SEMI M53-0219
PRACTICE FOR CALIBRATING SCANNING SURFACE INSPECTION SYSTEMS USING CERTIFIED DEPOSITIONS OF MONODISPERSE REFERENCE SPHERES ON UNPATTERNED SEMICONDUCTOR WAFER SURFACES

This Standard was technically approved by the Silicon Wafer Global Technical Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on December 17, 2018. Available at www.semiviews.org and www.semi.org in February 2019; originally published March 2003; previously published April 2018.

SUPERSEDED

1 Purpose

1.1 This Practice describes calibration of scanning surface inspection system (SSIS) dark field detector channels so that the SSIS will accurately size polystyrene latex (PSL) spheres deposited on unpatterned polished, epitaxial, or filmed semiconductor wafer surfaces.

1.2 The purpose of this calibration is to ensure that different SSISs of a given manufacturer and model will assign the same light scattering equivalent (LSE) diameter to a specific localized light scatterer (LLS).

1.3 This Practice defines the use of LSE diameters, as defined in SEMI M59, as a means of reporting real surface defects whose identity, true size, and morphology are unknown.

1.4 This Practice provides a basis for quantifying SSIS performance as used in related standards concerned with parameters such as sensitivity, repeatability, and capture rate.

2 Scope

2.1 This Practice covers:

2.1.1 Requirements for the surface and other characteristics of the semiconductor substrates on which the reference spheres are deposited to form reference wafers (see ¶ 8.1),

2.1.2 Selection of appropriate certified depositions of reference spheres for SSIS calibration, including size distribution requirements to be met by the reference sphere depositions, but not the deposition method (see ¶ 8.3),

2.1.3 Generation of calibration curves using model-predicted scatter data that have response curve oscillations and are thus not monotonic, and

2.1.4 Generation of monotonic calibration curves using model-predicted scatter data.

2.2 Although it was developed primarily for use in calibration of SSISs to be used for detection of LLSs on polished silicon wafers with geometrical characteristics as specified in SEMI M1, this Practice can be applied to SSISs to be used for detection of LLSs on other unpatterned semiconductor surfaces, provided that suitable reference wafers are employed.

2.3 This Practice does not in any way attempt to define the manner in which LSE values are used to define the true size of LLSs other than PSL spheres (see ¶ 3.1).

2.4 This Practice supports requirements listed in SEMI M52.

2.5 Appendix 1 describes a method that may be used to determine the index of refraction of reference spheres that are not PSL.

NOTE 1: Repeated exposure to deep UV (DUV) illumination is known to alter the light scattering response of PSL sphere depositions. Therefore, manufacturers and end-users of DUV SSISs generally use monodisperse depositions of DUV-stable materials, silica (SiO_2) for example, for long-term periodic calibration of SSISs. To maintain continuity with LSE sizing, the light scattering intensity of such materials are usually assigned to the diameter of hypothetical PSL sphere depositions that would produce the same intensity, rather than their actual physical diameters. As such, wafers with deposited spheres of any material in this Practice serve as 'light scattering intensity reference wafers' rather than 'size standards.'

Documents Document Sharing Hub

Full document details: SEMI M53-0219

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 LLSs are normally assigned only LSE sizes, not physical diameters, because the response of an SSIS to an LLS depends on the SSIS optical system characteristics as well as the size, shape, orientation and composition of the LLS. The LSE size assigned to a particular LLS by an SSIS calibrated against PSL spheres may be different from that assigned to the same LLS by another similarly calibrated SSIS of a different model, because different SSISs have different optical system characteristics.

3.2 Reference spheres as sold in bulk may have specified characteristics (mean diameter uncertainty, diameter distribution, spread between mean and modal diameter) that differ significantly from the characteristics of the resulting deposition due to the transfer function of the deposition system. For this reason, the Practice is limited to the use of reference sphere depositions that are appropriately characterized in accordance with SEMI M58 and properly certified (see § 8).

3.3 The largest reference sphere diameter that can be used in this Practice depends on individual SSIS characteristics, but is often limited to a diameter of about ten times the light source wavelength.

3.4 The smallest reference sphere diameter that can be used in this Practice is determined by the sensitivity of the SSIS under calibration.

NOTE 2: At the time of development of this edition of the Practice, the smallest practical deposited reference spheres have physical diameters approaching 20 to 25 nm, but as IC technology evolves to smaller and smaller critical dimensions, it is expected that depositions of smaller diameter reference spheres will become available.

3.5 The SSIS signal is not necessarily monotonic with the diameter of a PSL sphere, especially for those having diameters approaching the wavelength of the light. As a result, the response curve (RC) determined by this Practice may not provide a unique determination of LSE diameter for all LLS.

3.6 If a monotonic response curve is used and if the usable signal range of the detector channel under calibration extends into a region where there are oscillations in the physical response curve, then LSE size assigned to a PSL sphere in the region is not necessarily accurate. Nevertheless, this Practice ensures an SSIS assigns *reproducible* LSE size to an LLS of any size, shape, and material composition.

3.7 *Background Contamination*

3.7.1 Both the deposition process and calibration procedures must be carried out in a Class 4 or better environment as defined in ISO 14644-1.

3.7.2 The presence of contamination with LSE sizes near that of the nominal reference sphere diameter on the reference wafer may skew the results. This condition may result in a large error or poor sizing accuracy.

3.7.3 High levels of contamination on the reference wafer or wafers may overload the SSIS or obscure the peak of the deposited reference sphere diameter distribution. This condition may also result in a large error or poor equivalent sizing accuracy.

3.7.4 For these reasons, both the deposition process and calibration procedures must be carried out in a clean environment, and the reference wafers must be handled in such a way as to avoid contamination between deposition process and calibration.

3.8 If the surface roughness of the reference wafer or wafers is excessive, the peak of the reference sphere diameter distribution may be obscured or distorted.

3.9 If the SSIS being calibrated is not operating in a stable condition, the calibration may not be appropriate for subsequent use of the system. System stability can be evaluated by making repeated calibrations, in accordance with this Practice, over suitable time periods.

SUPERSEDED

Documents
Document Sharing Hub
Full document details: SEMI M53-0219

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI M1 — Specification for Polished Single Crystal Silicon Wafers

SEMI M12 — Specification for Serial Alphanumeric Marking of the Front Surface of Wafers

SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M50 — Test Method for Determining Capture Rate and False Count Rate for Surface Scanning Inspection Systems by the Overlay Method

SEMI M52 — Guide for Specifying Scanning Surface Inspection Systems for Silicon Wafers for the 130 nm to 11 nm Technology Generations

SEMI M58 — Test Method for Evaluating DMA Based Particle Deposition Systems and Processes

SEMI M59 — Terminology for Silicon Technology

4.2 *ISO Standard*[1]

ISO 14644-1 — Cleanrooms and Associated Controlled Environments – Part 1: Classification of Air Cleanliness by Particle Concentration

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

5 Terminology

5.1 Acronyms, definitions, and symbols used in silicon technology may be found in SEMI M59.

5.2 Other acronyms used only in this Standard are as follows:

5.2.1 *GNF* — gain-nonlinearity function

5.2.2 *MPRC* — monotonic predicted response curve

5.2.3 *MRC* — monotonic response curve

5.2.4 *PRC* — predicted response curve

5.2.5 *RC* — response curve

5.3 Other terms used only in this Standard are as follows:

5.3.1 *gain-nonlinearity function (GNF)* — the relationship between the actual SSIS response and the model-predicted SSIS response, given as a function with two or more independent and adjustable parameters. The GNF should be independent of the reference sphere material, because it is a relationship between the SSIS detector response and the amount of light predicted to be incident upon the detector.

5.3.2 *LSE sphere sizing uncertainty* — an estimate of the relative uncertainty in the diameter reported by an SSIS for a PSL sphere having any diameter in the calibration range, determined by combining contributions from the calibration diameter errors and the certified deposition uncertainty.

5.3.3 *monotonic predicted response curve (MPRC)* — a predicted response curve derived from a PRC and modified to be monotonic. A subscript appended to the MPRC (e.g., $MPRC_{silica}$ or $MPRC_{PSL}$), indicates the sphere material for which the MPRC applies.

5.3.4 *monotonic response curve (MRC)* — the monotonic relation between the actual SSIS signal and sphere diameter, which differs from the RC_{PSL} by being derived from the MPRC rather than the PRC_{PSL}. A subscript appended to the MRC (e.g., MRC_{silica} or MRC_{PSL}), indicates the sphere material for which the MRC applies.

5.3.5 *predicted response curve (PRC)* — the model-predicted relation between scattered light intensity (or SSIS signal response) and sphere diameter that is used to analyze scanner response near various sphere diameters. The PRC depends upon sphere material and scanner design and is in general non-linear. It may contain regions with response

[1] International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland; Telephone: +41.22.749.01.11, http://www.iso.org

SUPERSEDED
Documents Document Sharing Hub
Full document details: SEMI M53-0219

curve oscillations that make the response-diameter relationship multi-valued. A subscript appended to the PRC (e.g., PRC_{silica} or PRC_{PSL}), indicates the sphere material for which the PRC is calculated.

5.3.6 *response curve (RC)* — the relation between actual SSIS signal and sphere diameter. A subscript appended to the RC (e.g., RC_{silica} or RC_{PSL}), indicates the sphere material for which the RC applies. The RC depends on scanner design and is in general non-linear. It may contain regions with response curve oscillations that make the response-diameter relationship multi-valued.

5.3.7 *response curve oscillations* — peaks and valleys in the response curve, which prevent the response curve from being monotonic.

6 Summary of Practice

6.1 The SSIS being calibrated is set up with machine conditions identical with those to be used in examining wafers.

6.2 Reference wafers with appropriate certified depositions are scanned by the SSIS.

6.3 The peak of the reference sphere diameter distribution deposited on each reference wafer is assigned to the peak value of the SSIS signal units.

6.4 A predicted response curve is determined for each reference sphere material and for PSL using its index of refraction and the appropriate parameters for the measurement conditions.

6.5 The actual SSIS signals and the predicted responses are used to determine the gain-nonlinearity function (GNF).

6.6 The PRC_{PSL} and the GNF are used to determine the response curve for PSL (RC_{PSL}), which may have response curve oscillations.

6.6.1 *Discussion* — If PSL spheres were used as reference spheres, a graph of the RC_{PSL} will lie very close to, but may not exactly match, a graph of the recorded signal versus reference sphere diameter. If another sphere material were used, a graph of the RC_{PSL} will not match a graph of recorded signal versus reference sphere diameter. That is, an SSIS calibrated to assign LSE diameters to LLSs will not correctly size non-PSL reference spheres.

6.7 The expanded PSL sphere sizing uncertainty is determined and compared to the requirements of SEMI M52.

6.8 A monotonic predicted response curve ($MPRC_{PSL}$) may be generated from the PRC_{PSL} to remove response curve oscillations.

6.9 The $MPRC_{PSL}$ and the GNF may be used to determine the monotonic response curve (MRC_{PSL}), which does not have response curve oscillations.

6.10 A separate RC_{PSL} and MRC_{PSL} are developed for each detector channel.

6.11 Either the RC_{PSL} or the MRC_{PSL} is used to determine and report the LSE diameter.

7 Apparatus

7.1 *Scanning Surface Inspection System* — Designed to detect, size, and map LLSs on unpatterned semiconductor wafers, that has the following capabilities:

7.1.1 Scans the entire fixed quality area of the surface of a wafer with a laser beam,

7.1.2 Detects LLSs as laser-light scattering events (see Note 3),

7.1.3 Has a user definable sensitivity threshold used to distinguish between background noise and real LLSs,

7.1.4 Can create a histogram of SSIS signals (i.e., number of laser light scattering events as a function of raw SSIS signal) for any given region on the wafer,

7.1.5 Can either evaluate the histogram peak or output a data set file that can be imported to a spreadsheet or other application program that can be used to generate the histogram peak,

7.1.6 Can either accept a user-provided calibration curve for each detector channel or can automatically perform the steps given in § 9 below,

7.1.7 Is sufficiently repeatable for the intended application, and

SUPERSEDED

Documents
Document Sharing Hub
Full document details: SEMI M53-0219

7.1.8 Handles wafers in a Class 4 or better clean environment as defined in ISO 14644-1.

NOTE 3: The amplitude of the LSE signal into a single detector, as measured for any combination of incident beam direction and collection optics, does not by itself convey topographic information, for example, whether the LLS is a pit or a particle. It does not allow the observer to deduce the size or origin of the scatterer without other detailed knowledge, such as its index of refraction and shape.

8 Reference Wafers

8.1 *Substrates* — Use bare semiconductor wafers with a native oxide (or other filmed) surface of the type intended to be tested with the SSIS to be calibrated as substrates for the certified depositions of the reference spheres. This is particularly important because SSIS response is affected by the optical properties of the substrate. Bare silicon wafer surfaces have different optical properties than wafers with film layers or wafers of different material. The wafers must meet the dimensional requirements of SEMI M1 for the appropriate nominal wafer diameter. Wafers nominally 200 mm in diameter and smaller shall be laser marked in accordance with SEMI M12, and wafers nominally 300 mm in diameter shall be laser marked in accordance with ¶¶ 6.5.1.4 through 6.5.1.4.9 of SEMI M1, including the optional alphanumeric mark described in ¶ 6.5.1.4.1 of SEMI M1.

8.2 *Certified Depositions* — The deposition property value that must be certified is the peak sphere diameter. The diameter distribution on the wafer and the reference sphere material must be specified. The diameter distribution is determined by the deposition process, and the reference sphere material affects its index of refraction.

8.3 *Range and Number of Calibration Diameters* — Choose the diameters of the reference spheres for the certified depositions so that the measurement range for the intended application is significantly covered. Use spheres of size ranging from less than the largest measurable size down to a size greater than that with an estimated capture rate of 95% and spaced approximately evenly on a logarithmic scale. The minimum and maximum sphere sizes do not need to be at the extremes of the required calibration range, since this Practice allows for extrapolation. Do not exceed the signal range of the SSIS detector channel being calibrated. The number of certified depositions should be at least four more than the number of adjustable parameters used for the GNF. A reference wafer may contain one or more certified depositions.

NOTE 4: The useful signal range is limited on the small signal side by the background noise or the inherent resolution of the instrument and on the large signal side by saturation of the detector and/or the related electronics. The small signal limit is usually defined as the smallest LSE sphere diameter than can be measured with a capture rate of at least 95%.

8.3.1 The index of refraction of the reference spheres may not be the same as that of the bulk material. In the case of PSL spheres, industry practice is to use the index of refraction of bulk polystyrene, given by:

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} \tag{1}$$

where A = 1.5663, B = 0.00785 μm^2, C = 0.000334 μm^4, and λ is the wavelength of light. A method suitable for determining the index of refraction of non-PSL spheres is described in Appendix 2.

NOTE 5: The above coefficients have been shown to be valid over the wavelength range $0.42 < \lambda\ (\mu m) < 0.62$. Some state-of-the-art SSIS may use excitation at shorter wavelengths. However, good sizing correlation has been observed using this equation at shorter wavelengths.

NOTE 6: Best results are typically achieved when using the number, the sizes of reference spheres, and the extent of allowable extrapolation recommended by the SSIS manufacturer.

8.4 *Background Contamination*

8.4.1 Handle and store reference wafers with great care to avoid contamination and damage.

8.4.2 Establish that the unimodal peaks in the SSIS LLS histogram generated from the reference sphere depositions are well defined and well above the background level over all the response curve except near the low signal threshold. Also verify that each unimodal curve extends to less than 50% of its peak value on both sides of the peak within a diameter range of ±2.5% of the reference sphere diameter at the peak of the distribution. Do not use depositions that fail either of these criteria.

NOTE 7: The RC depends on scanner design and is in general non-linear. It may contain regions with response curve oscillations that make the response-diameter relationship multi-valued.

SUPERSEDED

Documents Document Sharing Hub
Full document details: SEMI M53-0219

8.5 *Data to Accompany Reference Wafers* — The following information must accompany each reference wafer.

8.5.1 For each certified deposition on a reference wafer provide:

8.5.2 The deposition peak diameter and the uncertainty in accordance with the requirements of Row 5.3 of Table 3 of SEMI M52.

8.5.3 The maximum possible value of the deposition diameter distribution full width at half maximum (FWHM) expressed as a percentage of peak diameter.

8.5.4 The approximate particle count of each certified deposition.

8.5.5 The approximate location of each certified deposition on the reference wafer by the *x*- and *y*-coordinates (as specified in SEMI M20) of the center of the deposition area or by a map or drawing of the wafer.

8.5.6 Identification of the deposition system used for the deposition by model and serial number.

8.5.7 The date of production.

8.5.8 Wafer identification.

8.5.9 Name and address of the reference wafer manufacturer.

8.5.10 Identification of the deposited reference spheres by material, supplier, lot number and model.

9 Procedure

9.1 Obtain the required number of suitable reference wafers with certified depositions (see ¶ 8.3) to cover each established signal range.

9.2 Set up the SSIS in accordance with the manufacturer's instructions for the wafer diameter, sizes of reference spheres, and other machine conditions to be used during the calibration procedure. Ensure that machine conditions are identical with those to be used in examining wafers with the calibrated SSIS.

9.3 Ensure that the SSIS is operating properly for the selected machine conditions.

9.4 Load the first reference wafer into the SSIS.

9.5 Scan the wafer.

9.6 Generate a data set file of the distribution of LLSs as a function of reported SSIS signal.

9.7 Repeat ¶¶ 9.2 through 9.6 for each of the remaining certified depositions.

9.8 Determine the peak of the reference sphere diameter distribution for each of the certified depositions used for the calibration.

NOTE 8: Many SSISs now feature automated determination of the peak of sphere diameter distributions. For SSISs where the determination is manual, users should carefully note histogram aspects such as scaling and nonuniform bin widths which may bias peak position.

9.9 For each reference sphere material and for PSL, create a PRC using the SSIS detector channel geometry, source wavelength, source polarization and appropriate material constants over the range from less than the minimum certified deposition diameter to greater than the maximum certified deposition diameter with a recommended diameter spacing of approximately the illumination wavelength divided by 50 in order to accurately predict RC oscillations. Calculate the PRC using the Bobbert-Vlieger model provided in the Modeled Integrated Scatter Tool (MIST) program.[2] Alternatively, use another program suggested by the instrument manufacturer, provided that it can be shown to have as good or better results. Record the PRC values for each certified deposition by interpolating the PRC for the reference sphere material at its certified diameter.

9.10 Obtain the GNF by adjusting the independent parameters for a best fit to the SSIS signals found in ¶ 9.8 versus the corresponding PRC values obtained in ¶ 9.9. Typically the curve is a smooth straight line on a log-log graph, so use the following form:

[2] This program can be downloaded without charge from the Web site of the National Institute of Standards and Technology: http://physics.nist.gov/scatmech

SUPERSEDED
Documents
Document Sharing Hub
Full document details: SEMI M53-0219