SEMI PV39-0912
TEST METHOD FOR IN-LINE MEASUREMENT OF CRACKS IN PV SILICON WAFERS BY DARK FIELD INFRARED IMAGING

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1 Purpose

1.1 Silicon (Si) wafers for PV applications cut from a Si ingot or Si brick contain a variety of micro- and macroscopic crystallographic defects and flaws that may impact the efficiency of a solar cells or the yield of a manufacturing line.

1.2 Theses defects can be categorized by their origin, either as grown-in defects that are generated during the solidification of the Si ingot or as process induced defects that are generated by abrasive processes during manufacturing of the wafers.

1.3 The grown-in defects consist of point defects (impurities, vacancies, self-interstitials and their complexes), dislocations, grain boundaries, and precipitates/inclusions.

1.4 The process induced defects consist of chips/indents (surface and edge) and cracks (not to mention the surface itself).

1.5 Inclusions, chips and cracks are detrimental for solar cell processing as they may enhance stress in the wafer bulk and the region surrounding them and trigger the breakage of a wafer.

1.6 Characteristic parameters of these defects are part of wafer specifications (SEMI PV22), such as number per wafer, maximum length or size. Standardized test methods for measuring them are required to avoid disagreement between business partners regarding wafer quality and specification.

1.7 This Standard defines a test method for reproducibly detecting and characterizing cracks and distinguishing them from other defects.

2 Scope

2.1 This Test Method characterizes cracks in single or multicrystalline Si wafers.

2.2 It covers an in-line, noncontacting and nondestructive method that determines the number of cracks per wafer and crack length of clean, dry as-cut Si wafers that are supported by two belts that move the test specimen through the measurement equipment.

2.3 This test method covers square and pseudo-square PV Si wafers, with a nominal edge length ≥125 mm and a thickness ≥100 µm.

2.4 Because this test method is intended for in-line high throughput measurements it is mandatory to operate the measurement system under a tight SPC (e.g., ISO 11462) for obtaining reliable, repeatable and reproducible measurement data.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Wafers with a resistivity less-than or equal to approximately 0.5 Ω·cm cannot be measured due to excessive absorption of infrared light. This resistivity limit depends on the thickness and the surface roughness of the wafer as well as on the light power and camera sensitivity.

3.2 The minimum detectable dimensions of cracks or other defects depend on the resolution of the detector used.

3.3 Cracks scattering light equivalent to the background may not be detected or distinguished from grain boundaries.

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3.4 Cracks are identified and classified in this test method based on a number of features they display in a dark field image of a wafer. Therefore results of measurement obtained with different equipment may differ depending on crack-characterization criteria used.

3.5 The temperature of wafers must be 23 ± 5°C when measured.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI E89 — Guide for Measurement System Analysis (MSA)

SEMI M59 — Terminology for Silicon Technology

SEMI MF1569 — Guide for Generation of Consensus Reference Materials for Semiconductor Technology

SEMI PV22 — Specification for Silicon Wafers for Use as Photovoltaic Solar Cells

4.2 *ISO Standards* [1]

ISO 11462-1 — Guidelines for Implementation of Statistical Process Control (SPC) – Part 1: Elements of SPC

ISO 11462-2 — Guidelines for Implementation of Statistical Process Control (SPC) – Part 2: Catalogue of Tools and Techniques

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 *Definitions*

5.1.1 *crack* — cleavage or fracture that extends to the surface of a wafer. [SEMI M59]

5.1.2 *chip* — region where material has been unintentionally removed from the surface or edge of the wafer. [SEMI M59]

6 Summary of Test Method

6.1 The wafer resting on two belts is moved by the belts past an infrared source and a digital imaging camera.

6.2 Narrow strips of infrared light are projected either on the wafer at an angle α or through the wafer edge into the wafer bulk parallel to the leading edge of a wafer as it moves along the transport direction (see Figure 1).

6.3 The infrared light wavelength is selected so that light is transmitted through Si.

6.4 If applicable, angle α is selected so that the directly transmitted light does not enter the line camera's aperture.

6.5 Defects in and on the Si wafer scatter light, part of which may enter the aperture of the line camera and forms a dark field image of the light strip.

6.6 Successive images of the illuminated region in the bulk of the wafer are recorded by a line array of sensors as the wafer is advanced creating a full-wafer scan.

6.7 The full wafer image is processed and evaluated by appropriate algorithms and number and length of the defects detected are reported.

7 Interferences

7.1 *Contamination* — On the wafer surfaces may impact the measurement result.

8 Apparatus (see Figure 1)

8.1 *Projector* — Projects a narrow strip of infrared light by either one of the following two methods.

[1] International Organization for Standardization, ISO Central Secretariat, 1 rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland; Telephone: 41.22.749.01.11, Fax: 41.22.733.34.30, http://www.iso.ch

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8.1.1 *Method A* — The light strip is projected at an angle of incidence α (angle between line of sight of the projector and the surface normal) on the wafer surface and across the entire width of the wafer perpendicular to the direction of belt transport.

8.1.2 *Method B* — Two light strips are projected into the wafer bulk through opposing wafer edges perpendicular to the direction of belt transport.

8.2 *Sensor* — Digital imaging camera with a line array of sensors (≥4096 pixels) and set up with its line of sight perpendicular to the wafer surface, recording the light scattered by the defects in and on the Si wafer. The noise level (3 σ) of the camera shall be ≤1% of the peak signal and the dynamic range shall be ≥255 gray levels. For Method *A* the camera is mounted at the side of the wafer opposite to the projector.

8.3 *Computer* — For controlling the measurement system and equipped with software for recording and processing the camera images according to § 14.

8.4 *Wafer Transport* — Consisting of belts, which transport the wafer continuously through the measurement apparatus and without obstructing the line of sight of the camera and the illumination. The belts shall not leave traces or residue on the wafer surface.

9 Safety Precautions

9.1 The entire equipment must be placed in a closed housing and secured with a safety lock that stops the belts and switches the tool off when the housing is opened.

9.2 The infrared light used is not visible to humans. Special provisions shall be taken to protect the eyes of operators during maintenance activities.

9.3 If required by local, national or international safety requirements, protecting goggles shall be used by operators and maintenance personnel.

10 Test Specimens

10.1 Clean, dry Si wafers with as-cut surfaces.

11 Preparation of Apparatus

11.1 The suitability of the equipment is determined by performing a statistically based measurement system analysis (MSA) to ascertain whether the equipment is operating within the manufacture's stated specification, for example, according to SEMI E89.

11.2 Use a single crystalline silicon wafer for:

11.2.1 Applying a flat-field correction to the wafer image to correct the intensity fall-off of the illuminated light strip towards the edges of the wafer, and

11.2.2 Adjusting the gain of the camera and the light intensity of projected the light strip so that the average gray value of the wafer image is at 60% to 70% of the sensitivity range of the camera.

11.3 Define the SPC control limits for the measurement equipment with a set of selected wafers.

NOTE 1: As this Test Method is intended for a high throughput, high volume measurement the equipment cannot be calibrated for measuring each individual wafer. Therefore careful SPC has to be performed.

12 Calibration and Standardization

12.1 Calibrate the equipment by using one or more reference wafers.

12.1.1 The reference wafers contain cracks.

12.1.2 Measure the reference wafer(s) according to §§ 13 and 14.

12.2 Adjust the parameters of § 14 so that the number of cracks is within a specified bias and precision range.

NOTE 2: The number of cracks of the reference wafers is determined by mutual agreement between customer and supplier of the equipment. The reference wafers may consist of other material than silicon, provide it is transparent in the wavelength range of the light source used.

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