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colour inside

Semiconductor devices – Micro-electromechanical devices – Part 36: Environmental and dielectric withstand test methods for MEMS piezoelectric thin films

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 36: Environmental and dielectric withstand test methods for MEMS piezoelectric thin films

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

FDIS	Report on voting
47F/329/FDIS	47F/334/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.

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INTRODUCTION

Piezoelectric MEMS technology belongs to an interdisciplinary field founded on a wide range of element technologies including piezoelectric thin film materials, thin film deposition and microfabrication processes, device design, and system formulation. Along with the increased sophistication of MEMS functionality, research on MEMS applications for piezoelectric thin films, such as $Pb(Zr,Ti)O_3$ (PZT) or AlN, has become increasingly popular in recent years. MEMS piezoelectric thin films have the capability of configuring simple compact devices that have a lower power consumption, higher sensitivity, and quicker response than conventional bulk-type, electrostatic, or electromagnetic thin films. However, their device performance is greatly affected by the properties of the thin film materials.

Several test methods for thin film materials have been established to date. Among these, the overriding property that determines device performance is the material's piezoelectric property. Standardization of IEC 62047-30 (*Semiconductor devices – Micro-electromechanical devices – Part 30: Measurement methods of electro-mechanical conversion characteristics of MEMS piezoelectric thin film*) has been promoted for the purpose of precisely measuring and evaluating MEMS piezoelectric thin films using simply structured test pieces and inexpensive equipment.

In order to realize a viable MEMS piezoelectric thin film, it is essential to gain a clear understanding of how its piezoelectric properties change as a result of the environmental stress of temperature and humidity, and degradation in the piezoelectric material over time at its surfaces and interfaces. Achieving a viable MEMS piezoelectric thin film will also require a clear understanding of dielectric withstand for the electrical stress of a voltage (electric field) higher than the drive voltage (electric field) used for normal operations.

The following summarizes the features of this standard.

- The degree of degradation in a device under test (DUT) is evaluated by measuring the piezoelectric properties of the DUT before and after applying the environmental stress of temperature and humidity using the measurement methods in IEC 62047-30.
- Test conditions for moist heat and dielectric withstand tests are derived from existing standards for semiconductor devices and fixed capacitors of ceramic dielectric.
- The dielectric withstand property is evaluated by measuring the leakage current under the DC bias voltage.

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 36: Environmental and dielectric withstand test methods for MEMS piezoelectric thin films

1 Scope

This part of IEC 62047 specifies test methods for evaluating the durability of MEMS piezoelectric thin film materials under the environmental stress of temperature and humidity and under electrical stress, and test conditions for appropriate quality assessment. Specifically, this document specifies test methods and test conditions for measuring the durability of a DUT under temperature and humidity conditions and applied voltages. It further applies to evaluations of converse piezoelectric properties in piezoelectric thin films formed primarily on silicon substrates, i.e., piezoelectric thin films used as actuators.

This document does not cover reliability assessments, such as methods of predicting the lifetime of a piezoelectric thin film based on a Weibull distribution.

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 62047-30, *Semiconductor devices – Micro-electromechanical devices – Part 30: Measurement methods of electro-mechanical conversion characteristics of MEMS piezoelectric thin film*

IEC 60068-2-14:2009, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

3 Terms and definitions

No terms and definitions are listed in this document.

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

4 Testing procedure

4.1 General

The degree of degradation in a device under test (DUT) is evaluated by measuring the piezoelectric properties of the DUT before and after applying the environmental stress of temperature and humidity. Figure 1 shows the general flow of the testing procedure.

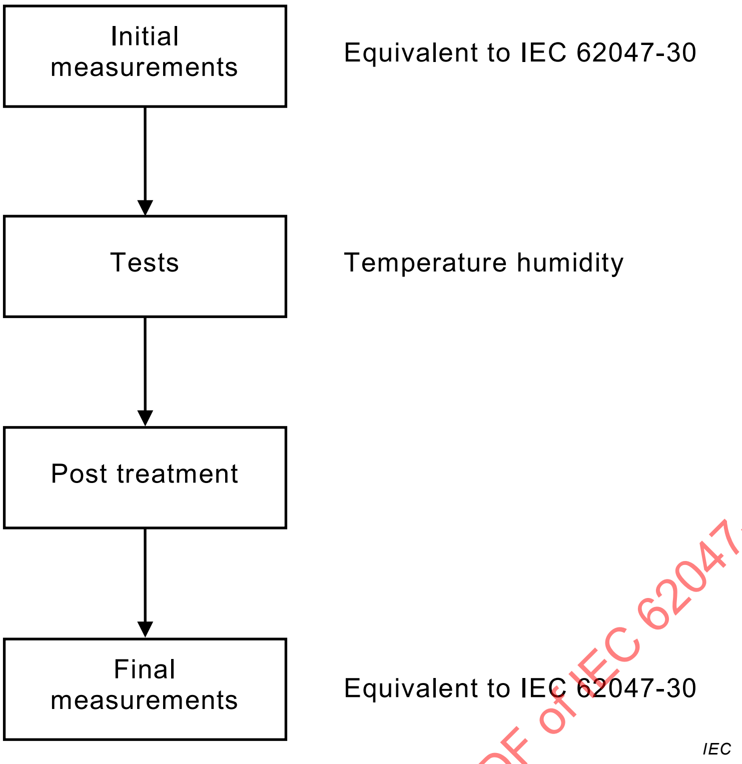


Figure 1 – Flow of the testing procedure

4.2 Initial measurements

The methods of measurement used in the environmental tests shall conform to the methods described in IEC 62047-30. The ambient conditions for measurements shall include an ambient temperature of 25 °C ± 3 °C, a relative humidity of 45 % to 75 %, and an atmospheric pressure of 86 kPa to 106 kPa.

4.3 Tests

4.3.1 DUT setup and environmental conditions

For tests requiring continuous operation of the DUT, the DUT is placed in a test bed for adjusting the temperature and humidity to prescribed conditions. The test conditions are monitored to verify that no abnormalities occur when the chamber environment reaches the prescribed conditions. For tests that do not require continuous operations of the DUT, the DUT may be placed in the test bed and the test bed may be deposited in the chamber, but the test bed need not be put in the chamber. When depositing and removing the DUT and test bed for either test, the operator shall ensure that:

- water does not drip onto the DUT;
- the DUT is not directly immersed in water.

4.3.2 Test duration

Test duration is described below in "5.1 Environmental testing" (see 5.1.1 through 5.1.7).

4.3.3 Number of tests and number of DUTs

Specifications for the number of tests and the number of DUTs shall take the failure mechanism, failure distribution, and other factors anticipated in each test into account. When intermediate measurements are required, such measurements may be performed according to the following timetable:

- 24 h (+8 h, −0 h);
- 48 h (+8 h, −0 h);
- 96 h (+24 h, −0 h);
- 168 h (+48 h, −0 h);
- 480 h (+72 h, −0 h).

Here, A h (+B h, −C h) means the time from (A-C) to (A+B) hours. The time spent removing the DUT and conducting the intermediate measurements shall be omitted from the test duration.

4.4 Post treatment

After completion of the tests, first the voltage is halted and then the DUT is removed from the chamber and returned to standard conditions. However, this shall not apply to cases in which the DUT clearly recovers from its degraded state after voltage is halted at the testing temperature because a correct result is not possible.

4.5 Final measurements

The methods of measurement used in moist heat tests shall conform to the methods set forth in IEC 62047-30. The degraded state of a DUT is evaluated by comparing the final measurements to the initial measurements. The environmental conditions for measurements shall include:

- ambient temperature: 25 °C ± 3 °C;
- relative humidity: 45 % to 75 %;
- atmospheric pressure: 86 kPa to 106 kPa.

As a general rule, final measurements shall be conducted within 48 h from the completion of tests after verifying that the surface of the DUT is dry. When conducting intermediate measurements prior to the final measurements, the DUT shall be deposited back into the testing chamber within 96 h after being removed for measurements. Final measurements are preferably completed within 96 h after halting voltage application to the DUT.

5 Environmental and dielectric withstand testing

5.1 Environmental testing

5.1.1 General

Equipment used in these experiments includes:

- a chamber capable of maintaining predetermined test temperatures and humidity and allowable temperatures and humidity;
- a power source for generating a predetermined AC voltage;
- a voltage application equipment having sufficient resistance for withstanding the test temperatures and humidity.

The chamber shall be capable of maintaining its entire interior at the set temperature ±2 °C and the set humidity ±5 % during the test. The applied voltage and operating method shall be established with consideration for the limits of the DUT. The application circuit shall be considered to account for load conditions and other factors in order that the operating state of the DUT be suitably maintained.

NOTE 1 The degree of degradation in a device under test (DUT) is evaluated by measuring the piezoelectric properties of the DUT before and after applying the environmental stress of temperature and humidity and electrical stress.

NOTE 2 The degree of degradation in a DUT is evaluated using the measurement methods in IEC 62047-30.

NOTE 3 A test circuit for testing a plurality of DUT simultaneously is designed so that failure of one DUT during a test does not affect the other DUT.

5.1.2 High temperature bias test

The objective of this test is to evaluate the ability of MEMS piezoelectric thin film to operate at a high temperature. Electrical stress (voltage) is applied to the piezoelectric film under a high temperature to evaluate the effects of these conditions over a long duration. The driving conditions to DUT, including the vibration mode (resonant mode or non-resonant mode), input waveform, the frequency, and the like shall be determined based on the expected application of the actuator. The following test conditions shall be applied:

- test temperature: 85 °C or higher;
- test voltage: maximum operating voltage (operation max.);
- test duration: 96 h or longer.

NOTE 1 Sample test temperatures can include 85 °C, 105 °C and 125 °C.

NOTE 2 Sample test durations can include 96 h, 480 h and 960 h.

5.1.3 High temperature and high humidity bias test

The objective of this test is to evaluate the ability of MEMS piezoelectric thin film to operate under high temperature and high humidity. A drive voltage is applied to the piezoelectric thin film under high temperature and humidity and the effects of these conditions are assessed over a long duration. The humidity test determines whether electronic products have sufficient electrical and mechanical properties to withstand heavy conditions with high relative humidity, regardless of whether condensation is present. The humidity test may also be used to inspect the resistance of the DUT to various corrosive actions. Based on the expected application of the actuator, the measurement parameters shall be determined as follows:

- resonant mode or non-resonant mode;
- input waveform;
- frequency.

Table 1 shows the selectable test conditions.

Table 1 – Selectable test conditions

Condition	**Temperature** (°C)	**Humidity** (%)
A	40	90
B	60	90
C	85	85

The test parameters shall be determined as follows:

- test voltage: maximum operating voltage (operation max.);
- test duration: 96 h or longer.

NOTE Sample test durations include 96 h, 480 h and 960 h.

5.1.4 High temperature storage

The objective of this test is to evaluate the ability of MEMS piezoelectric thin film to withstand storage at a high temperature. The piezoelectric thin film is kept under a high temperature for a long duration, and the effects of these conditions are evaluated. The following test conditions shall be applied:

- test temperature: 85 °C or higher;
- test duration: 96 h or longer.

NOTE 1 Sample test temperatures include 85 °C, 105 °C and 125 °C.

NOTE 2 Sample test durations include 96 h, 480 h and 960 h.

5.1.5 Low temperature storage

The objective of this test is to evaluate the ability of MEMS piezoelectric thin film to withstand storage at a low temperature. The piezoelectric thin film is kept under a low temperature for a long duration, and the effects of these conditions are evaluated. The following test conditions shall be applied:

- test temperature: −20 °C or lower;
- test duration: 96 h or longer.

NOTE Sample test durations include 96 h, 480 h and 960 h.

5.1.6 High temperature and high humidity storage

The objective of this test is to evaluate the ability of MEMS piezoelectric thin film to withstand storage under a high temperature and high humidity. The piezoelectric thin film is maintained under high temperature and high humidity conditions for a long duration, and the effects of these conditions are evaluated. Table 2 shows the selectable test conditions.

Table 2 – Selectable test conditions

Condition	**Temperature** (°C)	**Humidity** (%)
A	40	90
B	60	90
C	85	85

The test parameters shall be determined as follows:

- test voltage: Maximum operating voltage (operation max.);
- test duration: 96 h or longer.

NOTE Sample test durations include 96 h, 480 h and 960 h.

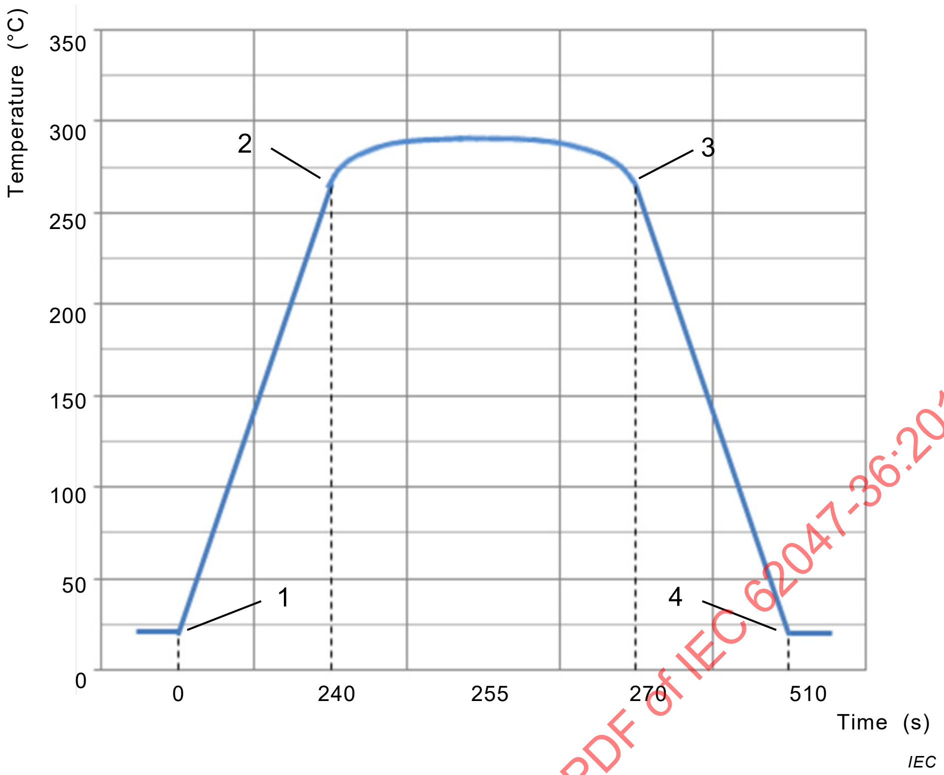
5.1.7 Soldering heat test

The objective of this test is to evaluate the resistance of MEMS piezoelectric thin film to heat generated during soldering. The temperature and time required for replicating thermal conditions expected in reflow soldering are specified in Table 3 as the test conditions.

Table 3 – Soldering heat test condition

	Specified temperature (°C)	**Hold time** (s)
Test conditions	265 ± 5	30 ± 5

Here, a temperature profile assuming reflow conditions for lead-free solder was created as an example as shown as Figure 2. The test may be repeated a maximum of three times at a duration of 10 s.



Key

1 starting point of soldering heat test

2 starting point of specified temperature or higher

3 finishing point of specified temperature or higher

4 finishing point of soldering heat test

Figure 2 – Temperature profile for reflow soldering with lead-free solder

Table 4 shows a condition of temperature profile for reflow soldering with lead-free solder.

Table 4 – Conditions of temperature profile for reflow soldering with lead-free solder

	Time (s)	**Ramp rate (°C/s)**	**Temperature** (°C)
1	0	1,02	20
2	240		265
3	270	1,02	265
4	510		20

5.1.8 Temperature cycling test

The objective of this test is to evaluate the resistance of MEMS piezoelectric thin film to cycling between high temperature and low temperature extremes. The test method used here is in accordance with IEC 60068-2-14:2009, Clause 8 (Test Nb: Change of temperature with specified rate of change).

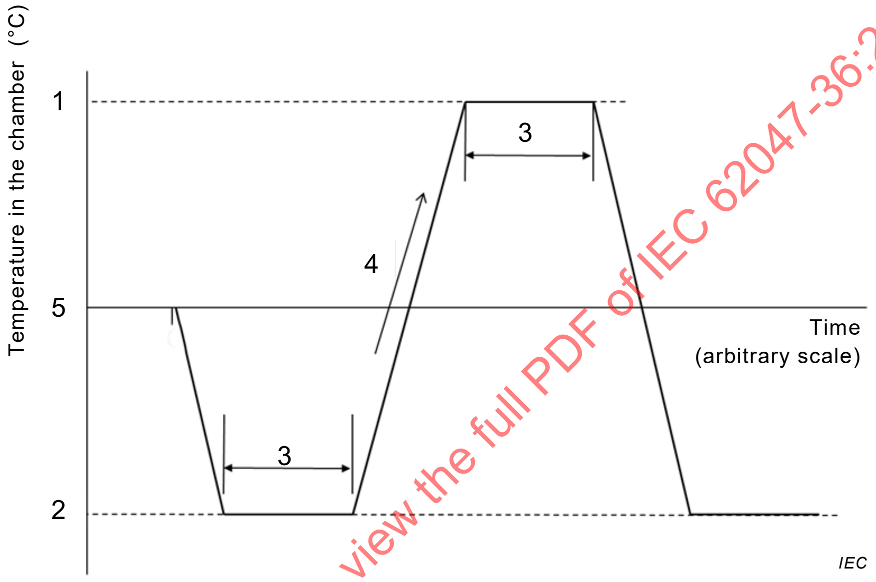
One cycle of test is as follows:

- The temperature of the testing chamber is lowered at a prescribed ramp-down rate R to a cold temperature T_A;

- After the internal temperature has stabilized, the DUT is exposed to cold temperature for a specified time t_1;
- The temperature of the chamber is raised at a prescribed ramp-up rate R to a hot temperature T_B;
- After the internal temperature has stabilized, the DUT is exposed to hot temperature for the specified time t_1;
- The temperature in the chamber is then lowered at a prescribed rate to 25 °C ± 5 °C.

The test is continually repeated N times. N may be determined arbitrarily.

Figure 3 shows the temperature profile of the temperature cycling test.



Key

1 hot temperature T_B: 85 °C (+15, -0)

2 cold temperature T_A: −20 °C (+0, -10)

3 upper or lower soak time t_1: 1 h or longer

4 ramp-up or down rate R: 100 °C/h

5 room temperature T_R: 20 °C (+10, -10)

Figure 3 – Temperature profile of the temperature cycling test

NOTE The number of cycles is arbitrary.

5.2 Dielectric withstand testing

The objective of this test is to evaluate the resistance of MEMS piezoelectric thin film to a voltage exceeding the rated voltage. The applied voltage and operating method shall be established with consideration for the limits of the DUT. Withstand voltage is defined when the leakage current between top and bottom electrodes increases to 10^3 times larger than initial leakage current at 100 kV/cm. The following test parameters and results shall be indicated with the value of withstand voltage:

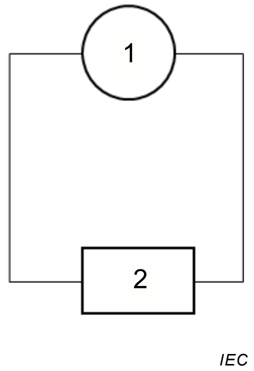
- electrode (material, size, shape, thickness);
- input waveform and /or increasing ratio of applied voltage;
- polarity of application voltage (positive or negative on a top electrode);
- I-V curves;

- photo images of electrodes after withstand test;
- test temperature and humidity.

EXAMPLE The voltage increasing rate is set to 2 V/s, the prescribed voltage value to 1,2 times the rated voltage, and the prescribed time to 60 s.

A test circuit for testing a plurality of DUT simultaneously is designed so that failure of one DUT during a test does not affect the other DUT.

Figure 4 shows the example of a dielectric withstand test circuit for DC voltage.



Key

1 leakage current tester with valuable DC voltage source and voltmeter

2 DUT

Figure 4 – Example of a dielectric withstand test circuit for DC voltage

Annex A
(informative)

Report of test results

A.1 General

Annex A describes an example of the environmental and dielectric withstand tests of the piezoelectric thin films. Clauses A.2 and A.3 summarize the procedures and measurement results of environmental (high temperature test) and dielectric withstand tests, respectively.

A.2 Environmental test

The following steps show an example of measuring procedures of a high-temperature environmental test.

a) The sample is a piezoelectric 3 µm-thick PZT thin film on the unimorph beam of 625 µm thickness of (100) single crystal silicon substrate.
b) Thicknesses of the platinum bottom and top electrodes are 0,2 µm and 0,05 µm respectively.
c) The sample is cut out to the beam shape of 20 mm length and 2 mm width by dicing saw along with <110> crystal orientation.
d) One end of the unimorph beam is clamped by the clamp.
e) Before the environmental test, converse piezoelectric coefficient ($e^{c}_{31,f}$) is measured according to IEC 62047-30.
f) The ambient condition of the measurement is 25 °C and 50 %, respectively. The initial values of piezoelectric coefficient are shown in Table A.1.
g) After the measurement of the initial piezoelectric properties, the sample is placed in the environmental testing apparatus.
h) This environmental test is high temperature bias test and test conditions are 100 °C, 96 h, – 10 V bias.
i) The results of the environmental test are shown in Table A.1.

Table A.1 – High-temperature test

Piezoelectric coefficient	**Initial** (N/Vm)	**96 h** N/Vm
$e^{c}_{31,f}(V_{in,0})$	9,9	9,8
$e^{c}_{31,f}(V_{in,min}$: -5 V)	10,9	10,8
$e^{c}_{31,f}(V_{in,max}$: -20 V)	13,8	13,6

A.3 Dielectric withstand test

The following steps show an example of measuring procedures of a dielectric withstand test.

a) The sample is a piezoelectric 2,5 µm-thick PZT thin film on the (100) single crystal silicon substrate.
b) Dot-shape 0,1 µm-thick top electrodes of 0,5 mm in diameter are deposited on the PZT thin film.
c) Leakage current is measured as a function of voltage (I-V measurement).