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Semiconductor devices – Micro-electromechanical devices – Part 6: Axial fatigue testing methods of thin film materials

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques – Partie 6: Méthodes d'essais de fatigue axiale des matériaux en couche mince

IEC 62047-6:2009

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Part 6: Axial fatigue testing methods of thin film materials

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International Standard IEC 62047-6 has been prepared by subcommittee 47F: Micro-electromechanical systems, of IEC technical committee 47: Semiconductor devices.

The text of this standard is based on the following documents:

FDIS	Report on voting
47F/15/FDIS	47F/17/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62047 series, under the general title *Semiconductor devices – Micro-electromechanical devices*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,
- replaced by a revised edition, or
- amended.

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 6: Axial fatigue testing methods of thin film materials

1 Scope

This International Standard specifies the method for axial tensile–tensile force fatigue testing of thin film materials with a length and width under 1 mm and a thickness in the range between 0,1 µm and 10 µm under constant force range or constant displacement range. Thin films are used as main structural materials for MEMS and micromachines.

The main structural materials for MEMS, micromachines, etc., have special features, such as typical dimensions of a few microns, material fabrication by deposition, and test piece fabrication by means of non-mechanical machining, including photolithography. This International Standard specifies the axial force fatigue testing methods for micro-sized smooth specimens, which enables a guarantee of accuracy corresponding to the special features. The tests are carried out at room temperatures, in air, with loading applied to the test piece along the longitudinal axis.

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 62047-2:2006, *Semiconductor devices – Micro-electromechanical devices – Part 2: Tensile testing method of thin film materials*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
maximum force
P_{max}
highest algebraic value of applied force in a cycle

NOTE Adapted from ASTM E 1823-05a [1][1].

3.2
minimum force
P_{min}
lowest algebraic value of applied force in a cycle

NOTE Adapted from ASTM E 1823-05a [1].

3.3
mean force
P_{mean}
algebraic average of the maximum and minimum forces in constant amplitude loading, or of individual cycles

NOTE Adapted from ASTM E 1823-05a [1].

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1 The figures between brackets refer to the Bibliography.

3.4
force range
ΔP
algebraic difference between the maximum and minimum forces in constant amplitude loading

3.5
maximum stress
σ_{max}
highest algebraic value of applied stress in a cycle

3.6
minimum stress
σ_{min}
lowest algebraic value of applied force in a cycle

3.7
mean stress
σ_{mean}
algebraic average of the maximum and minimum stress in constant amplitude loading, or of individual cycles

3.8
stress range
$\Delta\sigma$
algebraic difference between the maximum and minimum stresses in constant amplitude loading

3.9
maximum displacement
δ_{max}
highest algebraic value of applied displacement in a cycle

3.10
minimum displacement
δ_{min}
lowest algebraic value of applied displacement in a cycle

3.11
mean displacement
δ_{mean}
algebraic average of the maximum and minimum displacement in constant amplitude loading, or of individual cycles

3.12
displacement range
$\Delta\delta$
algebraic difference between the maximum and minimum displacements in constant amplitude loading

3.13
force ratio
stress ratio
R
algebraic ratio of the minimum force (or the minimum stress) to the maximum force (or the maximum stress)

4 Test piece

4.1 Design of test piece

In order to minimize the influence of size, the test piece should have dimensions of the same order as that of the objective device component. The shape and dimensions of the specimen should be based on Annex C of IEC 62047-2.

The dimensions of the plane shape of the specimen shall be within an accuracy range of ±1 % as specified in IEC 62047-2. The length of the parallel part of the test piece shall be more than 2,5 times the width. See C.1 in IEC 62047-2. The curved part between the gripped ends and the parallel part should have a radius of curvature sufficient to not cause a fracture at the curved part due to stress concentration. See C.2 in IEC 62047-2.

The gauge marks specified in IEC 62047-2 are not necessary if the marks may concentrate stress or initiate fatigue fractures.

4.2 Preparation of test piece

The test piece should be fabricated using a process as similar as possible to that of the device to which the thin film is to be applied. The test piece also should be fabricated following the procedures specified in IEC 62047-2. The substrate removal process should be carefully chosen to prevent damaging the test piece. See C.3 in IEC 62047-2.

The number of test pieces should be determined adequately according to the thin films tested. See Annex E.

4.3 Test piece thickness

The thickness of each test piece shall be measured, as the film thickness is not usually uniform over a wafer. The accuracy of the measurement shall be within 5 %. Each test piece should be measured directly. However, the film thickness at the step height of a window opening etched near the test piece can be used as the thickness of a specimen in order to avoid mechanical damage from the use of a stylus profiler, etc. Methods of measuring film thickness and measurement errors are given in C.4 of IEC 62047-2.

4.4 Storage prior to testing

In the case of thin films, the storage environment may affect the fatigue properties. If there is an interval between final preparation and testing, particular care should be taken in storing the test pieces, and the specimens should be examined by appropriate means to ensure that the surface has not deteriorated during the storage period. If any deterioration is observed that was not present after the specimens were prepared, testing shall not be performed. However, if the damage was introduced during the preparation processes, the test shall be performed.

5 Testing method and test apparatus

5.1 General

The testing machine should be equipped with a gripping mechanism appropriate for the test piece, as well as with a mechanism for applying cyclic loading. The cyclic loading applied to the test piece should be basically tensile-tensile mode loading.

For constant range force testing, maximum and minimum forces (or mean force and force range) shall be monitored and the testing machine should be equipped with a constant force range control system. For constant displacement range testing, the maximum and minimum displacements (or mean displacement and displacement range) shall be monitored and the testing machine should be equipped with a constant displacement range control system.

A test-piece failure detection system should be provided and the number of loading (or displacement) cycles to failure shall be recorded.

5.2 Method of gripping (mounting of test piece)

Each test piece shall be mounted so that the loading axis and test piece axis are aligned. When gripping both ends of the test piece, care shall be taken to avoid applying excess force and/or bending stress to the test piece. The gripping methods indicated in Annex A of IEC 62047-2 are recommended for mounting the test pieces. In addition, the testing apparatus should be equipped with a test piece alignment mechanism to ensure that the tensile axis of the test piece is aligned with the loading direction of the test apparatus.

5.3 Static loading test

Static tensile testing of the test piece is recommended before fatigue testing in order to determine the testing conditions. Static tensile testing shall be carried out according to the procedures specified in IEC 62047-2.

5.4 Method of loading

If the specimen was fractured during the first loading cycle, the fracture stress shall be recorded and described in the report. The maximum and minimum forces (or mean force and force range) shall be kept constant during the constant force range test. The maximum and minimum displacement (or mean displacement and displacement range) shall be kept constant during the constant displacement range test.

A load cell with a resolution adequate to guarantee 5 % accuracy of the applied force shall be used. The drift of the load cell should be less than 1 % of the full-scale force during the testing. See Annex B in IEC 62047-2 regarding the accuracy of the load cell.

For constant displacement range testing, a displacement measurement system with a resolution adequate to guarantee 5 % accuracy of the applied displacement shall be used. See Annex C.

5.5 Speed of testing

As the frequency of the stress cycle will depend upon the testing environment, the type of testing machine employed, and the stiffness of the test piece, the frequency shall be that which is most suitable for the particular combination of environment, material, test piece, and testing machine. Generally, the frequency should be chosen properly depending on the application of thin film materials. In addition, the frequency shall not heat the test piece during the application of cyclic loading due to the rapid dissipation of strain energy in the test piece.

This practice does not apply to fatigue testing of viscoelastic films.

5.6 Environment control

As the environment greatly affects the fatigue properties of thin films, the testing temperature and humidity shall be monitored during testing. The testing temperature and relative humidity should be controlled to within ±1 °C and ±5 %, respectively. See Annex E. If it is difficult to control the testing temperature and humidity, these values shall be described in the test report.

6 Endurances (test termination)

Fatigue testing shall continue until the test piece is fractured or a predetermined number of cycles has been applied to the test piece. The termination criterion (test piece fracture or predetermined number of cycles) shall be described in the test report.

7 Test report

The test report shall include the following information.

- Mandatory
  a) reference to this International Standard, i.e. IEC 62047-6
  b) test piece material
    – in the case of a single crystal: crystallographic orientation
  c) method and details of test piece fabrication
    – method of thin film deposition
    – fabrication processes
    – heat treatment (annealing) conditions
  d) shape and dimensions of test piece
  e) fatigue test conditions
    – mean stress (in the case of displacement control, mean displacement)
    – stress range (in the case of displacement control, displacement range)
    – testing environment (temperature and relative humidity)
    – wave form (sinusoidal, triangular, ramp)
    – frequency
  f) fatigue test result
    – number of applied cycles to failure. If the test piece is not fractured during a predetermined number of cycles, the number of cycles and the description “no failure” should be noted.
    – definition (type) of failure
- Optional
  a) microstructure
    – in the case of polycrystalline thin film: texture and grain size
  b) internal stress
  c) surface roughness of test piece
  d) brief description of fracture characteristics

Annex A
(informative)

Technical background of this standard

A.1 Significance of axial loading fatigue testing for thin films

MEMS devices are usually prepared from thin films deposited on a substrate. The micromachining techniques used are similar to the deposition and etching techniques employed in LSI processing. The microstructure and surface roughness of thin films depend upon the processing conditions, and micro/nano defects may occur during processing. These defects affect the mechanical properties of the thin films. Therefore, the mechanical properties of thin films should be measured using specimens prepared by the same process that is used to prepare the actual applied devices. In particular, the fatigue properties of thin films are essential data for designing durable and reliable MEMS devices. To date, fatigue tests of micro-sized components, including thin films, have been carried out using on-chip type test structures [2]-[4] and micro-sized specimens [5]-[6] prepared from thin films. These methods are, however, not standardized, making it difficult to compare fatigue data from different institutions. To date, ISO 1099 [8] and ASTM E 466-96 [9] have been specified as standard testing methods for fatigue testing of macro-sized materials. Of these standard testing methods, the axial fatigue testing method was established first, and extended testing methods, including data processing such as S-N curves, have been specified. Axial fatigue testing is thus a fundamental testing method for evaluating the fatigue properties of material, as is tensile testing under static loading. Therefore, a general discussion of the fatigue properties of MEMS devices is possible by first specifying the method used for axial fatigue testing of thin films.

A.2 Outline of round-robin tests performed in Japan [10]

This standard specifies the method for axial tensile–tensile force fatigue testing of thin film materials based on the results of round-robin tests (RRT) on axial fatigue testing of thin films that were performed from 2003 to 2005 in Japan.

The RRT was carried out with the participation of several universities and research institutes in Japan. The materials used were single and polycrystalline Si thin films, and polycrystalline Al thin film. These thin films were deposited on Si wafers. Micro-sized specimens were prepared from the thin film layer on the same wafer in accordance with IEC 62047-2 using a photolithography technique. The geometry of each test piece was such that it fit the testing machine at the specified institute, but the dimensions of the parallel parts of each test piece were standardized in accordance with IEC 62047-2. Axial fatigue tests were carried out mostly under force control, and the load application, force measurement, and displacement measurement were noted. The effect of the environment (mainly humidity) on fatigue life was also examined. The results were plotted as S-N curves and cross comparison of fatigue life was made. The validity of the testing as a standardized method was investigated and summarized in this standard.