

# INTERNATIONAL STANDARD



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

IECNORM.COM : Click to view the PDF of IEC 60747-5-15:2022



**THIS PUBLICATION IS COPYRIGHT PROTECTED**  
**Copyright © 2022 IEC, Geneva, Switzerland**

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Secretariat  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://www.iec.ch)

**About the IEC**

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

**About IEC publications**

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

**IEC publications search - [webstore.iec.ch/advsearchform](http://webstore.iec.ch/advsearchform)**

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, ...). It also gives information on projects, replaced and withdrawn publications.

**IEC Just Published - [webstore.iec.ch/justpublished](http://webstore.iec.ch/justpublished)**

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

**IEC Customer Service Centre - [webstore.iec.ch/csc](http://webstore.iec.ch/csc)**

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: [sales@iec.ch](mailto:sales@iec.ch).

**IEC Products & Services Portal - [products.iec.ch](http://products.iec.ch)**

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

**Electropedia - [www.electropedia.org](http://www.electropedia.org)**

The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IECNORM.COM : Click to view the full PDF of IEC 60147-5:2022

# INTERNATIONAL STANDARD



---

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

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 31.080.99

ISBN 978-2-8322-1065-3

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD.....	3
1 Scope.....	5
2 Normative references .....	5
3 Terms, definitions and abbreviated terms .....	5
3.1 Terms and definitions.....	5
3.2 Abbreviated terms.....	6
4 Measuring methods .....	6
4.1 Basic requirements .....	6
4.1.1 Measuring conditions.....	6
4.1.2 Measuring instruments and equipment.....	6
4.2 Purpose .....	6
4.3 Measurement.....	7
4.3.1 Measurement setup .....	7
4.3.2 Measurement principle.....	7
4.3.3 Measurement sequence.....	9
5 Test report.....	9
Annex A (informative) Test example.....	10
Annex B (informative) Background information.....	13
Bibliography.....	14
Figure 1 – Schematic diagram of the ER setup.....	7
Figure 2 – Schematic illustration of the quantum well and the ER signal under different voltages.....	8
Figure 3 – Sequence of the measurement of the flat-band voltage .....	9
Figure A.1 – $\Delta R/R$ versus wavelength at different bias voltages .....	10
Figure A.2 – ER peak as a function of reverse-bias voltage .....	11
Figure B.1 – Schematic illustration of polarizations in the InGaN/GaN material system and resulting internal electric field.....	13
Table A.1 – Summary of test report.....	12

IECNORM.COM · Click to view the full PDF of IEC 60747-5-15:2022

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## SEMICONDUCTOR DEVICES –

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

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 60747-5-15 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/737A/CDV	47E/764A/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](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/standardsdev/publications](http://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.

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](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
- amended.

**IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

IECNORM.COM : Click to view the full PDF of 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

#### 1 Scope

This part of IEC 60747-5 specifies the measuring methods of flat-band voltage of single GaN-based light emitting diode (LED) die or package without phosphor, based on the electroreflectance (ER) spectroscopy. White LEDs for lighting applications are out of the scope of this part of IEC 60747-5.

#### 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*

#### 3 Terms, definitions and abbreviated terms

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 Terms and definitions

###### 3.1.1 spectral reflectance

$R(\lambda)$

ratio of reflected radiant flux to incident radiant flux for a wavelength  $\lambda$

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

[SOURCE: IEC 60747-5-6:2021, 3.1.8]

###### 3.1.2 flat-band voltage

$V_{FB}$

voltage at which the mean electric field across the wells can be considered to be zero

###### 3.1.3 built-in voltage

$V_{bi}$

voltage built into the pn junction of the LED when no external voltage is applied

### 3.1.4 unintentionally doped width

 $d_u$ 

width of the unintentionally doped layers in the LED

### 3.1.5 depleted width by $V_{FB}$

 $d_d$ 

width of the layers depleted at  $V_{FB}$  excluding the unintentionally doped layers in the LED

### 3.1.6 total well width

 $d_w$ 

total width of the wells in the LED

Note 1 to entry: If the width of the single quantum well is  $d$  and the number of quantum wells is  $N$ , then  $d_w = Nd$ .

## 3.2 Abbreviated terms

LED light emitting diode

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  $(25 \pm 3)$  °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.

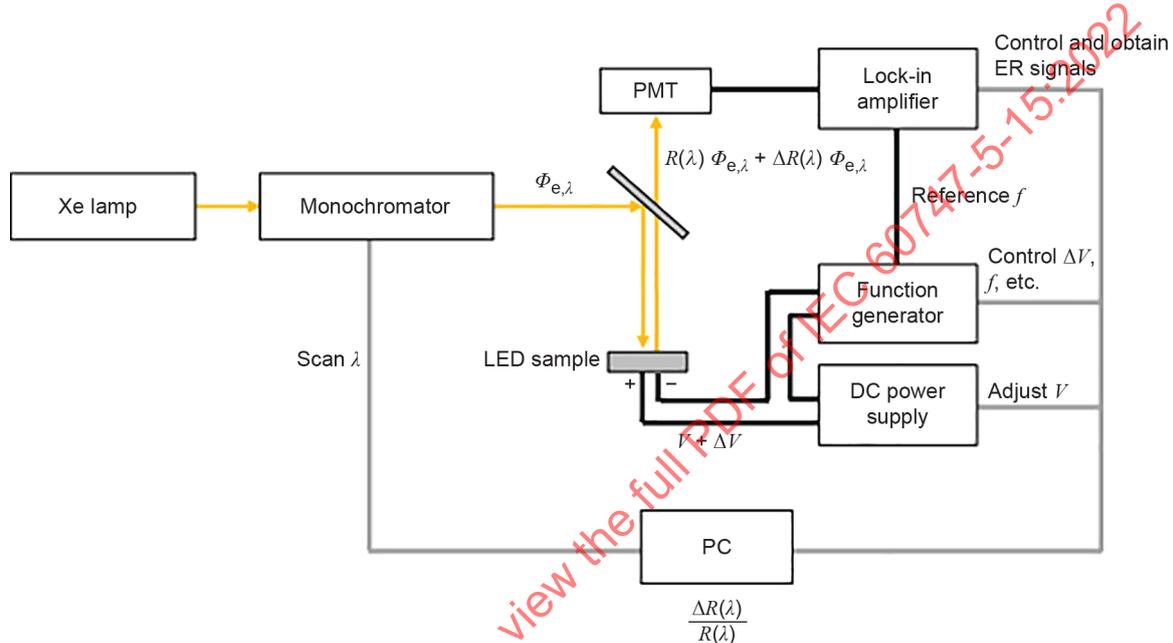
## 4.2 Purpose

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 ER spectroscopy, the internal electric field is determined.

### 4.3 Measurement

#### 4.3.1 Measurement setup

The measurement setup for the ER spectroscopy should be designed as shown in Figure 1 in principle. The input voltage to the LED sample is modulated by a function generator, i.e., the supplied voltage to the LED sample is  $V + \Delta V$ , where  $V$  is the DC voltage and  $\Delta V$  is the modulation voltage. Spectrally resolved light from a monochromator is incident on the LED sample. A photomultiplier tube measures the reflected light from the LED,  $R(\lambda)\Phi_{e,\lambda} + \Delta R(\lambda)\Phi_{e,\lambda}$ , and a lock-in amplifier amplifies the signal. The ratio of the modulated signal to the DC signal is the desired ER signal,  $\Delta R(\lambda)/R(\lambda)$ .



IEC

#### Key

$\Phi_{e,\lambda}$	spectral distribution
$R(\lambda)$	spectral reflectance at $\lambda$
PMT	photomultiplier tube
PC	personal computer

Figure 1 – Schematic diagram of the ER setup

#### 4.3.2 Measurement principle

Near the flat-band voltage  $V_{FB}$ , the electric field in the quantum well in the active region of the GaN-based LED is close to zero and the response to the modulation voltage  $\Delta V$  becomes minimal.

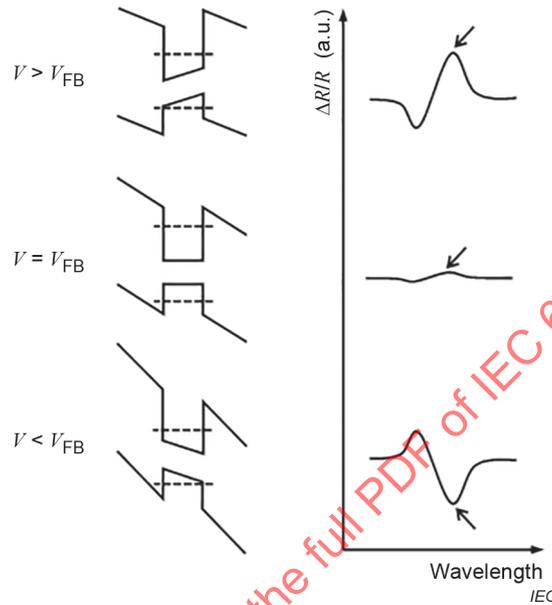
Theoretically, the ratio  $\Delta R/R$  can be written as

$$\frac{\Delta R}{R} = \left[ a \left( \frac{\delta E}{\delta F} \right) + b \left( \frac{\delta I}{\delta F} \right) + c \left( \frac{\delta \Gamma}{\delta F} \right) \right] \Delta F,$$

where  $a$ ,  $b$ , and  $c$  are fitting parameters,  $E$ ,  $I$ , and  $\Gamma$  are the transition energy, the oscillator strength, and the broadening parameter.  $F$  is the electric field in the quantum well and  $\Delta F$  is the modulated field due to  $\Delta V$ . Near the flat-band voltage  $V_{FB}$ , changes in transition energy,

$\Delta R/R$  becomes minimal at  $V_{FB}$  [1]<sup>1</sup>.

Figure 2 schematically illustrates the quantum well and the ER signal  $\Delta R/R$  under different DC voltages.  $\Delta R/R$  at different bias voltages have been translated by a constant amount along the  $y$ -axis. It is seen that  $\Delta R/R$  is inverted (or changes the phase) when the DC voltage is varied across  $V_{FB}$ . From this inversion in phase,  $V_{FB}$  is found from the ER spectroscopy.



**Key**

- $V$  bias DC voltage
- $V_{FB}$  flat-band voltage
- $\Delta R/R$  electroreflectance signal

**Figure 2 – Schematic illustration of the quantum well and the ER signal under different voltages**

From  $V_{FB}$  thus found, the internal electric field  $F_{int}$  is determined using the following formula if the microscopic parameters such as  $d_u$ ,  $d_d$ , and  $d_w$  are known [2], [3]:

$$F_{int} = \frac{V_{FB} - V_{bi}}{d_u + \frac{d_d}{2} - d_w}.$$

A typical value for  $V_{FB}$  is negative (i.e., reverse bias) in the case of GaN-based LEDs emitting blue or green wavelength. Consequently, the internal electric thus obtained field is given in negative value. The internal electric field thus found is from the p-side to the n-side.

<sup>1</sup> Numbers in square brackets refer to the Bibliography.

### 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.

- Step 1: Set a bias voltage for the ER measurement.
- Step 2: Measure the spectral reflectance  $\Delta R/R$  as a function of wavelength. Plot  $\Delta R/R$  vs. wavelength.
- Step 3: Check whether the phase inversion occurs in the plot of  $\Delta R/R$  vs. wavelength.

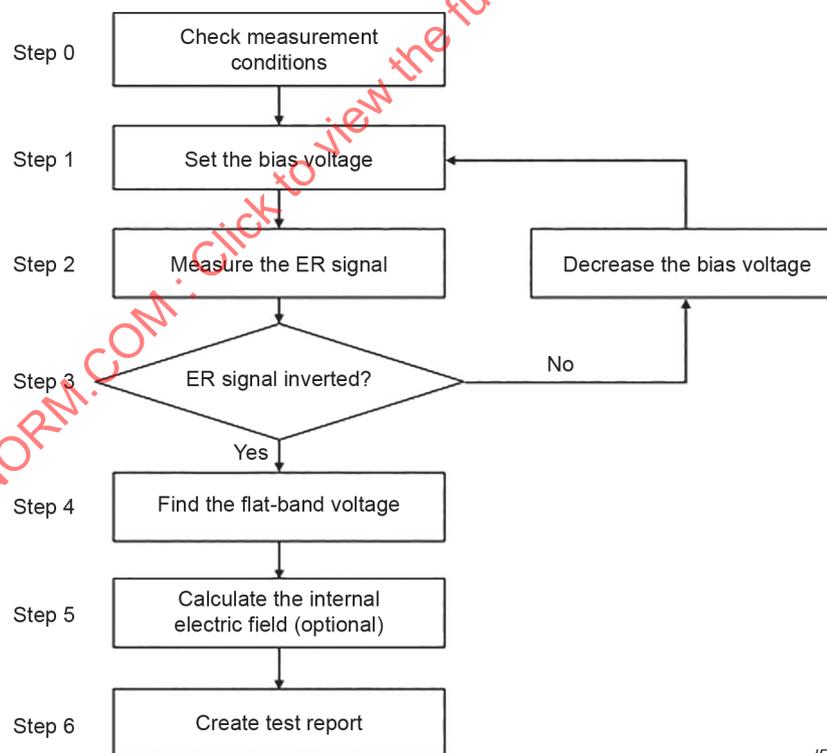
If the phase inversion has not occurred, decrease the bias voltage (i.e., more reverse bias) and go to step 2. If the phase inversion has occurred, go to step 4.

- Step 4: Find the flat-band voltage  $V_{FB}$ .

Plot the peak value  $\Delta R/R$  in as a function of bias voltage. To find the intercept point with the  $x$ -axis, interpolate the data if necessary.

- Step 5 (optional): Calculate the internal electric field.
- Step 6: Create the test report.

Figure 3 summarizes the measurement sequence of the internal electric field in the GaN-based LED.



IEC

Figure 3 – Sequence of the measurement of the flat-band voltage

## 5 Test report

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

## Annex A (informative)

### Test example

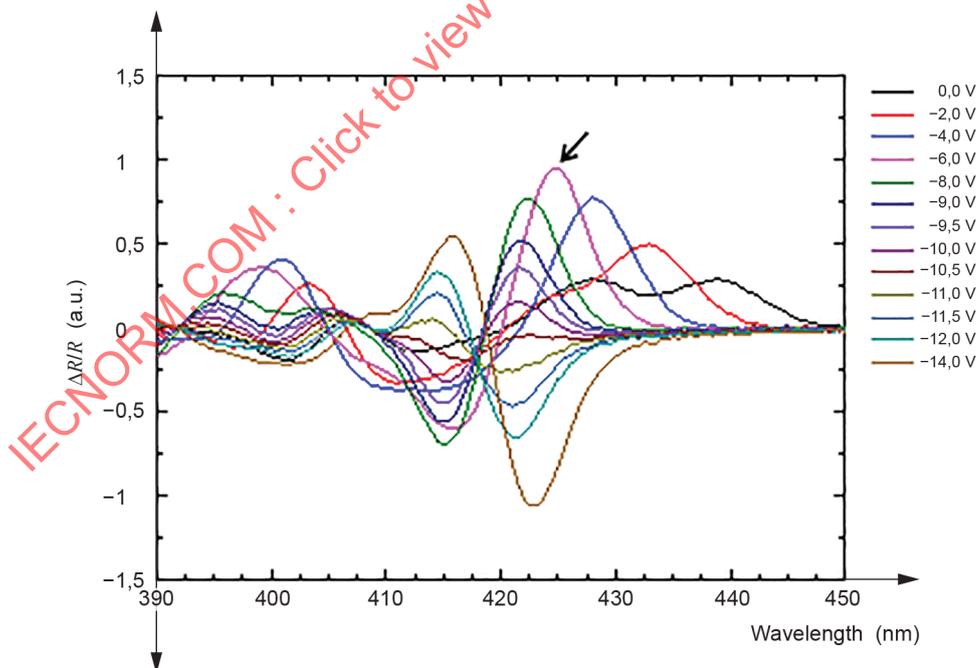
- Step 0: Test environmental specifications
  - sample: An InGaN/GaN multiple-quantum-well LED grown on a *c*-plane sapphire substrate;
  - die size: 800 μm × 800 μm;
  - peak wavelength: ~440 nm at  $T = 25\text{ °C}$ ;
  - humidity: 50 % RH;
  - modulation frequency  $f$ : 500 Hz;
  - modulation voltage  $\Delta V$ : 100 mV (peak-to-peak);
- Step 1: Set a bias voltage  $V$ .
- Step 2: Measure the spectral reflectance  $\Delta R/R$  from the ER spectroscopy.

Plot the spectral reflectance  $\Delta R/R$  vs. wavelength.

- Step 3: Check whether the phase inversion occurs in the plot of  $\Delta R/R$  vs. wavelength.

Decrease the bias voltage and repeat Steps 1 and 2 until the phase inversion occurs.

Figure A.1 shows the result of the ER spectroscopy at different bias voltages. The arrow indicates the peak in the ER signal to check the phase inversion. The phase inversion occurs between  $-10\text{ V}$  and  $-11\text{ V}$ . Several more bias voltages have been used after the phase inversion to highlight the changes.

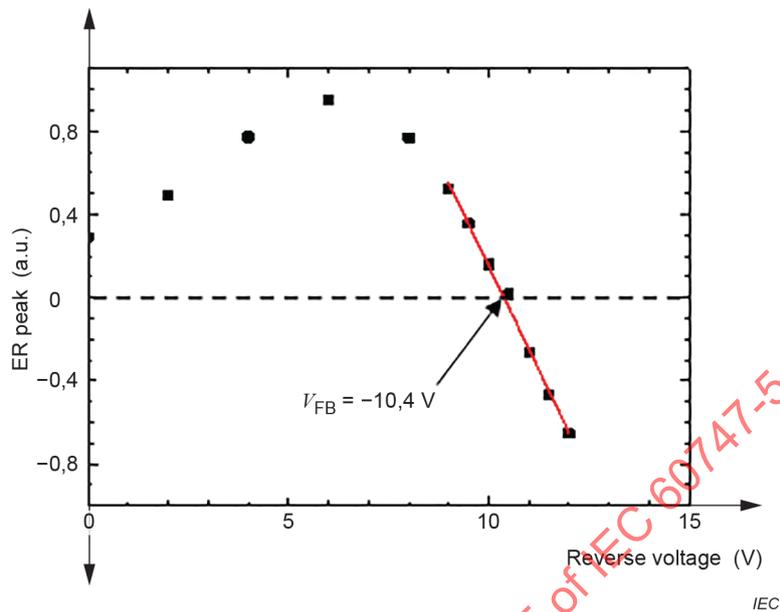


IEC

**Figure A.1 –  $\Delta R/R$  versus wavelength at different bias voltages**

- Step 4: Plot the magnitude of the ER peak versus bias voltage.

As shown Figure A.2, interpolate to find the  $x$ -intercept if necessary and identify the flat-band voltage  $V_{FB}$ .



#### Key

ER electroreflectance

$V_{FB}$  flat-band voltage

**Figure A.2 – ER peak as a function of reverse-bias voltage**

- Step 5: Calculate the internal electric field.

The parameters for this sample are  $d_u = 112,3 \text{ nm}$ ,  $d_w = 19,2 \text{ nm}$ , and  $d_d = 18,4 \text{ nm}$  with  $V_{FB} = -10,4 \text{ V}$  and  $V_{bi} = 3,3 \text{ V}$ . Using the following formula:

$$F_{\text{int}} = \frac{V_{FB} - V_{bi}}{d_u + \frac{d_d}{2} - d_w},$$

the internal electric field is  $F_{\text{int}} = -1,32 \text{ MV/cm}$ .

- Step 6: Create the test report.

**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
Die size	$\mu\text{m} \times \mu\text{m}$		
Package type	-		Ex. SMD
Peak wavelength	nm		
Operating temperature	$^{\circ}\text{C}$		
Humidity	% RH		
Modulation frequency	Hz		
Modulation voltage	mV		
Flat-band voltage	V		
$d_u$	nm		
$d_d$	nm		
$d_w$	nm		
Internal electric field	MV/cm		

IECNORM.COM : Click to view the full PDF of IEC 60747-5-15:2022