

SEMI PV71-0116

TEST METHOD FOR IN-LINE, NONCONTACT MEASUREMENT OF THICKNESS AND THICKNESS VARIATION OF SILICON WAFERS FOR PHOTOVOLTAIC (PV) APPLICATIONS USING LASER TRIANGULATION SENSORS

This Standard was technically approved by the Photovoltaic – Materials Global Technical Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on December 4, 2015. Available at www.semiviews.org and www.semi.org in January 2016.

1 Purpose

- 1.1 Wafer thickness and its variation across a wafer are important parameters for solar cell manufacturing. Excessive thickness variations within a lot from wafer to wafer or within a wafer may negatively impact process yield and solar cell efficiency.
- 1.2 Both parameters are part of the specification for solar cell wafers (see SEMI PV22), which define a thickness range as well as an upper limit for the total thickness variation (TTV).
- 1.3 In addition, careful process and quality control of the wafer thickness and its variation during wafer and solar cell manufacturing requires continuous monitoring of thickness by the supplier of wafers for PV applications as well as by the user of such wafers.
- 1.4 Therefore a standardized test method providing reproducible data for thickness and its variation is required to establish agreement between business partners regarding the specification of wafers.
- 1.5 The present Document defines a noncontact, high throughput in-line method for measuring wafer thickness and its total variation using laser triangulation sensors.

2 Scope

- 2.1 This Test Method covers the in-line, noncontact, nondestructive measurement of the thickness and the TTV of clean, dry silicon (Si) wafers supported on two belts that move the test specimen through the measurement equipment.
- 2.2 The test method is applicable to square or pseudo-square multi- as well as single-crystalline Si wafers with edge length ≥ 125 mm and with thickness ≥ 100 μm .
- 2.3 The Test Method is based on simultaneously measuring the wafer top and bottom surface position with an aligned pair of laser triangulation sensors when the wafer passes through the gap formed between the laser triangulation sensor pair.
- 2.4 The Test Method does not cover measurement of surface flatness, warp, bow or sori of wafers.
- 2.5 The Test Method is intended for in-line high throughput measurements. Therefore it is mandatory to operate system under tight statistical process control (SPC), for example ISO 11462, in order to obtain 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 The Test Method averages the thickness measurement over a wafer in constant motion so that averaging effects may impact measurement results due to belt speed and triggering differences.
- 3.2 Differences between surface finishes or contamination of the wafers also may affect the measurement results.
- 3.3 Laser triangulation sensors have only a limited calibrated range for position measurement. Exceeding this range may result in erroneous measurement results.

3.4 Exceeding the temperature range and humidity range for which the measurement equipment is qualified may also result in erroneous measurement results.

3.5 Different alignments of laser triangulation sensor pairs, such as gap distance, sensor centering and sensor parallelism, is known to impact thickness measurement results.

3.6 Variations in the positions of the scan lines between subsequent measurements or between measurements on different equipment may impact the measurement results.

3.7 Wafer surface height vibration and tilting caused by transport during measurement may adversely impact measurements.

3.8 Although laser triangulation sensors require very small amount of laser beam reflection into its receiver to determine position, it is possible that the laser beam is reflected away totally from the receiver and invalid position data is produced. This can result in erroneous measurement results but in most cases it can be removed by software algorithm and replaced by interpolated values.

4 Referenced Standards and Document

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

SEMI PV40 — Test Method for In-Line Measurement of Saw Marks on PV Silicon Wafers by a Light Sectioning Technique Using Multiple Line Segments

SEMI PV41 — Test Method for In-Line, Noncontact Measurement of Thickness and Thickness Variation of Silicon Wafers for PV Applications Using Capacitive Probes

4.2 ISO Standards

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

NOTE 1: Refer to SEMI's Compilation of Terms (COTs) for a list of the most current terms and their definitions.

5.1 Terms and acronyms relating to silicon and other semiconductor technology are defined in SEMI M59.

5.2 Terms and acronyms relating to measurement of thickness and saw marks on PV silicon wafers are defined in SEMI PV40 and SEMI PV41. Some terms are re-used with modified definition to suit this Standard.

5.3 Other Abbreviations and Acronyms

5.3.1 *CL* — center line

5.3.2 *MSA* — measurement system analysis

5.3.3 *SL* — scan line

5.3.4 *L3V5* — total thickness variation, 5-point

5.3.5 *L3V9* — total thickness variation, 9-point

5.4 Other Terms Used in this Standard

5.4.1 *best focus position, of laser triangulation sensor* — the position where the laser from the laser triangulation sensor produces the smallest laser spot. Laser triangulation sensor is usually designed such that the laser spot is imaged onto the center of the array of light receiver when it is at the best focus position.

5.4.2 *ignore zone (IZ)* — the distance from the wafer leading edge and trailing edge where the recorded data will be discarded for measurement. It is possible to use different ignore zone for all-points and fixed-points thickness metric.

5.4.3 *laser spot, of laser triangulation sensor* — the illuminated spot on wafer surface produced by the laser output of the laser triangulation sensor which the position of the surface is measured. The shape of the laser spot can be a dot or a line segment.

5.4.4 *laser triangulation sensor* — a sensor consists of a laser output and a linear array light receiver. The laser and the light receiver are arranged in the manner where laser spot of a surface at different position will be imaged through optical components onto different element of the light receiver. Surface position can be determined by reading the brightness signal from the light receiver.

5.4.5 *leading edge (LE)* — the position where first valid thickness data is found after acquisition is started.

5.4.6 *sampling rate* — the number of positions read by the laser triangulation sensor per second. Sampling rate is usually expressed in hertz (Hz).

5.4.7 *sampling resolution* — the distance between each position reading by the laser triangulation sensor. It is equal to the belt speed divide by the sampling rate.

5.4.8 *sampling range (SR)* — the distance where laser triangulation sensor data recorded within this range will be used to calculate a thickness point. Two sampling ranges are used for different thickness metric. Sampling range SR_{all} is used for all points thickness metric to detect high thickness variation at small range. Sampling range SR_{point} is used for fixed points thickness metric and usually have larger sampling range so that cross-correlation can be performed with a thickness measurement tool using capacitance probes.

5.4.9 *sampling interval (SI)* — the center to center distance between two sampling ranges. It is possible to use different sampling interval for all-points and fixed-points thickness metric.

5.4.10 *three line scan (L3)* — the thickness data acquisition technique using three pairs of stationary laser triangulation sensors and a wafer transport belt system. The three scan lines consist of the center scan line, and two outer scan lines on opposite sides of it and offset equidistantly towards the wafer edges.

5.4.11 *thickness point (TP)* — an arithmetic average over thickness values measured by a sensor pair across a sampling range. The number of thickness point for each scan line can be calculated as below:

$$n = Integer \left(\frac{(TE - LE) - 2 \times IZ - SR}{SI} \right) + 1 \quad (1)$$

The thickness points are populated from the center line towards the leading and trailing edge.

5.4.12 *thickness, 5-point (L3T5)* — the average over the thickness measured at five thickness points on the wafer by a three line scan. Four thickness points are located after and before the ignore zones, respectively, on the outer scan lines. The fifth thickness point is the center point on the center scan line.

5.4.13 *thickness, 9-point (L3T9)* — the average over the thickness measured at nine thickness points on the wafer by a three line scan. Three points each are from the center scan line and the two outer scan lines. Along each scan line the three thickness points are located after the ignore zone at the leading edge and before the ignore zone at trailing edge and at the center point.

5.4.14 *thickness, all-point (L3TA)* — the average over the thickness measured at all thickness points on the wafer by a three line scan. The thickness points are located between the leading and trailing edge and exclude the ignore zones.

5.4.15 *thickness, center point (L3TC)* — the thickness at the center thickness point of the center scan line.

5.4.16 *total thickness variation, all-point (L3VA)* — the measurement range or difference between the maximum and minimum of all the thickness point values used to calculate the average thickness L3TA.

5.4.17 *trailing edge (TE)* — the position where the last valid thickness data is found after acquisition is started.

6 Summary of Test Method

- 6.1 The wafer resting on two belts is moved by the belts between three or more aligned pairs of opposing laser triangulation sensors. The pairs of sensors are named C, L and R (see Figure 1).
- 6.2 The laser position is adjusted so that top and bottom surface of the wafer is at the best focus position of the top and bottom laser triangulation sensors respectively.
- 6.3 The wafer is oriented so that the saw marks are perpendicular to the transport direction of the belts, and the centerline of the wafer intersects the center of the middle sensor-pair, C.
- 6.4 The scan lines of the L3 data acquisition are therefore named SL c, SL l and SL r, where SL c is along the CL.
- 6.5 Consecutive position measurements of the wafer top and bottom surface are performed at the sampling rate of the laser triangulation sensors along the center scan line SL c, and the outer scan lines SL l and SL r (Figure 1) as the wafer is moved along by the belts between the laser triangulation sensors.
- 6.6 The wafer thickness is then the sum of the measured distance by the sensor pair plus a calibration constant.
- 6.6.1 The calibration constant can be established using thickness calibration procedures, typically with traceable thickness reference materials.
- 6.7 The wafer data acquisition is started by trigger sensors located before the laser triangulation sensors and stopped after a delay. The delay is calculated based on the known belt speed and wafer size such that the acquisition will stop only after the wafer trailing edge left the laser spot.
- 6.8 Wafer thickness as a function of position is recorded along each scan line from the sensor trigger point until the end of delay. Since the acquired data consists of invalid data before/after the laser spot is found the wafer surface, software will be used to find the leading and trailing edges of the wafer in the acquired data.
- 6.9 Metrics of thickness and thickness variation are then reported per wafer.

7 Interferences

- 7.1 *Contamination* — In the space between the sensors as well as on the wafer may impact the measurement result.
- 7.2 *Misalignment* — Within a pair of sensors may impact the measurement result.
- 7.3 *Vibration* — Wafer vibration in vertical direction caused by mechanical movement during transport may also impact the measurement result.
- 7.4 *Temperature* — Drift in temperature over time or sudden change in temperature, e.g. open and close safety doors, may also impact the measurement result.

8 Apparatus

- 8.1 *Laser Triangulation Sensors* — Three or more pairs of opposing laser triangulation sensors are aligned in two rows perpendicular to the belt direction and mounted so that a wafer on the belts traverses at the best focus position of each sensor (see Figures 1 and 2).
- 8.1.1 The distance between the position sensors of a pair is w , which is two times of the best focus position of the laser triangulation sensors plus the nominal wafer thickness.
- 8.1.2 The outer sensors (L and R) are mounted in the first row.
- 8.1.3 The middle sensor C is mounted in the second row and has a distance of d from the first row. d is usually slightly larger than the width of the laser triangulation sensor.
- 8.1.4 The outer sensor laser spots are equidistant from the center line and are set at a distance l_2 from the wafer edges where that l_2 is in the range of 5 to 15 mm.
- 8.1.5 The center-to-center distance of middle sensor to outer sensors on each side is l_1 and depends on wafer size in order to achieve l_2 within the range specified above.
- 8.2 *Trigger Sensors* — Pairs of opposing light emitting devices and sensors form light beams that detects the presence of a wafer to start the measurement.

8.2.1 Two trigger sensors are positioned along the center line and at l_3 distance from each row (see Figure 1). l_3 is typically in the range of 3 to 5mm so that leading edge can be detected with enough margin.

8.2.2 The first trigger sensor is used to start the data acquisition for sensor pairs L and R at the first row. The second trigger sensor is used to start the data acquisition for the sensor pair C at the second row.

8.3 *Computer* — For controlling the measurement system and equipped with software for synchronously acquiring and processing the position data according to § 14.

8.4 *Wafer Transport Device* — Consists of two belts, or any other method which transport the wafer continuously through the measurement apparatus and do not obstruct the space between the laser triangulation sensors and the wafer surfaces.

9 Safety Precautions

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

9.2 If required by local, national or international safety requirements, eye protection goggles have to be used by operators and maintenance personnel.

10 Test Specimen

10.1 Clean, dry Si wafers.

11 Preparation of Apparatus

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

11.2 Adjust the position of laser triangulation sensors with respect to the transport belts so that the wafers are placed in the best focus position of the laser triangulation sensors.

11.3 Verify that the laser triangulation sensors are aligned and adjusted according to the manufacturer's specifications.

11.4 Verify that the equipment is operating within its specified temperature range.

11.5 Define the control limits for SPC for the measurement equipment with a set of selected wafers (see ISO 11462).

NOTE 2: 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 The equipment is calibrated by using reference wafers the thickness of which is known at marked positions corresponding to the positions of the laser triangulation sensor pairs.

12.2 For calibrating the equipment a reference wafer is positioned in the equipment so that the marked positions are precisely located between the sensor pairs C, L and R.

12.3 The calibration is performed while the transport belts are not moving.

12.4 Calibration has to be performed under the same ambient conditions (temperature, humidity, illumination) as the measurements of the test specimens and within the ranges specified by the supplier of the laser triangulation sensors.

12.5 Care has to be taken when a tool is selected for establishing the wafer thickness at the reference positions of the reference wafer. This tool shall be calibrated with traceable reference materials.

13 Procedure

13.1 Adjust the equipment and calibrate it according to the instructions of the supplier.

13.2 Verify the equipment is within the SPC limits.

13.3 Select the values for ignore zone (IZ), sampling range (SR) and sampling interval (SI).

13.4 Put a wafer on the transport belts.