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**Micro-electromechanical systems(MEMS) technology -
Micro-pillar compression test for MEMS materials**

微机电系统（MEMS）技术 MEMS材料微柱压缩试验方法

(English Translation)

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1 Scope

This document describes a micro-pillar compression testing method designed for the high-precision and highly repeatable measurement of the compressive properties of

MEMS materials, featuring specimens that are of moderate difficulty to fabricate. The method measures the uniaxial compressive stress-strain relationship of the specimen to determine its compressive elastic modulus and yield strength.

The specimen consists of a cylinder fabricated on a rigid (or high-stiffness) substrate using micromachining techniques. Ideally, its aspect ratio (the ratio of height to diameter) shall exceed 3. This document applies to the testing of micropillars with heights of less than 100 μm , prepared from materials such as metals, ceramics, and polymers.

2 Normative references

The following referenced documents are indispensable for the application 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 62047-8, Semiconductor devices -- Microelectromechanical devices -- Part

8.Strip bending test method for tensile property measurement of thin films

3 Terms and definitions

This document contains no terms or definitions requiring definition.

4 Symbols and names

For the purpose of this document, the shapes and symbols of the test specimens are presented in Figure 1 and Table 1, respectively. The test specimens referred to in this document are generally termed columnar specimens.

Figure 1 -- Schematic diagram of cylindrical shape (symbols are shown in Table

1)

Table 1 -- Specimen symbols and names

5.1 General requirements

Test specimens shall be prepared using the same fabrication processes employed for the actual devices. To minimize the influence of size effects, the structure and dimensions of the test specimens shall be similar to those of the device components.

5.2 Specimen shape

This document specifies the test method for determining the compressive characteristics of cylindrical micropillars. The micropillars are fabricated on a substrate using microfabrication processes. The shape and verticality of the micropillars shall be examined using electron or optical microscopy. The boundary condition at the base surface of the micropillar is typically considered to be a fixed boundary - a distinction from cylinders at the macroscopic bulk scale, where the top and bottom surfaces are typically regarded as frictionless boundaries. During the test, it is difficult to directly measure the compressive strain of the micropillar. Instead, compressive strain values are calculated based on the displacement of a rigid indenter, in accordance with formula (2). This approach introduces errors in strain measurement - and subsequently in the calculated elastic modulus and yield strength - as detailed in Annex A. The accuracy of this method is contingent upon the coefficient of friction between the indenter and the top surface of the micropillar, as well as the

micropillar's height-to-diameter ratio.

Provided that no bulging occurs, micropillar specimens with a high aspect ratio represent an ideal choice for minimizing strain estimation errors. The upper limit of the aspect ratio depends on the boundary conditions and the material properties of the micropillar. It is recommended that the maximum aspect ratio not exceed 10 (see

Bibliography [4]). When a micropillar with a height-to-diameter ratio greater than 10 exhibits no expansion following testing, the test data shall be considered valid. The maximum change in the cross-sectional diameter of the micropillar shall be less than 1% of its nominal diameter. Otherwise, its actual cross-sectional area shall be measured.

NOTE: While applying a lubricating layer to cylinders at the macro scale (see Bibliography [4]) can reduce the friction coefficient of their top surfaces, doing so for micro-pillars is very difficult.

5.3 Dimensional measurement

The dimensions of the test specimen must be measured accurately, as this dimensional information is used to calculate the mechanical properties of the material under test.

The diameter and height of the micropillars shall be measured with high precision, with an error margin of less than $\pm 1\%$. Interferometry or focused ion beam slicing can be used to precisely measure height values. Cross-sections at different longitudinal positions along the specimen may vary, and the diameter of the cross-section or top surface may differ from that of the bottom surface. This dimensional error shall preferably be less than $\pm 1\%$. When the aforementioned conditions are not met, microscopic techniques shall be employed to measure the specimen's geometry, and finite element analysis methods shall be utilized to analyze the test results.

6.1 Test principle

MEMS material stress and strain are calculated using formulas (1) and (2), respectively.

6.2 Test instruments

Based on the dimensions and material of the micropillar, the force and displacement sensors must be carefully selected. Their respective resolutions shall ideally be less than 1/1000 of the maximum force and displacement. The actuator shall execute linear motion in the loading direction, without exhibiting any parasitic motion in other directions. Its displacement resolution is required to be less than 1/10 of the displacement sensor's resolution. The ideal choice for the actuator is a piezoelectric or voice-coil actuator; Linear Variable Differential Transformers (LVDTs), capacitive sensors, or optical sensors are suitable for use in this type of testing. The stiffness of the test machine frame shall be significantly greater than that of the specimen. The deformation of the test machine shall be monitored and/or compensated for. Examples of test machine compensation can be found

in IEC 62047-8.

The indenter is a critical component of testing instruments. Flat indenters are widely employed in this type of testing. The use of a large-radius spherical indenter helps to minimize errors resulting from misalignment between the indenter and the specimen.

The surface roughness of the indenter shall be superior to that of the specimen. The flatness and parallelism of a flat indenter shall be better than 0.0002 m/m (see

Bibliography [4]). The radius of a spherical indenter shall be greater than 100 times the diameter of the test specimen.

6.3 Test procedures

The test procedures are as follows.

a) A large number of micropillars are fabricated on a substrate using a batch manufacturing process, and the substrate is then mounted onto the platform of a testing instrument. Note that the deviation angle between the pillar axis and the loading direction of the indenter shall be minimized. Ideally, this deviation shall be less than 0.0002 m/m (see Bibliography [4]). Subsequently, mechanical testing is performed on individual micropillars.

b) Determine the position of the test specimen. Observe the position of the specimen using an optical camera module. The positioning error shall be less than one-tenth of the specimen's diameter.

c) The indenter applies a compressive displacement to the top surface of the micropillar at a constant velocity. This constant velocity results in a constant strain rate. For rate-insensitive materials, the strain rate shall be set to $5 \times 10^{-3}/\text{min}$ (see Bibliography [4]). For rate-sensitive materials, the influence of the strain rate shall be investigated. The maximum strain shall be selected appropriately based on the material and the objective of the test. When measuring stress-strain curves, the maximum strain range shall be selected to adequately capture the plastic behavior of the specimen. For ductile materials, the maximum strain range shall

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