

SEMI M78-0923

GUIDE FOR DETERMINING NANOTOPOGRAPHY OF UNPATTERNED SILICON WAFERS HIGH VOLUME MANUFACTURING

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NOTICE: Paragraphs entitled ‘NOTE:’ are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

1 Purpose

1.1 Front-surface wafer height variations over specified distances need to be properly controlled to assure that wafers are acceptable for selected process steps. Nanotopography parameters are included in the International Technology Roadmap for Semiconductors (ITRS) since 2003. Nanotopography on a wafer surface prior to chemical-mechanical planarization (CMP) processes can result in variations of post-CMP film thickness with potential negative consequences for circuit performance, process cost, and yield.¹ Nanotopography features are characterized by their height variation within an area, and are discriminated from other features of similar height by their spatial wavelength range. Back-surface Nanotopography may also impact wafer suitability for selected process steps. This Guide may be applicable to either front- or back-surface measurements of Nanotopography.

1.2 This Guide provides procedures and a decision tree (refer to Figure 1) for selecting the different possible options in generating Nanotopography data. The key options used in the calculation are specified to define the data reported. This Guide is intended for use in the exchange of silicon wafers and is not intended for process development where a wider range of options and data reporting formats may be appropriate.

NOTE 1: SEMI M43 provides a framework for reporting Nanotopography surface features on silicon wafers but does not offer specific guidance on important topics such as filtering. The present Guide gives such guidance and also addresses industry standard practices applied to wafers for advanced technology nodes. Not all Nanotopography reported by SEMI M43 complies with the requirements of this Guide.

2 Scope

2.1 This Guide covers the determination and reporting of the Nanotopography of unpatterned silicon wafer surfaces. Typical examples include dips, bumps or waves on the wafer surface that have dominant spatial wavelengths less than 20 mm and vary in peak-to-valley (P-V) height from a few nanometers to several hundred nanometers.

2.2 This Guide specifies the technique for collecting and analyzing Nanotopography data.

2.3 Use of P-V metric is specified for Nanotopography quantification. An alternative deviation metric is described in Related Information 1.

2.4 Spatial representations of the defective areas on a wafer surface are outside the scope of this Guide.

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 Use of this Guide is intended to reduce measurement system specific effects. However, this Guide is not intended to fully describe the signal processing algorithms applied to determine the Nanotopography. The reported Nanotopography is influenced by limitations and parameters of the measurement system. These limitations include:

¹ Boning, D., Lee, B., Poduje, N., Valley, J., and Baylies, W. “Modeling and Mapping of Nanotopography Interactions with CMP.” Chemical-Mechanical Planarization, Materials Research Society Symposium Proceedings Vol. 732, Cambridge University Press, 2002, p. 28–39.

3.1.1 The finite spatial bandwidth of the measurement system and the applied filtering may result in surface variations outside the bandwidth of operation not being measured accurately. Also, the finite out-of-band rejection of filtering may produce artifacts in regions where the power in the rejected bands is high.

3.1.2 Measurement results may differ between systems of different design because different measurement systems employ different measurement methodologies and operate over different spatial bandwidths. Some measurement systems measure the surface height directly, while others determine it indirectly through measurement of the local surface slope or local curvature. Use of these different methods also may result in differences of the reported Nanotopography.

3.1.3 All measurement systems have a noise floor; features with height variations near this noise floor may be reported improperly.

3.1.4 The reported shape of some features may also depend on the spatial sampling methodology employed by the measurement systems.

3.1.5 Both the spatial extent of a surface height sample and the spatial sampling interval may affect the bandwidth limits as well as the measured magnitude of surface height features.

3.1.6 The overall response of a spatial-domain high-pass filter will depend on the spatial-filter digital implementation used to produce the specified Double Gaussian high-pass filtering.

3.1.7 The measurement system itself may impact the reported height data, that is, wafer handling or holding, the measurement principle and the design of the system may result in non-wafer related contributions or artifacts in the reported height values.

3.2 Reported Nanotopography also varies with interactions between wafer and measurement system. These limitations include:

3.2.1 Measurements within or near regions of extreme topography, such as the edge region of wafers with strong edge roll-off, may cause incorrect height measurement within the fixed quality area (FQA).

3.2.1.1 These regions tend to accentuate mechanical differences between measurement systems.

3.2.1.2 These regions tend to accentuate differences in the implementation of the measurement system filtering and analysis.

3.2.2 Closely spaced features may be counted as a single feature, or as no feature, if the spatial extent of the surface height sample is larger than the feature, or is larger than the spacing between features.

3.2.3 Reported features may result from the combination of the actual surface features, the manner in which the wafer is supported, or be caused by particles trapped between the wafer and the support.

3.2.4 High-pass (spatial frequency) filtering is used with these measurements to remove the (long-spatial wavelength) effects of wafer shape (such as bow, warp and sori). This filtering along with the wafer shape and wafer edge roll-off may affect the reported results.

3.2.5 At some spatial locations anomalous or extreme surface height variations of the wafer may exceed the ability of the measurement system to properly acquire the original height data in those locations.

3.3 Nanotopography characterization does not include microroughness, which applies to a shorter spatial wavelength range.

3.4 Use of either the constant or shrinking filter requires a different data treatment in the near edge region compared to the inner area of the wafer.

3.5 The choice of constant or shrinking filter in the near edge region will produce different results.

3.5.1 A shrinking filter (without extrapolation) results in lower reported Nanotopography in the affected region.

3.5.2 A constant filter (requiring extrapolation) can result in either higher or lower reported Nanotopography.

3.6 P-V measurements for analysis areas that extend beyond the FQA boundary (partial analysis areas) are based on fewer data points than analysis areas completely within the FQA boundary. Statistically this tends to reduce the reported P-V for these partial analysis areas.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M43 — Guide for Reporting Wafer Nanotopography

SEMI M59 — Terminology for Silicon Technology

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

5 Terminology

5.1 Definitions of general terms for silicon technology are found in SEMI M59.

5.2 Definitions

5.2.1 *analysis area* — an area on the height map of a wafer inside of which height variations are used to calculate Nanotopography.

5.2.2 *analysis map* — a map where the value at any coordinate represents the metric-determined Nanotopography for an analysis area centered on that coordinate in the height map.

5.2.3 *height map* — a representation of surface height as a function of position on a wafer surface $[z(x, y)]$.

5.2.4 *Nanotopography metric* — the parametric technique applied to data within each analysis area of filtered height map to quantify Nanotopography, for example, the P-V metric or deviation metric.

5.2.5 *partial analysis area* — an analysis area whose area is partly outside FQA while its center is still inside FQA.

5.2.6 *support area of filter* — for a spatial-domain filter, the area of the height map, centered on a surface height sample, which affects the filtered output at that height sample.

5.2.7 *surface height sample* — the measured or derived out-of-plane height value of the wafer surface at a known spatial coordinate.

NOTE 2: Both extrapolated and filtered data are derived surface heights. All derived surface heights are subject to limitations, even at the limit of perfect height measurement. Derived data must never be assumed to correspond to physical features on the wafer. However, prudent use of derived data is a required aspect of this Guide.

6 Procedure

6.1 *Data Acquisition* — Measure the height map of the wafer front surface or back surface within the FQA. Support the wafer during measurement in such a way as to minimize support-induced height artifacts in the wavelength range of interest. The minimum height map sample density is two points per mm in both x - and y -direction.

NOTE 3: The data density determines the high spatial-frequency of the height data unless a low-pass smoothing filter is applied.

6.2 Calculation of the High-Pass Filtered Wafer Height Map

6.2.1 *Near Edge Treatment* — Select between applying a shrinking filter or constant filter for near edge data treatment. Constant and shrinking refer to the spatial-domain filter's support area. For the case of constant filtering data extrapolation beyond the FQA boundary is typically required. An appropriate data extrapolation method, agreed upon between the supplier and customer, is implemented to derive the height map outside the FQA before filtering is performed.

NOTE 4: Different extrapolation methods (e.g., Zernike functions or Chebyshev polynomials) are feasible. The extrapolation algorithm is provided by the measurement system. Extrapolated height data must be physically reasonable compared to the adjacent measured data. Ideally the extrapolation enables the high-pass filter to result in reported Nanotopography which is not impacted by the closeness to the FQA boundary.

6.3 High-Pass Filtering

6.3.1 Implement a spatial-domain high-pass filter such that its overall response approximates that of a frequency-domain Double Gaussian filter with a cut-off wavelength (50% response) of 20 mm (refer to Appendix 1).