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Semiconductor devices – Micro-electromechanical devices – Part 34: Test methods for MEMS piezoresistive pressure-sensitive device on wafer

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SEMICONDUCTOR DEVICES –
MICRO-ELECTROMECHANICAL DEVICES –

Part 34: Test methods for MEMS piezoresistive pressure-sensitive device on wafer

FOREWORD

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International Standard IEC 62047-34 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/328/FDIS	47F/333/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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 34: Test methods for MEMS piezoresistive pressure-sensitive device on wafer

1 Scope

This part of IEC 62047 describes test conditions and test methods of electric character, static performances and thermal performances for MEMS pressure-sensitive devices. This document applies to test for both open and closed loop piezoresistive MEMS pressure devices on wafer.

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 61193-2, *Quality assessment systems – Part 2: Selection and use of sampling plans for inspection of electronic components and packages*

IEC 60747-14-3, *Semiconductor devices – Part 14-3: Semiconductor sensors – Pressure sensors*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60747-14-3 and the following 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
piezoresistive pressure-sensitive device
device that transforms pressure signal into electric signal due to piezoresistive effect, usually including cavity-membrane structure on silicon substrate and Wheatstone bridge in the membrane fabricated by MEMS technology

[SOURCE: IEC 62047-33: –, 3.1]

3.2
closed loop piezoresistive pressure-sensitive device
piezoresistive pressure-sensitive device that employs closed loop Wheatstone bridge for signal detection

3.3
open loop piezoresistive pressure-sensitive device
piezoresistive pressure-sensitive device that employs open loop Wheatstone bridge for signal detection

3.4
output under normal pressure
output of the pressure-sensitive device under the standard reference atmosphere pressure(101,3 kPa)

3.5
zero output
output of the pressure-sensitive device when the pressure difference between both sides of the membrane structure is zero

4 Test conditions

4.1 Atmospheric conditions

The measurement of characteristics shall be carried out under the following atmospheric conditions unless otherwise specified.

a) Standard atmospheric conditions

   Temperature range: 15 °C to 35 °C;

   Relative humidity range: 20 % to 80 %;

   Atmospheric pressure range: 86 kPa to 106 kPa.

b) Standard reference atmospheric conditions

   Temperature: 20 °C;

   Relative humidity: 65 %;

   Atmospheric pressure: 101,3 kPa.

The standard reference atmospheric conditions are corrected values derived from testing values under any other atmospheric conditions. In most circumstances, temperature and atmospheric pressure are the only factors to be considered.

4.2 Electromagnetic conditions

No other external magnetic field should exist in the testing environment except geomagnetic field. The specific requirements should be in accordance with the device technical conditions.

4.3 Vibration conditions

No mechanical vibration should exist in the testing environment. The specific requirements should be in accordance with the device technical conditions.

4.4 Test system

The test system consists of probe station, pressure control device, heating and cooling system, excitation power supply, as well as reading and recording device. The tolerance errors of the test system are listed below.

a) The absolute value of the intrinsic error of pressure control device should be under 1/3 of the intrinsic error bound of the pressure-sensitive device.

b) The temperature measurement accuracy of heating and cooling system should be ±2 °C around the preset temperature.

c) The fluctuation of excitation power supply should be under 1/5 of the intrinsic error bound of the pressure-sensitive device.

d) The absolute value of the intrinsic error of the reading and recording device should be under 1/5 of the intrinsic error bound of the pressure-sensitive device.

5 General provisions

5.1 Certificate documents

The verification certificates of instrument and meter issued by metrological verification institutions should be required and valid.

5.2 Placement and preheating time

The instrument and meter should be powered on for preheating before the test. The preheating time should be in accordance with the operation manual.

5.3 Connection

The test system is built according to its spool drawing and circuit diagram.

6 Test items and methods

6.1 Test preparation

The resistance test system of the probe station should be calibrated using standard resistance substrate. Build the test system according to 5.3. Fix the wafer on the probe station and the probe (or probe card) should be in the same horizontal plane. Adjust the height of the wafer supporting stage and the scanning horizontal line to insure reliable connection between the wafer pins and the probes during testing. Set the parameters of the system.

6.2 Resistance

6.2.1 Purpose

To measure the resistance value of the pressure-sensitive device.

6.2.2 Test methods

Connect the pressure-sensitive device pins with the reading and recording device through probes complying with the general provisions set out in 5.1 to 5.3 and the test preparation described in 6.1.

a) Closed loop piezoresistive pressure-sensitive device

For closed loop bridge shown in Figure 1, measure the resistance between pin 1 and pin 3, as well as the resistance between pin 2 and pin 4.

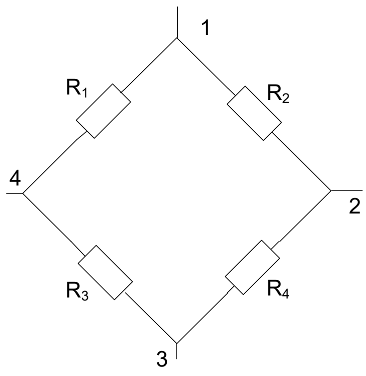

Figure 1 – Closed loop bridge

b) Open loop piezoresistive pressure-sensitive device

For the open loop bridge shown in Figure 2, measure the resistance between every adjacent pins. For example in Figure 2, measure the resistances between pin 1 and pin 2, pin 2 and pin 3, pin 4 and pin 5, as well as between pin 5 and pin 1.

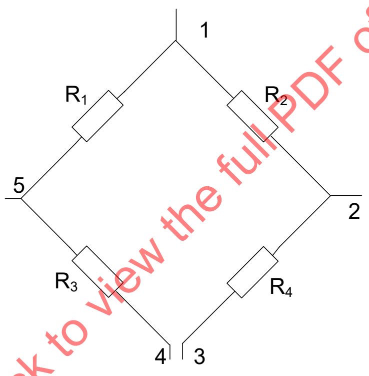

Figure 2 – Open loop bridge

NOTE The consistency of the four resistance values will affect the zero output.

6.3 Static performances

6.3.1 Purpose

To measure the static performances of the device.

6.3.2 Test items

The test items are the following:

a) zero output;
b) output under normal pressure;
c) full-scale span output;
d) nonlinearity;
e) hysteresis;
f) repeatability;
g) accuracy;
h) sensitivity;

i) zero drift.

6.3.3 Test method

6.3.3.1 General

The test system is built in accordance with the general provisions set out in 5.1 to 5.3 and the test preparation described in 6.1.

The test of the static performance shall use the five-point sampling method or be in accordance with the user requirements. As shown in Figure 3, the same number of dice in the five regions of upper, lower, left, right and middle of the wafer shall be tested. According to a normal sampling of general inspection level II in IEC 61193-2, the sampling shall be carried out and the sampling amount shall be more than it is in IEC 61193-2.

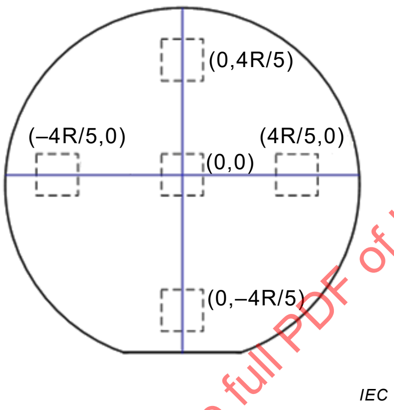

Figure 3 – Five-point sampling

Turn on the pressure source and control the pressure to be stable at the full-scale pressure for at least 1 minute and then at the zero-scale pressure for at least 1 minute. Recycle this process for 3 times.

Select $m(m \geq 3)$ test points uniformly between zero-scale pressure and the full-scale pressure in measure range.

This test shall be started from the zero-scale pressure and approach full-scale pressure (i.e. forward stroke) by increasing load steadily in accordance with the provision. For each testing point, when the pressure is stable, read the output values of the devices on the wafer. Then start from full-scale pressure and approach the zero-scale pressure (i.e. backward stroke) by decreasing the load steadily in accordance with the provision.

There are m test points in the full range and n cycle tests. Then there are n test data at each point in forward and backward stroke respectively. Calculate the average value of each test point in the forward or backward stroke and the overall average value of each test point in the forward and backward stroke.

The average value during forward stroke of the i^{th} test point $\overline{Y_{\text{U}i}}$,

$$\overline{Y_{\text{U}i}} = \frac{1}{n}\sum_{j=1}^{n} Y_{\text{U}ij} \tag{1}$$

The average value during backward stroke of the i^{th} test point $\overline{Y_{\text{D}i}}$,

$$\overline{Y_{Di}} = \frac{1}{n}\sum_{j=1}^{n} Y_{Dij} \tag{2}$$

The overall average value of the forward and backward stroke of the i^{th} test point $\overline{Y_i}$,

$$\overline{Y_i} = \frac{1}{2}\left(\overline{Y_{Ui}} + \overline{Y_{Di}}\right) \tag{3}$$

where

Y_{Uij} is the output value of the i^{th} test point in the j^{th} forward stroke (i = 1,2,3, …m,j = 1,2,3, …n);

Y_{Dij} is the output value of the i^{th} test point in the j^{th} backward stroke (i = 1,2,3, …m, j = 1,2,3, …n);

n is the number of cycle test.

The working characteristic formula of the device is given as follows:

$$Y = a + bX \tag{4}$$

The intercept a and slope b (i.e. sensitivity) shall be fitted using least squares method, as follows:

$$a = \frac{\sum_{i=1}^{m} X_i^2 * \sum_{i=1}^{m} \overline{Y_i} - \sum_{i=1}^{m} X_i * \sum_{i=1}^{m} X_i \overline{Y_i}}{m\sum_{i=1}^{m} X_i^2 - (\sum_{i=1}^{m} X_i)^2} \tag{5}$$

$$b = \frac{m\sum_{i=1}^{m} X_i \overline{Y_i} - \sum_{i=1}^{m} X_i * \sum_{i=1}^{m} \overline{Y_i}}{m\sum_{i=1}^{m} X_i^2 - (\sum_{i=1}^{m} X_i)^2} \tag{6}$$

where

X_i is the pressure value of the i^{th} test point (i = 1,2,3, …m);

$\overline{Y_i}$ is the overall average value of the i^{th} test point in the forward and backward stroke;

m is the number of test pressure points.

6.3.3.2 Zero output

For absolute pressure-sensitive device, measure the output of the device under the input pressure within 10 Pa. For differential pressure-sensitive device, measure the output with both high and low pressure ends connected to the atmosphere.

6.3.3.3 Output under normal pressure

Connect the testing cavity with atmosphere to measure the voltage output of the device and correct the value to standard reference atmosphere pressure(101,3 kPa). Calculate the voltage output under normal pressure with the following formula.

$$Y_c = Y + b(P_c - X) \tag{7}$$

where

Y_c is the voltage output corrected to standard reference atmosphere pressure(101,3 kPa);

Y is the voltage output under the practical atmosphere pressure;

P_c is the standard reference atmosphere pressure(101,3 kPa);

X is the actual atmosphere pressure in the test.

6.3.3.4 Full-span output

The full-span output value of the device is the absolute difference between the outputs of zero-scale pressure and full-scale pressure in measure range, based on the calculated value of theoretical working characteristic formula. The full-span output value $Y_{F·S}$ is given as

$$Y_{F·S} = b \times (X_H - X_L) \tag{8}$$

where

b is the slope of theoretical working characteristic formula, i.e. sensitivity;

X_H, X_L are the full-scale pressure and zero-scale pressure value in measure range respectively.

6.3.3.5 Nonlinearity

Nonlinearity describes the deviation extent between the measure curve and a specific straight line. The nonlinearity ξ_L is given as

$$\xi_L = \frac{\left|\overline{Y_i} - Y_i\right|_{max}}{Y_{F·S}} \times 100\% \tag{9}$$

where

$\overline{Y_i}$ is the overall average value of the forward and backward stroke of the i^{th} test point given by Formula (3);

Y_i is the value calculated by Formula (4);

$Y_{F·S}$ is the full-span output value given by Formula (8).

6.3.3.6 Hysteresis

Hysteresis is the maximum difference between the outputs of the same testing point when increasing and decreasing pressure within the range. The hysteresis ξ_H is given as

$$\xi_H = \frac{\left|\overline{Y_{Ui}} - \overline{Y_{Di}}\right|_{max}}{Y_{F·S}} \times 100\% \tag{10}$$

where

$\overline{Y_{Ui}}$ and $\overline{Y_{Di}}$ are the average value of the i^{th} test point during forward and backward stroke respectively, given by Formula (1) and Formula (2);

$Y_{F·S}$ is the full-span output value given by Formula (8).

6.3.3.7 Repeatability

Repeatability is defined to describe the consistency of many testing results for the same measurand under all the following circumstances:

a) same testing method;
b) same tester;
c) same testing devices;
d) same location;
e) same working/testing condition;
f) repeated testing within a short period.

The repeatability ξ_R is derived from Formula (11) to Formula (14). Use the Bessel formula to calculate the standard deviation of each testing point in forward/backward stroke.

The standard deviation of the i^{th} test point in forward strokes, S_{Ui}, is the following:

$$S_{Ui} = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(Y_{Uij} - \overline{Y_{Ui}})^2} \quad (11)$$

The standard deviation of the i^{th} test point in backward strokes S_{Di} is given as

$$S_{Di} = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(Y_{Dij} - \overline{Y_{Di}})^2} \quad (12)$$

The standard deviation S of the device among the full testing range is given as,

$$S = \sqrt{\frac{1}{2m}\left(\sum_{j=1}^{m} S_{Ui}^2 + \sum_{j=1}^{m} S_{Di}^2\right)} \quad (13)$$

The repeatability ξ_R is given as

$$\xi_R = \frac{\lambda S}{Y_{F \cdot S}} \times 100\% \quad (14)$$

where

Y_{Uij} is the output value of the i^{th} test point in j^{th} forward stroke (i = 1,2,3, …m, j = 1,2,3, …n);

Y_{Dij} is the output value of the i^{th} test point in j^{th} backward stroke (i = 1,2,3, …m, j = 1,2,3, …n);

$\overline{Y_{Ui}}$ is the average value of the i^{th} test point during all forward strokes;

$\overline{Y_{Di}}$ is the average value of the i^{th} test point during all backward strokes;

n is the number of cycle test;

m is the number of test points;

λ is the coverage factor, which should be given by the method presented in 6.3 of ISO/IEC Guide 98-3:2008 .

6.3.3.8 Accuracy

Accuracy is defined to describe the consistency between the testing result and the (conventional) true value of the device. In addition, the accuracy is determined by systematic error range and random error range, which is derived from Formulae (15) to (18).

Systematic error during forward stroke $(\Delta Y)_{Ui}$ is given as

$$(\Delta Y)_{Ui} = \left|\overline{Y_{Ui}} - Y\right|_{max} \tag{15}$$

Systematic error during backward stroke $(\Delta Y)_{Di}$ is given as

$$(\Delta Y)_{Di} = \left|\overline{Y_{Di}} - Y\right|_{max} \tag{16}$$

where

Y is the value calculated by Formula (4).

Define U_1 to be the larger one between $(\Delta Y)_{Ui}$ and $(\Delta Y)_{Di}$. And the random error range of sensitive device U_2 is given as

$$U_2 = \pm 3S \tag{17}$$

The accuracy of the device is given as

$$\xi = \pm \frac{|U_1| + |U_2|}{Y_{F \cdot S}} \times 100\,\% \tag{18}$$

6.3.3.9 Sensitivity

The slope b given by Formula (6) is defined as the sensitivity.

6.3.3.10 Zero drift

Read and record the zero output value of sensitive device every 20 minutes for at least 2 hours following the test method in 6.4.3.2. And the zero drift D_0 is given as

$$D_0 = \frac{|Y_{max} - Y_{min}|}{Y_{F \cdot S}} \times 100\,\% \tag{19}$$

where

Y_{max} is the maximum value of zero output;

Y_{min} is the minimum value of zero output.

6.4 Thermal performances

6.4.1 Purpose

To test temperature influence on the zero output and sensitivity of the device.

6.4.2 Test items

The test items are the following:

a) thermal zero drift;
b) thermal sensitivity drift;
c) thermal zero output hysteresis;
d) thermal sensitivity hysteresis.

6.4.3 Test method

6.4.3.1 General

The test system should be built in accordance with the general provisions in 5.1 to 5.3 and the test preparation in 6.1. Perform test cycle for three times sequentially under room temperature, the upper limit of working temperature, the lower limit of working temperature, and then back to the same room temperature. Maintain each temperature for 1 hour and test zero output, as well as full-span output of the devices.

The performance index can be calculated in accordance with 6.4.3.2 to 6.4.3.5. The sampling of the test shall use the five-point sampling method or be in accordance with the user requirement.

6.4.3.2 Thermal zero drift

Thermal zero drift α is given as

$$\alpha = \frac{Y_0(t_2) - Y_0(t_1)}{Y_{F \cdot S}(t_1)(t_2 - t_1)} \times 100\% F \cdot S / ℃ \tag{20}$$

where

t_1 is room temperature;

t_2 is the upper or lower limit of working temperature;

$Y_0(t_1)$ is zero output under room temperature before the thermal cycles;

$Y_0(t_2)$ is zero output under the upper or lower limit of operating temperature;

$Y_{F \cdot S}(t_1)$ is full-span output under the room temperature before the thermal cycles.

6.4.3.3 Thermal sensitivity drift

$$\beta = \frac{Y_{F \cdot S}(t_2) - Y_{F \cdot S}(t_1)}{Y_{F \cdot S}(t_1)(t_2 - t_1)} \times 100\% F \cdot S / ℃ \tag{21}$$

where

t_1 is room temperature;

t_2 is the upper or lower limit of operating temperature;

$Y_{F \cdot S}(t_1)$ is full-span output under the room temperature before the thermal cycles;

$Y_{F \cdot S}(t_2)$ is full-span output under the upper or lower limit of operating temperature.

6.4.3.4 Thermal zero output hysteresis

The thermal zero output hysteresis α_H is given as