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Semiconductor devices – Micro-electromechanical devices – Part 44: Test methods for dynamic performances of MEMS resonant electric-field-sensitive devices

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CONTENTS

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Part 44: Test methods for dynamic performances of MEMS resonant electric-field-sensitive devices

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

Draft	Report on voting
47F/456/FDIS	47F/463/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 44: Test methods for dynamic performances of MEMS resonant electric-field-sensitive devices

1 Scope

This part of IEC 62047 describes terminology, definitions and test methods that are used to evaluate and determine the dynamic performance of MEMS (Micro-Electromechanical Systems) resonant electric-field-sensitive devices. It also specifies sample requirements and test equipment for dynamic performances of MEMS resonant electric-field-sensitive devices. The statements made in this document are also applicable to MEMS resonant electric-field-sensitive devices with various driving mechanisms such as electrostatic, electrothermal, electromagnetic, piezoelectric, etc.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

3.1
MEMS electric-field-sensitive device
electric-field-sensitive device fabricated by MEMS technology, which can sense the electric field strength and convert it into electrical signal for output

Note 1 to entry: For a detailed description of the MEMS electric-field-sensitive device, see Annex A.

3.2
MEMS resonant electric-field-sensitive device
electric-field-sensitive device fabricated by MEMS technology, which senses the electric field strength by driving its sensitive structure to vibrate in the resonant state

Note 1 to entry: For a detailed description of the MEMS resonant electric-field-sensitive device, see Annex A.

3.3
standard electric field equipment
standard electric field equipment that is composed of parallel metal plate calibration system, shielding cover, high voltage source, etc., and can produce uniform electric field environment

Note 1 to entry: The high voltage source with continuous adjustable voltage is connected with the parallel metal plate calibration system. When the high voltage is loaded on the parallel metal plate calibration system, the uniform electric field can be maintained between the parallel metal plate calibration system.

Note 2 to entry: The electric-field-sensitive devices are placed in the standard electric field for dynamic performance test.

4 Essential ratings and characteristics

4.1 Composition of MEMS resonant electric-field-sensitive devices

MEMS resonant electric-field-sensitive device is generally composed of driving electrode, detecting electrode, shielding electrode, supporting substrate and so on. Some types of field sensitive devices do not have shielding electrodes, such as piezoelectric MEMS resonant electric-field-sensitive devices. More information on the work principle and the sensitive structure of typical MEMS resonant electric-field-sensitive devices are given in Annex A and Annex B respectively.

4.2 Identification and types

General description of the function of MEMS resonant electric-field-sensitive devices and their applications shall be stated. The statement shall include the details of manufacturing technologies about the MEMS resonant electric-field-sensitive devices with different operation, configuration, and actuation mechanism. More information on typical MEMS resonant electric-field-sensitive devices with different drive structures is given in Annex B.

4.3 Description of application and specification

Information on application of the MEMS resonant electric-field-sensitive devices shall be given. Block diagrams of MEMS resonant electric-field-sensitive devices and the applied systems should be also given. All terminals should be identified in the block diagram and their functions shall also be stated.

Figure 1 is an example of MEMS resonant electric-field-sensitive device.

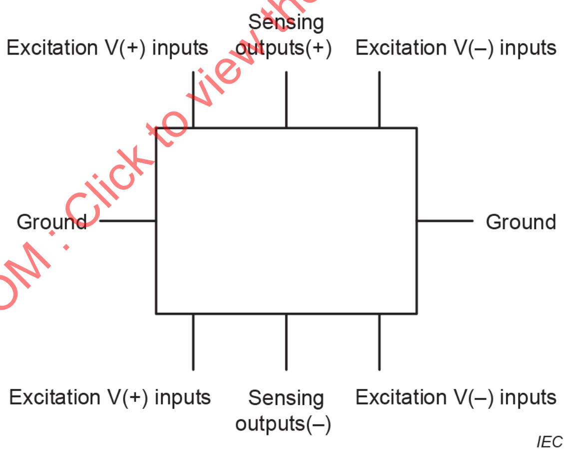


Figure 1 – Terminals of MEMS resonant electric-field-sensitive devices

4.4 Recommended operating conditions

The following items should be described in the specification, unless otherwise stated in the relevant procurement specifications. These conditions are recommended in order to keep the characteristics of the MEMS resonant electric-field-sensitive devices stable state during operation:

- power supply voltage;
- input voltage;
- operating temperature.

4.5 Additional information

Some additional information shall be given such as equivalent input and output circuits (e.g., Input/output impedance, DC block capacitors, etc.), internal protection circuits against high static voltages or electric fields, handling precautions, and application data/information, etc.

5 Dynamic characteristics

5.1 Resonant frequency

The resonant frequency is the corresponding excitation frequency when the working condition is resonance state. When in resonance, the amplitude gain of the vibration system reaches the maximum value.

5.2 Quality factor Q

Q value is the main parameter to measure the device in the sensitive period of electric field. It reflects the magnitude of damping ratio and the degree of energy consumption. The higher Q value is, the smaller the loss is, the higher the efficiency is, the more stable the resonant frequency is, and the better the repeatability is.

5.3 Response time

The response time is the time required for the output of the electric-field-sensitive devices to reach 90 % of the final value when a step electric field value is applied.

6 Measuring methods

6.1 General

This Clause 6 specifies measuring methods for dynamic performances of MEMS resonant electric-field-sensitive devices at a certain electric field strength.

The sensitive device is fixed on the fixture and remains stationary during the characteristic test. The induction direction of the electric-field-sensitive devices should be consistent with the applied electric field direction, and the sensing plane of the sensitive device should be flush with the grounded plate in the parallel plate system of standard electric field equipment. The diagram is shown in Figure 2.

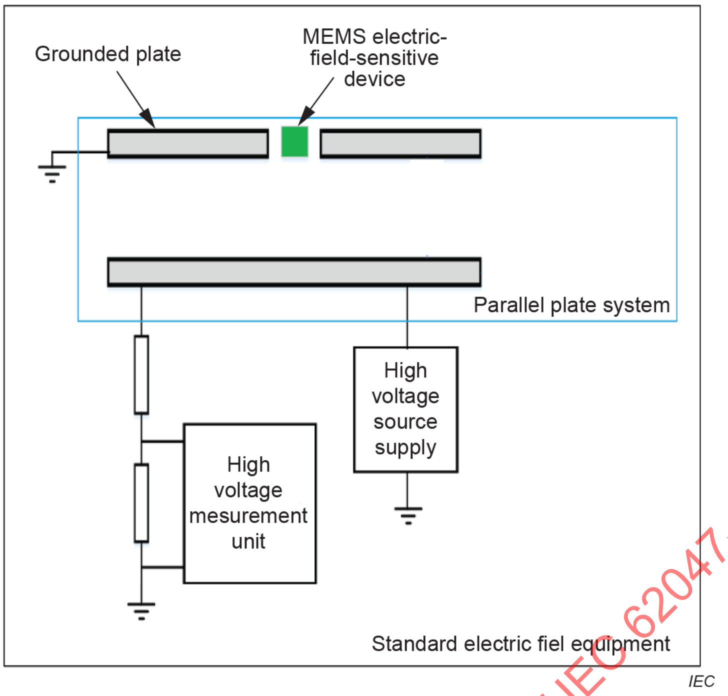


Figure 2 – Diagram of the MEMS resonant electric-field-sensitive device on the parallel plate system

6.2 Resonant frequency

6.2.1 Purpose

The response and efficiency of electric-field-sensitive devices are the highest in resonant state. In order to set its operating frequency as resonant frequency, the resonant frequency value should be measured.

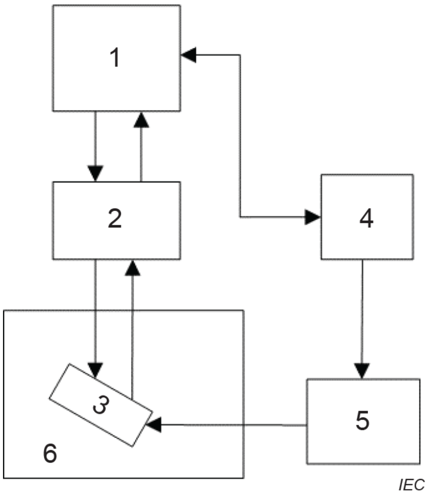
6.2.2 Optical test method

6.2.2.1 General

The resonant frequency can be measured by measuring the displacement change with the interference of light. The optical measurement method is based on the principle of optical interference. The vibration displacement of the sensitive element is measured by using a laser vibrometer, and the amplitude and phase spectra can be obtained. The resonance frequency can be obtained by simultaneously fitting amplitude and phase spectra to a simple harmonic oscillator model.

6.2.2.2 Test system diagram

Figure 3 provides the structure diagram of the resonant frequency measurement system of MEMS resonant electric-field-sensitive devices by optical measurement method.



Key

1 laser vibrometer

2 optical microscope

3 sensitive device

4 computer control unit

5 excitation circuit

6 vacuum chamber

Figure 3 – Test system diagram of optical test method

6.2.2.3 Principle block diagram of optical test system

The optical measurement method is based on the principle of optical interference.

6.2.2.4 Test conditions and precautions

The test environment temperature was kept at 23 °C ± 5 °C.

6.2.2.5 Measurement procedure

a) Adjust the micro optical device to allow the light spot focusing within the surface of the sensitive element.

b) For transparent elements such as quartz or glass sensitive elements, the spot of laser vibrometer should be focused within the metal electrode surface of the sensitive element to increase the reflected light intensity received by the laser vibrometer.

c) The fixing of the sensitive element on the mounting fixture and the fixing of the mounting fixture in the vacuum chamber should be firm and reliable, so as to avoid displacement during the test which affects the test accuracy.

d) For the out of plane vibration sensitive element, the angle between the fixture mounting surface and the horizontal plane should be adjusted according to the geometry of the sensitive element to make the laser vibrometer obtain higher signal-to-noise ratio.

e) Flexible bellows are used for the connection between vacuum pump and vacuum chamber. Effective vibration isolation should be adopted between vacuum pump and vacuum chamber, micro optical device and laser vibrometer. The actual vacuum degree of cavity equipment can be adjusted to the specified vacuum degree.

f) During the operation of the laser vibrometer, the vacuum pump should be turned on so that the actual vacuum degree of the cavity is consistent with the specified vacuum degree.

6.2.3 Electrical test method

6.2.3.1 General

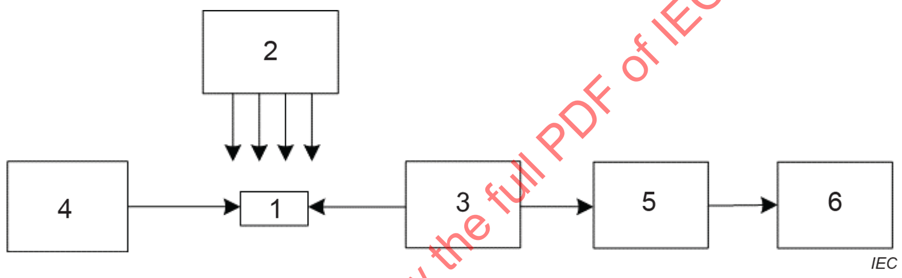
The electrical test method is to use the vibration pick-up unit of the resonator itself to convert the vibration of the resonance sensitive element into electrical signal, and then use the lock-in amplifier to detect the electrical signal, so as to obtain the vibration characteristics.

When the optical test cannot be carried out after the sensor is packaged, the electrical test method should be used.

6.2.3.2 Test system diagram

Figure 4 provides the test system diagram of the resonant frequency measurement system of MEMS resonant electric-field-sensitive devices by electrical test method.

Power the excitation circuit, and drive MEMS resonant electric-field-sensitive devices to work in resonant state. A certain electric field value, generally 10 kV/m, unless a specific value specified, is set for the standard electric field equipment to make the sensitive part of the electric-field-sensitive device in a stable electric field.



Key

1 sensitive devices

2 standard electric field equipment

3 preprocessing circuit

4 excitation circuit

5 detection device

6 data processing and display terminal

Figure 4 – Test system diagram of electrical test method

6.2.3.3 Principle block diagram of electrical test system

According to the theoretical frequency range of the device, the frequency sweep is carried out. When the response output of the device is the maximum, the sensitive device works in the resonant state, and the corresponding operating frequency is the resonant frequency of the device.

6.2.3.4 Precaution to be observed

When the electric-field-sensitive device is put into the standard electric field equipment, ensure that the electric-field-sensitive direction of the electric-field-sensitive device is consistent with the electric field direction.

6.2.3.5 Measurement procedure

a) Start the electric-field-sensitive device and preheat it for a few minutes, for example 5 minutes.

b) Set the frequency range and step size of device sweep test.

c) Start from the minimum frequency of the test frequency range, carry out frequency sweep test until the device works at the maximum working frequency value, and record the response output value of the device at each test frequency.

6.2.4 Data processing method

Compare all the response output values collected, find out the maximum response value. At this time, the device works in the resonance state, and the corresponding frequency of the response output is the resonant frequency.

6.2.5 Specified conditions

- strength of the electric field applied;
- ambient temperature;
- power supply voltage.

6.3 Quality factor (Q)

6.3.1 Purpose

The resonance state of the device is determined by the Q value of its quality factor. The higher the Q value is, the closer the resonant frequency is to the natural frequency of the system, the more stable the resonant frequency is, and the better the repeatability is. Therefore, it is very important to improve the Q value in the design of the device. At the same time, it is also very important to detect the actual Q value of the device. Through the detection of the Q value, the performance of the device can be evaluated.

6.3.2 Circuit diagram

The measuring circuit diagram adopts Figure 3.

6.3.3 Principle of measurement

Q value can be calculated by the following formula:

$$Q = \frac{\omega_r}{|\omega_2 - \omega_1|} \tag{1}$$

where

ω_1 and ω_2 are the half power points that are extracted from the harmonic oscillator fitting of the measured resonant amplitude spectrum, and the corresponding amplitude is exactly $\frac{1}{\sqrt{2}}$ of the amplitude at the resonant frequency.

ω_r is resonant angular frequency of MEMS resonant electric-field-sensitive devices, which is extracted from the harmonic oscillator fitting of the measured resonant amplitude spectrum.

6.3.4 Precaution to be observed

The initial frequency range and step size shall be set within the working frequency range of the electric-field-sensitive device.

6.3.5 Measurement procedure

a) Start the electric-field-sensitive device and preheat it for a few minutes, for example 5 minutes.

b) Set the frequency range and step size of device sweep test.

c) Start from the minimum frequency of the test frequency range, carry out frequency sweep test until the device works at the maximum working frequency value, and record the frequency when the response output reaches the maximum value and the half power point.

6.3.6 Data processing method

Compare all the response output values collected, find out the half power points. The quality factor Q can be found out from Formula (1).

6.3.7 Specified conditions

- strength of the electric field applied;
- ambient temperature;
- power supply voltage.

6.4 Response time

6.4.1 Purpose

The response time of the electric-field-sensitive device is a very important performance, which directly reflects its sensitivity to the electric field. It is necessary to detect the response time of the device.

6.4.2 Circuit diagram

The measuring circuit diagram adopts Figure 3.

6.4.3 Principle of measurement

The standard electric field equipment is controlled to output a certain step electric field signal, such as 10 kV/m, and the output signal of the MEMS resonant electric-field-sensitive device is collected synchronously with a sufficiently high sampling frequency. Record the time when the output of the sensitive device reaches 90 % of the theoretical output from zero, and make the average value for three consecutive tests, and the average value is the response time.

6.4.4 Precaution to be observed

The electric field value of the loaded step signal shall not exceed the working range of the electric-field-sensitive device to avoid damage to the device.

6.4.5 Measurement procedure

a) Start the electric-field-sensitive device and preheat it for a few minutes, for example 5 minutes.

b) The standard electric field equipment is controlled to output the first step electric field signal, and the output signal of the electric-field-sensitive device is collected synchronously with the sampling frequency.

c) Record the output of the sensitive device from zero to 90 % of the theoretical output for three times.

6.4.6 Data processing method

Take the average value of three consecutive tests. The average value is the response time of the electric-field-sensitive device.

6.4.7 Specified conditions

- strength of the electric field applied;
- ambient temperature;
- power supply voltage.

Annex A
(informative)

Work principle and general description of MEMS resonant electric-field-sensitive devices

MEMS electric-field-sensitive devices are a kind of devices used to detect the electric field, which are used in many fields. The atmospheric electrostatic field is an important physical parameter for the study of meteorological phenomena such as lightning. Lightning is one of the important weather factors that affect the success or failure of space launch. Lightning can also cause serious harm to power grid. Petrochemical industry is a sensitive industry with frequent lightning and electrostatic disasters. So, it is very important for lightning protection and disaster reduction to use electric-field-sensitive devices to monitor and analyse the changes of the intensity and polarity of the atmospheric electric field, and to identify and forewarn the changes of the atmospheric electric field that can potentially cause lightning stroke danger.

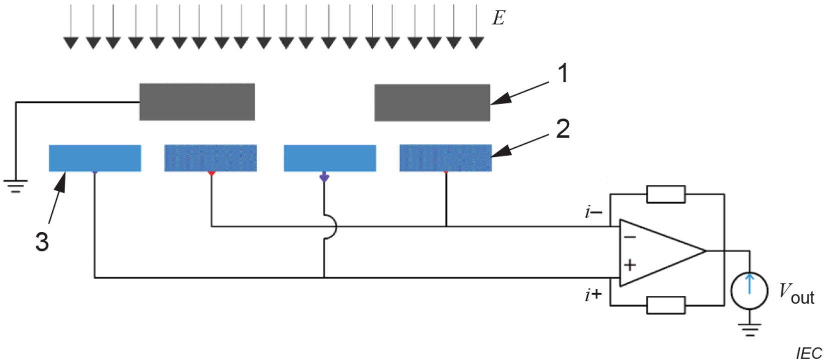
MEMS electric-field-sensitive devices have the advantages of small size, light weight, easy to mass production and so on. They have important application requirements in aerospace, meteorology, electric power, petrochemical, industrial production and other fields.

The working principle of MEMS resonant electric-field-sensitive devices is as shown in Figure A.1. When there is an electric field in the space, the driving component drives the shielding electrode to vibrate regularly, and the induced charge on the positive and negative induction electrodes has a regular change, which is proportional to the external electric field. The detection of the external electric field is realized by testing the change of the induced charge.

The dynamic performance of the electric-field-sensitive device directly determines its performance, so it is necessary to test the dynamic characteristics of the device to evaluate and determine whether the performance of the device meets the requirements. This document mainly specifies the test methods of resonant frequency, quality factor, response time and other characteristics of the device.

MEMS resonant electric-field-sensitive device mainly uses the driving structure to drive its sensitive structure to vibrate periodically in the resonant state and modulates the measured electric field periodically to realize the detection of external electric field. According to the driving mode of MEMS resonant electric-field-sensitive devices, it mainly includes electrostatic driving electric-field-sensitive devices, thermally excited electric-field-sensitive devices, piezoelectric ceramic driving electric-field-sensitive devices, etc.

In the fabrication process, MEMS resonant electric-field-sensitive devices can be fabricated by surface technology and bulk silicon technology.



Key

1 shielding electrode

2 positive induction electrode

3 negative induction electrode

Figure A.1 – Example for working principle of MEMS resonant electric-field-sensitive device

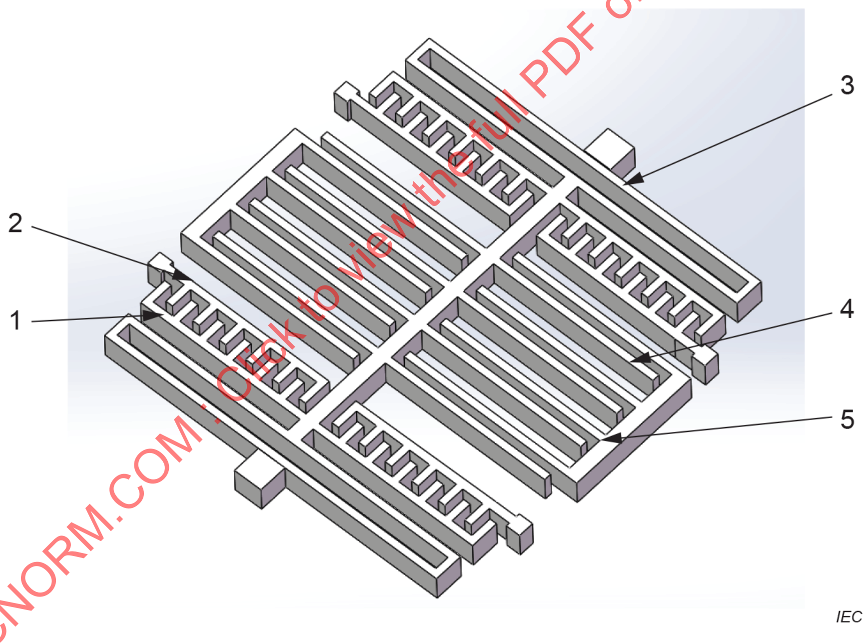
Annex B
(informative)

Sensitive structure and test of typical MEMS resonant electric-field-sensitive devices

B.1 Electrostatically driven MEMS resonant electric-field-sensitive devices

The electrostatic comb type electric-field-sensitive device includes driving structure, induction electrode and shielding electrode. The driving structure includes driving electrode and driven electrode. There is no physical contact between the two electrodes. The driven structure is usually used as a shielding electrode, which is grounded. The periodic voltage signal is applied to the driving structure to generate electrostatic power, and the periodic vibration of shielding electrode is generated to realize the modulation of external electric field.

Figure B.1 shows the design of electrostatically driven MEMS resonant electric-field-sensitive device. It mainly includes shielding electrode, positive induction electrode, negative induction electrode and electrostatic driving structure. The driving structure drives the shield electrode to move periodically, and the induced charge on the surface of the induction electrode changes periodically so as to detect the external electric field.



Key

1 driven electrode of the driving structure

2 driving electrode of the driving structure

3 suspension folded beam

4 shielding electrode

5 induction electrode

Figure B.1 – Example for electrostatically driven MEMS resonant electric-field-sensitive device

Figure B.2 is the circuit diagram of electrical testing system of electrostatic comb type electric-field-sensitive device.