

ICS 27.160

Strength testing for photovoltaic wafers

Festigkeitsprüfung von Photovoltaikwafern

Essai de stabilité pour les tranches photovoltaïques

Zur Erstellung einer DIN SPEC können verschiedene Verfahrensweisen herangezogen werden:
Das vorliegende Dokument wurde nach den Verfahrensregeln einer PAS erstellt.

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Dieses Dokument wurde durch die im Vorwort genannten Verfasser erarbeitet und verabschiedet.

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Foreword

This DIN SPEC has been developed according to the PAS procedure. The development of a DIN SPEC according to the PAS procedure is carried out in workshops and does not require the participation of all stakeholders.

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At present, there are no standards covering this topic.

DIN SPECs are not part of the body of German Standards.

A draft of this DIN SPEC has not been published

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Introduction

Strength testing of thin silicon solar wafers is a complex process which requires a high level of knowledge for the realization and especially for the evaluation. In particular nonlinear numeric models are required for the evaluation. This standard enables the gain of comparable strength data for silicon solar wafers. The strength can be used as a parameter which simplifies the communication within the value chain.

1 Scope

This DIN SPEC defines requirements for the strength testing for photovoltaic wafers by use of uniaxially bending tests for the experimental setup, procedure and evaluation.

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.

EN 843-5, *Advanced technical ceramics — Mechanical properties of monolithic ceramics at room temperature — Part 5: Statistical analysis*

3 Terms and definitions

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

3.1

wafer

final product of silicon processing which is the input product for solar cell production

3.2

strength

stress at which a sample fails for a given loading condition

3.3

fracture displacement

displacement of the rollers in 4-point-bending at which the sample fails

3.4

adhesive foil

adhesive substance in the form of foil

Note 1 to entry: Two different types of adhesive foils are used for the test. The first one is required to reduce the friction between the rollers and the testing sample. The adhesive side has to be put on the rollers and the clean side is in contact with the wafer. Therefore PTFE foil can be used. The other one is required to be used with the adhesive side on the compressive side of the wafer in case a fractography analysis should be performed. Therefore sticky tape can be used.

3.5

area of maximum stress

area on the wafer where the maximum stress is applied

Note 1 to entry: The area is between the inner rollers in the 4-point-bending on the tensile side of the wafer. The area of maximum stress is part of the loaded area.

3.6

loaded area

wafer surface area under tensile stress between the outer rollers

Note 1 to entry: The loaded area includes the area and edges of maximum stress between the inner rollers and the area between the inner and outer rollers where the stress is increasing towards the maximum stress.

3.7

initial force

initial force at which the displacement measuring starts

Note 1 to entry: The start point is necessary, because the fracture displacement is used for the calculation of the fracture stress.

3.8

sawing direction

axial movement direction of the wire within the sawing process

Note 1 to entry: Can be seen as optical visible wire marks on the wafer surface.

3.9

macro cracks

cracks on the wafer surface visible to the naked eye

Note 1 to entry: in range of a few millimeters, induced during the sawing process or handling processes

3.10

micro cracks

crack on the wafer surface visible only under the microscope

Note 1 to entry: in range of a few micrometers, induced during the sawing process or handling processes

3.11

fractography

analysis of patterns and features on fracture surfaces, usually with the purpose of identifying the fracture origin and hence the flaw type

4 Symbols and abbreviations

N	number of test samples in one batch
d_F	fracture displacement
F_F	force at fracture
F_{init}	initial force
σ_i	maximum stress in the i^{th} test sample at failure
σ_θ	characteristic fracture stress
$\widehat{\sigma}_a$	estimated characteristic fracture stress
m	Weibull modulus
$\widehat{m}$	estimated Weibull modulus
L_1	length of the inner span for a bend test sample
L_2	length of the outer span for a bend test sample
L	length of the sample
B	width of the sample
w	weight of the sample
t	thickness of the sample
ρ	density of silicon ($\rho = 2\,329\text{ kg} \cdot \text{m}^{-3}$)
TTV	total thickness variation

5 Requirements

The following measuring devices are required:

Testing machine:

- increasing hitchless loading
- maximum loading speed: 0,2 mm/s
- force and displacement measuring system
- 4-point-bending setup (see Figure 2)
 - bearing/loading rollers with:
 - diameter of 10 mm
 - minimum length of 160 mm
 - rollers need to be fixed
 - adhesive foil with the adhesive side on rollers for minimum friction (PTFE material is recommended)

Additional measuring systems:

- determination of sample thickness with weight measurement (accuracy $\pm 0,01$ g).

For additional reduction of friction it is possible to use four loose films (with smooth surface on both sides) to be put between the rollers and the sample.

6 Sampling

6.1 Number of test sample in one batch:

At minimum 30 samples are required. It is recommended to use at least 50 samples.

6.2 Dimensions of the test sample:

The fracture stresses are calculated using numerical methods. For standard dimensions look-up-tables (see Table 1 till Table 4) were created. The standard dimensions (angle between sides 90°) are:

156 mm ($\pm 0,5$ mm) $\times$ 156 mm ($\pm 0,5$ mm)

If wafers with dimensions of 156 mm (± 4 mm) $\times$ 156 mm (± 4 mm) are used, the error for the fracture stresses is within ± 1 %.

6.3 Alignment of the sample:

Rollers should be put parallel to the sawing direction. If the rollers are put perpendicular to the sawing direction or the sawing direction is unknown, it is required to be mentioned in the protocol. The wafer has to be aligned centered on the 4-point-bending setup.

The maximum stress has to be applied on the area which shall be investigated. Therefore the respective side has to be put on the tensile side in the 4-point-bending test between the inner rollers (see bottom side in Figure 2).

6.4 Adhesive foil for determination of fracture origin:

It is possible to perform a fractography analysis after the fracture test. In this case it is required to use adhesive foil with the adhesive part on the compressive side of the wafer to prevent the wafer from falling into pieces. For that purpose it is possible to use sticky tape which has to be put in parallel direction to the rollers on the compressive side of the wafer.

6.5 Influence of surface and edge quality:

The strength of silicon wafers is defined by defects (cracks) on the wafer surface induced during the sawing process. However additional treatments e.g. laser cutting or mechanical scribing in the loading area (surface or edge) can decrease the strength, while etching processes are leading to an increase in strength. To evaluate the strength data, the following information needs to be given in the protocol:

— sawing process:

The sawing technology has a strong influence on the wafer strength. Wafers sawn with diamond wire have a strong anisotropic strength behavior for testing with the rollers parallel or perpendicular to the sawing direction compared to slurry sawn wafers.

— etching process:

During the wafer cleaning process sometimes etching processes are performed. The etching leads to higher strength so the information is important to evaluate the resulting strength data.

— laser process:

Laser treatments on the wafer surface often lead to a decrease in strength. Usual treatments are marker or cutting processes.

— chipping:

Chipping on the wafer edge within the tested area leads to stress concentrations, which decrease the wafer strength.

— macro cracks:

Besides micro cracks, macro cracks have a much higher magnitude and lead to a strong decrease in wafer strength.

7 Test method

7.1 Measurement of wafer thickness

The thickness of a full square wafer is calculated with integral measurement through determination of wafer weight:

$$t = \frac{w}{L B \rho} \quad (1)$$

If the wafer area is not full square, this has to be considered.