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INTERNATIONAL STANDARD

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Semiconductor devices – Micro-electromechanical devices – Part 29: Electromechanical relaxation test method for freestanding conductive thin films under room temperature

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FOREWORD

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International Standard IEC 62047-29 has been prepared by subcommittee 47F: Micro-electromechanical systems, of IEC technical committee 47: Semiconductor devices.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
47F/295/FDIS	47F/298/RVD

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

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

A list of all parts in the IEC 62047 series, published 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 document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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SEMICONDUCTOR DEVICES –
MICRO-ELECTROMECHANICAL DEVICES –

Part 29: Electromechanical relaxation test method for freestanding conductive thin films under room temperature

1 Scope

This part of IEC 62047 specifies a relaxation test method for measuring electromechanical properties of freestanding conductive thin films for micro-electromechanical systems (MEMS) under controlled strain and room temperature. Freestanding thin films of conductive materials are extensively utilized in MEMS, opto-electronics, and flexible/wearable electronics products. Freestanding thin films in the products experience external and internal stresses which could be relaxed even under room temperature during a period of operation, and this relaxation leads to time-dependent variation of electrical performances of the products. This test method is valid for isotropic, homogeneous, and linearly viscoelastic 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.

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

IEC 62047-3:2006, *Semiconductor devices – Micro-electromechanical devices – Part 3: Thin film standard test piece for tensile testing*

IEC 62047-8:2011, *Semiconductor devices – Micro-electromechanical devices – Part 8: Strip bending test method for tensile property measurement of thin films*

IEC 62047-21:2014, *Semiconductor devices – Micro-electromechanical devices – Part 21: Test method for Poisson's ratio of thin film MEMS materials*

IEC 62047-22:2014, *Semiconductor devices – Micro-electromechanical devices – Part 22: Electromechanical tensile test method for conductive thin films on flexible substrates*

3 Terms and symbols

3.1 Terms and definitions

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

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

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

3.1.1
gauge factor

G_F

ratio of the relative change in electrical resistance R to the change in mechanical strain ($\Delta\varepsilon$)

Note 1 to entry: Gauge factor is defined as G_F = $(\Delta R/R)/\Delta\varepsilon$, where ΔR is the change in resistance, R is the unstrained resistance, $\Delta\varepsilon$ is the change in the mechanical strain. R and ΔR are expressed in ohms and $\Delta\varepsilon$ in µm/m.

3.1.2
piezoresistive coefficient

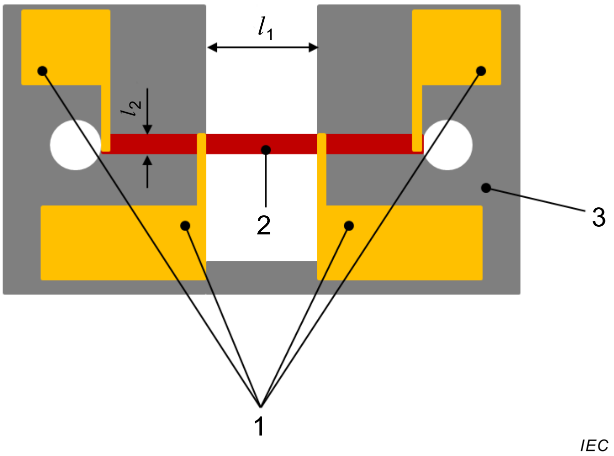
π

ratio of the relative change in electrical resistivity ρ, to the change in applied mechanical stress

Note 1 to entry: Piezoresistive coefficient is defined as $\pi = (\Delta\rho/\rho)/\Delta\sigma$, where $\Delta\rho$ is the change in resistivity, ρ the unstressed resistivity, $\Delta\sigma$ the applied mechanical stress. Stress is expressed in Pascal [Pa].

3.2 Symbols and designations

The shape of a test piece and symbols are presented in Figure 1 and Table 1, respectively. The overall shape of the test piece is similar to a conventional thin film or sheet test piece for strip bending test (see IEC 62047-8:2011), and it has a freestanding structure and four electric contacts for electrical measurements.



Key

1 electrical contacts for four wire measurement

2 test piece

3 substrate

Figure 1 – Freestanding test piece

Table 1 – Symbols and designations of a test piece

Symbol	Unit	Designation
l_1	µm	Gauge length for strain and resistance change measurements
l_2	µm	Width of a test piece
h	µm	Thickness of a test piece

4 Test piece

4.1 General

A test piece shall be prepared using the same fabrication process as the target film of an actual MEMS device. Shaping the test piece shall be performed to prevent formation of cracks, flaws, or delamination in the test piece.

4.2 Shape of a test piece

The shape of a test piece is shown in Figure 1. Because the change in electrical resistance is related to strain or stress, electrical resistance shall be measured in a region of uniform strain. The electrical resistance shall be measured using four wire method, and this requires four electric contacts on the test piece. To eliminate the effect of the fixed boundary near the grips, the gauge length (l_1) shall be at least 20 times larger than the width (l_2). The width shall be more than 10 times the thickness (h).

4.3 Measurement of dimensions

Gauge length (l_1), width (l_2), and thickness (h) should be measured with an error of less than ± 5 %. The thickness should be measured according to Annex C of IEC 62047-2:2006 and in Clause 6 of IEC 62047-3:2006.

5 Test principle and test apparatus

5.1 Test principle

The test is performed by applying a prescribed tensile strain to a test piece and by measuring the change in electrical resistance under constant strain for a testing period. Both the electrical resistance and the mechanical stress relax as time, and the ratio of these two quantities characterizes the piezoresistive behaviour of a tested material. To this end, the tensile strain induced by the tensile load shall be uniform in a pre-defined gauge section and shall be in the elastic region of the test piece. The actuator of the test machine shall be controlled with a feedback loop to keep the strain constant since the strain in thin films usually creeps even under room temperature, and this leads to deviation of strain in the test piece. To measure the change in electrical resistance under constant strain, the gauge section for measuring mechanical strain shall be coincident with or scalable to that for measuring electrical resistance.

5.2 Test environment

Because electrical properties are temperature sensitive, fluctuations in temperature during the test shall be controlled to be less than ± 2 °C. Flexible substrates made of certain polymeric materials can be sensitive to humidity; thus, the change in relative humidity (RH) in the testing laboratory shall be controlled to be less than ± 5 % RH for such materials.

5.3 Test machine

The test machine is similar to a conventional tensile test machine except that it is capable of feedback control of applied strain and measurement of electrical resistance during the test. The electrical resistance shall be measured with four wire method (Kelvin method) to exclude the effects of parasitic resistances from contact and lead wires. The electrical current for the four wire method measurement shall be as small as possible to prevent the test piece from heating, but to provide sufficient measurement resolution and accuracy. A schematic of the test machine is shown in Figure 2. A noncontact strain measurement method like digital image correlation shall be used to measure the strain not to disturb a test piece. The measured strain signal shall be connected to the test machine for the feedback control.

5.4 Test procedure

The test procedure is as follows:

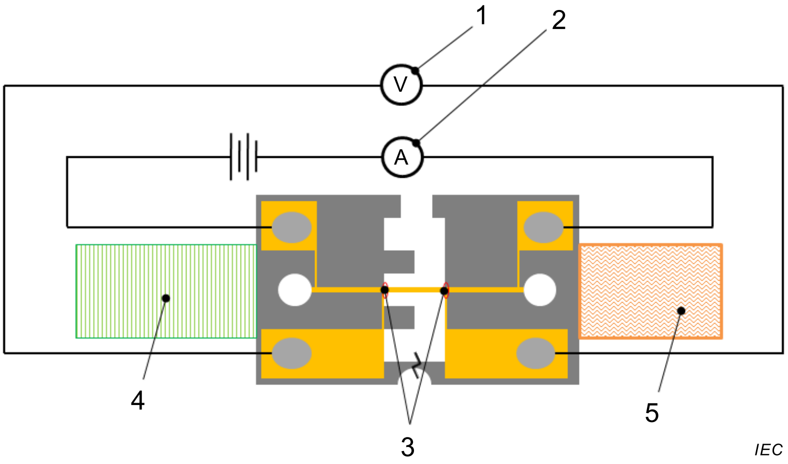
a) Fix a test piece to the relaxation test machine. The longitudinal direction of the test piece shall be aligned with the actuating direction of the test apparatus, and the deviation angle shall be less than 1° as described in 4.4 of IEC 62047-8:2011.

b) Verify the electrical measurement unit as well as the loadcell and strain measurement unit. The three signals of force, strain and resistance shall be recorded simultaneously (see 5.3 of IEC 62047-22:2014). The loadcell shall be accurate to the nominal value within 0,25 %.

c) Apply a tensile strain up to a predetermined level in a short period. The straining period is typically less than 1 s for metallic conductors, but shall be shorter when the target material is highly time-dependent. The predetermined strain level shall be chosen in an elastic range of the test piece. For example, when the maximum elastic strain of the test piece is E_{el} [μm/m], the strain levels can be chosen as $E_{el}/4$, $2E_{el}/4$, $3E_{el}/4$, and E_{el}.

d) Hold the applied strain for a testing period, and measure the force and resistance signals simultaneously. During this holding period, the strain shall be controlled to be constant, and this shall be verified using a strain measurement technique such as digital image correlation. The strain resolution shall be less than $E_{el}/500$, and the measured strain shall be accurate to the nominal value of the maximum strain within 0,2 %.

e) Unload the test piece after the testing period. After testing, carefully remove the test piece from the test apparatus to prevent any additional damage on the test piece. If possible, preserve the test piece for investigation using electron and optical microscopes.



Key

1	voltmeter
2	current source
3	markers for strain measurement
4	actuator for applying a load to the test piece
5	loadcell

Figure 2 – Experimental setup

5.5 Data analysis

The piezoresistive coefficient (π) is obtained from the ratio between two relaxation data of electrical resistance and mechanical stress. See Annex A for the test example of freestanding Au thin film. The relaxation modulus is obtained by dividing the relaxation data of mechanical stress with the applied strain. The gauge factor is directly measured by using IEC 62047-22:2014, and is obtained from $(1+2\nu+\pi E)$, where ν is Poisson's ratio (should be measured by using IEC 62047-21:2014), and E is Young's modulus (should be measured by using IEC 62047-2:2006).

6 Test report

The test report shall contain the following information:

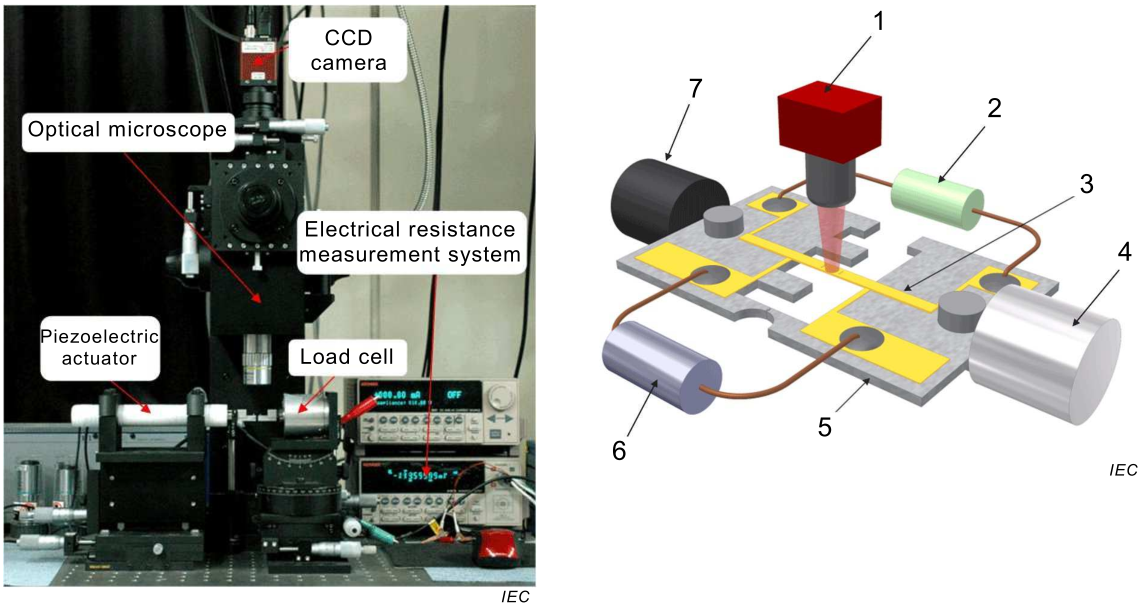
a) reference to this International Standard;
b) test piece identification number;
c) test piece preparation procedures;
d) test piece dimensions and their measurement method;
e) description of the testing apparatus;
f) measured properties and results: piezoresistive coefficient, stress relaxation curve (stress versus time), controlled strain curve (strain versus time), electrical relaxation curve (resistance change versus time).

Annex A
(informative)

Electromechanical relaxation test example of freestanding Au film

A.1 Testing overview

The testing equipment shown in Figure A.1 is utilized to measure electromechanical relaxation of freestanding Au thin film. A piezoelectric actuator applies tensile strain to the freestanding Au film and the corresponding force and electrical resistance are measured simultaneously by a load cell and an electrical measurement system. The applied strain is measured by correlation with the images obtained by an optical microscope and an imaging camera. The piezoelectric actuator is controlled to maintain the applied strain constant.



a) **Photograph of test equipment** b) **Schematic for experimental setup**

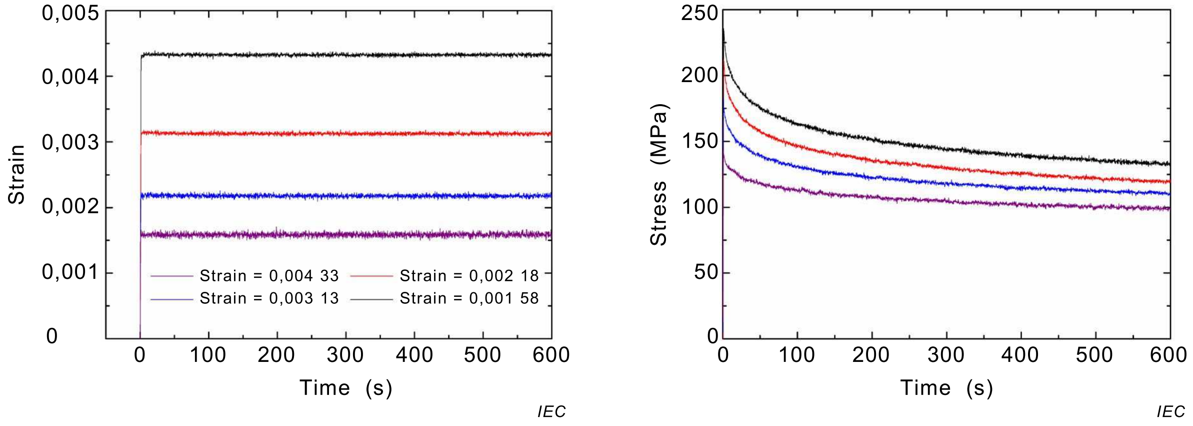
Key

1	optical system for strain measurement
2	current source
3	gold specimen
4	loadcell
5	substrate
6	voltmeter
7	piezoelectric actuator

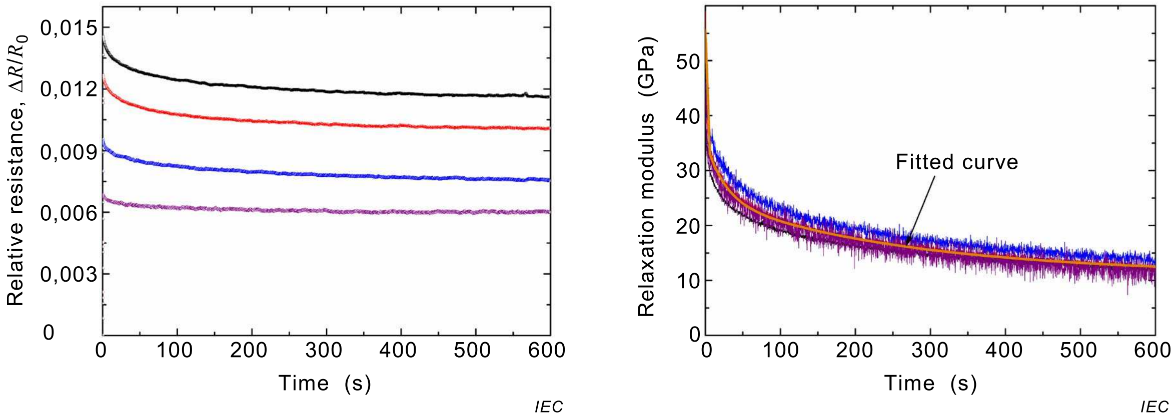
Figure A.1 – Photograph of test equipment and a schematic for experimental setup

A.2 Testing results

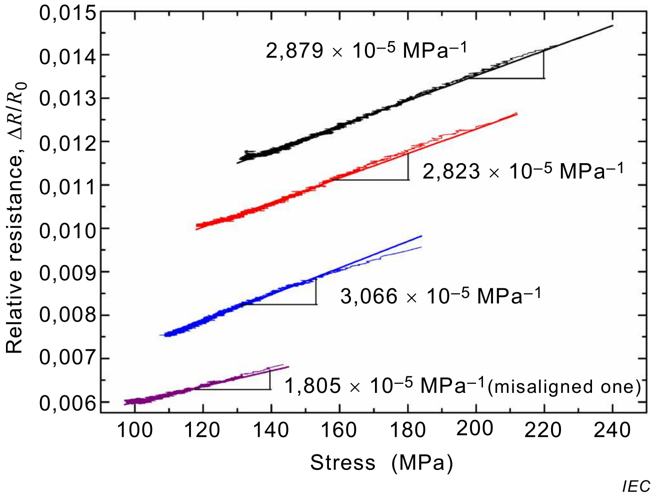
The testing results are shown in Figure A.2. The measured strain shown in Figure A.2 a) indicates that the applied strain is controlled to be constant. The measured strain history can be regarded as the Heaviside step function. The rising time for maximum strain value is less than 1 s and the overshoot is negligible. The strain is kept constant during the entire period of test for 4 different strain levels. The measured stress data in Figure A.2 b) show that the Au thin film has a stress relaxation behaviour, which is typical for the metallic thin film even under room temperature. Figure A.2 c) shows that the electrical resistance also relaxes as time. When the relaxation modulus is estimated from the measured strain and stress, the relaxation moduli measured from 4 different levels of applied strain are overlapped on a single curve as shown in Figure A.2 d), and a single fitted curve is displayed in the figure. This verifies the linear viscoelastic behaviour of the tested Au film. The resistance change versus stress graph shown in Figure A.2 e) indicates that the resistance change can be fitted by a linear curve during stress relaxation tests. The slope of the fitted curve corresponds to a piezoresistive coefficient. The slope varies from $2,82 \times 10^{-5}$ MPa^{-1} to $3,07 \times 10^{-5}$ MPa^{-1}. Since the strain is kept constant during the test, the stress relaxation induces the change in the electrical resistivity without any dimensional change. Even though both stress and electrical resistance relax with time, but they are linearly proportional to each other.



a) Strain versus time **b) Stress versus time**



c) Relative resistance change versus time **d) Relaxation modulus versus time**



e) Relative resistance change versus stress

Figure A.2 – Electromechanical relaxation data of freestanding Au film with a thickness of 1 µm

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