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INTERNATIONAL STANDARD

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inside

Semiconductor devices – Micro-electromechanical devices –
Part 9: Wafer to wafer bonding strength measurement for MEMS

Dispositifs à semiconducteurs – Dispositif microélectromécaniques –
Partie 9: Mesure de la résistance de collage de deux plaquettes pour les MEMS

IEC 62047-9:2011

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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FOREWORD

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International Standard IEC 62047-9 has been prepared by subcommittee 47F: Micro-electromechanical systems, of IEC technical committee 47: *Semiconductor devices*:

The text of this standard is based on the following documents:

FDIS	Report on voting
47F/82/FDIS	47F/92/RVD

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

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

The contents of the corrigendum of March August 2012 have been included in this copy.

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SEMICONDUCTOR DEVICES –
MICRO-ELECTROMECHANICAL DEVICES –

Part 9: Wafer to wafer bonding strength measurement for MEMS

1 Scope

This standard describes bonding strength measurement method of wafer to wafer bonding, type of bonding process such as silicon to silicon fusion bonding, silicon to glass anodic bonding, etc., and applicable structure size during MEMS processing/assembly. The applicable wafer thickness is in the range of 10 µm to several millimeters.

2 Normative references

The following referenced documents are indispensable for the application 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 60749-19, *Semiconductor devices – Mechanical and climatic test methods – Part 19: Die shear strength*

ISO 6892-1: 2009, *Metallic materials – Tensile testing – Part1: Method of test at room temperature*

ASTM E399-06e2: 2008, *Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K Ic of Metallic Materials*

3 Measurement methods

3.1 General

There are different ways to measure bonding strength such as visual test, pull test, double cantilever beam test using blade, electrostatic test, blister test, three-point bend test, and die shear test.

3.2 Visual test

3.2.1 Types of visual test

From colour change of silicon substrate and surface of glass, this method tells you only a general information like whether the material is bonded or not. The visual test shall be performed to confirm whether substantial other bonding tests are required, and/or to identify the area that the bonding tests shall be conducted.

Optical microscope shall be used to evaluate the bonding interface of glass to silicon and glass to glass.

An infrared (IR) camera shall be used to observe voids existing in the bonding interface of silicon to silicon

NOTE Visual test is a simple qualitative test method.

3.2.2 Equipment

One or a few equipments of optical microscope, scanning acoustic microscope, scanning electron microscope (SEM), transmission electron microscope (TEM), and IR or optical camera can be used.

3.2.3 Procedure

Steps to measure voids areas are as follows:

a) To observe voids, use the IR or optical microscope.
b) To take images of voids, use the IR or optical camera, or scanning acoustic microscope.
c) Measure voids areas using the observed images.

3.2.4 Expression of results

Check and simply indicate using the mark "V" the observation result based on Note 1 in Table 1 for each case.

Table 1 – Example of visual test

	good	fair	poor
Visual test			

NOTE 1 good – complete bonded area fraction larger than 95 %, fair – complete bonded area fraction larger than 75 %, poor – complete bonded area fraction less than 75 %.

3.3 Pull test

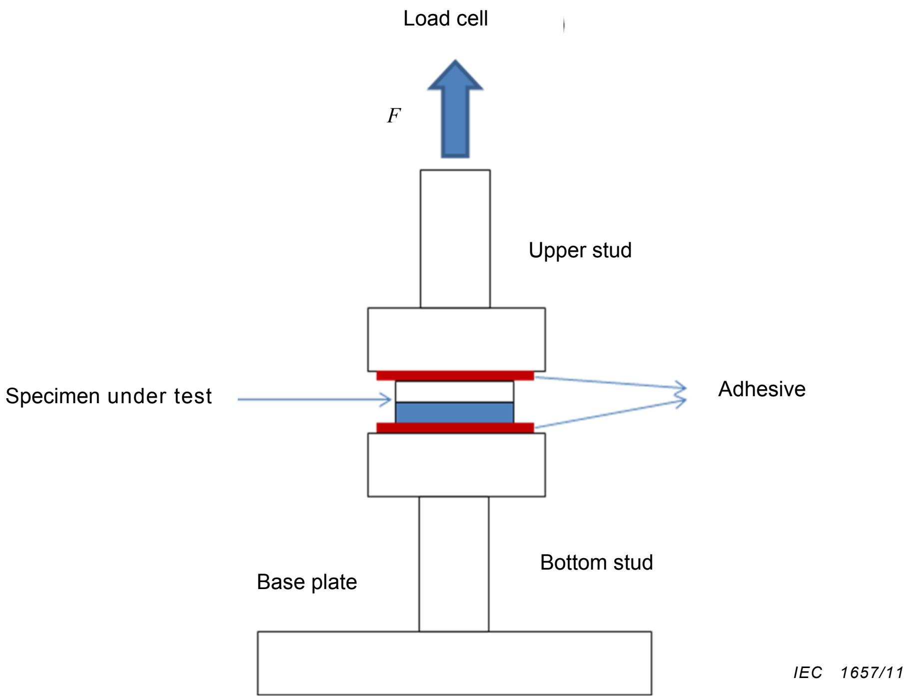
3.3.1 General

As shown in Figure 1 this method is used to measure wafer bonding strength using general tensile test method. After preparing for bonded wafer using various methods, a bonded wafer is divided to square shaped specimens by dicing process. After dicing, dimensions of areas (A) are measured. Top-side and back-side of a specimen of wafer bonded are glued to top stud connected with load cell and bottom stud, respectively, using selective adhesive. And then it is pulled upward until fracturing. In case that the wafer-to-wafer bonding to be tested is very strong, fracture often occurs from the adhesive. In the case, pull test is not applicable. Therefore, pull test is applicable only the case that bonding is not very strong and fracture occurred at the bonding interface. During pulling process, applied force or fracture force (F_c) is measured with time as shown in Annex A. Therefore, bonding strength could be calculated by Equation (1).

$$\sigma_c = \frac{F_c}{A} \tag{1}$$

where

σ_c is bonding strength when debonding or fracture occurs;
F_c is applied force (fracture force) when the debonding or fracture occurs;
A is the area of the test sample.



Key

Components	
specimen under test:	a dice of bonded wafer
adhesive:	to glue with upper stud and bottom stud
upper stud:	to connect with a load cell
bottom stud:	to connect with a base plate
base plate:	fixture to keep a rigid state

Connections and supplies	
load cell:	variable source of force
F	force: supplying for a testing specimen

Figure 1 – Bonding strength measurement – pull test

3.3.2 Equipment

General tensile tester with force meter or load cell should be used as shown in ISO 6892.

3.3.3 Procedure

Steps to observe fractured specimens are as follows:

a) After bonding processes, for example, silicon to silicon bonding, silicon to glass bonding, bonded wafers are cut into square shape with dimension, for example, 5 mm by 5 mm to 10 mm by 10 mm using dicing process. Maximum load to specimens is limited by the capacity of load cell. So, maximum specimen size is also limited by the capacity of load cell. And the accuracy of load cell shall be equal to or less than 1 % of full scale and 1 % of reading.

b) Specimens attached to upper and lower studs using adhesive. Adhesives should be well selected through consideration of specifications of them to endure until fracturing. And adhesive should not be applied at sides of bonded wafers.

c) Lower stud is fixed to the bottom of apparatus and upper stud is connected to load cell or force meter to measure stress at fracture of specimens at room temperature. Stress vs. time curve shows maximum stress at fracture. Loading rate is in the range of 0,5 mm/min to 1,5 mm/min. From fracture load data, we can calculate maximum strength. An example of load vs. time curve is shown in Annex B.

d) After fracturing, observe fractured specimens by optical microscope or SEM.

e) At least 10 specimens shall be tested for reliable data.

3.3.4 Expression of results

Check and write the force measured value in Table 2.

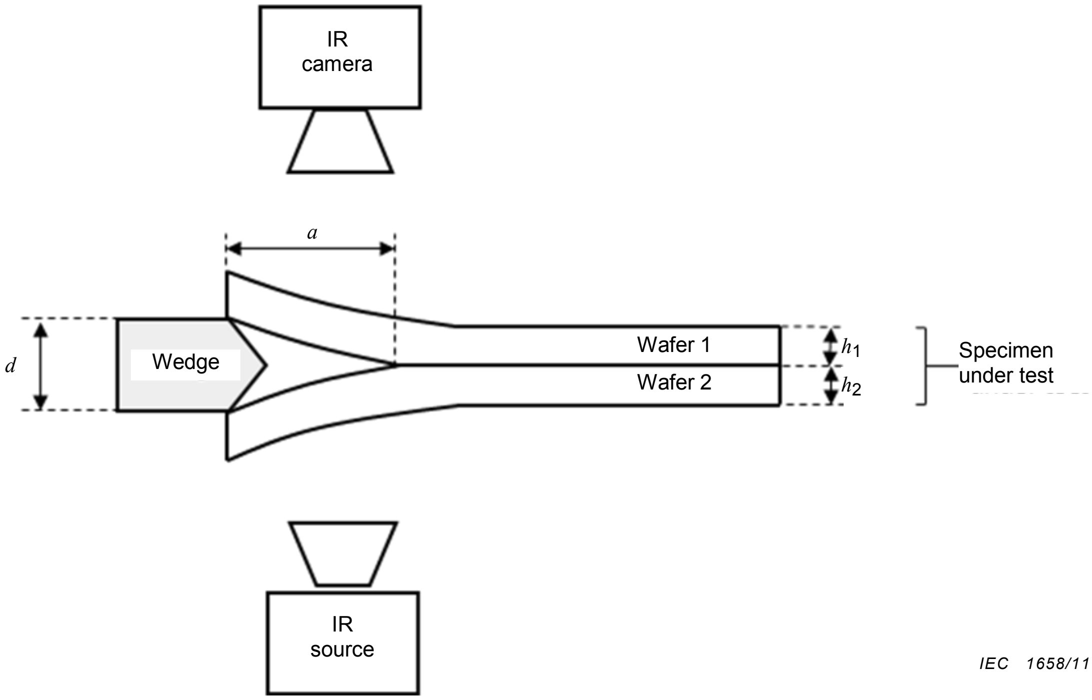
Table 2 – Example of pull test

Reference standard	
Type of material (fabrication method)	
Bonding method	
Shape and size of specimen	
Type of adhesive (or glue)	
Number of specimen	
Loading speed	
Measured fracture force (F_c)	
Bonded area of the test specimen (A)	
Bonding strength (σ_c)	

3.4 Double cantilever beam test using blade

3.4.1 General

The wedge-opening test is also called the double cantilever beam test (DCB) as shown in Figure 2. This testing method is suitable for bonded wafers using silicon to silicon fusion bonding and anodic bonding. In case that examined wafer-to-wafer bonding is too strong, one of the bonded wafers often breaks during this test procedure. In such a case, this method cannot be used as a quantitative test but as a qualitative test.



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Key

Components or observation tool	
specimen under test:	a piece of wafer bonded with different kinds of wafer 1 and wafer 2.
wafer 1:	bonded with wafer 2
wafer 2:	bonded with wafer 1
wedge:	part of a blade to drive a cracking layer in the specimen
IR source:	infrared beam source
IR camera:	to measure cracked state length of the specimen

Dimensions of components	
h_1:	thickness of wafer 1
h_2:	thickness of wafer 2
a:	cracking length of split state layer between bonded wafer 1 and wafer 2
d:	thickness of wedge part of the blade

Figure 2 – Bonding strength measurement – double cantilever beam (DCB) test specimen using blade

The crack length is resulted from energy balance between strain energy of freely loaded cantilevers and bonding energy at the bonding interface. Therefore, in this method, bonding strength is evaluated not by fracture stress but by critical strain energy release rate. Critical train energy release rate is calculated as follows

$$G_\mathrm{c} = \frac{3}{8} \frac{E_1 E_2 h_1^3 h_2^3}{(E_1 h_1^3 + E_2 h_2^3)} \frac{d^2}{a^4} \tag{2}$$

where

G_c is critical strain energy release rate (interfacial fracture toughness),

E_1 and E_2 are elastic coefficient of wafer 1 and 2;

h_1 and h_2 are thickness of wafer;

d is thickness of blade;

a is crack length.

In case of E_1=E_2 and h_1= h_2, Equation (2) becomes

$$G_c = \frac{3}{16}\frac{Eh^3 d^2}{a^4} \tag{3}$$

In case of h_1<<h_2, Equation (2) becomes

$$G_c = \frac{3}{8}\frac{E_1 h_1^3 d^2}{a^4} \tag{4}$$

3.4.2 Equipment

Blade to test and sample fixture to fix should be used [1][1].

Recommended blade thicknesses are in the range of 30 µm to 200 µm.

3.4.3 Procedure

a) After bonding processes, for example, silicon to silicon bonding, silicon to glass bonding, the bonded wafer pair is cut into strips with the edges of wafers on at least one of their ends. Width of strip specimens should be smaller than the width of the blade.

b) Set the stripe specimen to the sample fixture.

c) Insert a blade from one end of the stripe specimen using a gap resulted from rounded wafer edges. Drive a crack along interface.

d) Measure the crack length using an optical or IR camera, or a scanning acoustic microscope.

e) Calculate the interfacial fracture toughness using Equation (2)

f) At least 10 specimens should be tested for reliable data.

3.4.4 Expression of results

Write the measured values in Table 3. Then calculate G_c according to Equation (2), (3) or (4) and write the value in Table 3.

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[1] Numbers in square brackets refer to the Bibliography.

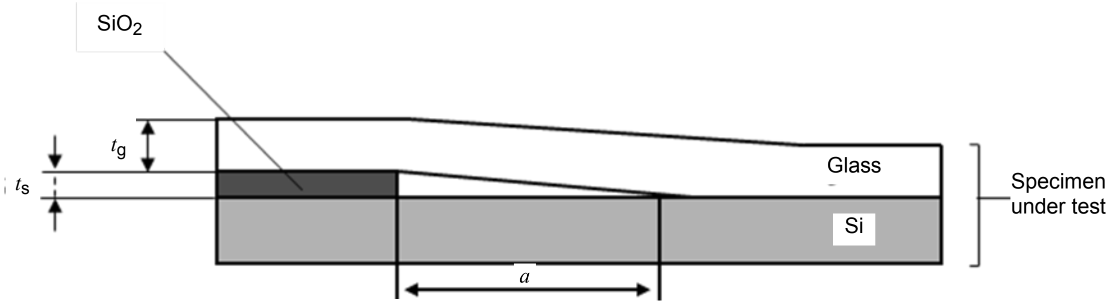
Table 3 – Example of Double Cantilever Beam test using blade

Shape of bonded specimen	
Fixing method of specimen	
Inserting speed of blade (optional)	
Number of specimens	
Crack length (a)	
Thickness of blade (d)	
Material of wafer 1	
Material of wafer 2	
Thickness of wafer 1 (h_1)	
Thickness of wafer 2 (h_2)	
Elastic coefficient of wafer 1 (E_1)	
Elastic coefficient of wafer 2 (E_2)	
Critical strain energy release late (G_c)	

3.5 Electrostatic test

3.5.1 General

As shown in Figure 3, between Si wafer with patterned SiO_2 films and glass wafer, anodic bonding is done. Ranges of wafer thicknesses are normally 50 μm to 1 mm. By the measurement of unbonded lengths depended on bonding strengths around patterned SiO_2 films on Si wafer, we can compare bonding strengths of anodic bonded wafers. So, this method is convenient to utilize and allows you to compare qualitative bonding strength. The measurement condition was at room temperature. Wafer level sizes in the range of 1 ” to 8 ” or chip level sizes in the range of 1 cm^2 to 4 cm^2 are suitable for this experimental. Even though this method could be used for bonded wafer using other bonding methods, in order to avoid the difficulty to observe the unbonded length after bonding, it is better to use for only anodic bonded wafer between Si and glass wafers.



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Key

Configurations or specimen		**Dimensions of specimen under test**	
specimen under test:	bonded piece between Si wafer with patterned SiO_2 films and glass wafer	t_g:	thickness of glass
SiO_2:	patterned film state layer bonded with a kind of glass layer and a silicon layer	t_s:	thickness of silicon
Si: silicon base layer	to be observed unbonded length at a cross sectional view	a:	unbonded length
glass:	layer bonded with Si and SiO_2 by anodic bonding processes		

Figure 3 – Bonding strength measurement – electrostatic test

3.5.2 Equipment

Anodic bonder shall be used. General anodic bonder consists of vacuum chamber, holders for holding top wafer and bottom wafer before bonding process, load cell to push top wafer toward bottom wafer for initial bonding, electrical system to supply negative field to positive ion contained wafer, for example, Na^+ contained glass, and heater to maintain constant temperature during process.

3.5.3 Procedure

Steps to measure the length of the unbonded area are as follows:

a) In order to make specimens, the anodic bonding between Si wafer with patterned SiO_2 films and glass wafer is performed. SiO_2 thickness is more than 1 µm [2]. Anodic bonding is a simple process to join together a silicon wafer and a alkali ion containing glass substrate. The bonding is performed at a temperature between 200 °C and 500 °C in vacuum, air or in an inert gas environment. The application of 500 V to 1500 V across the two substrates, with the glass held at negative potential, causes mobile positive ions (mostly Na^+) in the glass to migrate away from the silicon glass interface toward the cathode, leaving behind fixed negative charges in the glass. The bonding is complete when the ion current vanishes, indicating that all mobile ions have reached the cathode. The electrostatic attraction between the fixed negative charge in the glass and positive mirror charge induced in the silicon holds the two substrates together and facilitates the chemical bonding of glass to silicon [3]. Make the sample as shown in Figure 3 using anodic bonding process.

b) Measure the length of the unbonded area using optical microscope or SEM (scanning electron microscope) for cross-section observation.

c) At least ten specimens shall be tested for reliable data.