



BSI Standards Publication

Nanotechnologies — Matrix of properties and measurement techniques for graphene and related two-dimensional (2D) materials

National foreword

This Published Document is the UK implementation of ISO/TR 19733:2019.

The UK participation in its preparation was entrusted to Technical Committee NTI/1, Nanotechnologies.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2019
Published by BSI Standards Limited 2019

ISBN 978 0 539 00656 8

ICS 07.120

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 March 2019.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

TECHNICAL REPORT

ISO/TR
19733

First edition
2019-03-31

Nanotechnologies — Matrix of properties and measurement techniques for graphene and related two-dimensional (2D) materials

*Nanotechnologies — Matrice des propriétés et des techniques de
mesure pour le graphène et autres matériaux bidimensionnels (2D)*



Reference number
ISO/TR 19733:2019(E)

© ISO 2019



COPYRIGHT PROTECTED DOCUMENT

© ISO 2019, Published in Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions, symbols and abbreviated terms	1
3.1 Terms and definitions	1
3.2 Symbols and abbreviated terms	2
4 Matrix of properties and measurement techniques for graphene and related 2D materials	3
5 Properties and measurands	4
5.1 Structural properties	4
5.1.1 Crystal defect	4
5.1.2 Domain (grain) size	5
5.1.3 Flake size	6
5.1.4 Number of layers	6
5.1.5 Stacking angle	6
5.1.6 Surface area	6
5.1.7 Thickness	6
5.2 Chemical properties	6
5.2.1 Metal contents	6
5.2.2 Non-graphene contents and residue	7
5.2.3 Oxygen content	7
5.3 Mechanical properties, elastic modulus	7
5.4 Thermal properties, thermal conductivity	7
5.5 Optical properties, optical transmittance	7
5.6 Electrical and electronic properties	7
5.6.1 Charge carrier concentration (density)	7
5.6.2 Charge carrier mobility	8
5.6.3 Sheet resistance	8
5.6.4 Work function	8
6 Measurement techniques	8
6.1 Atomic force microscopy (AFM)	8
6.2 Brunauer, Emmett and Teller method (BET)	9
6.3 Combustion analysis	9
6.4 Electron probe X-ray microanalysis (EPMA)	9
6.5 Electron spin resonance (ESR)	10
6.6 Fourier transform- infrared spectroscopy (FT-IR)	10
6.7 Hall bar measurement	10
6.8 Inductively coupled plasma — Mass spectrometry (ICP-MS)	11
6.9 Kelvin probe force microscopy (KPFM)	11
6.10 Low energy electron microscopy (LEEM)	11
6.11 Optical microscopy	12
6.12 Raman spectroscopy	12
6.13 Scanning electron microscopy (SEM)	12
6.14 Secondary-ion mass spectrometry (SIMS)	13
6.15 Scanning tunnelling microscopy (STM)	13
6.16 Transmission electron microscopy (TEM)	13
6.17 Thermogravimetric analysis (TGA)	14
6.18 Titration	14
6.19 Ultraviolet photoelectron microscopy (UPS)	14
6.20 Ultraviolet, visible, near-infrared (UV-VIS-NIR) spectroscopy	14
6.21 X-ray diffraction (XRD)	15

6.22	X-ray photoelectron spectroscopy (XPS).....	15
6.23	4-point probe.....	15
Bibliography		16

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared jointly by Technical Committee ISO/TC 229, *Nanotechnologies* and Technical Committee IEC/TC 113, *Nanotechnology for electrotechnical products and systems*. The draft was circulated for voting to the national bodies of both ISO and IEC.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Graphene is a single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure^[1]. Since its discovery in 2004^[2], graphene has become one of the most attractive materials in application research and device industry due to its supreme material properties such as mechanical strength, stiffness and elasticity, high electrical and thermal conductivity, optical transparency, etc. It is expected that applications of graphene could replace many of current device development technology in flexible touch panel, organic light emitting diode (OLED), solar cell, supercapacitor, and electromagnetic shielding. To gain deeper understanding of the material properties and to find the ways of mass producing with fine quality, much research on graphene, and similarly on related two-dimensional (2D) materials is being done in universities, research institutes, and laboratories around the globe. However, to lead these revolutionary materials to full commercialization, it is essentially demanded that characterization and measurement techniques for important material properties need to be standardized and globally recognized. In this document, characterization and measurement techniques for particular properties of graphene and related 2D materials which need to be standardized are organized in a form of a matrix. The matrix could serve as an initial guide for developing the necessary international standards in characterization and measurements of graphene and related 2D materials.

Nanotechnologies — Matrix of properties and measurement techniques for graphene and related two-dimensional (2D) materials

1 Scope

This document provides a matrix which links key properties of graphene and related two-dimensional (2D) materials to commercially available measurement techniques. The matrix includes measurement techniques to characterize chemical, physical, electrical, optical, thermal and mechanical properties of graphene and related 2D materials.

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.

ISO/TS 80004-13, *Nanotechnologies — Vocabulary — Part 13: Graphene and related two-dimensional (2D) materials*

3 Terms and definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 80004-13 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1.1

graphene

single layer of carbon atoms with each atom bound to three neighbours in a honeycomb structure

Note 1 to entry: It is an important building block of many carbon nano-objects.

Note 2 to entry: As graphene is a single layer, it is also sometimes called monolayer graphene or single-layer graphene and abbreviated as 1LG to distinguish it from bilayer graphene (2LG) and few-layered graphene (FLG).

Note 3 to entry: Graphene has edges and can have defects and grain boundaries where the bonding is disrupted.

[SOURCE: ISO/TS 80004-13:2017, 3.1.2.1]