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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Semiconductor devices – Micro-electromechanical devices –
Part 14: Forming limit measuring method of metallic film materials

Dispositifs à semiconducteurs – Dispositifs microélectromécaniques –
Partie 14: Méthode de mesure des limites de formage des matériaux à couche métallique

IEC 62047-14:2012

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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FOREWORD

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

FDIS	Report on voting
47F/108/FDIS	47F/118/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.

A list of all parts of 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 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- withdrawn,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.

SEMICONDUCTOR DEVICES – MICRO-ELECTROMECHANICAL DEVICES –

Part 14: Forming limit measuring method of metallic film materials

1 Scope

This part of IEC 62047 describes definitions and procedures for measuring the forming limit of metallic film materials with a thickness range from 0,5 μm to 300 μm. The metallic film materials described herein are typically used in electric components, MEMS and micro-devices.

When metallic film materials used in MEMS (see 2.1.2 of IEC 62047-1:2005) are fabricated by a forming process such as imprinting, it is necessary to predict the material failure in order to increase the reliability of the components. Through this prediction, the effectiveness of manufacturing MEMS components by a forming process can also be improved, because the period of developing a product can be reduced and manufacturing costs can thus be decreased. This standard presents one of the prediction methods for material failure in imprinting process.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62047-1:2005, *Semiconductor devices – Micro-electromechanical devices – Part 1: Terms and definitions*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62047-1 and the following apply.

3.1.1
circular grid
grid used for measuring the localized deformation of the specimens within the circle

3.1.2
grid patterns
pattern marked on the surface of the testing material permitting immediate and direct measurement of the formability for the metallic film materials

Note 1 to entry The grid consists of a pattern of small circles or rectangles.

3.1.3
major axis
longest line of the deformed elliptical shape, which passes through both focuses of the ellipse

3.1.4
minor axis
longest line of the deformed elliptical shape, which is perpendicular to the major axis

3.1.5
square grid
grid used for measuring the overall deformation of the testing material

3.2 Symbols

For the purpose of this document, letter symbols given in Table 1 are used.

Table 1 – List of letter symbols

Name and designation	Letter symbol
Grid size	
– initial diameter of the grid before deformation	d_0
– diameter of the grid along the major axis after deformation	d_1
– diameter of the grid along the minor axis after deformation	d_2
Strain	
– major strain	ε_1
– minor strain	ε_2
Equipment, tool and specimen size	
– diameter of the hemispherical punch	D_{punch}
– inner diameter of the die hole	D_{die}
– diameter of the bead ring	D_{bead}
– fillet radius of the upper die edge	r_{de}
– thickness of the testing specimen	t
– height of the testing specimen	h
– width of the testing specimen	w

4 Testing method

4.1 General

The forming limit diagram (FLD) is determined by pressing the micro film material using a hemispherical punch. This pressing process is performed until the film material fractures. The major and minor strains of a deformed specimen can be measured in many ways, for example, by using a digital camera module or an optical device. However, using a digital camera module with sufficient resolution and a high magnifying power lens is recommended.

NOTE See Annex A for principles of forming limit diagram.

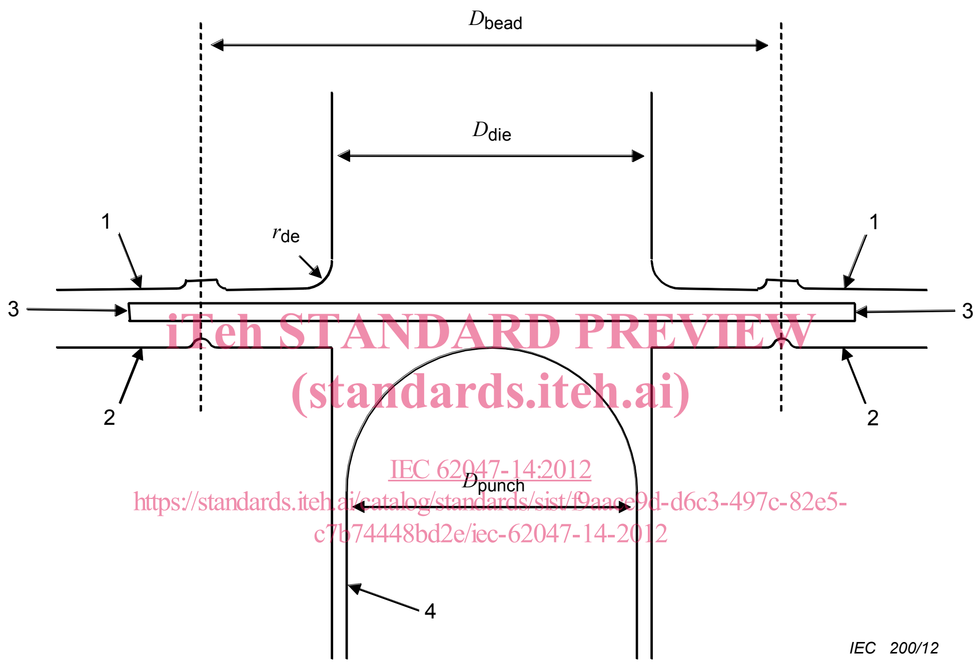
4.2 Equipment

Micro press equipment is utilized as the loading equipment for FLD tests as described in Figure 1. A hemispherical punch is attached to the micro press to stretch the film material to measure the forming limits of the specimen. Conventional hard chrome coating to the punch surface using hexavalent chromium is recommended to guarantee a surface roughness less than 0,8 µm (RMS: Root Mean Square). In addition, lubricants such as graphite can be applied for reducing the friction force between the surfaces of the punch and the specimen. The movement of the punch is controlled by a constant crosshead speed of the measuring devices in the micro press. The punch speed shall be lowered to the quasi-static condition. A punch speed of less than 20 µm/s is recommended in order not to result in the dynamic inertia effect during the test. Although the dimension of the hemispherical punch and the test samples can be varied with forming product and inspected measuring region, it is recommended that the dimension should be determined as the following ratio.

$$D_{\text{die}} = D_{\text{punch}} + 2{,}5t \qquad (1)$$

$$D_{\text{bead}} = 2 \times D_{\text{punch}} \qquad (2)$$

It is also recommended that the hemispherical punch diameter and the die edge radius should be 5 mm and 0,5 mm respectively.



Key

1 upper die

2 lower die

3 specimen

4 hemispherical punch

Figure 1 – Equipment and tools for forming limit tests

4.3 Specimen

Rectangular specimens with different aspect ratios shall be used in the test. At least six kinds of specimens with the aspect ratios of 1,0, 1,5, 1,75, 2,0, 3,5 and 7,0 are recommended as shown in Figure 2 in order to cover the various loading paths on the domain of the forming limit diagram.

$$h = 2{,}5 \times D_{\text{punch}} \qquad (3)$$

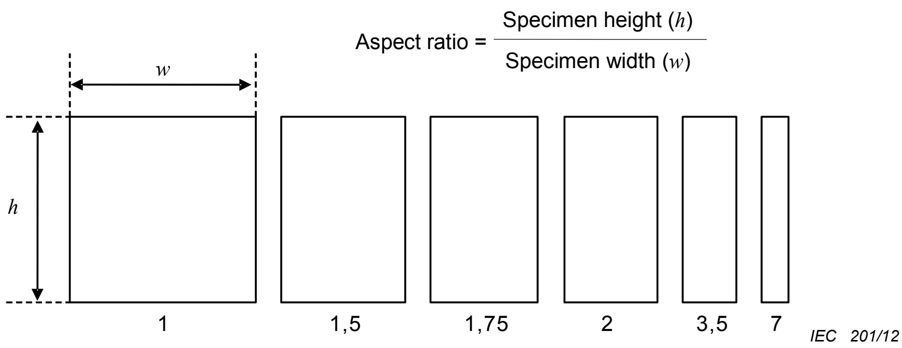


Figure 2 – Rectangular specimens with six kinds of aspect ratio

Grids shall be marked to the surface of the testing sample to measure the localized and overall deformation of the film material. The grid consists of a pattern of small circles or rectangles. It is recommended to arrange the grid patterns with an interval range from 50 μm to 200 μm and that the thickness of the grid is less than 10 % of the specimen thickness.

NOTE See Figure A.3 for detailed grid pattern.

5 Test procedure and analysis

5.1 Test procedure

In a FLD test, the following items from a) to e) are steps to obtain a localized fracture of a specimen which is firstly observed. Then the values of a major strain and a minor strain which are used to quantify the deformation of the specimen will be measured.

a) Preparation of the specimen

Specimens with different aspect ratios are prepared to conduct the test.

NOTE 1 Both the positive and negative region of the FLD curve can be obtained by varying the aspect ratio of the specimen and the lubricant.

b) Grid marking on the specimen

Appropriate marking conditions which have a lesser effect on the microstructure and the properties of materials should be applied in the grid marking since the thickness of the film is relatively smaller.

NOTE 2 See Annex B for detail expression of several grid marking methods.

c) Gripping the specimen

In order to measure the strain only in the testing region, it is important that the sample should be clamped without any sliding. Also, pre-fracture should not occur when it is being clamped.

NOTE 3 See Annex C for several recommended gripping methods.

d) Moving the punch until the specimen fails

The hemispherical punch moves by controlling the constant crosshead speed of equipment until the localized fracture of the specimen is first observed.

e) Measuring the major and minor strains of deformed specimen

Major and minor strains of the deformed specimen are measured representatively using the digital camera module with a high magnifying power lens. The recommended magnification factor of the camera lens is less than 5 μm/pixel in order to measure the strain precisely.

NOTE 4 See Annex D for strain measuring method.

f) Construct the FLD by plotting the measured major and minor strains (refer to Figure 4).

5.2 Data analysis

In order to quantify the deformation of the specimen, two kinds of strains – major and minor strains – are measured between the initial state of the circle and the deformed elliptical shape. After the circular grid deforms, the longest dimensions of the ellipse is major axis and the dimension perpendicular to the major axis is the minor axis, as explained in Figure 3.

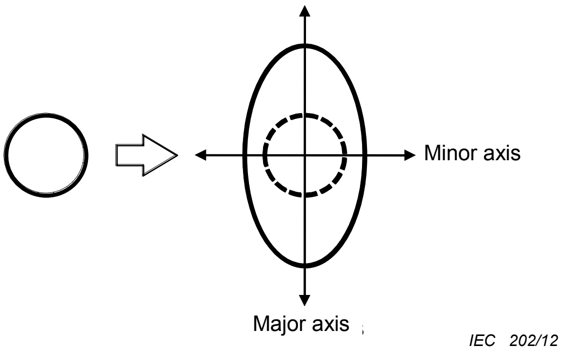


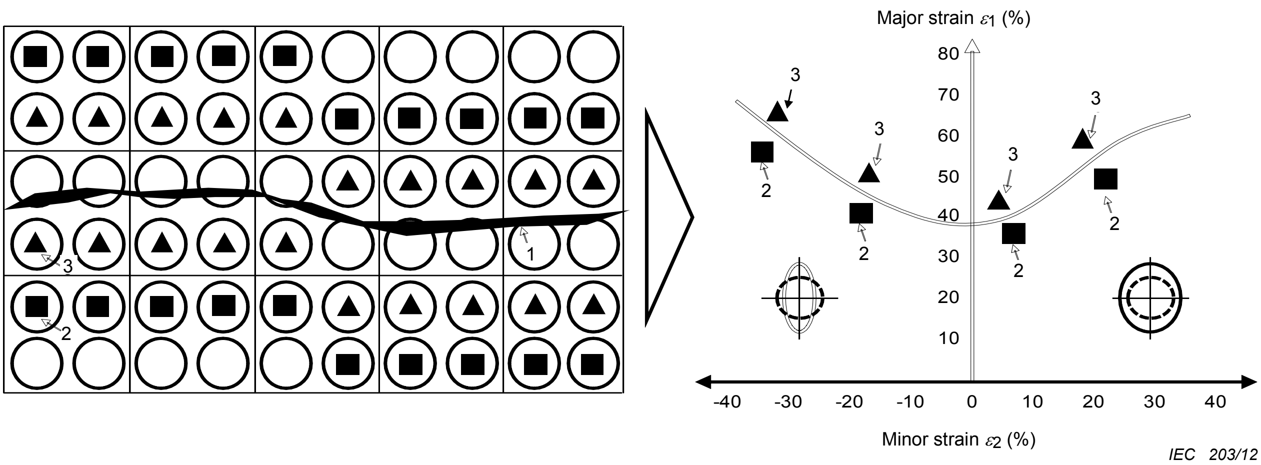
Figure 3 – Strain for forming limit measurement

The major strain, ε_1, and the minor strain, ε_2, are calculated with following equations:

$$\varepsilon_1 = \ln \frac{d_1}{d_0} \tag{4}$$

$$\varepsilon_2 = \ln \frac{d_2}{d_0} \tag{5}$$

Here, d_0 is the initial diameter of the circular grid while d_1 and d_2 represent the major and the minor diameters of the grid after deformation.



Key

1 fracture

2 good

3 failure

Figure 4 – Construct the forming limit diagram by plotting the major and minor strains

The major and minor strains calculated from the grids in the neighbourhood of the failure zone of the specimen are regarded as critical failure strains. By conducting a series of experiments with various specimens, it is possible to find combinations of major strain and minor strain for which neither necking nor fracture occurs by plotting on the strain domain. The diagram plotting the combinations of major and minor strains is a forming limit diagram as shown in Figure 4.

6 Test report

The test report should contain at least the following information:

a) reference to this international standard;
b) testing material;
c) grid marking method;
d) number of specimens used in the test;
e) dimensions of the specimen(s);
f) description of testing apparatus (punch diameter, gripping method, punch roughness, etc.);
g) lubrication condition;
h) crosshead speed of testing apparatus;
i) strain measurement module: specification of the digital camera, scale factor of each pixel;
j) measured diameters and calculated strains of each specimen;
k) forming limit diagram.