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Date: 07 October 2024

Origin: International

Latest date for receipt of comments: 27 November 2024

Project No. 2024/02380

Responsible committee: EPL/47 Semiconductors

Interested committees:

Title: BS EN IEC 63601 Guideline for Evaluating Bias Temperature Instability of Silicon Carbide Metal-Oxide-Semiconductor Devices for Power Electronic Conversion (Fast track)

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



COMMITTEE DRAFT FOR VOTE (CDV)

PROJECT NUMBER:

IEC 63601 ED1

DATE OF CIRCULATION:

2024-10-04

CLOSING DATE FOR VOTING:

2024-12-27

SUPERSEDES DOCUMENTS:

IEC TC 47 : SEMICONDUCTOR DEVICES

SECRETARIAT:

Korea, Republic of

SECRETARY:

Mr Cheolung Cha

OF INTEREST TO THE FOLLOWING COMMITTEES:

TC 91, TC 104

HORIZONTAL FUNCTION(S):

ASPECTS CONCERNED:

☐ SUBMITTED FOR CENELEC PARALLEL VOTING☒ NOT SUBMITTED FOR CENELEC PARALLEL VOTING

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TITLE:

Guideline for Evaluating Bias Temperature Instability of Silicon Carbide Metal-Oxide-Semiconductor Devices for Power Electronic Conversion (Fast track)

PROPOSED STABILITY DATE: 2028

NOTE FROM TC/SC OFFICERS:

This CDV is based upon JEDEC document JEP184 (title: Guideline for Evaluating Bias Temperature Instability of Silicon Carbide Metal-Oxide Semiconductor Devices for Power Electronic Conversion) and is circulated according to the IEC fast-track procedure (see F.2 of ISO/IEC Directives, Part 1, 2024). This document is proposed by the US National Committee and TC 47/WG 8 at the November 2023 meeting approved fast-track procedure and was presented to TC 47 Plenary meeting in November 2023.

This project is allocated to TC 47/WG 8 and Project Leader: Peter Friedrichs.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**GUIDELINE FOR EVALUATING BIAS TEMPERATURE INSTABILITY OF SILICON
CARBIDE METAL-OXIDE-SEMICONDUCTOR DEVICES FOR POWER ELECTRONIC
CONVERSION**

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

FDIS	Report on voting
XX/XX/FDIS	XX/XX/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.

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

The objective of this publication is to provide useful definitions and procedures for characterizing the threshold voltage instability of SiC-based power electronic conversion semiconductor (PECS) devices having a gate dielectric region biased to turn devices on and off. This typically refers to MOS devices such as field-effect transistors (MOSFETs) and insulated-gate bipolar transistors (IGBTs). Monitoring of threshold-voltage instability in MOS devices is commonly referred to by the term “bias-temperature instability” (BTI), while the applied stress to check for instability is usually referred to as “bias-temperature-stress” (BTS). The terms BTI, BTS, and threshold-voltage instability will be used throughout this document.

GUIDELINE FOR EVALUATING BIAS TEMPERATURE INSTABILITY OF SILICON CARBIDE METAL-OXIDE-SEMICONDUCTOR DEVICES FOR POWER ELECTRONIC CONVERSION

1 Scope

The scope of this document covers SiC-based PECS devices having a gate dielectric region biased to turn devices on and off. This typically refers to MOS devices such as MOSFETs and IGBTs. In this document, only NMOS devices are discussed as these are dominant for power device applications; however, the procedures apply to PMOS devices as well.

This document does not define device failure criteria, acceptable use conditions or acceptable lifetime targets. That is up to the device manufacturers and users. But it provides stress procedures such that the threshold voltage stability over time as affected by gate bias and temperature can be demonstrated and evaluated.

2 Normative References

JEP183, *Guidelines for Measuring the Threshold Voltage (V_T) of SiC MOSFETs*.

3 Terms and definitions

3.1 metal-oxide-semiconductor field-effect transistor, MOSFET: an insulated-gate field-effect transistor in which the insulating layer between the gate electrode and the channel is oxide (or dielectric) material and the gate is metal or another highly conductive material. (Ref. IEC 747-8 and JESD77).

3.2 silicon carbide, SiC: A wide bandgap semiconducting material that serves as the active device semiconductor material, for example the channel and drift region. Typically the 4H hexagonal polytype is preferred, denoted 4H-SiC, in the (0001) wafer orientation (other polytypes sometimes used are 6H-SiC, or 3C-SiC).

3.3 power electronic conversion semiconductor (PECS) devices: Power devices used for power conversion to different voltage or current levels, or as inverters between alternating and direct current power (or vice versa).

3.4 gate oxide: oxide (or dielectric) region under the gate electrode in the MOS portion of the MOS device

3.4.1 oxide thickness (T_{ox}): gate oxide (or dielectric) thickness, measured electrically, optically, or physically.

3.4.2 oxide field (E_{ox}): oxide field (V/cm), V_{ox}/T_{ox} .

3.4.3 oxide voltage (V_{ox}): voltage drop across gate oxide (V).

3.4.4 **gate to source voltage (V_{GS}):** Voltage drop from gate to source (V).

3.4.5 **gate current (I_G):** Gate current (A) measured with a bias on the gate electrode.

3.5 **drain to source voltage (V_{DS}):** Voltage drop from drain to source (V).

3.6 **drain current (I_D):** Drain current (A) measured with a bias on the drain.

3.7 **voltage of tied gate and drain to source (V_{GDS}):** Voltage drop of gate and drain to source (V), when gate and drain biases are tied together (gated diode configuration).

3.8 **gate-source voltage maximum (V_{GSmax}):** Maximum gate-source voltage recommended for a device, for any time period during operation.

3.9 **gate-source voltage recommended operating value (V_{GSop}):** Recommended range of gate to source bias during normal on-state or off-state operation.

3.10 **bias temperature instability (BTI):** susceptibility of the threshold voltage of an MOS device to change over time under bias and temperature stress.

3.11 **negative BTI (NBTI):** BTI due to a negative gate bias stress, at a fixed stress temperature.

3.12 **positive BTI (PBTI):** BTI due to positive gate bias stress, at a fixed stress temperature.

3.13 **bias-temperature stress (BTS):** stressing a device by simultaneous exposure to gate bias and elevated temperature. Often used in place of the acronym BTI; the difference (if any) is that BTI refers more specifically to the effect of stress on V_{th} , whereas BTS is more of a descriptor of the stress condition on the device.

3.14 **threshold voltage V_T :** the gate-source voltage V_{GS} value (at some specified drain voltage V_{DS}) at which the device conducts forward current of a specified current value. A drain-current-defined threshold is used in this document, with the selected current at threshold being a very small fraction of the rated device current.

3.14.1 **threshold current (I_T):** the drain current at which V_T is defined.

3.14.2 **threshold voltage, gate-source sweep configuration ($V_{T(GS)}$):** V_T measurement performed by sweeping the gate bias with a constant and relatively low drain bias (~ 100 mV min, up to a few Volts typically) until a certain I_D current value is reached.

3.14.3 **threshold voltage, gated-diode configuration ($V_{T(GDS)}$):** V_T measurement performed by sweeping the gate and drain together ($V_{GS} = V_{DS}$) until reaching a chosen constant I_D value. The gated-diode configuration allows for fast and reproducible point measurements of the V_T and guarantees a constant electron density in the channel during V_T readout.

3.14.4 threshold voltage measurement, following a Negative Bias Stress (V_T^{UP}): the V_T measurement performed immediately following a negative gate bias stress during NBTI, or following a negative V_{GS} conditioning pulse (as in a hysteresis measurement), or if performed by sweeping the gate bias starting from a negative gate voltage and sweeping up until I_T is reached. In general, V_T^{UP} will represent the low V_T side of the hysteresis in V_T . To minimize recoverable fast charge-trapping effects and achieve repeatable results, it is recommended to stabilize the traps by holding at the negative V_{GS} for a sufficient duration; 100 ms is a typical recommended value for SiC.

3.14.5 threshold voltage measurement, following a Positive Bias Stress (V_T^{DOWN}): the V_T measurement performed immediately following a positive gate bias stress during PBTI, or following a positive V_{GS} conditioning pulse (as in a hysteresis measurement), or if performed by sweeping the gate bias starting from a positive gate voltage and sweeping down until I_T is reached. In general, V_T^{DOWN} will represent the high V_T side of the hysteresis in V_T . To minimize recoverable fast charge-trapping effects and achieve repeatable results, it is recommended to stabilize the traps by holding at the positive V_{GS} for a sufficient duration; 100 ms is a typical recommended value for SiC.

3.14.6 threshold voltage at a given stress time ($V_{T\#}$): the V_T is measured over time during the BTI stress, thus a time-related subscript can be used when referring to a particular stress time. For improved extrapolation of V_T over time, the initial measured V_T during BTI should be after a brief (~100ms) initial stress and/or conditioning, such that V_{Ti} (or V_{Ti0}) occurs after the initial brief stress. The initial pre-stress V_T and the final post-stress V_T may be defined using different subscripts, such as V_{Tpre} and V_{Tpost} , respectively.

3.15 threshold voltage shift (ΔV_T^{shift}): a change in the measured V_T value from an initial to a final condition, here particularly focused on the V_T shift during BTI stress. This shift is described as the ongoing shift over time ($V_{T\#} - V_{Ti}$), which by the end of the stress would be the final V_{Tf} minus the initial V_{Ti} . This shift value could be due to: 1) transient charging effects (ΔV_T^{trans}) which are fully recoverable, 2) transient effects which have a permanent component (ΔV_T^{HYST}), or 3) permanent (non-transient) interface effects (ΔV_T^{drift}). More generally, V_T shift is the change in V_T between any two measured values, and can arise from a change in gate bias, or the continued application of the same gate bias.

3.15.1 threshold voltage drift (ΔV_T^{drift}): threshold voltage drift describes BTI changes in V_T (ΔV_T^{shift}) which are relatively permanent, after transient V_T recovery effects are removed. For example, if a V_T^{shift} is measured without a change in transient effects, there would be a shift in the voltage location of the threshold voltage due only to a ΔV_T^{drift} effect.

3.15.2 threshold voltage transient shift (ΔV_T^{trans}): portion of the BTI threshold shift (ΔV_T^{shift}) that quickly recovers after removal of gate stress. This is typically larger or beyond what a short hysteresis measurement would reveal, due to time at bias effects during BTI that result in charging on a time scale that a short hysteresis measurement does not capture.

3.16 threshold voltage hysteresis ($V_T^{HYST} = V_T^{DOWN} - V_T^{UP}$): difference in threshold voltage measured after a positive gate bias stress (V_T^{DOWN}) and that measured after a negative gate-bias stress (V_T^{UP}) of equal stress time. For normal devices, with at least some active interfacial traps (and little or no mobile ions), this hysteresis value will be positive. For what is here considered intrinsic device hysteresis, the timing for the stress and sense portions of a hysteresis measurement called for are on the order of 100ms. Faster or slower measurements can be useful to reveal more complete details of the transient effects.

3.16.1 change in threshold voltage hysteresis ($\Delta V_T^{HYST} = V_T^{HYST}_{(f)} - V_T^{HYST}_{(i)}$): the difference between final (post-BTS) and initial (pre-BTS) hysteresis values would comprise a change in hysteresis. Because there is a stress time dependence of the magnitude of this value, this term is used to describe the permanent (repeatable) hysteresis effects observed when performing a standard 2-sequence hysteresis measurement as described above.

3.17 conditioning: term to describe applying a gate bias to induce a certain charge state immediately prior to a V_T measurement. To make a fair comparison of changes in V_T due to a BTS, the same V_{GS} conditions (conditioning) should be used before each measurement.

3.18 relaxation: term referring to charge redistribution over time after gate bias is removed, which typically allows the V_T to shift back towards values before stress was applied.

3.19 recovery: term to describe the change of the V_T value after BTI towards the previous value due to a removal of bias (similar to relaxation), or due to the application of a different fixed bias.

3.20 degradation: a change in the charge state or trap density of the interface or near-interface regions as a result of BTI stress, which will manifest itself as a change in ΔV_T^{drift} , V_T^{HYST} , or ΔV_T^{trans} , depending on the physical nature of the interface changes.

3.21 drain-source on-state resistance ($R_{DS(on)}$): resistance of the device (Drain-Source) in the on-state with the rated V_{GS} applied, and at a specified (typically the rated) on-state current.

3.22 off-state drain current ($I_{DSS(off)}$): drain leakage from source with device in the off-state (at $V_{GS} = 0$ V or the rated off-state V_{GS} value), in the static mode (non-switching), at a specified high V_{DS} bias (such as the rated blocking voltage).

4 General introduction to threshold voltage (V_T) stability and SiC-based MOS devices

Threshold voltage (V_T) stability is a general aspect of MOS device reliability that has been studied extensively for Si-based MOS devices [1-4] and has been touched upon in existing JEDEC documents focused on Si device reliability [5-11]. However, numerous literature reports have shown that SiC devices have more excessive threshold instability and much larger fast V_T recovery effects than Si-based devices [12-16], and unlike Si have appreciable shift in both PBTI and NBTI stress conditions. Thus, a more detailed BTI document is needed to address SiC MOS device behavior.

The different behavior of SiC MOS devices is believed to be related to the much more complex interface and near-interface trap levels (differences in both density and energy level compared to Si devices). Although high interface trap density (D_{IT}) levels at the oxide/SiC interface have been reduced by using N interface passivation for SiC (as H passivation is ineffective for the (0001) Si-face of SiC), the interface trap density of modern SiC MOS devices is still >10X higher than that of silicon MOS devices, covering a wider range of energy levels as well. In addition to interface traps, the near-interface oxide trap (also known as a border trap) density is also high. Border traps may be charged more readily due to the larger bandgap of SiC and the smaller band offsets to the oxide. The wide bandgap of SiC allows existing oxide defects that may be electrically inactive in Si to now fall within the SiC bandgap and act as traps.

The higher density of charge traps (regardless of origin) and other interface bonding differences can result in larger amounts of threshold voltage shift with time, temperature and bias; this phenomenon is commonly referred to as bias-temperature instability (BTI). This higher trap density can also result in faster V_T recovery when bias is removed, if the density of traps close to the conduction band energy level is very high. This means that V_T shift due to permanent and transient effects need to both be well understood and evaluated. Although both silicon-based and SiC-based devices display BTI likely due to the same general physical phenomena, the BTI in SiC-based devices is higher and transient effects are larger in magnitude. Therefore, it is critical to have well described approaches to characterize the BTI of SiC devices.

The trap charging and discharging process also results in a threshold voltage hysteresis (V_T^{HYST}) when V_T is measured after positive and negative gate bias sequences. Some portion of the BTI shift may not recover over time in an unbiased state; this would be defined as a (permanent) drift (ΔV_T^{drift}) arising from the BTI stress. It may also be the case that the threshold hysteresis magnitude (V_T^{HYST}) increases during BTI stress, termed a change in hysteresis (ΔV_T^{HYST}). Because the faster transient portion of the ΔV_T^{shift} has a time dependence and may increase with stress time, this fast-transient shift is termed here ΔV_T^{trans} (this can contain changes in the hysteresis as well, depending on the measurement conditions).

In summary, the measured threshold shift (ΔV_T^{shift}) during BTI is composed of possibly three components: permanent drift (V_T^{drift}) + transient effects (ΔV_T^{trans}), wherein the transient effects may include changes in hysteresis (ΔV_T^{HYST}). The inherent hysteresis (V_T^{HYST}) which is present may or may not be monitored during BTI, depending on the method of the BTI measurement.

SiC PECS devices are typically used in switching applications, in which the gate can either be switched continually from zero to positive gate bias or from a small negative gate bias to positive gate bias. In those cases, the V_T shift would depend on frequency of switching and duty cycle as well as V_{GS} levels of the positive and negative switching states. However, the most straightforward stress for the determination of MOS device stability is BTI stress performed under constant gate bias, as also occurs in qualification stress methods such as high temperature gate bias (HTGB) called out in JESD47 [8]. The procedures described here can be applied to HTGB stress as well. BTI under constant positive (PBTI) and negative (NBTI) bias results in V_T shifts which serve as a good metric to demonstrate MOS interface quality. Both PBTI and NBTI need to be characterized because they represent device on-state and off-state situations, and can show different time, temperature, and bias dependences.

Measurement of device switching characteristics, whether under conditions of high-power dissipation or not, while extremely important, falls outside the scope of BTI stress methods discussed here. However, a general description of device behavior during gate switching is included in Annex C.