IEC 63068-4

Edition 1.0 2022-07

INTERNATIONAL STANDARD

Semiconductor devices – Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power devices – Part 4: Procedure for identifying and evaluating defects using a combined method of optical inspection and photoluminescence

IEC 63068-4:2022-07(en)

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

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.080.99
ISBN 978-2-8322-4307-7

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Part 4: Procedure for identifying and evaluating defects using a combined method of optical inspection and photoluminescence

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

Draft	Report on voting
47/2751/CDV	47/2768/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 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 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- withdrawn,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

Results of evaluating defects on silicon carbide homoepitaxial wafer by a single test method using optical inspection or photoluminescence often depends on examined wafer conditions such as surface morphology and spatial variation of impurity concentration, and thus need human visual confirmation of the results after inspection using equipment. The procedure described in this part of IEC 63068 uses a combined method of optical inspection and photoluminescence and can yield more accurate and reproducible results of defect recognition compared to when a single test method is used.

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

Part 4: Procedure for identifying and evaluating defects using a combined method of optical inspection and photoluminescence

1 Scope

This part of IEC 63068 provides a procedure for identifying and evaluating defects in as-grown 4H-SiC (Silicon Carbide) homoepitaxial wafer by systematically combining two test methods of optical inspection and photoluminescence (PL). Additionally, this document exemplifies optical inspection and PL images to enable the detection and categorization of defects in SiC homoepitaxial wafers.

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 63068-1, *Semiconductor devices – Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power devices – Part 1: Classification of defects*

IEC 63068-2, *Semiconductor devices – Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power devices – Part 2: Test method for defects using optical inspection*

IEC 63068-3, *Semiconductor devices – Non-destructive recognition criteria of defects in silicon carbide homoepitaxial wafer for power devices – Part 3: Test method for defects using photoluminescence*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological 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

4 Principle

Defects can be more accurately and reproducibly identified by systematically combining two test methods of optical inspection and PL.

A grey scale image (or colour image) is produced from the original digital image of defects on the wafer surface. This image is converted into a binary image. The size and shape of defects are measured, and the distribution and number of defects within a specified area of wafer are calculated.

First, both optical and PL images of defects are captured and transformed into a digital format. Each image is captured via an optical image sensor such as a CCD image sensor. Then, the obtained digital images are 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.

5 Requirements

5.1 General

The defects in SiC homoepitaxial wafers, which are defined in IEC 63068-1, shall be identified and evaluated by systematically conducting the two test methods using optical inspection and PL. Visual features pertinent to each defect class, given in Table 1, are acquired from the data sets of the two test methods. The methods for detecting defects using optical inspection and PL shall be carried out under the conditions specified in IEC 63068-2 and IEC 63068-3, respectively. Table 1 shows representative PL data obtained through analysis of images captured by detecting emissions from defects at wavelengths longer than 650 nm. It is noted that contrasts of defects in PL images vary depending on the specifications of homoepitaxial wafers such as doping concentration and surface topology, and the size of observed defects is different between optical inspection and PL imaging for micropipe, TSD, and TED. The reason is that in the optical inspection method, the shape and size of observed defects are exactly the same as those of defects on the wafer surface, whereas, in the PL method, the size of observed defects is larger than the actual size of defects because excited carriers (electrons and holes) diffuse a relatively long distance in SiC epilayers. None indicates that each test method is not adequate to identify the defect class in target.

Defects that belong to different defect classes but show similar visual features should be evaluated by other test methods such as X-ray topography. Those defects include micropipe, TSD, TED, and particle inclusion.

Table 1 – Combination table for identifying defects

No	Defect class IEC 63068-1	Optical inspection IEC 63068-2	Photoluminescence IEC 63068-3	Figure
1	Point defect	None	None	None
2	Micropipe	Individual defects exhibiting hexagonal-shaped, round-shaped, linear pits or through-holes	Individual defects exhibiting dark point-shaped contrasts of 30 µm or more in diameter or bundles of multiple bright line-shaped contrasts	A.1
3	TSD	Individual minute defects exhibiting a pit less than 5 µm in diameter They show larger pits than those caused by TEDs on the same test wafer Undetectable if there is no pit formation	Individual defects exhibiting dark point-shaped contrasts less than 30 µm in diameter	A.2

No	Defect class IEC 63068-1	Optical inspection IEC 63068-2	Photoluminescence IEC 63068-3	Figure
4	TED	Individual minute defects exhibiting a pit less than 2 µm in diameter They show smaller pits than those caused by TSDs on the same test wafer Undetectable if there is no pit formation	Individual defects exhibiting dark point-shaped contrasts less than 25 µm in diameter	A.3
5	BPD	None	Individual defects exhibiting bright straight line-shaped or curve-shaped contrasts, and in some cases as those of dark contrasts	A.4
6	Scratch trace	Individual linear defects extending in various direction	Individual defects exhibiting line-shaped contrasts extending in various directions	A.5
7	Stacking fault	Individual planar defects providing faintly-outlined features extending in oblique directions with respect to the off-cut direction	Individual planar defects often exhibiting dark triangle-shaped contrasts	A.6
8	Propagated stacking fault	Individual planar defects providing faintly-outlined features extending in oblique directions with respect to the off-cut direction	Individual planar defects often exhibiting dark trapezoid-shaped contrasts	A.7
9	Stacking fault complex	Individual planar defects providing needle-shaped features extending in the off-cut direction	Individual planar defects exhibiting dark contrasts and/or bright line-shaped contrasts	A.8
10	Polytype inclusion	Individual volume defects providing triangular features expanding in the off-cut direction	Individual volume defects often exhibiting dark triangle-shaped contrasts	A.9
11	Particle inclusion	Individual volume defects exhibiting irregular-shaped structures	Individual volume defects exhibiting circle-shaped contrasts	A.10
12	Bunched-step segment	Individual surface defects exhibiting obtuse triangle-shaped or trapezoid-shaped features expanding in the off-cut direction	None	A.11
13	Surface particle	Individual volume defects providing various shapes and sizes	Individual volume defects exhibiting contrasts of various shapes and sizes	A.12
14	The others	None	None	None

5.2 Parameter settings

5.2.1 General

Test wafers should be compared with reference wafers. Both optical inspection and PL images should be compared with those acquired from the same 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 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 defects.

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

5.2.2 Parameter setting process

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

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

5.3 Procedure

Prepare test wafers for detecting defects as follows:

Create both optical and PL images of the test wafers using the procedures given in IEC 63068-2 and IEC 63068-3, respectively. Once suitable threshold values are established, a digitized image provides, on analysis, feature and contrast pertinent to each defect class.

5.4 Image evaluation

5.4.1 General

In contrast to manual assessment of defects, both test methods can directly determine the size and shape of each detected defect (See 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.

5.4.2 Mean width of planar and volume defects

With the known thickness of homoepitaxial layer d, in micrometres, and an off-cut angle of 4°, 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:

$$l = \frac{d}{\tan(4°)}$$

For example, values of the mean width l of defects for 10 μm- and 30 μm-thickness homoepitaxial layers are approximately 145 μm and 430 μm, 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.