

SEMI 3D12-0315

GUIDE FOR MEASURING FLATNESS AND SHAPE OF LOW STIFFNESS WAFERS

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1 Purpose

- 1.1 The control of parameters, such as thickness, total thickness variation (TTV), bow, warp, and flatness, is well known to be essential to many, if not all, semiconductor processes as reflected in a number of existing standards.
- 1.2 The general trend in wafer geometry is to a larger diameter but even so the thickness increases correspondingly, it may not be enough to sustain adequate stiffness of the wafer. With growing aspect ratio of a wafer (e.g., diameter/thickness), gravity compensation errors increase until they become larger than the actual wafer surface variations. This is already the case for many special purpose wafers with lower modulus of elasticity and is becoming more common in mainstream applications. For example many wafer substrates are very thin such as germanium wafers used in specialized solar applications, and many other substrates are being made thinner such as lithium tantalate, and lithium niobate used in communication filters.
- 1.3 Manufacturing processes incorporating bonded wafers typically require thinned wafers; these wafers are then extremely low stiffness. In addition, since non-planarity of the wafers can lead to problems in subsequent processing steps, including lithography and electrical contact between metal layers on the bonded wafers, these technologies demand higher precision wafers and more accurate depiction of the true topography of the wafer.
- 1.4 This Guide is designed to provide definitions for describing a more suitable measurement strategy for low stiffness wafers and geometries.
- 1.5 The more suitable measurement process consists of an alternative mounting for wafers with high aspect ratios and the use of high resolution measurements.
- 1.6 This Guide also provides a measurement procedure for local bow, which denotes small areas of imperfection of the otherwise flat wafer or substrate.
- 1.7 This Guide's alternative measurement process is suitable for use in materials acceptance and process control, but may also be useful in other applications, such as wafer design and production.

2 Scope

- 2.1 This Guide is intended in general for metrology on low stiffness substrates like wafers or other geometrical shapes such as panels. As low stiffness can occur with any material, this Guide can be applied to all materials that show low stiffness in certain deformation modes.
- 2.2 This Guide applies in particular to glass and silicon wafers with a diameter equal to or exceeding 300 mm and their thickness equal to or less than $775 \mu\text{m} \pm 20 \mu\text{m}$.
- 2.3 This Guide also applies to wafers or other geometrical shapes of any material type that show deflections more than 200% of the allowable bow tolerance when tested for bow using the conventional three-point mounting method.
- 2.4 Although the accuracy of TTV measurement is not as dependent on deflection as bow and warp are, it makes sense to use the same wafer support configuration when measuring TTV.
- 2.5 This Document is a guide for a nondestructive procedure that uses a semicontinuous flat mounting surface and high resolution measurement methods.

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 As this Guide is designed for wafers with low stiffness, the following environmental considerations should be taken into account. Wafers with a high aspect ratio or low modulus of elasticity tend to be sensitive to airflow, vibration, and acoustics from the environment. It is desirable to minimize the introduction of these influences in order to minimize movement of the specimen wafer, as this will impact the precision of the measurement.

3.2 For transparent materials, the optical thickness can be directly measured with this technique. Knowledge of the index of refraction and the group index of refraction of the material being measured is needed to properly relate the optical thickness to the physical thickness of the wafer.

3.3 This Guide applies to the measurement of a single wafer or other geometrical shape of low stiffness and not to stacks although the principles of this Guide could be applied to stacks as well.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI M1 — Specifications for Polished Single Crystal Silicon Wafers

SEMI M59 — Terminology for Silicon Technology

SEMI MF533 — Test Method for Thickness and Thickness Variation of Silicon Wafers

SEMI MF534 — Test Method for Bow of Silicon Wafers

SEMI MF657 — Test Method for Measuring Warp and Total Thickness Variation on Silicon Slices and Wafers by a Noncontact Scanning Method

SEMI MF1390 — Test Method for Measuring Bow and Warp on Silicon Wafers by Automated Noncontact Scanning

SEMI MF1451 — Test Method for Measuring Sori on Silicon Wafers by Automated Noncontact Scanning

SEMI MF1530 — Test Method for Measuring Flatness, Thickness, and Thickness Variation on Silicon Wafers by Automated Noncontact Scanning

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

5 Terminology

5.1 Terms, acronyms, and symbols associated with silicon wafers and silicon technology are listed and defined in SEMI M59.

5.2 Other Abbreviations and Acronyms Used in this Standard

5.2.1 *CWS* — chromatic white light sensor

5.2.2 *FQA* — fixed quality area

5.2.3 *IR* — infrared

5.2.4 *GBIR* — global backside indicated reading

5.2.5 *SBIR* — site backside ideal focal plane range

5.2.6 *SFQR* — site frontside least squares focal plane range

5.3 Other Terms Defined in this Standard

5.3.1 *aspect ratio* — the ratio of the diameter to the thickness of the wafer, or the ratio of the longest length to the thickness of the substrate, for instance the longest length of a rectangle is the diagonal.

5.3.1.1 *high aspect ratio* — large diameter and small thickness of the wafer lead to high aspect ratios.

5.3.2 *chromatic white light sensor (CWS)* — a noncontact method based on the principal of confocal optics, which relies on chromatic scanning. A lens is used that refracts white light differentially based on its wavelength in order to carry out distance measurements. Resolution depends on the intensity of reflected light. The term refers to a sensor (CWS).

5.3.3 *coplanarity* — a measure of the magnitude of how far out of an ideal plane a series of points is. This is similar to flatness but measured on an incomplete surface.

5.3.4 *correction* — the mathematical compensation for outside forces, such as gravitation.

5.3.5 *deflection* — a change in shape induced by an outside force, for instance by gravitation.

5.3.6 *full surface bow* — a bow that occurs over the full surface of the substrate.

5.3.7 *group index of refraction* — index of refraction of the beginning and the end of the scan.

5.3.8 *interferometry* — high resolution, noncontact measurement technique that relies on the principle of superposition of multiple beams of light to determine the difference in distance traveled between two separate optical paths. Interferometry typically has a resolution $<1/100$ of the wavelength of the light being evaluated.

5.3.9 *local bow* — an area of a small, localized deviation of the general plane of a substrate.

5.3.10 *low stiffness wafer* — wafers that show deflections more than 200% of the allowable bow tolerance when tested for bow using the conventional three-point mounting method.

5.3.11 *noncontact-metrology* — a measurement technique that allows a surface to be measured without the requiring physical contact with the surface, preventing contamination or damage to the wafer substrate. Noncontact metrology also has the advantage of placing zero force on the surface of interest preventing measurement errors due to deformation induced by the force of the measurement.

5.3.12 *semicontinuous flat mounting surface* — a support structure that is horizontal, and has very low flatness and coplanarity of the contact surface, with minimized contact area distributed uniformly across the back surface of the wafer under test.

5.3.13 *wire grid* — sometimes also called a Harp. A mounting surface created by a precise monofilament strung across the surface of an optical flat to create a semicontinuous flat mounting surface support.

6 Comprehensive Explanation of Terms Related to Low Stiffness Wafers

6.1 *Geometrical Parameters* — The geometric parameters that are primarily measured, like bow, warp, TTV, need some further explanation. Figures 1 through 4 show schematic diagrams representing these terms. Explanations for flatness and sori are not included in this section.

6.1.1 *Full Surface Bow* — Full surface bow is a measure of the magnitude of concavity or convexity of a wafer is in its free, unclamped state. This is typically controlled to prevent excessive film stresses in the processing of the wafer or in the interaction between multiple wafers in the case of bonded wafer stacks. Typically, this is evaluated on the median surface of the wafer, which is midway between the front and back surfaces. In most cases, bow has been evaluated by measuring the deviation of the center point of the median surface of a free, unclamped wafer from a median surface reference plane established by three points equally spaced on a circle, with diameter a specified amount less than the nominal diameter of the wafer; SEMI MF534 provides a standard test method for measuring the bow of a single wafer in this fashion. In this Guide the full surface measurement is used to create a more robust measure of bow A least squares spherical fit is applied to the fixed quality area (FQA) of the sphere. The intersection of the edge of the FQA and the fitted sphere defines the reference plane for the Bow measurement. Bow is the height of the center point of the fitted sphere in the FQA with respect to the reference plane. Note that bow is a signed value to signify concave vs. convex. The reported bow, A , is given by the difference between the center point of a least squares spherical fit to the median surface of the wafer, B , and the center point of the intersecting plane, C , as shown in Figure 1.

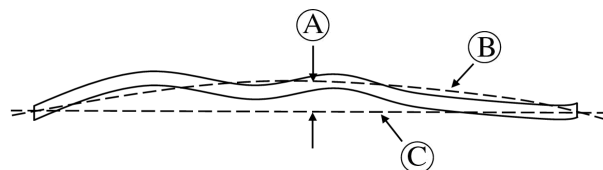


Figure 1
Bow

6.1.2 Warp — Warp is the difference between the most positive, A , and most negative, B , distances of the median surface of a free, unclamped (but gravity-compensated) wafer from a reference plane. SEMI MF657 and SEMI MF1390 provide standard test methods for measuring the warp of a single wafer, they were written with low aspect ratio and therefore stiff silicon wafers in mind. Warp can be zero, even for a wafer with surface curvature, if the front surface curves are mirror images of the back surface curves. Some forms of warp (see SEMI MF657) are with respect to the same 3-point surface as bow; while in other cases (see SEMI MF1530), a least squares reference plane is fitted to the measured median surface. This measurement can also be applied to the front surface or the back surface of the wafer.

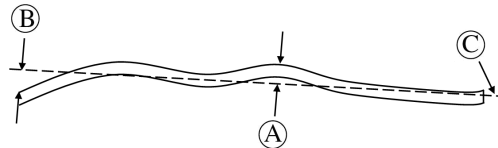


Figure 2
Warp

6.1.3 Local Bow — A measure of the local curvature, and directly related to the induced stress on a film or stacked wafer. The local bow measurement is evaluated the same way as the global bow, but on a subsection of the wafer. As is done in stepper simulation measurements (such as SFQR or SBIR) a local quality area is scanned across the surface of the wafer and a new plot is constructed showing the magnitude of the bow at every possible location on the wafer. The local quality area for local bow should be round, and the size of the local area should be at least ten times the thickness of the wafer, and ideally should be the size of an exposure site on the wafer (typically on the order of 25 mm). The increment of the local quality area evaluation can be, and should be, smaller than the quality area size. For example, a typical configuration would be to evaluate the local bow on a 25 mm round site scanned every 5 mm in x and 5 mm in y . This would yield a local bow map with reported values every 5 mm. The local bow should be evaluated statistically. The maximum, minimum and average values of local bow should be provided.

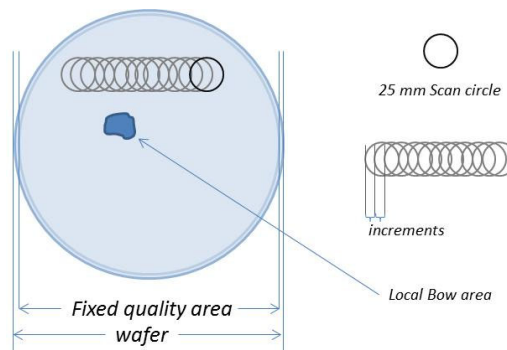


Figure 3
Local Bow Measurement

6.1.4 Total Thickness Variation — Global backside ideal focal plane range (GBIR) is the difference between the highest and lowest elevation on the entire wafer surface. These elevations are measured with respect to an ideal back surface plane, which is parallel to the reference surface of the interferometer. The ideal back surface plane is constructed by constraining the back surface of the wafer such that it is ideally flat. This emulates the condition the wafer sees when clamped to a stepper chuck, or some other chuck for processing. Some measurement techniques use a chucking surface to construct the thickness variation measurement, though it can be constructed virtually by measuring both surfaces simultaneously.

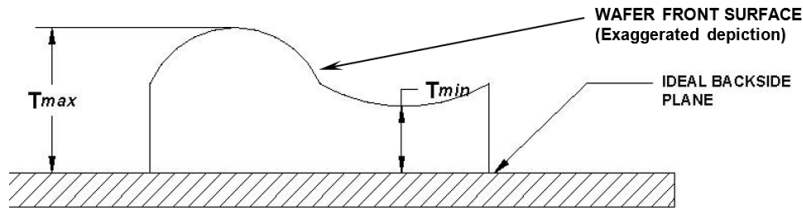


Figure 4
TTV

6.2 Considerations on Gravity Compensation and Support Structure

6.2.1 Deflection — A deflection is a change in shape induced by an outside force. In the context of this Document, the deflection is induced by the force of gravity bending the wafer over the support structure of the measurement system. Since the shape and magnitude of this deflection is determined by the distribution of the force over the support points, most support configurations have a distribution of force that is unpredictable as it is a function of the topography of the wafer as well as the position of the support points. For low stiffness wafers, the variation of the deflection can be quite large, as the base deflection is quite large, therefore having a very negative impact on the measurement reproducibility. For the three point support case there is a deterministic solution for the magnitude and shape of the deflection; however, the result is heavily dependent on the load position. If the position shifts laterally a small amount, the change in deflection can be very large for low stiffness wafers.

6.2.2 Gravity Compensation — A mathematically calculated correction factor that is used to remove the effects of gravity upon a warp and bow measurement.

6.2.2.1 Gravity Compensation for Horizontally Supported Wafers — Gravity causes substantial deformation of large diameter wafers, whether they are supported at the edge or in the middle. Unless compensated, gravity will induce a large error in warp measurements. SEMI MF1390 describes two compensation approaches. One approach is to correct for the gravitational effect of warp measurements by inverting the wafer and simultaneously measuring both the top and bottom surfaces of the wafer. Any differences between two values at the same site are due to the effect of gravity and can be used to correct for single-side measurements. Measurements obtained on representative wafers can also be performed and the deformation resulting from gravity determined.

6.2.2.2 Gravity Compensation for Vertically Supported Wafers — On tools that support the wafer vertically, effects due to gravity are negligible and therefore do not require compensation. Bow is only measured on one side, so there is no need to reverse the wafer.

6.2.2.3 Wafer Support — There are also various wafer supporting strategies, most of which were created with stiff wafers in mind (low aspect ratio).

6.2.2.3.1 Single or 3-Point Support — Stiff wafers may be supported on a single point, which typically takes the form of a small-area chuck at the wafer center. The shape of the front side of the wafer is determined first. This measurement includes gravity-induced deflection. The wafer is then inverted and the measurement performed again. The effect of gravity is removed by subtraction. For various methods, many other support strategies are applied. In gravity compensating methods on stiff wafers, often a 3-point support is utilized and either a calculated gravity compensation, or the reversal technique is applied (measure, invert, measure), or a ‘representative wafer’ is measured with the reversal process, and the error in this measurement is removed from subsequent measurements. Mathematical modeling can only accurately compensate for the 3-point support, as this is the only case where the part is only distorted by gravity and not by its own flatness characteristics.

6.2.2.3.2 4-Point or Ring-Support — For larger numbers of support points, such as a 4-point mount or a ring mount, only an approximation for compensation of gravity can be applied. As wafers become higher and higher in their aspect ratio, the errors in the gravity compensation methods become more and more significant.

6.2.2.3.3 Semicontinuous Flat Mounting Surface Support — A support structure constructed to have very low surface contact area, with a high degree of coplanarity (flatness of the contact area) with the contact area distributed in such a way to emulate a perfectly flat support structure. The low contact area minimizes the probability of a particulate disrupting the coplanarity of the support.