

THICKNESS MEASUREMENT

THICKNESS

ASTM F657: The distance through a wafer between corresponding points on the front and back surface. Thickness is expressed in microns or mils (thousandths of an inch).

TOTAL THICKNESS VARIATION (TTV)

ASTM F657: The difference between the maximum and minimum values of thickness encountered during a scan pattern or series of point measurements. TTV is expressed in microns or mils (thousandths of an inch).

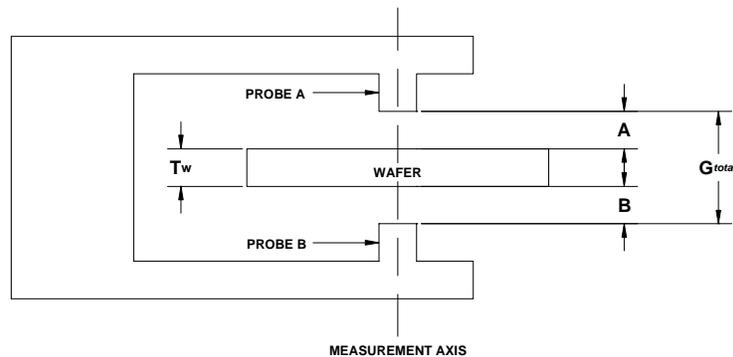


Figure 1

Figure 1 above shows a wafer placed between two non-contact measurement probes. By monitoring changes between the upper probe face and the upper wafer surface (A) and the bottom probe face and the bottom wafer surface (B), thickness can be calculated.

First the system must be calibrated with a wafer of known thickness (T_w). The area of known thickness is placed between the probes and an upper probe to wafer gap (A) and a lower probe to wafer gap (B) is acquired. The total gap (G_{total}) between the upper and lower probes is then calculated as follows:

$$G_{total} = A + B + T_w$$

With the system calibrated, wafers of unknown thickness can now be measured. When the wafer is placed between the probes, a new value of A and B is acquired. Thickness is calculated as follows:

$$T_w = G_{total} - (A + B)$$

During an automated scanning of the wafer, a series of point measurements is taken and stored. Following completion of the scan, TTV is calculated as follows:

$$TTV = T_{max} - T_{min}$$

BOW MEASUREMENT

BOW

ASTM F534 3.1.2: The deviation of the center point of the *median surface* of a free, unclamped wafer from the median surface reference plane established by three points equally spaced on a circle with a diameter a specified amount less than the nominal diameter of the wafer.

Median Surface: The locus of points in the wafer equidistant between the front and back surfaces.

When measuring and calculating bow, it is important to note that the location median surface of the wafer must be known. By measuring deviations of the median surface, localized thickness variations at the center point of the wafer are removed from the calculation.

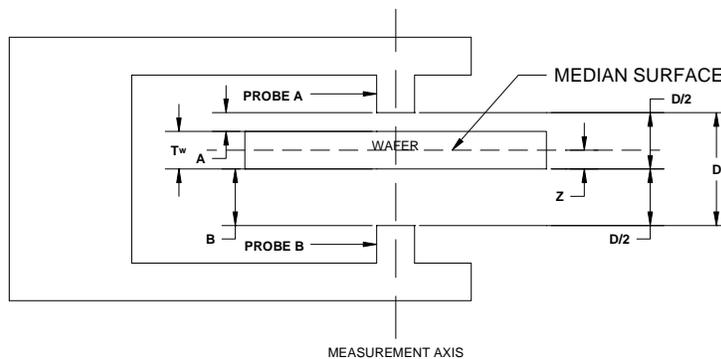


Figure 2

Figure 2 shows the relationship of the wafer median surface between the two probe faces where:

- D = Distance between upper and lower probe face
- A = Distance from upper probe to top wafer surface
- B = Distance from lower probe to bottom wafer surface
- Z = Distance between wafer median surface and the point halfway between the upper and lower probe (D/2).

To determine the value of Z at any location on the wafer, there are two equations:

$$Z = D/2 - A - T/2 \quad \text{and} \quad Z = -D/2 + B + T/2$$

Solving both equations for Z, the value can be determined simply by:

$$Z = (B - A)/2$$

Since bow is measured at the center point of the wafer only, a three (3) point reference plane about the edge of the wafer is calculated. The value of bow is then calculated by measuring the location of the median surface at the center of the wafer and determining its distance from the reference plane. Note that bow can be a positive or negative number. Positive denotes the center point of the median surface is above the three point reference plane. Negative denotes the center point of the median surface is below the three point reference plane.

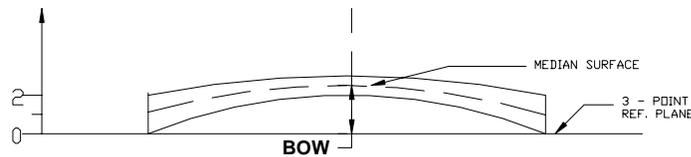


Figure 3

WARP MEASUREMENT

WARP

ASTM F1390: The differences between the maximum and minimum distances of the median surface of a free, unclamped wafer from a reference plane.

Like bow, warp is a measurement of the differentiation between the median surface of a wafer and a reference plane. Warp, however, uses the entire median surface of the wafer instead of just the position at the center point. By looking at the entire wafer, warp provides a more useful measurement of true wafer shape.

The location of the median surface is calculated exactly as it is for bow and shown in Figure 2. For warp determination, there are two choices for construction of the reference plane. One is the same three point plane around the edge of the wafer. The other is by performing a least squares fit calculation of median surface data acquired during the measurement scan. Warp is then calculated by finding the maximum deviation from the reference plane (RPD_{max}) and the minimum differentiation from the reference plane (RPD_{min}). RPD_{max} is defined as the largest distance above the reference plane and is a positive number. RPD_{min} is the largest distance below the reference plane and is a negative number.

$$\text{Warp} = RPD_{max} - RPD_{min}$$

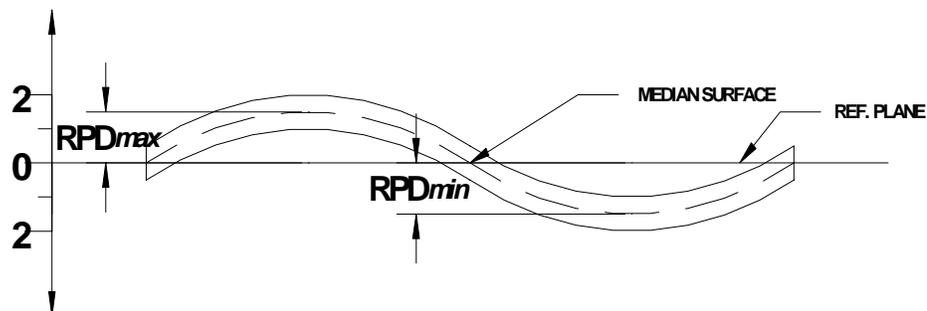


Figure 4

Figure 4 is an illustration of the warp calculation. In this example RPD_{max} is 1.5 and is shown as the maximum distance of the median surface above the reference plane. RPD_{min} is -1.5 and is shown as the maximum distance of the median surface below the reference plane. Note warp is always a positive value.

$$\text{Warp} = 1.5 - (-1.5) = 3$$

The example shown in Figure 4 also illustrates the usefulness of taking both bow and warp readings. The median surface of the wafer shown intersects the reference plane at the wafer center, therefore, bow measurement would be zero. The calculated warp value is more useful in this case as it tells the user the wafer does have shape irregularities.

FLATNESS MEASUREMENT

FLATNESS

ASTM F1530: The deviation of the front surface, expressed in total indicator reading (TIR) or maximum focal plane deviation (FPD), relative to a specified reference plane when the back surface of the wafer is ideally flat.

Global Flatness: The total indicator reading (TIR) or the maximum focal plane deviation (FPD) relative to a specified reference plane within the fixed quality area.

Site Flatness: The total indicator reading (TIR) or the maximum focal plane deviation (FPD) of the portion of the site that falls within the fixed quality area.

Total Indicator Reading (TIR): The span of readings, from maximum to minimum, for any dimension measured.

Focal Plane Deviation (FPD): The largest of the absolute values of the deviations from a reference plane.

Bow and warp measurements are based on the median surface of the wafer relative to a reference plane. Flatness measurements are based on the front (top) surface of the wafer relative to a reference plane. Like bow and warp, there are different reference planes that can be specified based on the type of processing to be done on the wafer in subsequent manufacturing steps.

SEMI describes the method for choosing the flatness calculation methods in the *MI Specifications – Appendix A*. Global flatness is used if the lithography tool uses a single, global exposure of the wafer. Site flatness is used if the lithographic tool steps across the wafer exposing only a specific site at a time. The reference plane, front or back surface, is then chosen based on which wafer surface the lithographic tool references.

Once the appropriate method is chosen, it is then decided which reporting method to use, either TIR or FPD. Wafer acceptance criteria for flatness will then be based on the reporting method chosen.

The reporting of flatness values is done using acronyms which define the type of flatness measurement, the reference plane used, and the reporting method.

GBIR – (G)lobal (B)ackside (I)deal Focal Plane (R)ange

This flatness measurement is used if the lithographic tool is referenced to the backside of the wafer as it is held to a chuck considered to be an ideal plane.

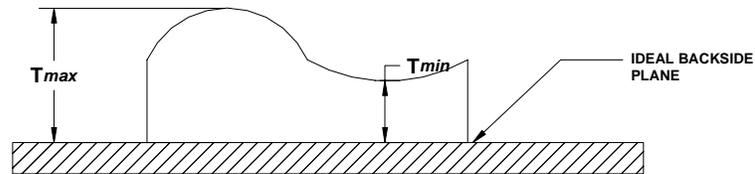


Figure 5

As Figure 5 shows, the wafer is held to an ideally flat backside plane. In this case, the reading of flatness simply becomes the maximum minus the minimum distance from the wafer backside, or more simply the maximum thickness minus the minimum thickness.

$$GBIR = T_{max} - T_{min} = TTV$$

For lithographic tools referenced to the front surface of the wafer there are different flatness values and calculations.

GF3R – (G)lobal (F)rontside (3) Point Focal Plane (R)ange

GF3D – (G)lobal (F)rontside (3) Point Focal Plane (D)eviation

GFLR – (G)lobal (F)rontside (L)east Squares Focal Plane (R)ange

GFLD – (G)lobal (F)rontside (L)east Squares Focal Plane ((D)eviation

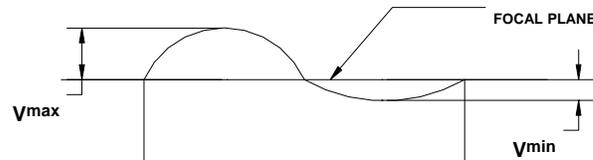


Figure 6

Figure 6 shows the reference plane based on either a 3 point or least squares fit method for the front surface of the wafer. The 3 point plane is appropriate if the lithographic tool does not allow interactive gimbaling of the wafer. If the tool does allow gimbaling, the least squares fit method for reference plane calculation is appropriate. Calculation of each of the values of flatness is relative to a maximum deviation above the reference plane (V_{max}) expressed as a positive number and a maximum deviation below the

reference plane (V_{min}) expressed as a negative number. The value are calculated as follows:

$$\text{GF3R, GFLR} = V_{max} - V_{min}$$

$$\text{GF3D, GFLD} = |V_{max}| \text{ or } |V_{min}| \text{ whichever is larger}$$

Site flatness values are specific to individual sites on the wafer. The size and position of each site is specified prior to measurement. When reporting site flatness values the results can be displayed as either the maximum site flatness value found on all of the wafer sites, or the flatness values for each site individually.

SBIR – (S)ite (B)ackside (I)deal Focal Plane (R)ange
 SBID - (S)ite (B)ackside (I)deal Focal Plane (D)eviation

SBIR and SBID are measured relative to a global ideal backside plane and center point of each individual site. The difference in the values is that SBIR is the maximum variation (V_{max}) minus the minimum variation (V_{min}) while SBID is the greater of the absolute values of V_{max} and V_{min} .

So:

$$\text{SBIR} = V_{max} - V_{min}$$

$$\text{SBID} = |V_{max}| \text{ or } |V_{min}| \text{ whichever is greater.}$$

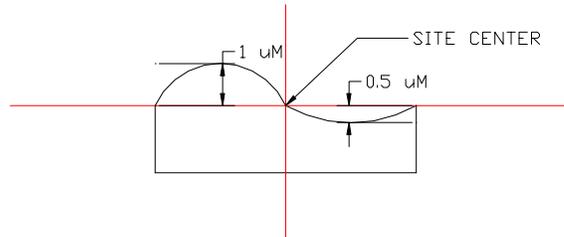


Figure 7

In the example shown above, $V_{max} = + 1 \mu\text{M}$ and $V_{min} = -0.5 \mu\text{M}$

By definition:

$$\text{SBIR} = 1 - (-0.5) = 1.5 \mu\text{M}$$

$$\text{SBID} = \text{greater of } |1| \text{ or } |-0.5| = 1 \mu\text{M}$$

For sites where the maximum or minimum thickness occurs at the center of the site, SBIR and SBID will be equal.

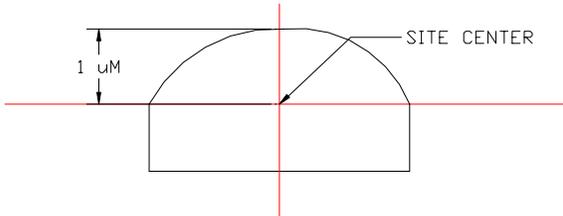


Figure 8a

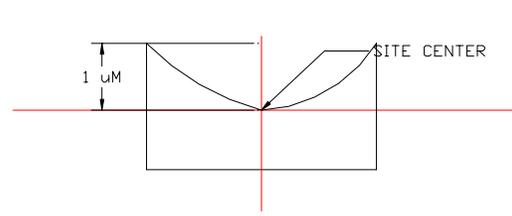


Figure 8b

$V_{max} = 0$
 $V_{min} = -1 \mu\text{M}$
 $SBIR = 0 - (-1) = 1 \mu\text{m}$
 $SBID = |0| \text{ or } |-1| = 1 \mu\text{M}$

$V_{max} = 1 \mu\text{M}$
 $V_{min} = 0 \mu\text{M}$
 $SBIR = 1 - 0 = 1 \mu\text{m}$
 $SBID = |1| \text{ or } |0| = 1 \mu\text{M}$

In addition to SBIR and SBID there are other ASTM/SEMI definitions for flatness that are relative to a different plane in each specific site on the wafer. Like SBIR and SBID, these values do use a global reference plane, but the reference plane is based on the entire front side of the wafer.

SF3R – (S)ite (F)rontside (3) Point Reference Focal Plane (R)ange

SF3D – (S)ite (F)rontside (3) Point Reference Focal Plane (D)eviation

SFLR – (S)ite (F)rontside (L)east Squares Focal Plane (R)ange

SFLD – (S)ite (F)rontside (L)east Squares Focal Plane (D)eviation

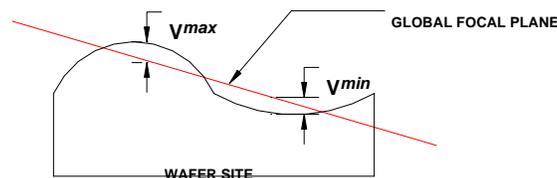


Figure 9

As shown in Figure 9, the global focal plane is constructed by either a 3 – point reference plane for SF3R and SF3D or by a least squares fit method for SFQR and SFQD. Maximum and minimum deviations from the global focal plane are determined at each site and the site flatness is expressed in terms of range or maximum deviation.

For lithographic tools that allow the wafer to be re-gimballed at each site, a site least squares fit reference plane (denoted by a Q) may be more appropriate. Instead of using a

single, global plane for all sites, these flatness values calculate a separate reference plane in each site. The acronyms are:

SFQR – (S)ite (F)rontside Least S(Q)uares Focal Plane (R)ange

SFQD – (S)ite (F)rontside Least S(Q)uares Focal Plane (D)eviation

References

ASTM F534 *Standard Test Method for Bow of Silicon Wafers*

ASTM F657 *Standard Test Method for Measuring Warp and Total Thickness Variation on Silicon Slices and Wafers by a Non-contact Scanning Method*

ASTM F1241 *Terminology of Silicon Technology*

ASTM F1390 *Standard Test Method for Measuring Warp on Silicon Wafers by Automated Non-Contact Scanning*

ASTM F1530 *Standard test method for Measuring Flatness, Thickness, and Thickness Variation on Silicon Wafers by Automated Non-Contact Scanning.*

Semiconductor Equipment and Materials International *Materials Volume – Appendix 1 – Flatness Decision Tree*

