IEC 62047-30

Edition 1.0 2017-09

INTERNATIONAL STANDARD

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

IEC 62047-30:2017-09(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 31.080.99; 31.140

ISBN 978-2-8322-4820-1

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Part 30: Measurement methods of electro-mechanical conversion characteristics of MEMS piezoelectric thin film

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International Standard IEC 62047-30 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/286/FDIS	47F/289/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- withdrawn,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 30: Measurement methods of electro-mechanical conversion characteristics of MEMS piezoelectric thin film

1 Scope

This part of IEC 62047 specifies measuring methods of electro-mechanical conversion characteristics of piezoelectric thin film used for micro sensors and micro actuators, and its reporting schema to determine the characteristic parameters for consumer, industry or any other applications of piezoelectric devices. This document applies to piezoelectric thin films fabricated by MEMS process.

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 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
unimorph beam
beam composed of piezoelectric thin film on substrate

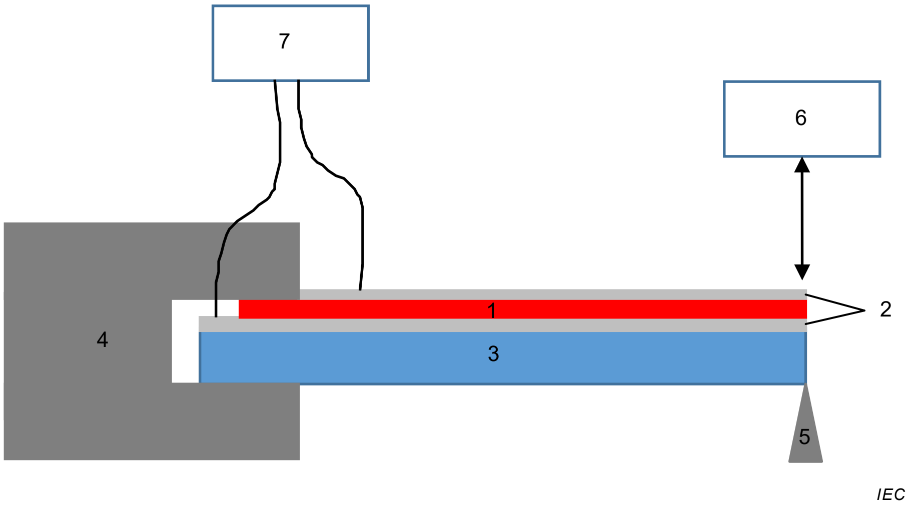
3.2
direct transverse piezoelectric coefficient
transverse piezoelectric coefficient of the piezoelectric thin film calculated from generated charge or voltage caused by strain or stress

3.3
converse transverse piezoelectric coefficient
transverse piezoelectric coefficient of the piezoelectric thin film calculated from strain or stress caused by electric field or voltage

4 Test bed of MEMS piezoelectric thin film

4.1 General

These measuring methods of the transverse piezoelectric properties apply to the unimorph beam. Symbols and designations of test bed are shown in Table 1.



Key

1 thin film under testing

2 electrodes

The Electrodes are contacted with the top side and bottom side surface of the thin film under testing.

3 substrate

4 clamp

5 linear actuator (not in use for converse piezoelectric measurement)

6 displacement meter

7 electric measurement instrument (i.e. voltmeter, charge meter, ammeter, oscilloscope, or lock-in amp) in direct piezoelectric measurement, power source (function generator and amplifier) in converse piezoelectric measurement

Figure 1 – Test bed of direct and converse transverse piezoelectric coefficient of MEMS piezoelectric thin film

Table 1 – Symbols and designations of test bed

Kind of properties	Symbol	Unit	Designation
Dimension of cantilever specimen	l	m	length of cantilever
	w	m	width of cantilever
	h_{s}	m	thickness of base cantilever
	h_{p}	m	thickness of piezoelectric thin film
Electro-mechanical conversion properties	$e_{31,\mathrm{f}}$	C/m^2	effective transverse piezoelectric coefficient
	$e^{\mathrm{d}}{}_{31,\mathrm{f}}$	C/m^2	effective transverse piezoelectric coefficient (direct effect)
	$e^{\mathrm{c}}{}_{31,\mathrm{f}}$	N/Vm	effective transverse piezoelectric coefficient (converse effect)
	$e^{\mathrm{c}}{}_{31,\mathrm{f}}(V_{\mathrm{in},0})$	N/Vm	extrapolated effective transverse piezoelectric coefficient at 0 V (converse effect)
	$e^{\mathrm{c}}{}_{31,\mathrm{f}}(V_{\mathrm{in,min}})$	N/Vm	minimum effective transverse piezoelectric coefficient (converse effect at the lowest V_{in})
	$e^{\mathrm{c}}{}_{31,\mathrm{f}}(V_{\mathrm{in,max}})$	N/Vm	maximum effective transverse piezoelectric coefficient (converse effect at the highest V_{in})
	d_{31}	m/V	transverse piezoelectric coefficient (d-form)
Electrical properties	C	F	capacitance of piezoelectric thin film
	V_{out}	V	output voltage
	V_{in}	V	input peak-to-peak voltage
	$\tan\delta$		dielectric loss
Mechanical properties	$s_{11}{}^{\mathrm{E}}$, $s_{12}{}^{\mathrm{E}}$	m^2/N	elastic compliances of piezoelectric thin film
	D_{in}	m	input tip displacement
	D_{out}	m	output tip displacement
	E_{s}	N/m^2	Young's modulus of base cantilever
	ν_{s}		Poisson's ratio of base cantilever
	E_{p}	N/m^2	Young's modulus of piezoelectric thin film
	y_{c}	m	position of neutral plane of the unimorph cantilever from the bottom

4.2 Functional blocks and components

4.2.1 General

Figure 1 provides fundamental configurations consisted of functional blocks or components for test bed of direct and converse transverse piezoelectric coefficient of MEMS piezoelectric thin film. Details of the functional blocks or components named as keys are provided in 4.2.2 to 4.2.6.

4.2.2 Clamp

The clamp holds one end of the unimorph beam to make a cantilever.

NOTE The clamping condition is confirmed by mechanical Q factor at the resonance of the cantilever.

4.2.3 Linear actuator

The linear actuator provides displacement to the tip of the cantilever with triangular wave. It is used for direct piezoelectric measurements.

4.2.4 Displacement meter

The displacement meter measures the tip displacement of the cantilever.

4.2.5 Electric measurement instrument

In measurements of direct piezoelectric effect, the thin film under testing generates electric output between electrodes. An electric measurement instrument (i.e. voltmeter, charge meter, ammeter, oscilloscope, or lock-in amplifier) measures the generated voltage, charge or current synchronizing with the displacement by the linear actuator.

4.2.6 Power source

In measurements of converse piezoelectric effect, the power source applies an electric input signal between the top and bottom electrodes. The input sinusoidal signal from the function generator is amplified by the power amplifier.

5 Thin film under testing

5.1 General

The top surface of the MEMS piezoelectric thin film is coated with a top electrode to measure output voltage in direct transverse coefficient measurement, or to provide input voltage in converse piezoelectric coefficient measurement.

The thickness of the base material of the unimorph beam shall be much larger than that of the thin film under testing, typically at least 100 times, in order to approximate the neutral plane of the unimorph beam to be the half of the substrate thickness. The theoretical equation of the neutral plane is described in Clause A.5 (this approximation is used in the Stoney's formula).

Generally, the thickness of the electrodes should be much smaller than that of the thin film under testing.

In the case of ferroelectric thin films, a poling treatment is indispensable to align the polar direction and maximize their piezoelectric characteristics.

5.2 Measurement principle

In general, the effective transverse piezoelectric coefficient of the piezoelectric thin film is defined as follows (see [1]–[3][1]):

$$e_{31,\mathrm{f}} = \frac{d_{31}}{s_{11}^{\mathrm{E}} + s_{12}^{\mathrm{E}}} \tag{1}$$

The effective transverse piezoelectric coefficient of direct piezoelectric effect ($e^{\mathrm{d}}_{31,\mathrm{f}}$) is calculated as follows:

$$e^{\mathrm{d}}_{31,\mathrm{f}} = \frac{4lC}{3wh_{\mathrm{s}}(1-\nu_{\mathrm{s}})} \cdot \frac{V_{out}}{D_{in}} \tag{2}$$

1 Numbers in square brackets refer to the Bibliography.