IEC TS 62607-6-26

Edition 1.0 2025-12

TECHNICAL SPECIFICATION

Nanomanufacturing - Key control characteristics -
Part 6-26: Graphene-related products - Fracture strain and stress, Young's modulus, residual strain and residual stress: bulge test

IEC TS 62607-6-26:2025-12(en)

ICS 07.120

ISBN 978-2-8327-0910-8

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CONTENTS

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

Draft	Report on voting
113/924/DTS	113/939/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 of the IEC TS 62607 series, published under the general title *Nanomanufacturing - Key control characteristics,* 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

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INTRODUCTION

When the characteristic dimensions of materials are reduced to the nanoscale regime, their mechanical properties exhibit significant changes compared to their bulk counterparts. These changes include enhancements in elasticity, residual strain, and fracture resistance, which are critical for reliable and high-performance nanoscale devices. Low-dimensional materials, such as graphene and nanometre-thick films, have gained widespread attention because of their exceptional thermal, optical, electrical, and mechanical properties. These unique characteristics make them indispensable in the development of advanced nanoscale technologies.

The mechanical properties of two-dimensional (2D) materials, such as Young's modulus (or elastic modulus), residual strain, residual stress, and fracture stress, are essential for their integration into diverse applications. As shown in Figure 1, these properties are utilized in several applications. These include

a) strain sensors for precise mechanical deformation detection,

b) energy harvesting devices using piezoelectric effects to convert mechanical to electrical energy,

c) vibrational acoustic applications supporting sound generation or absorption, and

d) pellicle membranes for EUV lithography that maintain structural stability under high thermal and mechanical stresses during device operation [1][1], [2], [3], [4], [5].

These applications highlight the versatility of mechanical properties in enabling innovative engineering solutions at the nanoscale.

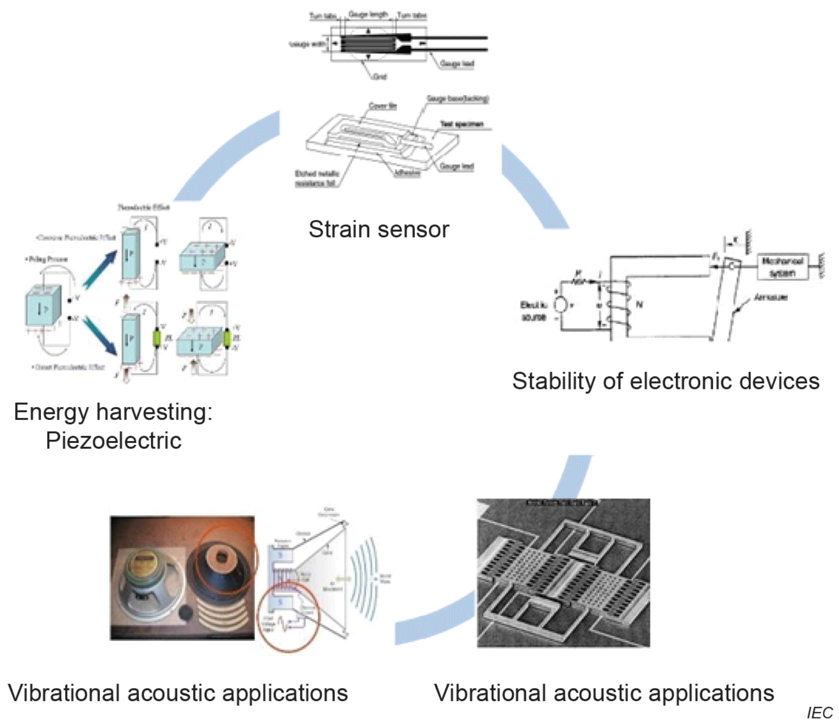

Figure 1 – Applications of mechanical properties to electrical devices

[1] Numbers in square brackets refer to the Bibliography.

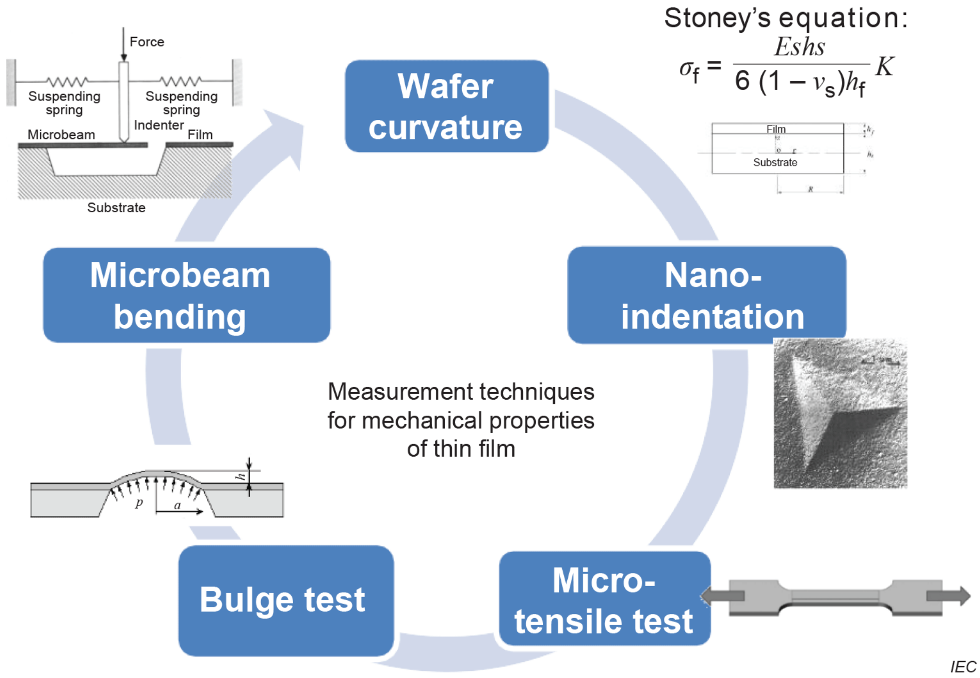

Figure 2 – Various measurement methods to evaluate mechanical properties of 2D and thin films

Accurate characterization of the mechanical properties of 2D materials and thin films is essential for their effective use in applications. However, conventional methods face significant challenges. For example, (i) substrate interference often affects techniques like nano-indentation or wafer curvature, making it difficult to isolate the intrinsic material properties, and (ii) sample preparation complexity limits the applicability of methods such as micro-tensile tests and microbeam bending. To overcome these limitations, it is important to adopt methods designed specifically for freestanding films, which can provide more accurate and reproducible results.

Figure 2 presents the various techniques used for evaluating the mechanical properties of 2D materials and thin films. These techniques include

– nano-indentation, suitable for localized measurements but limited by its focus area,
– wafer curvature, effective for measuring residual stress but influenced by the substrate,
– microbeam bending and micro-tensile tests, useful in specific cases but requiring labour-intensive preparation, and
– bulge test, a reliable method for freestanding films, which measures Young's modulus (or elastic modulus), residual strain, residual stress, and fracture stress under well-controlled conditions.

Among these, the bulge test stands out for its practicality and scalability, enabling the characterization of large areas of freestanding films without substrate interference.

1 Scope

This part of IEC TS 62607 establishes a standardized method to determine the mechanical key control characteristics (KCCs)

– Young's modulus (or elastic modulus),
– residual strain,
– residual stress, and
– fracture stress

of 2D materials and nanoscale films using the

– bulge test.

The bulge test is a reliable method where a pressure differential is applied to a freestanding film, and the resulting deformation is measured to derive the mechanical properties.

– This method is applicable to a wide range of freestanding 2D materials, such as graphene, and nanometre-thick films with thicknesses typically ranging from 1 nm to several hundred nanometres.
– This document ensures the characterization of mechanical properties essential for assessing the structural integrity and performance of materials in applications such as composite additives, flexible electronics, and energy harvesting devices.

2 Normative references

There are no normative references in this document.

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