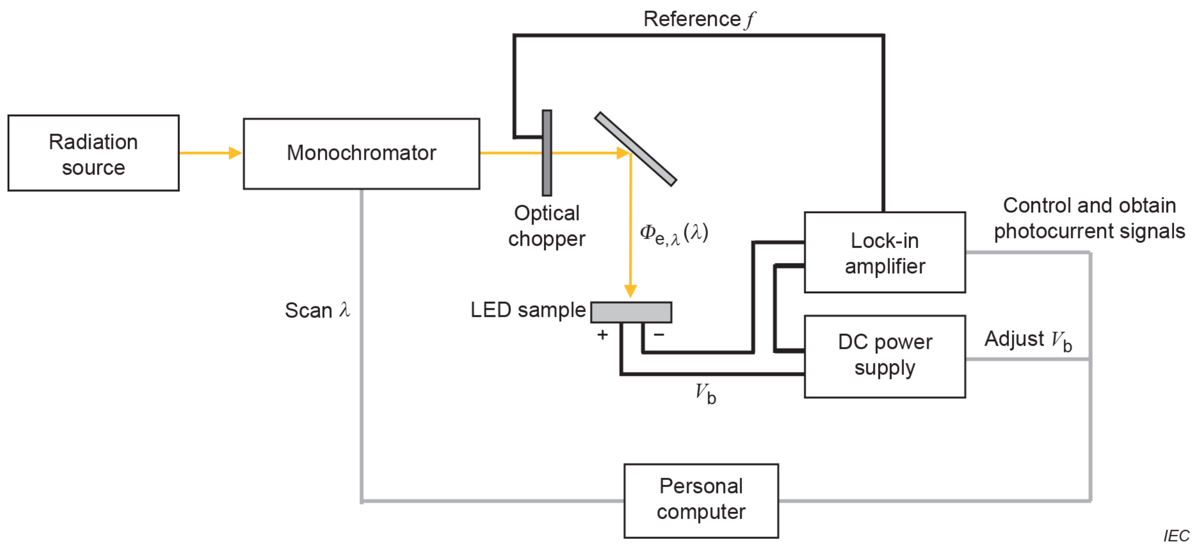
4.2 Purpose

To measure the internal electric field of the GaN-based LED die or package, the method needs the flat-band voltage. Once the flat-band voltage is obtained from the PC spectroscopy, the internal electric field is determined if desired.

4.3 Measurement

4.3.1 Measurement setup

The measurement setup for the PC spectroscopy can be designed as shown in Figure 1. Spectrally resolved radiation from a monochromator is modulated by an optical chopper supplied with a reference frequency from a lock-in amplifier. The modulated radiation is incident on the LED sample and a signal from the LED sample is registered by the lock-in amplifier. The spectral radiant flux of the radiation source is measured separately from the monochromator. The spectral photocurrent is the ratio of the signal obtained by the lock-in amplifier to the spectral radiant flux of the radiation source, $I_{\mathrm{ph},\lambda}(\lambda)/\Phi_{\mathrm{e},\lambda}(\lambda)$. The DC power supply changes the bias voltage to the LED sample and a personal computer automates the measurement and collects the data.



Key

$\Phi_{e,\lambda}(\lambda)$ spectral radiant flux

V_b bias voltage

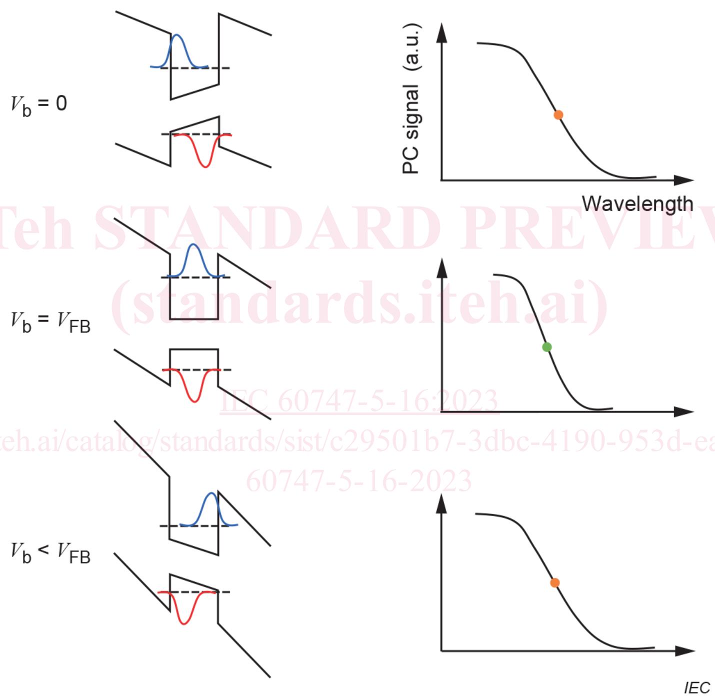
Figure 1 – Schematic diagram of the PC spectroscopy setup

4.3.2 Measurement principle

Near the flat-band voltage VFB, the electric field in the quantum well in the active region of the GaN-based LED is close to zero and the PC signal shows the steepest slope near the absorption edge. When there exists an electric field in the quantum well, the absorption near the effective band edge is broadened due to the quantum-confined Stark effect (QCSE) [3]. Consequently, the absolute slope of the PC signal should exhibit the maximum value at V_{FB}.

Figure 2 schematically illustrates the quantum well and the PC signal under different bias voltages. It is seen that each PC signal has a point of steepest slope (or the peak slope), marked by a dot. Figure 3 schematically depicts how the differential PC signal behaves under different bias voltages. When the bias voltage equals the flat-band voltage, the peak slope becomes the maximum as shown in Figure 4.

A typical value for V_{FB} is negative (i.e., reverse bias) in the case of GaN-based LEDs emitting blue or green wavelength.



Key

V_b bias voltage

V_{FB} flat-band voltage

Dotpeak slope

Figure 2 – Schematic illustration of the InGaN/GaN quantum well and the PC signal under different bias voltages

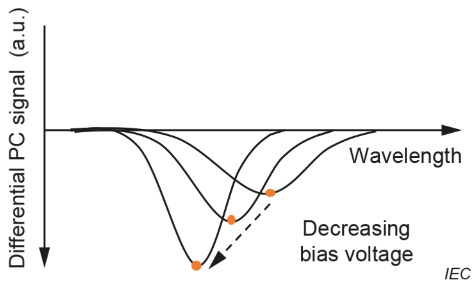


Figure 3 – Schematic illustration of how the differential PC signal behaves as the bias voltage is decreased

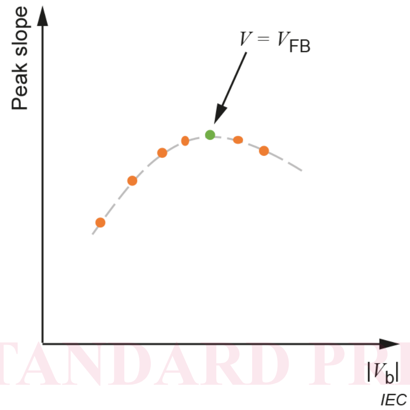


Figure 4 – Schematic illustration of the peak slope as a function of bias voltage

4.3.3 Measurement sequence

The measurement should proceed according to the following sequential steps. 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. Since the modulated signal is detected by a lock-in amplifier, the effect of the background illumination is suppressed and can be neglected in general. However, if minimizing the effect of the background illumination is further desired, the measurement can be conducted in a dark box.

– Step 1: Measure the spectral radiant flux of the radiation source. Either a spectrometer or a power meter after the monochromator can be used. In order to avoid saturation in the quantum wells, it is desirable to check whether a spectral photocurrent is increased by the same factor as the increase in spectral radiant flux, i.e., $I_{\text{ph},\lambda}(\lambda)/\Phi_{e,\lambda}(\lambda)$ is constant at a certain λ.

– Step 2: Set a bias voltage for the PC measurement.

– Step 3: Measure the PC signal.

  Measure first the spectral photocurrent as a function of wavelength. Plot the PC signal vs. wavelength after dividing the spectral photocurrent by the spectral radiant flux of the radiation source, i.e., $I_{\text{ph},\lambda}(\lambda)/\Phi_{\text{e},\lambda}(\lambda)$.

– Step 4: Plot the differential PC signal vs. wavelength.

– Step 5: Check whether the peak slope in the differential PC signal vs. wavelength decreases.