IEC 63229

Edition 1.0 2021-04

INTERNATIONAL STANDARD

colour inside

Semiconductor devices – Classification of defects in gallium nitride epitaxial film on silicon carbide substrate

IEC 63229:2021-04(en)

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

Tel.: +41 22 919 02 11
info@iec.ch
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
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 It also gives information on projects, replaced and withdrawn publications.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
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
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC online collection - oc.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
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 18 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC 63229

Edition 1.0 2021-04

INTERNATIONAL STANDARD

colour inside

Semiconductor devices – Classification of defects in gallium nitride epitaxial film on silicon carbide substrate

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 31.080.99

ISBN 978-2-8322-9669-1

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

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

SEMICONDUCTOR DEVICES – CLASSIFICATION OF DEFECTS IN GALLIUM NITRIDE EPITAXIAL FILM ON SILICON CARBIDE SUBSTRATE

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 63229 has been prepared by IEC technical committee 47: Semiconductor devices. It is an International Standard.

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

FDIS	Report on voting
47/2687/FDIS	47/2693/RVD

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/standardsdev/publications.

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.

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.

INTRODUCTION

Gallium nitride (GaN) as a representative of the wide band gap semiconductors has outstanding properties, such as wide band gap, high critical electric field, high electron saturation drift velocity, and good resistance to corrosion and radiation. Owing to these properties, GaN can bring significant improvements to electronic devices, such as high-voltage, high-frequency, and high-power, which will be widely used in wireless communication base stations, radars, automotive electronics, aerospace, the nuclear industry, and military electronics.

To date, the development of GaN epitaxial film and related devices is hindered by high cost, low yield, and poor reliability. Among them, the defects in GaN epitaxial film, which closely related to device reliability, are especially serious.

There are various defects found in GaN epitaxial film on silicon carbide (SiC) substrate. In addition, global researchers have not established a uniform definition and classification criterion for defects in GaN epitaxial film yet. Thus, it is essential to establish a set of international standards for GaN epitaxial film on SiC substrate, which will benefit the development of GaN epitaxial film and related devices.

To define and classify defects in GaN epitaxial film on SiC substrate, a new international standard is proposed. The main contents of this document are listing and illustrating the definition and classification of defects in GaN epitaxial film on SiC substrate, providing reference for future GaN-related research and device manufacture.

SEMICONDUCTOR DEVICES – CLASSIFICATION OF DEFECTS IN GALLIUM NITRIDE EPITAXIAL FILM ON SILICON CARBIDE SUBSTRATE

1 Scope

This International Standard gives guidelines for the definition and classification of defects in GaN epitaxial film grown on SiC substrate. They are identified and described on the basis of examples, mainly by schematic illustrations, optical microscope images, and transmission electron microscope images for these defects. This document covers only defects in as-grown GaN epitaxial film on SiC substrate and does not include defects caused by subsequent processes.

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
Gallium nitride
GaN
compound semiconductor crystal composed of gallium and nitrogen

3.2
substrate
material on which epitaxial layer is deposited

[SOURCE: IEC 63068-1:2019, 3.9, modified – "Homoepitaxial" has been replaced by "epitaxial".]

3.3
Silicon carbide
SiC
semiconductor crystal composed of silicon and carbon, which exhibits a large number of polytypes such as 4H and 6H

Note 1 to entry: A symbol like 4H gives the number of periodic stacking layers (2, 3, 4,…) and the crystal symmetry (H=hexagonal) of each polytype.

[SOURCE: IEC 63068-1:2019, 3.1, modified – Polytype of 3C has been deleted.]

3.4
4H-SiC
SiC crystal showing a hexagonal symmetry, in which four Si-C layers are periodically arranged along the crystallographic c-axis

Note 1 to entry: The crystal structure of 4H-SiC is similar to wurtzite with a unit cell having four periodical occupied sites along the <0001> directions.

[SOURCE: IEC 63068-1:2019, 3.3]

3.5
6H-SiC
SiC crystal showing a hexagonal symmetry, in which six Si-C layers are periodically arranged along the crystallographic c-axis

Note 1 to entry: The crystal structure of 6H-SiC is similar to wurtzite with a unit cell having six periodical occupied sites along the <0001> directions.

[SOURCE: IEC 63068-1:2019, 3.4]

3.6
crystal
monocrystalline material

[SOURCE: IEC 63068-1:2019, 3.11]

3.7
crystal direction
direction, denoted as [*uvw*], representing a vector direction in multiples of the basis vectors describing the *a*-, *b*- and *c*-axis

Note 1 to entry: In GaN showing a hexagonal symmetry, four-digit indices [*uvtw*] are frequently used for crystal directions.

Note 2 to entry: Families of symmetrically equivalent directions are written by <*uvw*> and <*uvtw*> for hexagonal symmetries.

[SOURCE: IEC 63068-1:2019, 3.6, modified – In Note 1 to entry, "4H-SiC" has been replaced by "GaN" and "cubic" has been deleted.]

3.8
lattice
specific form of atomic arrangement within the crystal

3.9
basal plane
plane perpendicular to the crystallographic *c*-axis, which is parallel to <0001>, in a hexagonal crystal

[SOURCE: IEC 63068-1:2019, 3.13, modified – The expression "which is parallel to <0001>", has been added.]

3.10
defect
interruption of crystallinity

Note 1 to entry: Defect in GaN epitaxial film on SiC substrate including point defect, linear defect, volume defect, surface defect and the others.

3.11
point defect
crystal defect that occurs at or around a single lattice site, such as vacancy, interstitial, substitutional defect and point defect complex

3.12
surface defect
morphological irregularity on the epitaxial layer surface, not associated with extended defects in the underlying layer

[SOURCE: IEC 63068-1:2019, 3.37, modified –"homoepitaxial" has been replaced by "epitaxial".]

3.13
Schottky defect
vacancy created at the original site when an atom escapes from its lattice site to the surface of the crystal

3.14
Frenkel defect
vacancy created at the original site when an atom delivers from its lattice site to an interstitial site of the crystal

3.15
shallow donor
defect which has a band emission below the conduction band but above 1/2 band gap

3.16
shallow acceptor
defect which has a band emission above the valence band but below 1/2 band gap

3.17
dislocation
linear crystallographic defect in monocrystalline material

[SOURCE: IEC 63068-1:2019, 3.22]

3.18
Burgers vector
vector representing the magnitude and direction of lattice distortion along a dislocation in monocrystalline material, which is denoted by ***b*** in this document

[SOURCE: IEC 63068-1:2019, 3.42, modified – The explanation "which is denoted by ***b*** in this document" has been added.]

3.19
edge dislocation
dislocation whose Burgers vector is perpendicular to the dislocation line

3.20
screw dislocation
dislocation whose Burgers vector is parallel to the dislocation line

3.21
threading dislocation
dislocation penetrating through the crystal approximately normal to the basal plane

3.22
transmission electron microscopy
TEM
technique employed to observe defect structures and wafer crystalline using a high voltage electron beam-penetration

3.23
optical microscopy
OM
technique employed to observe morphological features of wafer surface through the magnification by lenses with visible light

[SOURCE: IEC 63068-1:2019, 3.45]

3.24
macroscopic dislocation
dislocation which can be observed by naked eye directly

4 Classification of defects

4.1 General

The classification of defects in GaN epitaxial film on 4H-SiC (0001) and 6H-SiC (0001) substrate in this document is based on crystallographic type and dimension of the defects. Defects in GaN epitaxial film on SiC substrate shall be categorised into 11 patterns as given in Table 1.

Table 1 – Classification of defects in GaN epitaxial film on SiC substrate

No.	Type of defect	Dimension of defects	Figure
1	Vacancy	Point	Figure 1
2	Interstitial		Figure 2
3	Substitutional defect		Figure 3
4	Point defect complex		Figure 4
5	Threading dislocation	Linear	Figure 5
6	Crack	Volume	Figure 6
7	Inclusion		Figure 7
8	Hillock	Surface defects	Figure 8
9	Pit		Figure 9
10	Scratch		Figure 10
11	Others	Not specified	None

4.2 Description of the defect classes

4.2.1 General

The terminologies and schematic illustrations of each defect are shown in 4.2.2 to 4.2.11. Schematic illustrations, optical microscope images, or transmission electron microscope images are given based on the characteristics of each defect, respectively.

4.2.2 Vacancy

Vacancy space caused by the atom in the lattice site leaving its lattice site is called vacancy.