

SEMI HB6-0615

TEST METHOD FOR MEASUREMENT OF THICKNESS AND SHAPE OF CRYSTALLINE SAPPHIRE WAFERS BY USING OPTICAL PROBES

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1 Purpose

- 1.1 Crystalline sapphire wafers (CSW) are used as substrates for manufacturing compound semiconductor devices, in particular high brightness light emitting diodes (HB-LED).
- 1.2 In SEMI HB1 a multitude of requirements is defined for CSW qualified for device production, including geometry and surface characteristics.
- 1.3 Thickness (thickness, thickness variation, local thickness variation) and wafer shape (warp, bow, sori) are important characteristics for depositing layers of III-V compound on CSW during manufacturing HB-LED.
- 1.4 In addition, careful process and quality control of those wafer characteristics during CSW and device manufacturing requires continuous monitoring by the supplier as well as by the user of CSW.
- 1.5 An understanding of the measurements methods used for the qualification of CSW is required to enable agreement on specifications. Such an understanding is provided by standardized test methods for the wafer characteristics.
- 1.6 This Document provides standardized test methods for measuring selected characteristics of CSW, geometry and surface deviations. In addition, this document defines terms and metrics needed for quantifying the wafer geometry and surface characteristics.

2 Scope

- 2.1 This Test Method covers the non-contact, non-destructive measurement of clean CSW used for manufacturing semiconductor devices.
- 2.2 The diameter and thickness range covered by this Test Method depends on details of the specific set-up used.
- 2.3 The surface condition of the CSW may be as cut, etched or polished.
- 2.4 This Test Method does not cover measurements in the wafer edge profile.
- 2.5 This Test Method may also be applied to wafers of other materials within the constraints of diameter, thickness and surface condition.

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 method may result in erroneous data if the spatial wavelength of the thickness and shape variations are smaller than the pitch of the measurement points.
- 3.2 Thickness and shape data close to the fixed quality area (FQA) boundary may be affected by the measurement pattern chosen.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI E89 — Guide for Measurement System Analysis (MSA)

SEMI HB1 — Specifications for Sapphire Wafers Intended for Use for Manufacturing High Brightness-Light Emitting Diode Devices

SEMI M1 — Specification for Polished Single Crystal Silicon Wafers

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI MF1569 — Guide for Generation of Consensus Reference Materials for Semiconductor 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 Abbreviations and Acronyms

5.1.1 *CRM* — certified reference material

5.1.2 *CSW* — crystalline sapphire wafer(s)

5.1.3 *FQA* — fixed quality area

5.2 Definitions

5.2.1 *5-point thickness T5GU* — mean of the thickness measured at the center of the CSW (*TCG*) and at 4 additional points.

5.2.2 *5-point thickness variation T5GV* — difference between the maximum and minimum thickness measured at the 5-points of *T5GU*.

5.2.3 *average thickness TAGU* — mean of the thickness measured at all measurement points on a CSW.

5.2.4 *back face, of CSW* — that face of a CSW that is not intended for manufacturing a semiconductor device.

5.2.5 *center thickness TCGU, of CSW* — thickness of a CSW at the center-point of the wafer.

5.2.6 *front face, of CSW* — that face of a CSW that is intended for manufacturing a semiconductor device.

5.2.7 *full site, on CSW* — a site the area of which is completely within the FQA.

5.2.8 *global back face warp SWGB, of CSW* — sum of the unconstrained maximum positive and maximum absolute negative height deviations of the CSW back face from a reference plane. The reference plane is determined by a least-square fit to all measurement points of the point pattern on the back face for *TAGU*.

5.2.9 *global bow SBGE, of CSW* — distance between the CSW unconstrained median wafer surface center and a reference plane. The reference plane is determined by a least-square fit to the median of the measurement points around the periphery of the point pattern used for *TAGU*.

5.2.10 *global front face warp (Sori) SWGF, of CSW* — sum of the unconstrained maximum positive and maximum absolute negative height deviations of the CSW front face from a reference plane. The reference plane is determined by least-square fit to all measurement points of the point pattern on the front face for *TAGU*.

5.2.11 *global warp SWGM, of CSW* — sum of the unconstrained maximum positive and maximum absolute negative height deviations of the CSW median surface from a reference plane. The reference plane is determined by a least-square fit to all measurement points of the point pattern on the median surface for *TAGU*.

5.2.12 *global warp SWGE, of CSW* — sum of the unconstrained maximum positive and maximum absolute negative height deviations of the CSW median surface from a reference plane. The reference plane is determined by a least-square fit to the median of the measurement points around the periphery of the point pattern used for *TAGU*.

5.2.13 *local back face warp SWLB, of CSW* — maximum of the individual local bottom warp of all sites of a CSW.

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5.2.14 *local thickness TALU, of CSW* — mean of the thickness measured at all measurement points of a site.

5.2.15 *local thickness variation TALV, of CSW* — difference between the maximum and minimum thickness measured within a site. The value is assigned to the center of this region.

5.2.16 *local front face warp (Sori) SWLF, of CSW* — maximum of the individual local front warp of all sites of a CSW.

5.2.17 *local warp SWLM, of CSW* — maximum of the local median warp of all sites of a CSW.

5.2.18 *maximum shape deviation SXGM, of CSW* — largest deviation of the CSW unconstrained median surface from a reference plane. The reference plane is determined by a least-square fit to the median of the measurement points around the periphery of the point pattern used for TAGU.

5.2.19 *partial site, on CSW* — a site the area of which is only partially within the FQA.

5.2.20 *site, on CSW* — rectangular area on a CSW, the corners of which are defined by measurement points and the center of which is within the FQA.

5.2.21 *total thickness variation TAGV* — difference of the maximum and minimum thickness measured at the measurement points of TAGU.

6 Summary of Test Method

6.1 A scan of the wafer is performed by moving the wafer between a pair of fixed, opposing optical probes so that all measurement points in a predefined pattern (see Figure 2) are obtained.

6.2 The measurement points are the centers of spots with diameter ϕ within which the thickness measurement is averaged.

6.3 The distances to both faces of a wafer are simultaneously measured by the probes at each measurement point.

6.4 The wafer is supported at 3 points around its circumference near its edge during measurement.

6.5 The pattern of the measurement points consists of equidistant points in x - and y -directions (see §§ 7 and 2).

6.6 The thickness of the wafer is measured at each measurement point as a result of the known distance between the probes and the measured distances of the probes from adjacent wafer faces.

6.7 The set of thickness and distance values for the wafer are used to calculate values for the metrics for shape, thickness and thickness variation.

6.8 Corrections for gravitational sag are applied to the measurement results.

7 Coordinate System and Measurement Point Patterns

7.1 The origin of the coordinate system is at the wafer center-point and the y -axis is aligned perpendicular to the fiducial orientation flat or bisects the fiducial orientation notch as described in SEMI M20. This Document assumes that the wafer rests horizontally on its support. The origin of the z -axis is assumed at the beginning of the measurement range. If the wafer is held in an upright position the coordinate system shall be adjusted accordingly.

7.2 The coordinates p_x and p_y of the measurement points for thickness and shape measurement are defined by:

$$(p_x, p_y) = (n_x d, n_y d) \quad (1)$$

7.3 with the pitch d and $n_x, n_y = 0, 1, 2, \dots$ and the constraint that:

$$n_x^2 + n_y^2 \leq \left(\frac{r_{FQA} - \frac{\phi}{2}}{d} \right)^2 \quad (2)$$

where r_{FQA} ... radius of FQA (see § 2).

For wafers with a flat orientation fiducial there is an additional constraint that the measurement spot should not extend beyond the FQA boundary. This results in:

$$n_y \leq \frac{\sqrt{r_{FQA}^2 - \frac{f^2}{4}} - \frac{\phi}{2}}{d} \quad (3)$$

for the negative y -direction with the flat length f .

8 Apparatus

8.1 *Optical Probe Set* — A pair of opposing probes spaced a distance w apart that measure the distances to the respective wafer surfaces by using an optical technique.

8.2 *x-y-Stage* — Supports the wafer at three points around its periphery so that a) the wafer is not contaminated and b) measurement is not impacted. Stage lateral motion provides appropriate horizontal and vertical positioning.

8.3 *Electronics* — Controlled by a computer that is equipped with software for recording and processing the measured data according to § 14. The computer controls also wafer handling and movement of the wafer support.

9 Safety Precautions

9.1 In case equipment with automated wafer handling is used then the entire equipment has to be placed in a closed housing and has to be secured with a safety lock that stops the robot and safely switches the tool off when the housing is opened.

10 Test Specimens

10.1 Clean, dry sapphire 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 Verify that the probes and the wafer support are aligned and adjusted according to the manufacturer's manual.

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

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

12 Calibration and Standardization

12.1 The measurement equipment is calibrated by using reference material (RM), preferably certified reference material (CRM), the thickness of which is known.

12.2 The RM may either be a CSW the thickness and its uncertainty are known at marked positions, or gauge blocks.

12.3 Calibration is established only for the specified linear range of the optical probe pair about the gap position used during this calibration.

12.4 Large changes in product-specified wafer thickness may require changing the calibration when the thickness is changed.

12.5 Calibration has to be performed under the same ambient conditions (temperature, humidity, vibrations) as the measurements of the test specimens and within the ranges specified by the supplier of the measurement equipment.

13 Procedure

13.1 Choose the pattern to be used for thickness and shape measurement. Choose pitch d so that the side lengths of a site are whole numbered multiples of d and a corner of the site is at a measurement point (see Figure 2). Report d and the number N of measuring points.

NOTE 1: For example, for a 100 mm wafer and a pitch of 5 mm one obtains $N = 277$ assuming $\phi = 0.5$ mm that does not overlap with the edge exclusion zone of 3 mm width.

13.2 Put the wafer on the x - y -stage so that the fiducial mark points in the required direction.

13.3 Perform the thickness and shape measurement at each measurement point.

13.3.1 Record the distances h_{ij} between both probes and the respective wafer surfaces ($i = t, b$ for front and back surface, $j = 1, 2, \dots, N$) at the measurement points as well as their coordinates x_j, y_j .

13.3.2 Calculate the metrics for thickness and shape according to § 14.

13.3.3 Report the metrics.

14 Calculations

14.1 The following calculations are performed automatically within the instrument. The metrics shall be calculated as outlined in the following.

14.2 For an explanation of the acronyms used in the following see Appendix 1.

14.3 Thickness

14.3.1 Calculate the thickness t_j for each measurement point by

$$t_j = w - h_{tj} - h_{bj} \quad (3)$$

14.3.2 *Global Thickness*

14.3.2.1 Determine the center thickness $TCGU = t_c$ where the index c denotes the measurement point at the center of the wafer.

14.3.2.2 Calculate the global 5-point thickness $T5GU$ as the mean of $TCGU$ and the t_j of the four measurement points that are closest to, but completely inside, the edge exclusion zone along the directions of $0^\circ, 90^\circ, 180^\circ$ and 270° from the wafer center.

14.3.2.3 Calculate the global 5-point thickness variation $T5GV$ as the difference of maximum and minimum thickness at the 5 measurement points used for $T5GU$.

14.3.2.4 Calculate the global average thickness $TAGU$ by:

$$TAGU = \frac{\sum_{j=1}^N t_j}{N} \quad (5)$$

14.3.2.5 Calculate the global total thickness variation $TAGV$ ($GBIR$ according to SEMI M1) by:

$$TAGV = \max(t_j) - \min(t_j) \quad (6)$$

14.3.3 *Local Thickness*

14.3.3.1 Calculate the local thickness $TALU_s$ over all sites by:

$$TALU_s = \frac{\sum_{k=1}^K t_{sk}}{K} \quad (7)$$

where the index s denotes the site and the index k denotes the set of thickness values at measurement points along the edges and at the corners of the site s and within the site. K denotes the number of measuring points attributed to the site.

14.3.3.2 Calculate the local thickness variation $TALV_s$ over all sites ($SBIR$ according to SEMI M1) by:

$$TALV_s = \max(t_{sk}) - \min(t_{sk}) \quad (8)$$

NOTE 2: For example, a site with a size of $1d \times 1d$ consists of four measurement points, or, a site with a size of $2d \times 3d$ contains 10 measurement points along its edges and corners and two measurement points within the site. Adjacent sites share the measurement points along their common edges and at their common corners (see Figure 2).

14.3.3.3 Assign the value of $TALV$ to the center of the respective site.

14.4 Calculate the maximum local thickness variation $TALV$ of a CSW as:

$$TALV = \max(TAVL_s) \quad (9)$$

14.5 Shape

14.5.1 Global Warp

14.5.1.1 Calculate the median height m_j at each measurement point by:

$$m_j = h_{bj} + \frac{t_j}{2} \quad (10)$$

14.5.1.2 Define a reference plane M by a least-square fit to the set of m_j .

14.5.1.3 Calculate the global warp $SWGM$ of the wafer as the sum of the maximum absolute positive and negative deviations of the set of m_j from M .

14.5.1.4 Define a sub-set m_e of m_j consisting only of the median heights of the measurement points at the edge of the measurement point pattern ($e = 1, 2, \dots, < N$).

14.5.1.5 Define a reference plane E by a least-square fit to the set of m_e .

14.5.1.6 Calculate the global warp $SWGE$ of the wafer as the sum of the maximum absolute positive and negative deviations of the set of m_j from E .

14.5.1.7 Define a reference plane T by a least-square fit to the set of h_{ij} .

14.5.1.8 Calculate the global front face warp (sori) $SWGF$ as the sum of the maximum absolute positive and negative deviations of the set of h_{ij} from T .

14.5.1.9 Define a reference plane B by a least/square fit to the set of h_{bj} .

14.5.1.10 Calculate the global back face warp $SWGB$ as the sum of the maximum absolute positive and negative deviations of the set of h_{bj} from B .

14.5.2 Global Bow

14.5.2.1 Calculate the bow $SBGE$ of the wafer as the height difference between the center point of ME and m_c where the index c denotes the median height at the wafer center.

14.5.2.2 Calculate the maximum deviation $SXGM$ as the largest height difference between ME and m_j .

14.5.3 Local Warp

14.5.3.1 Define subsets m_{is} and h_{ijs} consisting only of the m_i and h_{ij} of the sites s .

14.5.3.2 Define reference planes LM_s by a least-square fit to the sets m_{is} where the index s denotes the site.

14.5.3.3 Define reference planes LF_s and LB_s by least-square fits to the sets h_{ijs} and h_{bjs} , respectively.

14.5.3.4 Calculate the local warp $SWLM_s$, $SWLF_s$ and $SWLB_s$ as the sum of the maximum absolute positive and negative deviations of the set of m_{js} and h_{ijs} from the reference planes LM_s , LF_s and LB_s , respectively, for each site.

14.5.3.5 Calculate the maximum $SWLM$, $SWLF$ and $SWLB$ of $SWLM_s$, $SWLF_s$ and $SWLB_s$, respectively, of a CSW as:

$$SWLB = \max(SWLB_s) \quad (11)$$

$$SWLM = \max(SWLM_s) \quad (12)$$

$$SWLF = \max(SWLF_s) \quad (13)$$

14.5.4 Correct the obtained results with respect to gravitational sag.

15 Report

15.1 The report shall contain the following elements.