

SEMI PV60-0115

TEST METHOD FOR MEASUREMENT OF CRACKS IN PHOTOVOLTAIC (PV) SILICON WAFERS IN PV MODULES BY LASER SCANNING

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1 Purpose

- 1.1 Multicrystalline and monocrystalline silicon wafers for photovoltaic (PV) cells are manufactured by casting, Czochralski technique or other controlled solidification methods.
- 1.2 In PV cell fabrication process using these silicon wafers, macroscopic defects such as chips, scratches, and cracks are often generated due to mechanical and thermal stresses. Chips and scratches can be origins for crack generation.
- 1.3 Cracked wafers are sometimes broken in module fabrication process causing lower productivity and cost increases. Also broken wafers in a module may result in degradation of the module reliability.
- 1.4 Therefore, in-line characterization methods are required that allow discriminately inspecting cracks with high throughput and repeatability, and that measure the number and the length of those.
- 1.5 This method is based upon the measurement of laser beam induced current (LBIC) and can detect only cracks in wafers of a module by controlling bias voltage applied to the module.

2 Scope

- 2.1 This Test Method identifies and measures cracks in crystalline silicon wafers of a module.
- 2.2 This Test Method employs an in-line, noncontacting and nondestructive method for characterizing multi- and monocrystalline silicon wafers of a module supported by a mechanism that moves the test specimen through the measurement equipment.
- 2.3 This Test Method covers square and pseudo-square silicon wafers of PV cells with nominal edge length ≥ 125 mm and a nominal thickness ≥ 100 μm .
- 2.4 It is more effective to operate this Test Method under the statistical process control (SPC) [e.g., ISO 11462] to obtain the data with high reliability and repeatability.
- 2.5 This Test Method detects cracks from the distribution of leakage current density on the PV cell obtained by scanning its front side by laser.
- 2.6 Other measurement methods may also provide similar information about the number and the length of cracks of wafers with this Test Method. Their subjects are, however, different from that of this Test Method.
- 2.7 This Test Method is also applicable to off-line measurement provided that the requirements of the test method are satisfied.

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 Minimum detectable size/dimension of a crack is affected by a resolution and frequency character of the detecting system.
- 3.2 Wafer temperature must be within $25 \pm 5^\circ\text{C}$.
- 3.3 Electrode pattern of PV cells and cycle of laser scanning may interfere with each other, which may cause interference patterns. In such a case the automatic recognition may be difficult.

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

4.2 ISO Standards¹

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 General terms, acronyms, abbreviations and symbols associated with silicon technology and used in this Standard are listed and defined in SEMI M59.

5.2 Other Abbreviations and Acronyms Used in this Document

5.2.1 *LS* — laser scanning

5.3 Definitions

5.3.1 *cluster* — series-connected photovoltaic cells protected by a bypass diode.

5.3.2 *cracked reference PV module (a reference module)* — PV modules in which positions and length of cracks are known beforehand.

5.4 Symbols

5.4.1 V_{OC} — open circuit voltage of cluster.

5.4.2 I_{SC} — short circuit current of PV devices.

6 Summary of Test Method

6.1 Inspection is done by controlling light sources in a cluster unit and laser-scanning by two rows.

6.2 Light sources should be a main light, laser beam, and sublights with high directionality.

6.3 Wavelength of lights should range from visible radiation (red) to near infrared (up to about 1,000 nm).

6.4 Laser power should be arbitrarily adjusted to conform to types of PV cells.

6.5 Illumination intensity of sublights should be set at the value with which I_{SC} of PV cells is larger than that at laser-beam irradiation.

6.6 Irradiate a PV module with sublights and scan cells with a laser light one by one.

6.7 A current induced in PV cells should be converted to voltage signals by a current-voltage converter.

6.8 Voltage signals are collected and converted to digital data.

6.9 For each scanning, data are recorded and stored as a line array.

6.10 Image processing software creates module images from line array data.

6.11 The system extracts liner dark areas appeared in images and reports existence or nonexistence of cracks and the number, if any.

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7 Apparatus

7.1 Schema of device compositions is shown in Figure 1, optical unit in Figure 2, and measurement system in Figure 3 respectively.

7.2 *Laser Head* — A laser head, configured with a laser, a scanner mirror and an optical lens, irradiates a laser beam and scans the light receiving surface of a PV cell.

7.3 *Sub Lights* — Highly directional sublights irradiate all cells except the cell under test.

7.4 *Start Sensor* — A start sensor detects a laser beam and generates a trigger signal for retrieving data.

7.5 *Light Unit* — A light unit is a unit comprising of items described in ¶¶ 7.2 to 7.4.

7.6 *Bipolar Power Supply* — A bipolar power supply applies a voltage to PV modules.

7.7 *Current-Voltage Converter* — A current-voltage converter amplifies a current of PV cells to a prescribed voltage value.

7.8 *Equalizer* — An equalizer improves a current response of PV cells generated by laser-scanning.

7.9 *AD Converter* — An AD converter converts a current of PV cells to digital data and transfers them to a computer. Resolution should be 8 bit or more.

7.10 *Computer* — Software described below is installed in a computer:

7.10.1 *Software for Controlling the Hardware* — Software for controlling the hardware controls a light unit, a current-voltage converter, an equalizer amplifier and a bipolar power supply.

7.10.2 *Signal Processing Software* — Signal processing software filters data retrieved by an AD converter.

7.10.3 *Image Processing Software* — Image processing software visualizes data processed by signal processing software beginning at detection of a start sensor signal, and determines cracks.

8 Safety Precautions

8.1 The entire machine must be contained in a housing and must be equipped with a security lock to stop the machine and to turn off power supply of all lights including a laser light when the housing is open.

8.2 If a laser light and other lights are infrared, which is invisible to human eyes, additional security measures must be taken to protect operators' eyes during maintenance.

8.3 Operators and maintenance personnel must wear protective goggles in compliance with the IEC safety standard.

9 Preparation of Apparatus

9.1 Move a target board, an optical adjustment device, to a test position and check alignment.

9.2 Misalignment must be adjusted.

9.3 Move the laser head to a position of central coordinate of the target board, and turn on the laser light.

9.4 Confirm that a position of laser beam irradiation is aligned on the center of target board.

9.5 If not, collimate an optical axis of laser beam and align on the center of the target board.

9.6 Confirm that an output irradiation of laser power is at a prescribed value using a laser power meter.

9.7 If not, adjust the power to a prescribed value.

9.8 Run the scanner and laser-scan cells.

9.9 If a track of scanning is not on a printed line of the target board, adjust an angle and modify a course.

10 Calibration and Standardization

10.1 Calibrate the machine by use of one or more reference modules.

10.2 Reference modules should include multiple cracks.