Background Statement for SEMI Draft Document 4274
New Preliminary Standard – TEST METHOD FOR DETERMINING WAFER FLATNESS USING THE MOVING AVERAGE QUALIFICATION METRIC BASED ON SCANNING LITHOGRAPHY

Notice: This background statement is not part of the balloted item. It is provided solely to assist the recipient in reaching an informed decision based on the rationale of the activity that preceded the creation of this document.

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The for lithography relevant wafer flatness specification is based on previously applicable lithography stepper models and has poor correlation with current lithography requirements. A new standard based on a scanner model would provide a more appropriate method by which silicon wafers could be qualified, ordered and used.

This standard provides a metric for wafer flatness specification that is consistent with scanning lithography focus control and is applicable to both back and front surface referenced measurements. It is also suitable for determining wafer flatness in the near edge region of the wafer.

The last document revision (061107) after discussion of the comments and rejects during the North American Advanced Wafer Geometry Task Force Meeting (San Diego, 30 October 2007) comprises the following changes:

- Changed title to: New preliminary standard,
- Removed the superiority claim of the MA metric in section 1.4, and
- Added site by site MA reporting metrics in section 9.4.

This document will be voted as Preliminary standard at the next Japan Silicon Wafer committee meeting on December 7 in Makuhari in conjunction with SEMICON Japan 2007.
SEMIDraft Document 4274
New Preliminary Standard – TEST METHOD FOR DETERMINING WAFER FLATNESS USING THE MOVING AVERAGE QUALIFICATION METRIC BASED ON SCANNING LITHOGRAPHY

1 Purpose
1.1 Wafer flatness significantly affects the focus control of lithography equipment and thereby the yield of semiconductor device processing.

1.2 Knowledge of this characteristic can help both suppliers and users of silicon wafers determine if the dimensional characteristics of a wafer satisfy given geometrical requirements.

1.3 This test method quantifies the flatness of wafers used in semiconductor device processing in the polished, epitaxial, SOI, or other layer condition through the use of the moving average (MA) as the measurement parameter. This test method covers the determination of MA at all points within the FQA, as well as specific area flatness (e.g. edge regions).

1.4 The MA metric is suitable for quantifying the wafer flatness for scanning lithography focus control. MA quantifies the wafer flatness fully and consistently with scanning lithography focus control at all positions on the wafer surface. SFQR on the other hand was developed to reflect stepping lithography rather than scanning lithography.

2 Scope
2.1 This test method covers determination of MA data arrays as well as wafer qualification quantities (one number per wafer or wafer area) derived from these arrays.

2.2 The moving average calculated by this test method is based on a thickness data array. This array represents the front surface of the wafer when the back surface of the wafer is ideally flat, as when pulled down onto an ideally clean flat chuck. The moving average can also be calculated from a height array of the front surface obtained when the wafer is chucked.

2.3 Other metrics/qualifications analogous to existing flatness metrics, for example based on 95% of the FQA or on partial sites, can also be calculated using MA, but these are outside the scope of this test method.

2.4 The test method was developed for 200 and 300 mm diameter wafers having dimensions in accordance with wafer categories 1.9.1, 1.9.2, 1.10.1, 1.10.2, and 1.15 of SEMI M1. It can also be applied to other diameter wafers.

2.5 This test method gives the required characteristics of the thickness data array, which can be acquired through the procedures of SEMI MF1530 or another method agreed upon by parties to the test.

2.6 This test method covers the flatness qualification metrics for full wafer and/or specifically near edge region of a wafer.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations
3.1 Deficiencies of data such as inadequate spatial resolution, mis-positioning, noise, in the thickness data array used to calculate the metrics may lead to erroneous results.

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3.2 The calculations of this test method do not remove wafer shape and therefore are not applicable to data obtained from unclamped wafer single-surface data. Since this method assumes a chucked measurement or application the shape is removed by the chucking process.

3.3 The metric for (part of) a wafer based on the MA array depends on the dimensions and/or location of the area over which the MA data is evaluated.

4 Referenced Standards

4.1 SEMI Standards

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers
SEMI M20 — Practice for Establishing a Wafer Coordinate System
SEMI M59 — Terminology for Silicon Technology
SEMI MF1530 — Practice for Measuring Flatness, Thickness, and Total Thickness Variation on Silicon Wafers by Automated Non-Contact Scanning

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

5 Terminology

5.1 Most terms, acronyms, and symbols used in silicon wafer technology are listed and defined in SEMI M59.

5.2 Other Acronyms

5.2.1 MA — Moving Average.
5.2.2 MSD — Moving Standard Deviation.

5.3 Other Definitions:

5.3.1 moving average — the average defocus at a point on the wafer, a metric for wafer thickness variation simulating the operation of a scanning lithography system.
5.3.2 moving standard deviation — the standard deviation of the defocus at a point on the wafer, a metric for wafer thickness variation simulating the operation of a scanning lithography system.

6 Summary of Test method

6.1 A thickness data array over the whole wafer is obtained.

6.2 Areas for MA metric calculation and evaluation are defined by FQA radius and field sizes. The field size in the \( x \)-direction must be specified, while the field size in the \( y \)-direction is optional. Required exclusion areas are defined (see section 8).

6.3 The layout for making the calculations is defined by the field sizes in the \( x \)- and \( y \)-directions, and a placement of the fields over the wafer. This can be a fixed, application specific or flexible layout (see section 8).

6.4 An MA value is calculated at every measured point of the thickness data array using all thickness data values within the FQA, yielding an MA data array (see section 9).

6.5 Areas for full wafer MA metric evaluation are defined by FQA radius and field sizes. Areas for MA metric evaluation in the near edge region are additionally defined by an edge region radius. Required exclusions are defined (see section 10).

6.6 Statistical quantities of the MA metric are calculated and reported for each wafer (see section 10) e.g., median, mean, range, standard deviation, 95th percentile, and 99.7th percentile.

7 Apparatus

7.1 Measuring Equipment, suitable for acquiring height data of a wafer, either front surface height (when chucked) or a thickness data array and transferring it to software that shall perform all necessary calculations and corrections.
needed to produce the thickness data array internally and automatically, including instrument-dependent exclusion areas.

7.1.1 Data point spacing shall be 1.0 mm or less in the scanning direction (y-direction), and 3.0 mm or less (at least 8 measurement points within a 26 mm slit width) in the non-scanning direction (x-direction).

NOTE 1: The x-y coordinate system used is that given by SEMI M20. With the front surface up, the fiducial (notch or flat) downward (270°), the x-axis positive toward the right (0°), and the y-axis positive in the direction away from the fiducial (90°).

7.1.2 The spatial resolution of the data shall be appropriate for the height data array data point spacing, agreed upon between the parties of the test and shall be no greater than 2.0 mm in the scanning direction (y-direction), and no greater than 6.0 mm in the non-scanning direction (x-direction).

7.2 Calculation Software, to perform the calculations of this test method as detailed in section 9 and to provide outputs of the results, including statistical parameters, as agreed upon by the parties to the test.

8 Procedure

8.1 Obtain a thickness data array, \( Z_w(x_w, y_w) \) with the properties defined in section 7.1 through 7.1.2 in accordance with the procedures in SEMI MF1530 or by another method agreed upon by the parties to the test. The thickness data array must cover the entire FQA (except in defined exclusion areas).

NOTE 2: Note that in SEMI MF1530, the thickness array is called \( t(x, y) \).

8.2 The layout is defined by the field sizes in x and y-direction, and a placement of the fields over the substrate. This can be a fixed layout, application specific or flexible

8.2.1 Select the fixed quality area (FQA) by specifying the nominal edge exclusion EE. The FQA radius, \( R_{FQA} = R_{NOM} - EE \) where \( R_{NOM} \) is the nominal radius of the wafer (200 mm or 300 mm).

8.2.2 Define the field size in x-direction: \( L_x \) (default 26.0 mm) but less than or equal to the slit size \( S_x \).

8.2.3 Define the field size in y-direction: \( L_y \) (default 32.0 mm).

8.2.4 Define the exposure slit size in x-direction (length): \( S_x = 26.0 \) mm.

8.2.5 Define the exposure slit size in y-direction (height): \( S_y = 8.0 \) mm.

NOTE 3: Areas for MA metric calculation are defined by FQA radius and field sizes. The field size in x-direction must be specified, the field size in y-direction is optional.

8.3 Select one layout of fields to convert the thickness data array into an MA data array:

NOTE 4: The field layout can be a fixed, application specific or flexible field layout.

8.3.1 Fixed Field Layout

8.3.1.1 Define a field of size \( L_x \times L_y, 26.0 \text{ mm} \times 32.0 \text{ mm} \).

8.3.1.2 Place the first field centered on the wafer.

8.3.1.3 Place the following fields butting outwards, until the whole wafer surface area is covered with fields in aligned columns and rows (see Figure 1). Fields extending outside the fixed quality area are size limited to the boundary of the fixed quality area.
8.3.2 Application Specific Field Layout

8.3.2.1 Define a field of an application specific size $L_x \times L_y$.

8.3.2.2 Place the first field on the wafer (not necessarily centered).

8.3.2.3 Place the following fields butting outwards, until the whole wafer surface area is covered with fields in aligned columns and rows (see Figure 2). Fields extending outside the fixed quality area are size limited to the boundary of the fixed quality area.

NOTE 5: Because the field size in the $y$-direction $L_y$ is not directly relevant for MA calculations, the MA calculations might also be performed on a set of fields which are aligned in columns with the field size in the $y$-direction set to the wafer diameter (see Figure 3). As with the other cases, fields extending outside the fixed quality area are size limited to the boundary of the fixed quality area.

9 Calculations

NOTE 6: The following calculations are performed automatically within the calculation equipment. An outline of the calculation structures is provided here to indicate the nature of the procedure.

9.1 Select one specific definition of field layout.

9.2 For each selected field layout convert the thickness data array into an MA data array.

9.2.1 Define the thickness data array $Z_w(x_w,y_w)$ at all points $x_w,y_w$ within the FQA.

9.2.2 Define an exposure slit with a center coordinate $x_s,y_s$, a slit length $S_x$, and a slit width $S_y$.

9.2.3 At each point $x_w,y_w$ of a field, calculate a vector of defocus values for every slit center coordinate, $x_s,y_s$, such that the slit includes $x_w,y_w$, i.e., for $(y_w - S_y/2) < y_s < (y_w + S_y/2)$. 

Figure 1
Schematic View of Placement of Fields According to the Fixed Field Layout

Figure 2
Schematic View of Placement of Fields According to an Example of an Application Specific Field Layout

Figure 3
Schematic View of Placement of Fields According to any Field Layout in which the Field Size in the $y$-Direction, $L_y$, is Set to the Wafer Size
9.2.4 Calculate the defocus \( D \) at \( x_w, y_w \) for slit center \( x_s, y_s \) as follows:

\[
D(x_s, y_s, x_w, y_w) = Z_w(x_w, y_w) - (Z + R_y(x_w - x_s) + R_x(y_w - y_s)),
\]

where \( Z, R_x, \) and \( R_y \) are the plane coefficients (z-displacement, x-slope and y-slope), evaluated at \( x_s, y_s \), of a least-squares fit plane to the thickness data array over the slit, that is, over \((x_s - S_x/2) < x < (x_s + S_x/2)\) and \((y_s - S_y/2) < y < (y_s + S_y/2)\) using only thickness data array values within the field and within the FQA (see NOTE 9).

\[\text{Figure 4}\]

Schematic drawing of the different variables and coordinates used within section 9

NOTE 7: This least squares fit can be calculated in accordance with Section 13.3.1.3 of SEMI MF1530 as minimized over the slit area or by another method agreed upon by the parties to the test.

NOTE 8: Note that \( R_y \) is defined as tilt around the \( y \)-axis (\( x \)-slope) and \( R_x \) is defined as tilt around the \( x \)-axis (\( y \)-slope).

NOTE 9: Since the exposure fields have a finite size in the \( y \)-direction \( L_y \), slit positions \( x_s, y_s \) associated with \( x_w, y_w \) near the edge of an exposure field may have portions of the slit outside the field. For such positions, the associated plane coefficients, \( Z, R_x, \) and \( R_y \) are calculated using only thickness data from within the field to calculate the plane coefficients. Since also the FQA is finite (in \( x \) and \( y \)-directions), slit positions \( x_s, y_s \) associated with \( x_w, y_w \) near the FQA may have portions of the slit outside the FQA. For such position, the associated plane coefficients, \( Z, R_x, \) and \( R_y \) are calculated using only thickness data from within the FQA.

9.2.5 At each point \( x_w, y_w \) of a field, the vector \( D(x_s, y_s, x_w, y_w) \) has \( S \) defocus values, corresponding to each slit position associated with exposure of the point. The value of \( S \) is given by the size of the exposure slit in scanning direction \( S_y \) divided by the data point spacing in the scanning direction (\( y \)-direction). The vector has as many components as there are measurement points within a slit length.

9.2.6 Calculate the MA value, or average defocus \( <D> \) at \( (x_w, y_w) \), as the average of the values of the vector,

\[
MA(x_w, y_w) = <D> = \frac{1}{S} \sum_{y_s + S_y/2}^{y_s - S_y/2} D(x_s, y_s, x_w, y_w)
\]

where the defocus quantities \( D(x_s, y_s, x_w, y_w) \) are given by Equation 1.

9.2.7 Calculate the MSD value, the standard deviation of the defocus \( D \) at \( (x_w, y_w) \), as the standard deviation of the values of the vector,

\[
\text{MSD}(x_w, y_w) = \sigma_{D(x_w, y_w)} = \left[ \frac{1}{S-1} \sum_{y_s + S_y/2}^{y_s - S_y/2} [D(x_s, y_s, x_w, y_w) - <D> (x_w, y_w)]^2 \right]^{1/2}
\]

9.2.8 The result of the calculation is that the thickness data array \( Z_w(x_w, y_w) \), defined at all points \( x_w, y_w \) within the FQA, is converted with a selected field layout into an MA data array \( MA(x_w, y_w) \), defined at all points \( x_w, y_w \) within the FQA for this given field layout.
9.2.8.1 In the case of the flexible field layouts, one calculates an MA data array for every possible field layout on the thickness data array. The result will be \((L_x \text{ divided by the data point spacing in x-direction})\) different MA data arrays containing MA values for every \((x_w, y_w)\) within the FQA. The MA value at a given point \((x_w, y_w)\) is then calculated as the maximum of all MA\((x_w, y_w)\) values over all possible field layouts.

NOTE 10: The above calculation has not needed the y-dimension of an exposure field (only of the exposure slit) as input. The field size in the y-direction \(L_y\) is therefore not directly relevant for MA calculations. As noted above, therefore, the MA calculations might also be performed on a set of fields which are aligned in columns, and then the field size in y-direction \(L_y\) can be set to the wafer diameter. That is, the “exposure” is done in continuous “strips” of width \(L_x\) tiled in x and running from the top to the bottom of the wafer in y. But then also only height data from within the FQA is used to calculate the plane coefficients.

9.2.9 In all cases the end result of the calculations is an array of MA\((x_w, y_w)\) for all \((x_w, y_w)\) within the FQA.

9.3 Derive the following qualification quantities from the MA data array (see also figure 5 from left to right):

9.3.1 For whole wafer qualification derive the following MA flatness parameters:
9.3.1.1 3 sigma value of all MA\((x_w, y_w)\) values within the FQA,
9.3.1.2 99.7% percentile value of all MA\((x_w, y_w)\) values within the FQA, and
9.3.1.3 Range value of all MA\((x_w, y_w)\) values within the FQA.

9.3.2 For wafer full sites qualification derive the following Full-MA (FMA) flatness parameters:
9.3.2.1 3 sigma value of all MA\((x_w, y_w)\) values within the full sites,
9.3.2.2 99.7% percentile value of all MA\((x_w, y_w)\) values within the full sites, and
9.3.2.3 Range value of all MA\((x_w, y_w)\) values within the full sites.

9.3.3 For wafer partial sites qualification derive the following Partial-MA (PMA) flatness parameters:
9.3.3.1 3 sigma value of all MA\((x_w, y_w)\) values within the partial sites and FQA,
9.3.3.2 99.7% percentile value of all MA\((x_w, y_w)\) values within the partial sites and FQA, and
9.3.3.3 Range value of all MA\((x_w, y_w)\) values within the partial sites and FQA.

9.3.4 For wafer inner area qualification in an effective inner region up to a defined radius (e.g., the inner radial 135 mm) use all MA\((x_w, y_w)\) values within the effective inner region and derive the following Inner-MA (IMA) flatness parameters:
9.3.4.1 3 sigma value of all MA\((x_w, y_w)\) values within the effective inner region,
9.3.4.2 99.7% percentile value of all MA\((x_w, y_w)\) values within the effective inner region, and
9.3.4.3 Range value of all MA\((x_w, y_w)\) values within the effective inner region.

9.3.5 For wafer edge qualification in an effective edge region between a defined edge radius and the edge exclusion (e.g., the outermost radial 15 mm of the FQA) use all MA\((x_w, y_w)\) values within the effective edge region and derive the following Edge-MA (EMA) flatness parameters:
9.3.5.1 3 sigma value of all MA\((x_w, y_w)\) values within the effective edge region,
9.3.5.2 99.7% percentile value of all MA\((x_w, y_w)\) values within the effective edge region, and
9.3.5.3 Range value of all MA\((x_w, y_w)\) values within the effective edge region.

9.4 For traditional site by site flatness reporting, a flatness parameter per selected field, select the layout of fields which is used to convert the thickness data array into an MA data array (see section 8.3) and derive the following qualification quantities after having grouped all MA data per selected field.

9.4.1 For the qualification of a selected field derive the following MA flatness parameters:
9.4.1.1 3 sigma value of all MA\((x_w, y_w)\) values within a selected field,
9.4.1.2 99.7% percentile value of all MA\((x_w, y_w)\) values within a selected field, and
9.4.1.3 Range value of all MA(xw,yw) values within a selected field.

10 Report

10.1 Report the following basic information:

10.1.1 Date, time of test,

10.1.2 Identification of operator,

10.1.3 Location (laboratory) of test,

10.1.4 Identification of measuring instruments, including measuring equipment and calculation equipment (identification of make, model, software version, etc.),

10.1.5 Acquisition spatial resolution,

10.1.6 Data point spacing/measurement grid, and

10.1.7 Lot identification and wafer identification,

10.2 Report the layout information:

10.2.1 The nominal edge exclusion, EE,

10.2.2 Any additional exclusion areas,

10.2.3 The field size in the x-direction: Lx, and

10.2.4 The field size in the y-direction: Ly.

10.2.5 In the case of an application specific field layout, also report the center field location on the wafer.

NOTE 11: For fixed and flexible field layouts this information is not needed.

10.3 Report the calculated MA parameter statistics (see Figure 5).
Figure 5
Schematic Overview of Statistically Representing all MA(xw,yw) Values Within the Wafer’ FQA, Using Either Full Wafer Qualification Parameters (Left Hand Side) or Selectively Sorting MA(xw,yw) Values for Edge Region Qualification Parameters (Middle and Right Hand Side).

11 Keywords
Wafer flatness; MA; ERO; lithography; semiconductor; silicon; wafer
APPENDIX 1 Flexible Field Layout

A1-1 For the purpose of being able to quantify wafer flatness for scanning lithography using the MA metric, but being independent of field layout and placement on a substrate, a flexible field layout is defined.

A1-2 Define a field of size $L_x \times L_y$.

A1-3 Define a first initial layout ($L_1$):

A1-3.1 Place the first field centered on the wafer.

A1-3.2 Place the following fields butting outwards, until the whole wafer surface area is covered with fields in aligned columns and rows. Fields extending outside the fixed quality area are size limited to the boundary of the fixed quality area.

A1-4 Define a second shifted layout ($L_2$):

A1-4.1 Place the first field on the wafer shifted one measurement point in the $x$-direction with respect to the first layout.

A1-4.2 Place following fields butting outwards, until the whole wafer surface area is covered with fields in aligned columns and rows. Fields extending outside the fixed quality area are size limited to the boundary of the fixed quality area.

A1-5 Define further shifted layouts ($L_n$) until the shifted layout equals the first initial layout ($L_1$) again. This results in a number ($n$) of different (shifted) layouts equal to $L_x$ divided by the data point spacing in the $x$-direction (see Figure 6).

NOTE: Every successive layout is shifted by one measurement point to the right (black to grey).

Figure 6
Schematic View of Placement of Fields According to a Flexible Field Layout

A1-6 For each selected field layout ($L_n$) convert the thickness data array into an MA data array $MA_{L_n}(x_w,y_w)$ as described in section 9.2.

A1-7 For each point $(x_w,y_w)$ within the FQA, calculate the maximum MA value over all field layouts, $\max_{L_n} MA_{L_n}(x_w,y_w)$.

A1-8 This results in one array of $MA(x_w,y_w)$ for all $(x_w,y_w)$ within the FQA

A1-9 Derive the following qualification quantities from the MA data array (as described in section 9.3)
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