IEC TS 62876-3-4

Edition 1.0 2025-12

TECHNICAL SPECIFICATION

Nanomanufacturing - Reliability assessment -
Part 3-4: Linearity of output characteristics for metal contacted 2D semiconductor devices

ICS 07.120

ISBN 978-2-8327-0928-3

IEC TS 62876-3-4:2025-12(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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Nanomanufacturing - Reliability assessment - Part 3-4: Linearity of output characteristics for metal contacted 2D semiconductor devices

FOREWORD

IEC TS 62876-3-4 has been prepared by IEC technical committee 113: Nanotechnology for electrotechnical products and systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
113/920/DTS	113/938/RVDTS

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 Technical Specification 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.

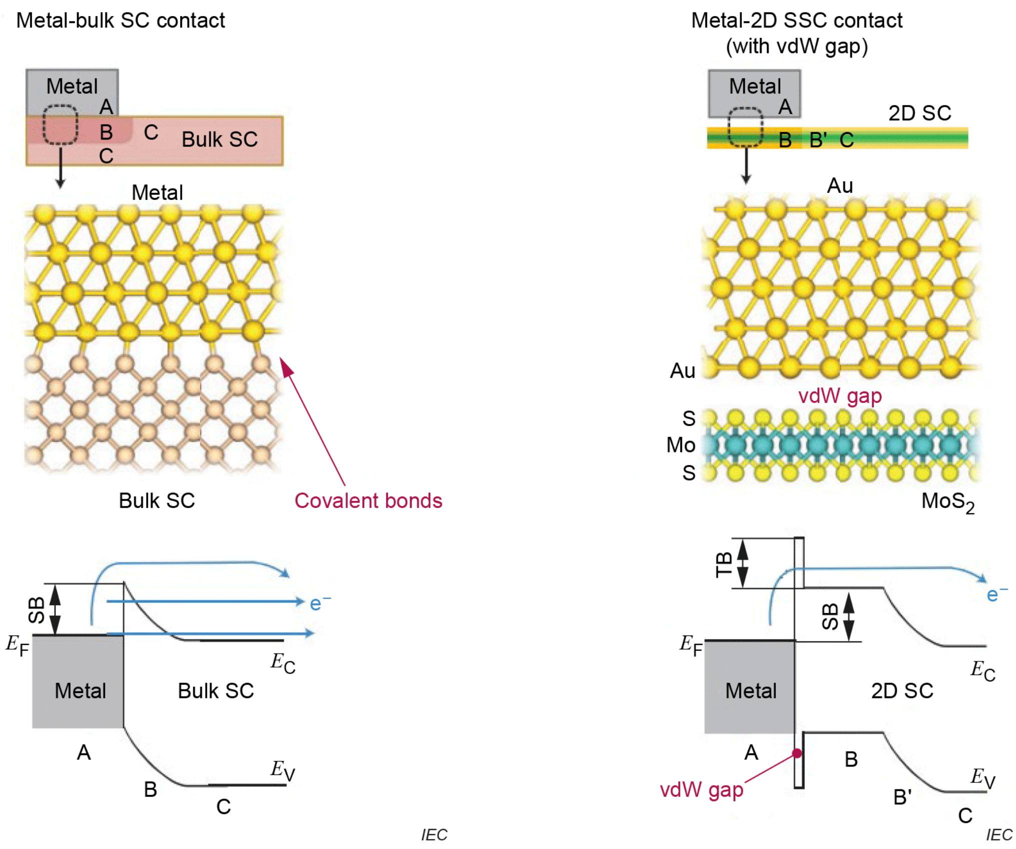
A list of all parts in the IEC 62876 series, published under the general title *Nanomanufacturing - Reliability assessment*, can be found on the IEC website.

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– withdrawn, or
– revised.

INTRODUCTION

- Atomically thin two dimensional (2D) nano-materials are expected to be used for future electrical sub-systems or electronic device applications.
- I-V measurements are the fundamental electrical characterization technique for assessing reliability of field-effect transistors (FETs) as well as semiconductor device performance.
- The performance of the FET is mainly characterized by measuring the output (drain current as a function of drain voltage at different gate voltages) and transfer (drain current as a function of gate voltage at different drain voltages) characteristics.
- If metallic electrical contacts have negligible effects on electronic transport, output characteristics show a linear behaviour according to the following formula: $I_d = \frac{\mu_n W C_{ox}}{L}\left[\left(V_g - V_{th}\right)V_d\right]$, where I_d is the drain current, μ_n is the electron mobility, W is the transport channel width, C_{ox} is the gate oxide capacitance, V_g is the gate voltage, V_{th} is the threshold voltage, and V_d is the drain voltage, which can indicate ohmic contact. In contrast, when metallic contact gives rise to high resistance to electronic transport, output characteristics do not show the linear behaviour, following the formula: $I_D = \frac{\mu_n W C_{ox}}{L}\left[\left(V_g - V_{th}\right)\left(V_d - I_d \times 2R_C\right)\right]$ [1] where R_c is the contact resistance, which is interpreted as Schottky contact which can bring about a reliability issue of ohmic-contact semiconductor transistor operation.
- Current transport at the metallic contact of 2D semiconductor material-based FETs mainly consists of two distinct components: thermal emission where charge injection occurs over the energy barrier and tunnelling (field emission) where the charge injection occurs through the barrier formed at the metal-semiconductor interface.
- Current transport at the metallic contact of 2D material-based FETs can be limited due to the van der Waals (vdW) gap that forms at the metal-2D semiconductor interface, creating a high contact resistance and suppressing current transport of the 2D FETs. However, being different from 2D material-based FETs, conventional FETs have good ohmic contact and usually have not had reliability issues in metallic contacts. But 2D materials involving vdW gap can give rise to uncontrollable Schottky contact leading to a serious reliability issue of metallic contact. See Figure 1.
- In addition, the lack of efficient doping techniques for 2D materials at the metal-semiconductor junction, also contributes to the high contact resistance and suppressed current transport, in contrast to 3D bulk semiconductors such as silicon. See Figure 1 for comparison.
- The issues arising from the vdW gap at the 2D material-metal interface and thus the resulted high contact resistance pose challenges to the reliability of metallic electrical contacts of 2D FETs. Therefore, we propose a standard method to quantify the reliability of the metallic electrical contacts by analyzing current-voltage (I-V) characteristics of 2D FETs.



a) **Typical metal/bulk SC interface**

b) **Au-MoS_2 interface with vdW**

Key

E_F	Fermi level of metal
E_c	conduction band of 2D SC
E_v	valence band of 2D SC
TB	tunnel barrier height
SB	Schottky barrier height
A, B, B' and C	Different regions in the current path from the metal to the SC.

Blue arrows from top to bottom: Thermionic emission, thermionic field emission, and field emission (tunnelling).

Figure 1 – Metal–semiconductor (SC) junctions and their respective band diagrams

– Therefore, it is important to obtain accurate current-voltage (I-V) characteristics and to assess linearity of the I-V output curves, so that reliable 2D FET device operation can be ensured. The reliability of the devices also needs to be evaluated over an extended time period.

NOTE Both capital and small letters in subscripts of device parameters are used with no differences each other, dependent on users (typically device engineers): e.g. I_D is the same as I_d, V_D is the same as V_d, and V_G is the same as V_g.

1 Scope

This part of IEC 62876 establishes a standardized guideline to assess

– reliability of metallic interfaces

of ohmic-contacted field-effect transistors (FETs) using 2D nano-materials by quantifying

– linearity of current-voltage (I-V) output curves

for devices with various materials combinations of van der Waals (vdW) interfaces.

For metallic interfaces with 2D materials (eg. graphene, MoS_2, $MoTe_2$, WS_2, WSe_2, etc) and metals (eg. Ti, Cr, Au, Pd, In, Sb, etc), the reliability of ohmic contact is quantified.

For FETs consisting of 2D materials-based channels (eg. MoS_2, $MoTe_2$, WS_2, WSe_2, etc), the reliability of ohmic contact when varying contacting metal, channel length, channel thickness, applied voltage, and surface treatment condition is quantified.

The reliability of the metallic contacts is quantified from the linearity of I-V characteristics measured over extended time periods.

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 TS 62607-6-5, *Nanomanufacturing - Key control characteristics - Part 6-5: Graphene-based materials - Contact and sheet resistance: transmission line measurement*

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