



BSI Standards Publication

# **Semiconductor devices — Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power devices**

---

Part 3: Test method for defects using photoluminescence



# IEC 63068-3

Edition 1.0 2020-07

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

---

**Semiconductor devices – Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power devices –  
Part 3: Test method for defects using photoluminescence**

**Dispositifs à semiconducteurs – Critères de reconnaissance non destructifs des défauts au sein d'une plaquette homoépitaxiale de carbure de silicium pour des dispositifs d'alimentation –  
Partie 3: Méthode d'essai pour les défauts à l'aide de la photoluminescence**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

COMMISSION  
ELECTROTECHNIQUE  
INTERNATIONALE

---

ICS 31.080.99

ISBN 978-2-8322-8614-2

**Warning! Make sure that you obtained this publication from an authorized distributor.  
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

## CONTENTS

|  |    |
|--|----|
| FOREWORD.....  | 4  |
| INTRODUCTION.....  | 6  |
| 1 Scope.....   | 7  |
| 2 Normative references .....                                     | 7  |
| 3 Terms and definitions .....                                    | 7  |
| 4 Photoluminescence method .....                                 | 11 |
| 4.1 General.....   | 11 |
| 4.2 Principle .....  | 11 |
| 4.3 Requirements .....   | 11 |
| 4.3.1 Measuring equipment .....                                  | 11 |
| 4.3.2 Wafer positioning and focusing.....                        | 13 |
| 4.3.3 Image capturing.....                                       | 13 |
| 4.3.4 Image processing .....                                     | 13 |
| 4.3.5 Image analysis .....                                       | 13 |
| 4.3.6 Image evaluation .....                                     | 14 |
| 4.3.7 Documentation .....  | 14 |
| 4.4 Parameter settings.....                                      | 14 |
| 4.4.1 General .....  | 14 |
| 4.4.2 Parameter setting process .....                            | 14 |
| 4.5 Procedure .....  | 14 |
| 4.6 Evaluation.....  | 14 |
| 4.6.1 General .....  | 14 |
| 4.6.2 Mean width of planar and volume defects .....              | 14 |
| 4.6.3 Evaluation process .....                                   | 15 |
| 4.7 Precision.....   | 15 |
| 4.8 Test report.....   | 15 |
| 4.8.1 Mandatory elements .....                                   | 15 |
| 4.8.2 Optional elements.....                                     | 15 |
| Annex A (informative) Photoluminescence images of defects.....   | 16 |
| A.1 General.....   | 16 |
| A.2 BPD .....  | 16 |
| A.3 Stacking fault.....  | 17 |
| A.4 Propagated stacking fault.....                               | 18 |
| A.5 Stacking fault complex .....                                 | 19 |
| A.6 Polytype inclusion.....                                      | 19 |
| Annex B (informative) Photoluminescence spectra of defects ..... | 21 |
| B.1 General.....   | 21 |
| B.2 BPD .....  | 21 |
| B.3 Stacking fault.....  | 21 |
| B.4 Propagated stacking fault.....                               | 23 |
| B.5 Stacking fault complex .....                                 | 23 |
| B.6 Polytype inclusion.....                                      | 24 |
| Bibliography.....  | 25 |
| Figure 1 – Schematic diagram of PL imaging system .....          | 12 |

|  |    |
|--|----|
| Figure A.1 – BPD .....   | 17 |
| Figure A.2 – Stacking fault.....   | 18 |
| Figure A.3 – Propagated stacking fault .....   | 18 |
| Figure A.4 – Stacking fault complex .....  | 19 |
| Figure A.5 – Polytype inclusion.....   | 20 |
| Figure B.1 – PL spectrum from BPD .....  | 21 |
| Figure B.2 – PL spectra from Frank-type stacking faults .....  | 22 |
| Figure B.3 – PL spectra from Shockley-type stacking faults .....                                     | 22 |
| Figure B.4 – PL spectra from various stacking faults in the wavelength range longer than 650 nm..... | 23 |
| Figure B.5 – PL spectrum from stacking fault complex .....   | 24 |
| Figure B.6 – PL spectrum from polytype inclusion .....   | 24 |

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SEMICONDUCTOR DEVICES –  
NON-DESTRUCTIVE RECOGNITION CRITERIA OF DEFECTS  
IN SILICON CARBIDE HOMOEPITAXIAL WAFER FOR POWER DEVICES –**

**Part 3: Test method for defects using photoluminescence**

**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.

International Standard IEC 63068-3 has been prepared by IEC technical committee 47: Semiconductor devices.

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

| FDIS         | Report on voting |
|--------------|------------------|
| 47/2628/FDIS | 47/2638/RVD      |

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 63068 series, published under the general title *Semiconductor devices – Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power 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 "<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.

## INTRODUCTION

Silicon carbide (SiC) is widely used as a semiconductor material for next-generation power semiconductor devices. SiC, as compared with silicon (Si), has superior physical properties such as a higher breakdown electric field, higher thermal conductivity, lower thermal generation rate, higher saturated electron drift velocity, and lower intrinsic carrier concentration. These attributes realize SiC-based power semiconductor devices with faster switching speeds, lower losses, higher blocking voltages, and higher temperature operation relative to standard Si-based power semiconductor devices.

SiC-based power semiconductor devices are not fully realized due to some issues including high costs, low yield, and low long-term reliability. In particular, one of the serious issues lies in the defects existing in SiC homoepitaxial wafers. Although efforts of decreasing defects in SiC homoepitaxial wafers are actively implemented, there are a number of defects in commercially available SiC homoepitaxial wafers. Therefore, it is indispensable to establish an international standard regarding the quality assessment of SiC homoepitaxial wafers.

The IEC 63068 series of standards is planned to comprise Part 1, Part 2, and Part 3, as detailed below. This document provides definitions and guidance in use of photoluminescence for detecting defects in commercially available silicon carbide (SiC) homoepitaxial wafers.

Part 1: Classification of defects

Part 2: Test method for defects using optical inspection

Part 3: Test method for defects using photoluminescence

# SEMICONDUCTOR DEVICES – NON-DESTRUCTIVE RECOGNITION CRITERIA OF DEFECTS IN SILICON CARBIDE HOMOEPITAXIAL WAFER FOR POWER DEVICES –

## Part 3: Test method for defects using photoluminescence

### 1 Scope

This part of IEC 63068 provides definitions and guidance in use of photoluminescence for detecting as-grown defects in commercially available 4H-SiC (Silicon Carbide) epitaxial wafers. Additionally, this document exemplifies photoluminescence images and emission spectra to enable the detection and categorization of the defects in SiC homoepitaxial wafers.

### 2 Normative references

There are no normative references in this document.

### 3 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

##### **photoluminescence**

##### **PL**

emission of light from materials as a subsequence of electronic excitation by absorption of photons

#### 3.2

##### **photoluminescence imaging**

##### **PL imaging**

technique for capturing, processing and analysing images of defects using light source for electronic excitation, focusing optics, optical filter, optical image sensor and computer systems

#### 3.3

##### **focusing optics**

lens system used for magnifying and capturing optical images

#### 3.4

##### **optical filter**

optical component designed to transmit only a specific wavelength region and to block other regions

#### 3.5

##### **optical image sensor**

device to transform an optical image into digital data

**3.6****image capturing**

process of creating a two-dimensional original digital image of defects in the wafer

**3.7****original digital image**

digitized image acquired by an optical image sensor, without performing any image processing

Note 1 to entry: An original digital image consists of pixels divided by a grid, and each pixel has a grey level.

**3.8****charge-coupled device image sensor**

CCD image sensor

light-sensitive integrated circuit chip that converts detected optical information to electrical signals

Note 1 to entry: A CCD consists of fine elements, each of which corresponds to a pixel of original digital images.

**3.9****pixel**

smallest formative element of original digital images, to which a grey level is assigned

**3.10****resolution**

number of pixels per unit length (or area) of original digital images

Note 1 to entry: If resolutions in the X- and Y-directions are different, both values have to be recorded.

**3.11****spatial resolution**

ability to distinguish two closely spaced points as two independent points

**3.12****grey level**

degree of brightness defined in a greyscale

Note 1 to entry: Degree of brightness is usually represented as a positive integer taken from greyscale.

**3.13****greyscale**

range of grey shades from black to white

EXAMPLE 8-bit greyscale has two-to-the-eighth-power (= 256) grey levels. Grey level 0 (the 1st level) corresponds to black, grey level 255 (the 256th level) to white.

**3.14****image processing**

software manipulation of original digital images to prepare for subsequent image analysis

Note 1 to entry: For example, image processing can be used to eliminate mistakes generated during image capturing or to reduce image information to the essential.

**3.15****binary image**

image in which either 0 (black) or 1 (white) is assigned to each pixel

**3.16****brightness**

average grey level of a specified part of optical images

**3.17****contrast**

difference between the grey levels of two specified parts of optical images

**3.18****shading correction**

software method for correcting non-uniformity of the illumination over the wafer surface

**3.19****thresholding**

process of creating a binary image out of a greyscale image by setting exactly those pixels whose value is greater than a given threshold to white and setting the other pixels to black

Note 1 to entry: To make a binary image, the grey level of each pixel in the original greyscale image is replaced with 0 (black) or 1 (white), depending on whether the grey level is greater than or less than or equal to a given threshold.

**3.20****edge detection**

method of isolating and locating edges of defects and surface features in a given digital image

**3.21****image analysis**

extraction of imaging information from processed digital images by software

**3.22****image evaluation**

process of relating a series of values resulting from image analysis of one or more characteristic images via a classification scheme of defects

**3.23****reference wafer**

specified wafer used for parameter settings, which has already been evaluated for checking the reproducibility and repeatability of optical inspection process for defects

**3.24****test wafer**

semiconductor wafer under test to evaluate defects

**3.25****crystal direction**

direction, usually denoted as  $[uvw]$ , representing a vector direction in multiples of the basis vectors describing the  $a$ ,  $b$  and  $c$  crystal axes

Note 1 to entry: In 4H-SiC showing a hexagonal symmetry, four-digit indices  $[uv\bar{t}w]$  are frequently used for crystal directions.

[SOURCE: ISO 24173:2009 [1]<sup>1</sup>, 3.3, modified – The original note has been replaced by a new note to entry.]

**3.26****defect**

crystalline imperfection

---

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

**3.27****micropipe**

hollow tube extending approximately normal to the basal plane

**3.28****threading screw dislocation****TSD**

screw dislocation penetrating through the crystal approximately normal to the basal plane

**3.29****threading edge dislocation****TED**

edge dislocation penetrating through the crystal approximately normal to the basal plane

**3.30****basal plane dislocation****BPD**

dislocation lying on the basal plane

**3.31****scratch trace**

dense row of dislocations caused by mechanical damages on the substrate surface

**3.32****stacking fault**

planar crystallographic defect in monocrystalline material, characterized by an error in the stacking sequence of crystallographic planes

**3.33****propagated stacking fault**

stacking fault propagating from substrate toward the homoepitaxial layer surface

**3.34****stacking fault complex**

stacking fault complex consisting of a basal plane stacking fault and a prismatic fault

**3.35****polytype inclusion**

volume crystal defect showing different polytypes from that of the homoepitaxial layer

**3.36****particle inclusion**

macroscopic size particle existing in the homoepitaxial layer

**3.37****bunched-step segment**

surface morphological roughness consisting of bunched-steps

**3.38****surface particle**

particle deposited on the epitaxial layer surface after epitaxial growth

## 4 Photoluminescence method

### 4.1 General

Defects with characteristic PL features shall be evaluated by PL method. The following descriptions concern such defects in n/n<sup>+</sup>-type 4H-SiC homoepitaxial wafers with an off-cut angle of 4° along the direction of  $[11\bar{2}0]$ , where their PL images are obtained by detecting emission wavelengths longer than 650 nm:

- individual linear defects exhibiting bright line images, e.g. BPDs;
- individual planar defects exhibiting dark contrast images, e.g. stacking faults, propagated stacking faults, stacking fault complexes, and polytype inclusions.

When emission wavelengths from 400 nm to 500 nm are used for the defect detection, stacking faults exhibit bright contrast images.

Defects without characteristic PL features or with weak PL contrasts against SiC area with no defects should be evaluated by other test methods such as optical inspection and X-ray topography. Those defects include micropipes, TSDs, TEDs, scratch traces, particle inclusions, bunched-step segments, and surface particles.

### 4.2 Principle

PL images of defects are captured and transformed into a digital format. In the course of this process, an SiC homoepitaxial wafer is irradiated with excitation light whose energy is greater than the bandgap of 4H-SiC crystals, and the resulting PL is collected and recorded as a PL image of a specified area of the wafer including defects. PL is detected using an optical image sensor such as a CCD image sensor, and PL image is usually acquired using an optical filter which transmits a specific range of PL appropriate for the detection of each type of defect. Then, the obtained PL image (digital image) is processed by manipulating the grey levels of the image. Through a specified scheme of image analysis, the image information is reduced to a set of values which are specific to the detected defects.

A greyscale image is produced from the original digital image of defects in the wafer. This image can be converted into a binary image (thresholding). The size and shape of defects are measured, and the distribution and number of defects within a specified area of wafer are calculated.

NOTE The size of planar and volume defects extending along the off-cut direction depends on the thickness of homoepitaxial layer. Details of such defects and the method of estimating the size of their PL images are described in Annex A and 4.6.2, respectively.

### 4.3 Requirements

#### 4.3.1 Measuring equipment

##### 4.3.1.1 PL imaging system

Measuring equipment for PL imaging of defects in 4H-SiC homoepitaxial wafers is shown in Figure 1. The measuring equipment consists of light source, focusing optics, optical filter, CCD, wafer stage, controller/processor, and dark box. Each component shall have the performance specified below. Different wafer specifications and defect types will require an optimum setup of light source, focusing optics and optical filter to acquire distinct PL features that are to be analysed. Therefore, a combination of light source, focusing optics and optical filter for a specific application needs to be prepared.



#### 4.3.1.4 Optical filter

Optical filters shall be selected to suit the inspection for specified defects in homoepitaxial wafers.

NOTE Typical PL spectra of defects are described in Annex B.

#### 4.3.1.5 Uniformity and constancy

A combination of light source and focusing optics should be optimized to achieve sufficient uniformity of the excitation light intensity on the wafer surface. The PL intensity at each point on the epitaxial layer is adjusted in an appropriate range so that defects are clearly detected. Uniformity of excitation light intensity can be achieved using hardware and/or software.

The spectral and power distributions of the excitation light are maintained constant during the whole measurement period.

#### 4.3.2 Wafer positioning and focusing

Wafers shall be positioned in the plane of Cartesian coordinate system (X–Y) or cylindrical coordinate system (R– $\theta$ ). The third axis (Z) is the optical axis of image capturing system. The Z-axis is perpendicular to the plane and its point of intersection with the plane shall be the point of focus. The distance between the front-end portion of image-capturing optics and the wafer surface shall be constant, independent of the thickness of the wafers, so that focusing and magnification are not mutually adversely affected.

#### 4.3.3 Image capturing

The PL imaging system is typically composed of a light source, focusing optics, CCD image sensor as an optical digital sensor, lighting-geometry adjustment system, wafer stage and light-tight enclosure. A dark box or a rack housing is often used to prevent the interference by external illumination. The spatial resolution of the PL imaging system shall be high enough to capture distinct features of small size defects. The image information is digitized directly within the optical image sensor unit.

To ensure the repeatability and reproducibility of the image capturing procedure, parameter settings should be carried out at a regular interval. This can be performed using specified reference wafers, for example, silicon or silicon carbide wafers.

#### 4.3.4 Image processing

The image processing covers numerous features such as brightness, contrast, edge detection, shading correction, and inversion.

Different software solutions may employ different mathematical algorithms for similar operations, and images processed by different image-processing algorithms will not be identical. Parameter settings, e.g. using reference wafers, are performed to ensure that results are comparable.

#### 4.3.5 Image analysis

Two different methods are used for image analysis: binary (black/white) analysis and grey-level analysis. To obtain a binary image from a grey-level image, threshold procedure is used.

An appropriate algorithm should be used for image analysis to detect successfully defects in test wafers.

### 4.3.6 Image evaluation

The result of image analysis is a set of values which are pertinent to a specific application. This set of values is transformed into one or more characteristic values via a classification scheme of defects.

### 4.3.7 Documentation

Relevant parameters for PL imaging system shall be documented. These comprise:

- a) wavelength of excitation light from light source;
- b) wavelength range detected by optical image sensor through optical filters;
- c) spatial resolution of PL imaging system.

## 4.4 Parameter settings

### 4.4.1 General

Test wafers should be compared with reference wafers.

The purpose of parameter settings is to fix the image capturing parameters in such a way that image analysis will be possible to identify the PL features of defects in test wafers by using reference wafers. A visual comparison is performed to confirm the correspondence between the reference wafers and test wafers with regard to the detected defect.

The reference wafers should be as similar as possible to test wafers on the structure and specification; thus, it is desirable to prepare both the reference wafers and test wafers in the same laboratory or factory, using the same equipment and process.

### 4.4.2 Parameter setting process

Parameter settings should be executed as described below using a set of reference wafers.

Take an image of each defect on test wafer using a selected PL imaging system. The images of defects on test wafer should be visually compared with those of reference wafers.

## 4.5 Procedure

Prepare test wafers for PL imaging as follows.

Create images of test wafers using a parameter-optimized PL imaging system. Once suitable threshold values are established, a digitized image provides, on analysis, contrasts pertinent to the defect structures.

## 4.6 Evaluation

### 4.6.1 General

In contrast to manual assessment of defects, PL imaging system can determine directly the size and shape of defects with characteristic PL features (see 4.1 and Annex A).

The image analysis provides data that identify the positions and types of defects. The edge exclusion of test wafers should be less than 5 mm.

### 4.6.2 Mean width of planar and volume defects

With the known thickness of homoepitaxial layer  $d$ , in micrometres, and an off-cut angle of  $4^\circ$ , calculate the mean width parallel to the off-cut direction  $l$ , in micrometres, of planar and volume defects except particle inclusions and surface particles using the following formula:

$$l = \frac{d}{\tan(4^\circ)}$$

For example, values of the mean width  $l$  of defects for 10  $\mu\text{m}$ - and 30  $\mu\text{m}$ -thickness homoepitaxial layers are approximately 145  $\mu\text{m}$  and 430  $\mu\text{m}$ , respectively.

When planar and volume defects are formed in the middle of epitaxial growth, the defect width is less than given by the above formula.

#### 4.6.3 Evaluation process

If the recognized objects are either extended or surface defects, the number of defects shall be counted for each type of defect.

Defect maps, which indicate the positions (plane coordinates) of detected defects across the entire wafer, should be formed. In the maps, the position of the orientation flat or notch of the wafer shall also be indicated. The coordinate origin of the map should be the centre of the circle, which corresponds to the main edges of the wafer. The horizontal axis of the coordinate should be parallel to the primary orientation flat of the wafer.

#### 4.7 Precision

Information on the precision of this test method is currently not available.

#### 4.8 Test report

##### 4.8.1 Mandatory elements

A test report shall contain the following information:

- a) inspection results:
  - 1) number of each type of defect detected by PL imaging;
- b) test wafers:
  - 1) manufacturer;
  - 2) trade name;
  - 3) wafer identification;
- c) reference to this part of IEC 63068;
- d) PL imaging system:
  - 1) wavelength of excitation light from light source;
  - 2) intensity of excitation light at the wafer surface;
  - 3) wavelength range detected by optical image sensor through optical filters;
  - 4) spatial resolution of PL imaging system;
- e) date of the test.

##### 4.8.2 Optional elements

The following information should be contained in the test report:

- a) inspection results:
  - 1) positions (plane coordinates) of all the detected defects;
  - 2) defect maps;
- b) any deviations from the procedure;
- c) any unusual features observed.

## **Annex A** (informative)

### **Photoluminescence images of defects**

#### **A.1 General**

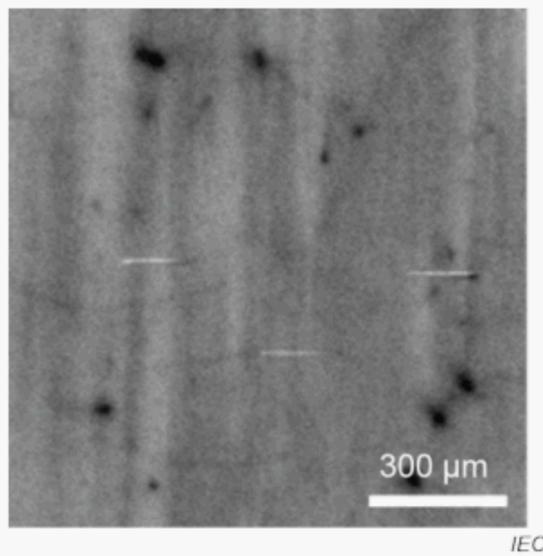
Annex A shows typical PL images and features of defects in 4H-SiC homoepitaxial wafers (epitaxial layer thickness: 10  $\mu\text{m}$ ) acquired by a PL imaging system using an excitation light of wavelength of 365 nm. A 650 nm long pass optical filter was used for detecting defects. The pixel resolution of the images was 2  $\mu\text{m}$ . In Figures Figure A.1 to Figure A.5, the subfigures in the left and right columns denote a photoluminescence (PL) image and a schematic illustration of the plan-view observation image of defect, respectively.

#### **A.2 BPD**

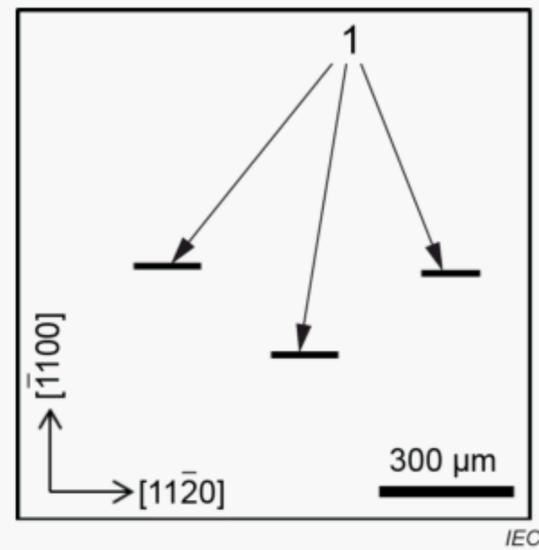
BPDs exhibit bright line contrasts in PL images when captured at emission wavelengths longer than 650 nm.

NOTE 1 The mean width  $l$ , in micrometres, of this type of defects depends on the thickness  $d$ , in micrometres, of the homoepitaxial layer (see 4.6.2).

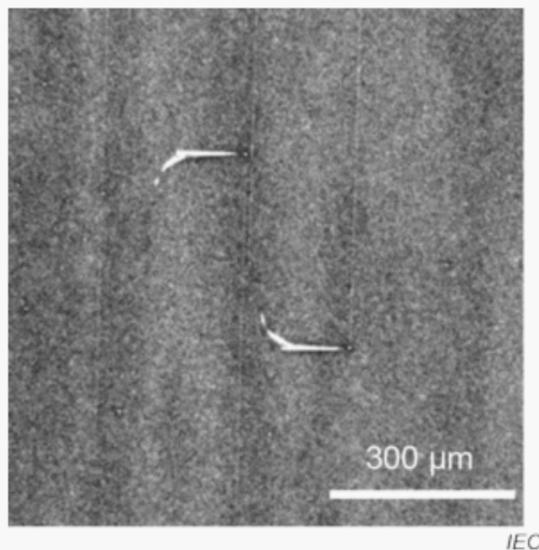
NOTE 2 The extension directions of BPDs are predominantly parallel or nearly parallel to the step flow direction. However, BPDs also often extend in other directions and can be curved.



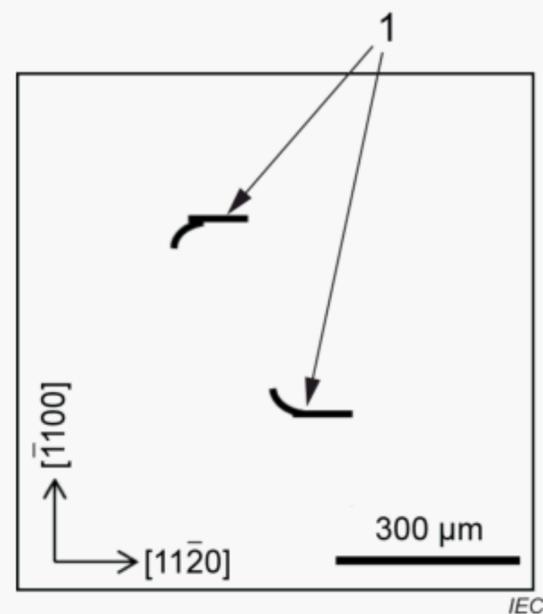
a) Example 1 of BPD: PL image



b) Example 1 of BPD: Schematic illustration



c) Example 2 of BPD: PL image



d) Example 2 of BPD: Schematic illustration

**Key**

1 BPD

**Figure A.1 – BPD****A.3 Stacking fault**

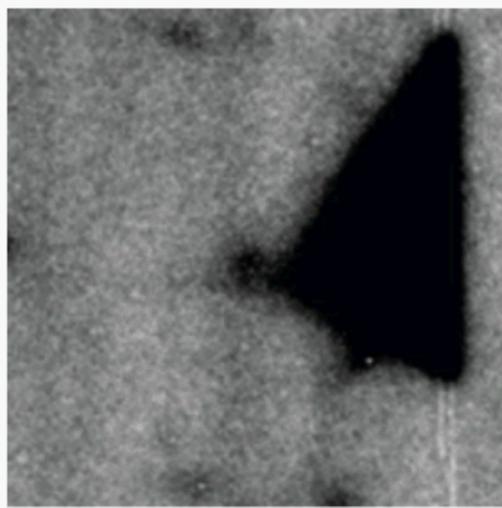
Stacking faults exhibit characteristic features in PL images of 4H-SiC homoepitaxial wafers. They exhibit characteristic PL spectra depending on their stacking sequences.

NOTE 1 The types of stacking faults can be distinguished by examining their emission spectra.

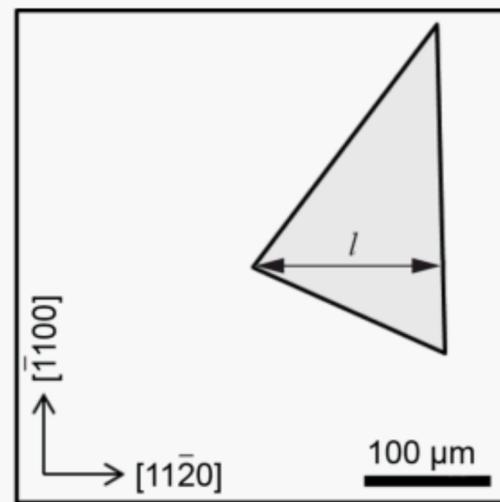
NOTE 2 Three types of Frank-type stacking faults are detected in the visible wavelength range at room temperature [see Figure B.2].

NOTE 3 Four types of Shockley-type stacking faults are detected in the visible wavelength range at room temperature [see Figure B.3].

NOTE 4 The mean width  $l$ , in micrometres, of this type of defects depends on the thickness  $d$ , in micrometres, of homoepitaxial layer (see 4.6.2).



IEC

a) Example of stacking fault:  
PL image

IEC

b) Example of stacking fault:  
Schematic illustration

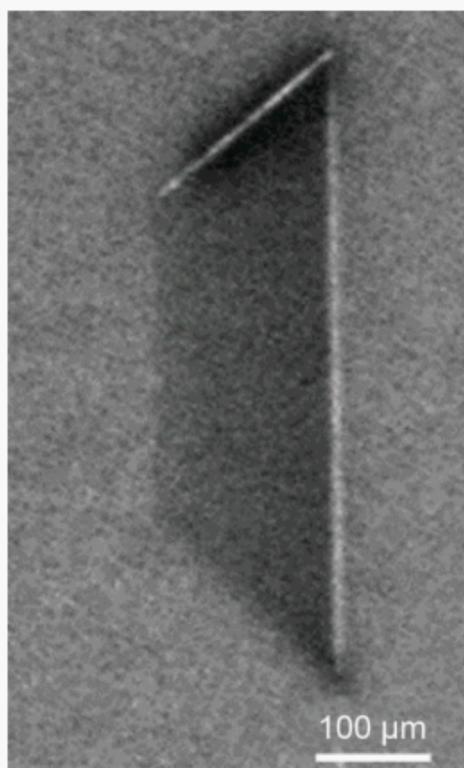
Figure A.2 – Stacking fault

#### A.4 Propagated stacking fault

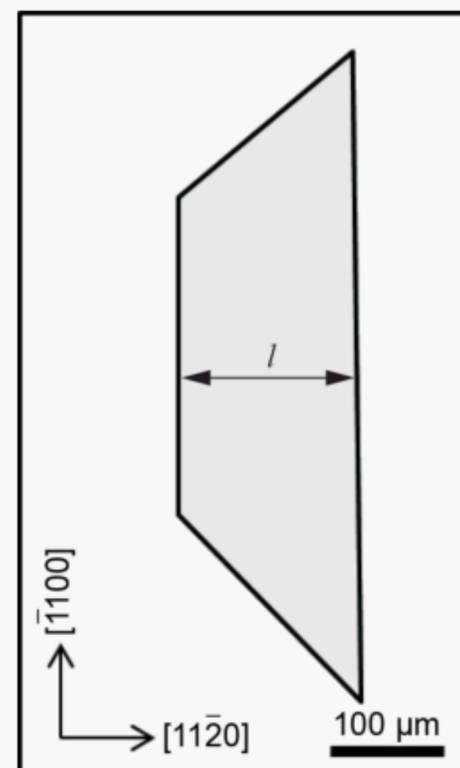
This is a stacking fault in a homoepitaxial layer formed by inheriting a stacking fault in a substrate. Propagated stacking faults exhibit the PL features determined by their stacking sequences, as illustrated in Clause A.3.

NOTE 1 The mean width  $l$ , in micrometres, of this type of defects depends on the thickness  $d$ , in micrometres, of homoepitaxial layer (see 4.6.2).

NOTE 2 These defects are often referred to as "bar-shaped stacking fault".



IEC

a) Example of propagated stacking fault:  
PL image

IEC

b) Example of propagated stacking fault:  
Schematic illustration

Figure A.3 – Propagated stacking fault

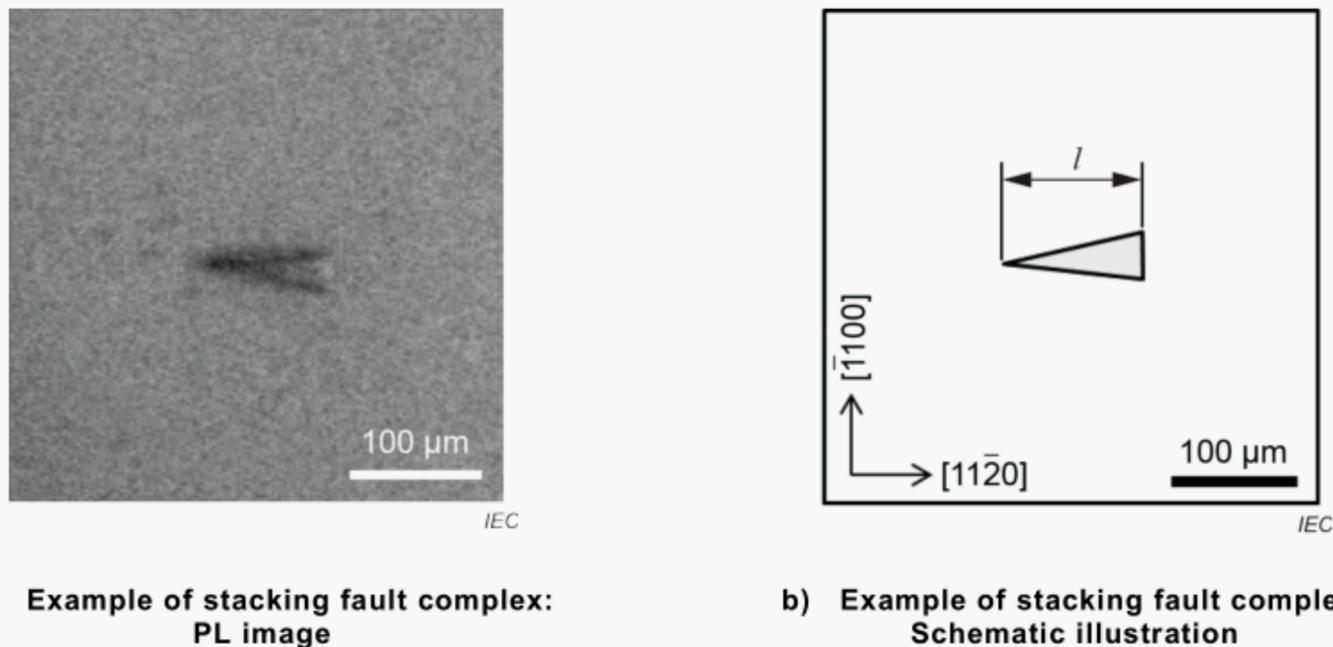
## A.5 Stacking fault complex

Stacking fault complexes exhibit characteristic features in PL images of 4H-SiC homoepitaxial wafers: for example, dark acicular (needle-shaped) morphological features extending along the off-cut direction when captured at emission wavelengths longer than 650 nm.

NOTE 1 Stacking fault complexes exhibit bright contrast images when captured at emission wavelength of 420 nm, which originates from their stacking sequence similar to a Frank-type stacking fault (extrinsic) (see Figure B.5).

NOTE 2 The mean width  $l$ , in micrometres, of this type of defects depends on the thickness  $d$ , in micrometres, of homoepitaxial layer (see 4.6.2).

NOTE 3 These defects are often referred to as "carrot defect".



a) Example of stacking fault complex:  
PL image

b) Example of stacking fault complex:  
Schematic illustration

**Figure A.4 – Stacking fault complex**

## A.6 Polytype inclusion

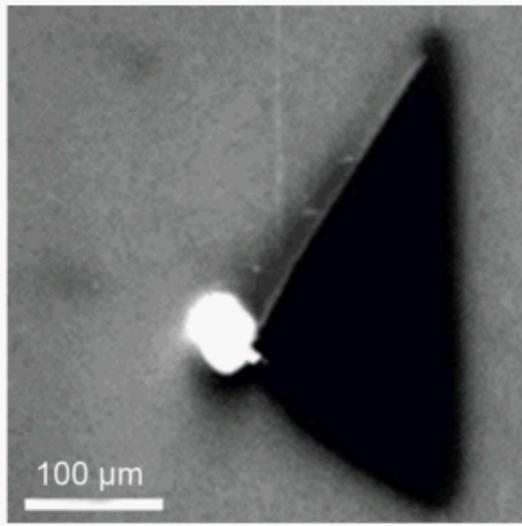
Polytype inclusions exhibit characteristic PL features on the 4H-SiC homoepitaxial layer surface: for example, dark triangles of various shapes extending along the off-cut direction when captured at emission wavelengths longer than 650 nm.

NOTE 1 Polytype inclusions exhibit bright contrast images when captured at emission wavelengths between 500 nm and 600 nm (see Figure B.6).

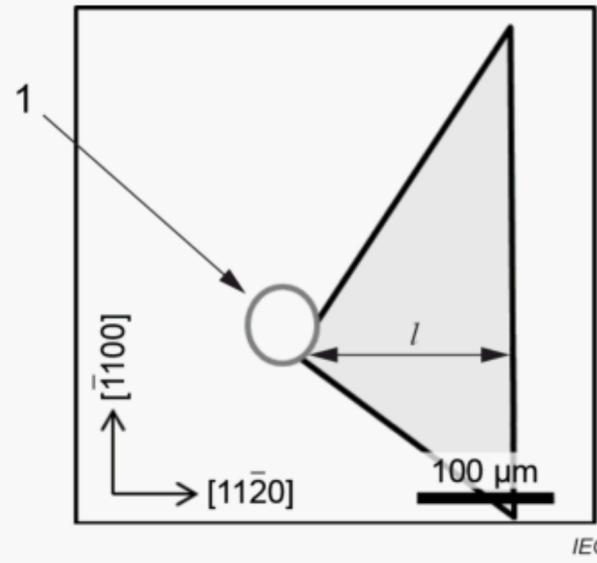
NOTE 2 The mean width  $l$ , in micrometres, of this type of defects depends on the thickness  $d$ , in micrometres, of homoepitaxial layer (see 4.6.2).

NOTE 3 These defects are formed not only due to particles, which is the case shown in Figure A.5, but also due to other causes such as mechanical surface damage as a result of the polishing process.

NOTE 4 These defects are often referred to as "triangular inclusion", "triangular defect", or "comet tail defect".



a) Example of polytype inclusion:  
PL image



b) Example of polytype inclusion:  
Schematic illustration

**Key**

1 particle

**Figure A.5 – Polytype inclusion**

## Annex B (informative)

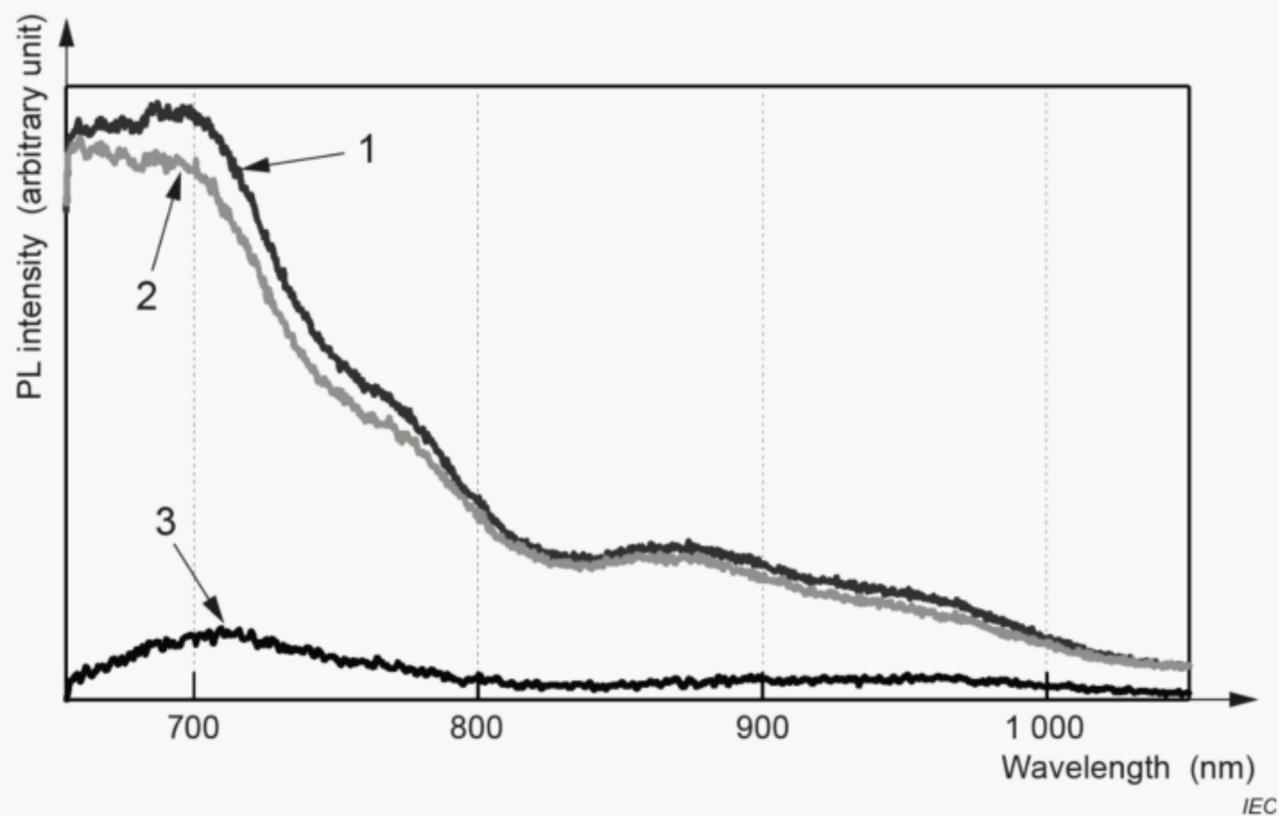
### Photoluminescence spectra of defects

#### B.1 General

Annex B shows typical PL spectra obtained at room temperature from defects which have characteristic PL features. PL spectra were obtained by using a spectrometer with focal length of 32 cm. The 325 nm line of a He-Cd laser was used as an excitation source. PL was dispersed by the spectrometer with a grating of 150 lines per millimetre and detected by a CCD detector. The laser beam was guided into a microscope and focused through an objective lens. The laser beam is focused to a spot size of about 2  $\mu\text{m}$  on the sample surface with a power density of 30  $\text{kW}/\text{cm}^2$  to 100  $\text{kW}/\text{cm}^2$ .

#### B.2 BPD

The "difference between with and without BPD" represents the subtraction of the PL spectrum acquired from area without BPD from that from area with BPD [see Figure B.1]. In this case, BPD exhibits a bright line contrast in PL image.



#### Key

- 1 with BPD
- 2 without BPD
- 3 difference between with and without BPD

Figure B.1 – PL spectrum from BPD

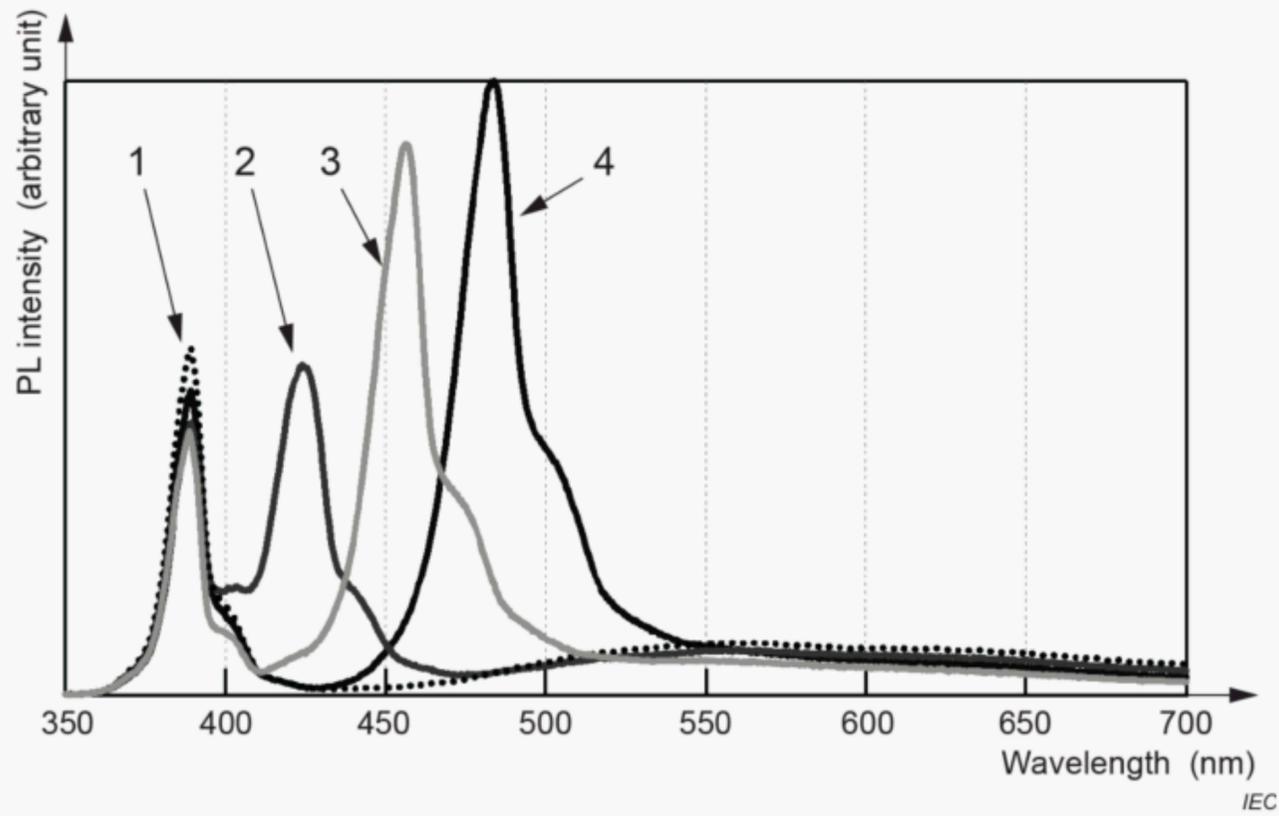
#### B.3 Stacking fault

The types of stacking faults can be distinguished by examining their emission spectra.

NOTE 1 Three types of Frank-type stacking faults are detected at emission wavelengths of 488 nm (intrinsic), 457 nm (multilayer), and 424 nm (extrinsic) at room temperature [2] [see Figure B.2].

NOTE 2 Four types of Shockley-type stacking faults are detected at emission wavelengths of 420 nm (single) [3], 455 nm (quadruple) [4], 480 nm (triple) [5], and 500 nm (double) [6] at room temperature [see Figure B.3].

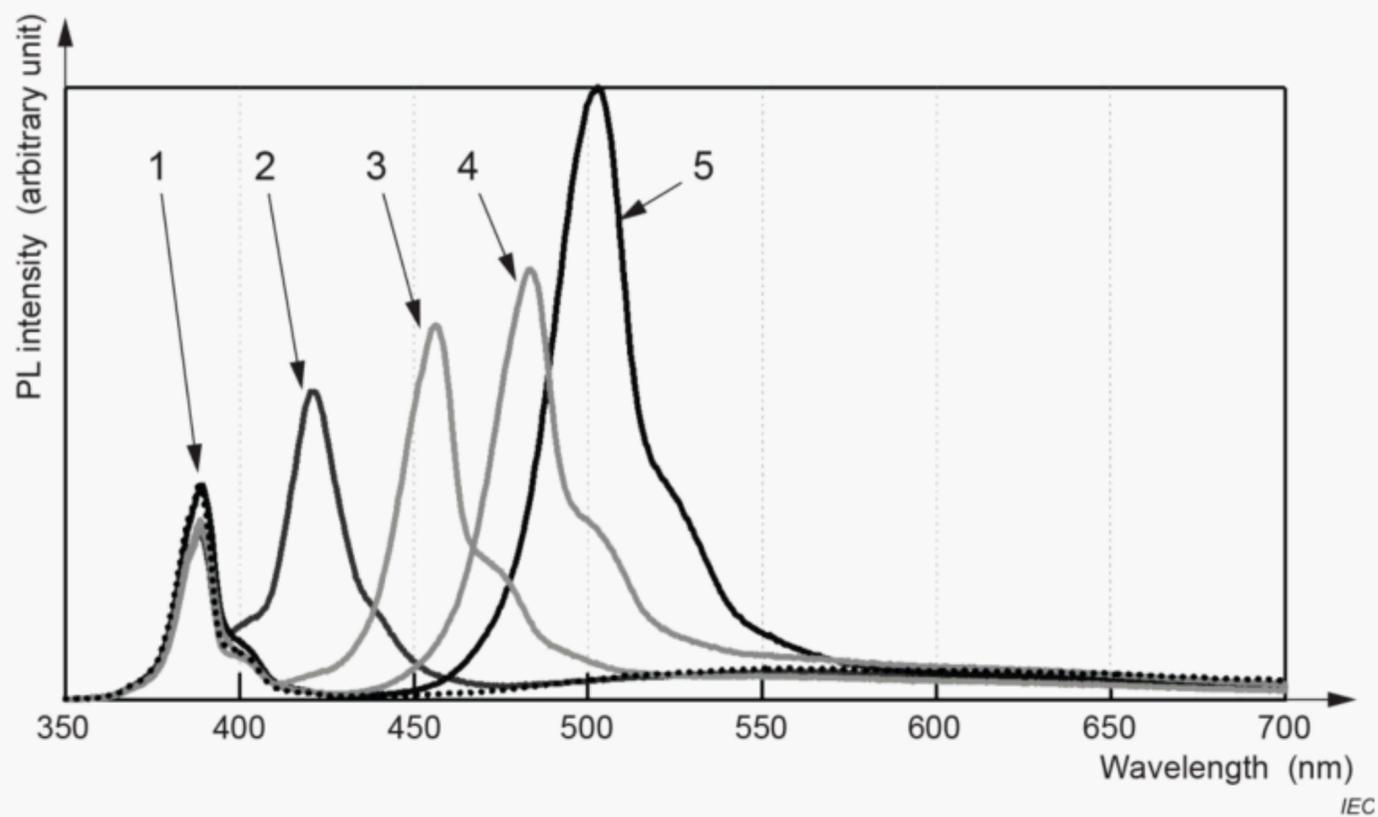
NOTE 3 All types of stacking faults exhibit dark contrast images when captured at emission wavelengths longer than 650 nm [see Figure B.4].



**Key**

- |                    |              |
|--------------------|--------------|
| 1 no defect region | 3 multilayer |
| 2 extrinsic        | 4 intrinsic  |

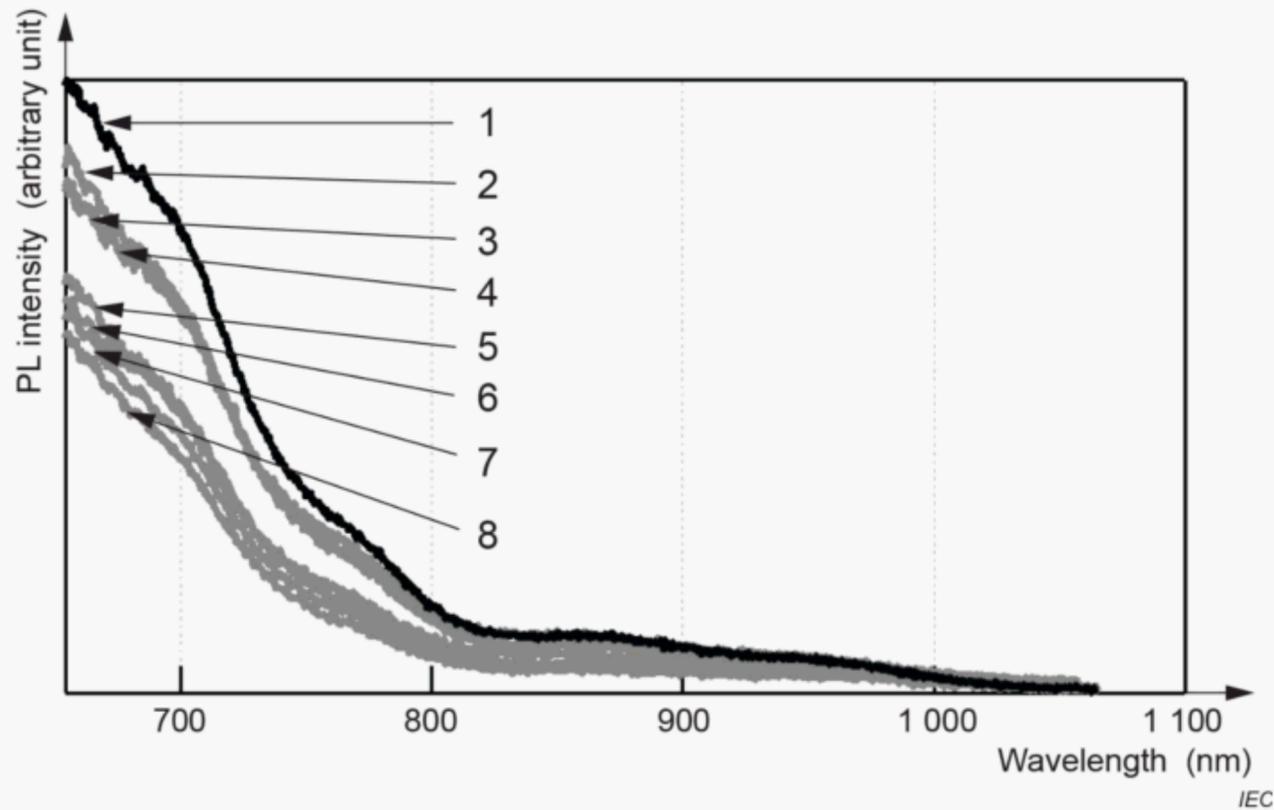
**Figure B.2 – PL spectra from Frank-type stacking faults**



**Key**

- |                    |          |
|--------------------|----------|
| 1 no defect region | 4 triple |
| 2 single           | 5 double |
| 3 quadruple        |          |

**Figure B.3 – PL spectra from Shockley-type stacking faults**

**Key**

|   |                        |   |                           |
|---|------------------------|---|---------------------------|
| 1 | no defect region       | 5 | Frank-type (multilayer)   |
| 2 | Frank-type (extrinsic) | 6 | Shockley-type (quadruple) |
| 3 | Shockley-type (single) | 7 | Frank-type (intrinsic)    |
| 4 | Shockley-type (triple) | 8 | Shockley-type (double)    |

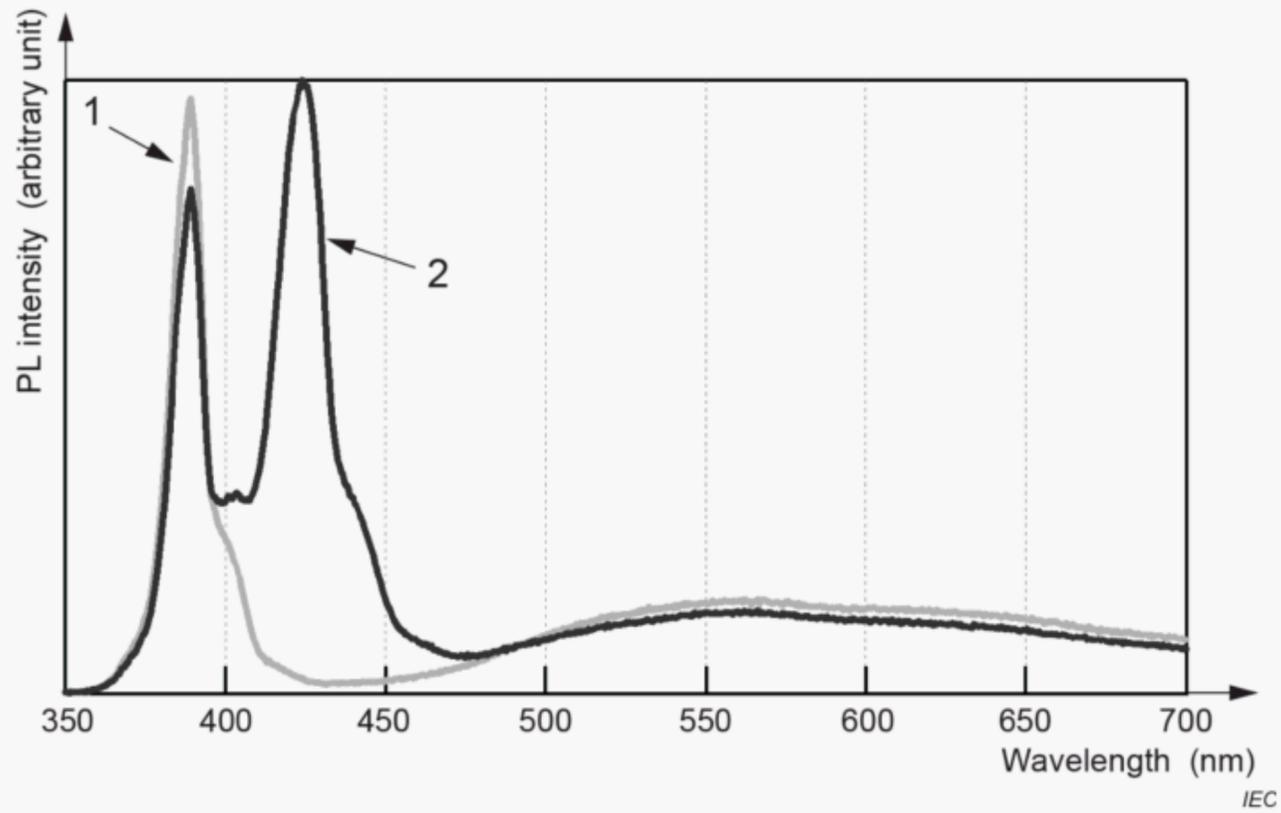
**Figure B.4 – PL spectra from various stacking faults in the wavelength range longer than 650 nm**

#### B.4 Propagated stacking fault

Propagated stacking faults exhibit the PL spectra determined by their stacking sequences, as illustrated in Clause B.3.

#### B.5 Stacking fault complex

Stacking fault complexes exhibit characteristic PL features at an emission wavelength of 420 nm, which originates from their stacking sequence similar to a Frank-type stacking fault (extrinsic).

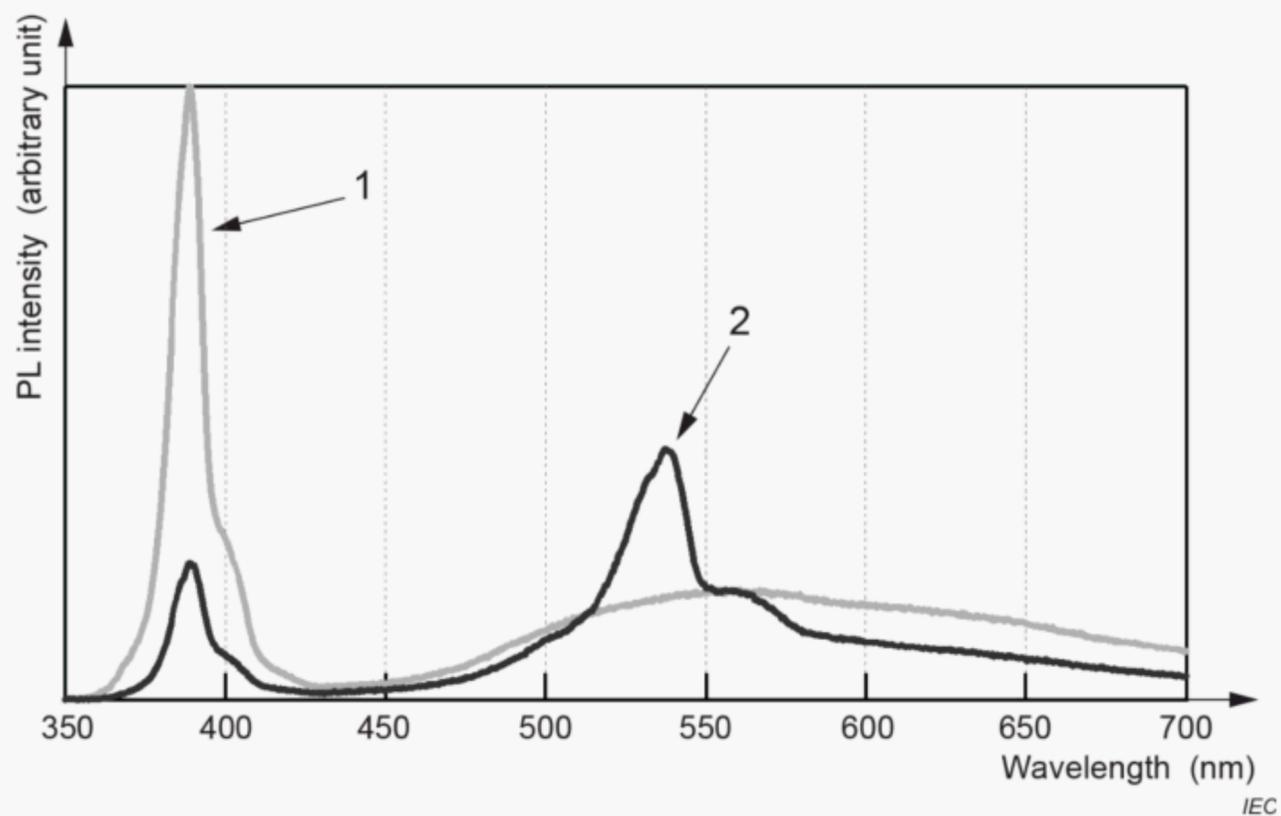
**Key**

- 1 no defect region
- 2 Frank-type stacking fault (extrinsic) in a stacking fault complex

**Figure B.5 – PL spectrum from stacking fault complex**

## B.6 Polytype inclusion

Polytype inclusions exhibit characteristic PL features in emission wavelengths between 500 nm and 600 nm, which originates from their stacking sequence similar to 3C-SiC bands reported in [7].

**Key**

- 1 no defect region
- 2 polytype inclusion

**Figure B.6 – PL spectrum from polytype inclusion**

### Bibliography

- [1] ISO 24173:2009, *Microbeam analysis – Guidelines for orientation measurement using electron backscatter diffraction*
  - [2] I. Kamata, X. Zhang, H. Tsuchida, *Applied Physics Letters*, 97, 172107 (2010)
  - [3] J. Hassan, J. P. Bergman, *Materials Science Forum*, 645-648, 327 (2010)
  - [4] S. Izumi, H. Tsuchida, I. Kamata, T. Tawara, *Applied Physics Letters*, 86, 202108 (2005)
  - [5] G. Feng, J. Suda, T. Kimoto, *Applied Physics Letters*, 94, 091910 (2009)
  - [6] G. Feng, J. Suda, T. Kimoto, *Applied Physics Letters*, 92, 221906 (2008)
  - [7] N. A. Mahadik, R. E. Stahlbush, S. B. Qadri, O. J. Glembocki, D. A. Alexson, K. D. Hobart, J. D. Caldwell, R. L. Myers-Ward, J. L. Tedesco, C. R. Eddy Jr., D. K. Gaskill, *Journal of Electronic Materials*, 40, 413 (2011)
-

# British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

## About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards-based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

## Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at [bsigroup.com/standards](http://bsigroup.com/standards) or contacting our Customer Services team or Knowledge Centre.

## Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at [bsigroup.com/shop](http://bsigroup.com/shop), where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

## Copyright in BSI publications

All the content in BSI publications, including British Standards, is the property of and copyrighted by BSI or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use.

Save for the provisions below, you may not transfer, share or disseminate any portion of the standard to any other person. You may not adapt, distribute, commercially exploit or publicly display the standard or any portion thereof in any manner whatsoever without BSI's prior written consent.

## Storing and using standards

Standards purchased in soft copy format:

- A British Standard purchased in soft copy format is licensed to a sole named user for personal or internal company use only.
- The standard may be stored on more than one device provided that it is accessible by the sole named user only and that only one copy is accessed at any one time.
- A single paper copy may be printed for personal or internal company use only.

Standards purchased in hard copy format:

- A British Standard purchased in hard copy format is for personal or internal company use only.
- It may not be further reproduced – in any format – to create an additional copy. This includes scanning of the document.

If you need more than one copy of the document, or if you wish to share the document on an internal network, you can save money by choosing a subscription product (see 'Subscriptions').

## Reproducing extracts

For permission to reproduce content from BSI publications contact the BSI Copyright and Licensing team.

## Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to [bsigroup.com/subscriptions](http://bsigroup.com/subscriptions).

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

**PLUS** is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit [bsigroup.com/shop](http://bsigroup.com/shop).

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email [cservices@bsigroup.com](mailto:cservices@bsigroup.com).

## Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

## Useful Contacts

### Customer Services

**Tel:** +44 345 086 9001

**Email:** [cservices@bsigroup.com](mailto:cservices@bsigroup.com)

### Subscriptions

**Tel:** +44 345 086 9001

**Email:** [subscriptions@bsigroup.com](mailto:subscriptions@bsigroup.com)

### Knowledge Centre

**Tel:** +44 20 8996 7004

**Email:** [knowledgecentre@bsigroup.com](mailto:knowledgecentre@bsigroup.com)

### Copyright & Licensing

**Tel:** +44 20 8996 7070

**Email:** [copyright@bsigroup.com](mailto:copyright@bsigroup.com)

## BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK