

SEMI M53-0706

PRACTICE FOR CALIBRATING SCANNING SURFACE INSPECTION SYSTEMS USING CERTIFIED DEPOSITIONS OF MONODISPERSE POLYSTYRENE LATEX SPHERES ON UNPATTERNED SEMICONDUCTOR WAFER SURFACES

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1 Purpose

1.1 This Practice describes calibration of SSIS dark field channels so that the SSIS accurately sizes PSL spheres deposited on unpatterned polished, epitaxial, or filmed semiconductor wafer surfaces.

1.2 This Practice defines the use of latex sphere equivalent (LSE) signals as a means of reporting real surface defects whose identity and true size are unknown.

1.3 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 PSL spheres are deposited to form reference wafers (see ¶ 8.1),

2.1.2 Selection of appropriate certified depositions of PSL spheres for SSIS calibration, including size distribution requirements to be met by the PSL sphere depositions, but not the deposition method (see ¶ 8.2),

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 localized light scatterers (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 covers a single-point calibration procedure that may be used in limited production applications but which does not support requirements listed in SEMI M52.

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 PSL 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 PSL sphere depositions that are appropriately characterized in accordance with SEMI M58 and properly certified (see ¶ 8.4).

3.3 The largest PSL 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 lower diameter limit is imposed by the sensitivity of the SSIS under calibration.

NOTE 1: At the time of development of this edition of the practice, the smallest practical deposited PSL spheres have diameters approaching 30 nm, but as IC technology evolves to smaller and smaller critical dimensions, it is expected that depositions of smaller diameter PSL spheres will become available.

3.5 If the monotonic response curve is used and if the dynamic range of the channel under calibration extends into a region where there are response curve oscillations in the non-monotonic response curve, then the PSL sphere sizing accuracy will be reduced in that region.

3.6 Background Contamination

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

NOTE 2: ISO class 4 is approximately the same as Class M2.5 (Class 10) as defined in Federal Standard 209E.

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

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

3.6.4 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.

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

3.7 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.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI M1 — Specifications for Polished Monocrystalline 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, 90 nm, 65 nm, and 45 nm Technology Generations

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

SEMI M59 — Terminology for Silicon Technology

4.2 Federal Standard¹

Fed Std 209E — Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones

4.3 ISO Standard²

ISO 14644-1 Cleanrooms and Associated Controlled Environments — Part 1: Classification of Airborne Particulates

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 CR — capture rate

5.1.2 CV — coefficient of variation

5.1.3 GNF — gain-nonlinearity function

5.1.4 LLS — localized light scatterer

5.1.5 LSE — latex sphere equivalent

5.1.6 MPRC — monotonic predicted response curve

5.1.7 MRC — monotonic response curve

5.1.8 PRC — predicted response curve

5.1.9 PSL — polystyrene latex

5.1.10 RC — response curve

5.1.11 SSIS — scanning surface inspection system

5.2 Definitions of Terms

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

5.2.2 Other Definitions

5.2.2.1 *calibration diameter error* — the deviation between the RC and the certified deposition diameter.

5.2.2.2 *capture rate (CR)* — the probability that a scanning surface inspection system (SSIS) detects a localized light scatterer (LLS) of latex sphere equivalent (LSE) signal value at some specified SSIS operational setting.

5.2.2.3 *certified deposition* — a PSL sphere deposition on an unpatterned wafer with the same surface films and finish as the wafers to be examined by the calibrated SSIS with specific property values certified by a technically valid procedure, accompanied by or traceable to a certificate that is issued by a certifying body.

5.2.2.3.1 *Discussion* — The deposition property values that must be certified are the peak sphere diameter and the diameter distribution on the wafer and are determined by both the PSL sphere source and the deposition process.

5.2.2.4 *coefficient of variation (CV)* — one standard deviation, σ , expressed as a percentage of the mean of a Gaussian distribution.

5.2.2.5 *deposition* — an approximately known number of PSL spheres of known size distribution placed in a known location on the surface of a reference wafer.

5.2.2.6 *deposition process* — the procedure used to place the PSL spheres on the reference wafer.

5.2.2.7 *dynamic range* — of a scanning surface inspection system, the signal range covered by an instrument with one set of measurement conditions.

¹ Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS (This Standard has been Superseded by ISO 14644-1 and may no longer be available.)

² International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland; Telephone: +41.22.749.01.11, Fax: +41.22.733.34.30, <http://www.iso.org>

5.2.2.7.1 *Discussion* — The useful dynamic 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 PSL sphere diameter than can be measured with a capture rate of at least 95%.

5.2.2.8 *false count* — a laser-light scattering event that arises from instrumental causes rather than from any feature on or near (in) the wafer surface; also called *false positive*; compare *nuisance count*.

5.2.2.8.1 *Discussion* — False counts would not be expected to occur at the same point on the wafer surface during multiple inspection scans, and hence they could be considered as random ‘noise’ that could be identified by examining the results of repeated scans.

5.2.2.9 *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.

5.2.2.10 *histogram* — a representation of a partitioned (binned) data set as a bar graph in which the widths of the bars are proportional to the sizes of the bins of the data set variable, and the height of each bar is proportional to the frequency of occurrence of values of the variable within the bin.

5.2.2.10.1 *Discussion* — In presenting data for the size distribution of LLSs, the data set variable is usually the derived LSE size; in presenting haze data, the data set variable is usually the haze in ppm. The data set is usually partitioned into bins of equal size on either a linear or logarithmic scale, as appropriate. The bins at the low and high ends of the data set variable range are customarily plotted with the same width as the remainder of the histogram even though they may represent a larger or smaller range of the independent variable than the rest of the bins.

5.2.2.11 *laser-light scattering event* — a signal pulse that exceeds a preset amplitude threshold, generated by the interaction of a laser beam with an LLS at a wafer surface as sensed by a detector.

5.2.2.11.1 *Discussion* — The amplitude of the 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. In a scanning surface inspection system, laser-light scattering events and the background signal due to haze together comprise the signal due to light scattering from a wafer surface.

5.2.2.12 *latex sphere equivalent (LSE)* — pertaining to a monodisperse polystyrene latex sphere that, under identical test conditions, produces the same detected scattering intensity as the LLS under investigation.

5.2.2.12.1 *Discussion* — If the LLS is assumed to be due to a particle (or pit), the LSE size (diameter) of the particle (or pit) is given in units of length followed by LSE; for example, 0.12 μm , LSE. This unit varies in different ways for different materials from instrument to instrument because of differences in the optical systems and signal processing procedures of different instruments. Therefore a particular LLS generally does not have the same LSE size when measured on different model instruments or on different channels of the same instrument. If elements of the optical system, such as incidence angle, collection solid angle, or polarization, of an SSIS can be varied, the LSE size of a particular LLS is not necessarily the same for each configuration of the optical system.

5.2.2.13 *localized light scatterer (LLS)* — an isolated feature, such as a particle or a pit, on or in a wafer surface, resulting in increased light scattering intensity relative to that of the surrounding wafer surface; historically called *light point defect* because under high intensity optical illumination features of sufficient size appear as isolated points of light.

5.2.2.13.1 *Discussion* — Localized light scatterers are observed by automated inspection techniques as laser-light scattering events. Automated inspection techniques are quantitative in the sense that scatterers with different scattering intensities can be segregated. However, the amplitude of the scattered light intensity, or ‘laser-light scattering event,’ as measured by any combination of incident beam direction and collection optics, does not by itself convey topographical information about the LLS; particles and pits cannot be distinguished solely on the basis of single-channel amplitude data. Also, the observer cannot deduce the size, shape, or composition of the LLS from single-channel amplitude alone. The presence of LLSs does not necessarily decrease the utility of the wafer.

5.2.2.14 *missing count* — the case in which an LLS fails to produce a laser-light scattering event; also called *false negative*.

5.2.2.15 *monotonic predicted response curve (MPRC)* — a predicted response curve derived from the PRC and modified to be monotonic.

5.2.2.15.1 *Discussion* — The MPRC is identical to the PRC in regions of small diameter and removes the response curve oscillations in the PRC at larger diameters. The MPRC may, for example, be a running average of the PRC, a fit to a function which has the appropriate limiting behavior (e.g., $\sim D^6$ at small diameter and $\sim D^2$ at large diameter), or a modeled average response for an ensemble of real-world particles. The MPRC should be developed by the SSIS manufacturer so that identical SSIS models will have the same MPRC.

5.2.2.16 *monotonic response curve (MRC)* — the monotonic relation between the actual SSIS signal and LSE diameter, which differs from the RC by being derived from the MPRC rather than the PRC.

5.2.2.17 *nuisance count* — a signal pulse that arises from discrete or area surface or near-surface features other than the localized light scatterers being investigated; compare *false count*.

5.2.2.17.1 *Discussion* — The presence of nuisance counts is dependent on the threshold and gain settings and may be a function of the optical configuration of the SSIS, the orientation of the wafer surface, or both.

5.2.2.18 *polystyrene latex (PSL)* — a colloidal aqueous solution of polystyrene microspheres from which certified depositions are made.

5.2.2.19 *predicted response curve (PRC)* — the model-predicted relation between scattered light intensity (or SSIS signal response) and PSL sphere diameter that is used to analyze scanner response near various PSL sphere diameters. The PRC 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.

5.2.2.20 *PSL 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.

5.2.2.21 *reference wafer* — for calibrating an SSIS in accordance with this Practice, an unpatterned wafer with the same surface films and finish as the wafers to be examined by the calibrated SSIS and upon which one or more PSL sphere depositions have been certified to specified uncertainties for peak diameter and diameter distribution.

5.2.2.22 *response curve (RC)* — the relation between actual SSIS signal and PSL sphere diameter.

5.2.2.22.1 *Discussion* — 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.

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

5.2.2.23.1 *Discussion* — The purpose of a calibration is to relate the amount of light captured by an SSIS to the physical size of the light scatterer. The amount of light scattered from a localized light scatterer (LLS) that is captured by the SSIS is a function of both the scattering characteristics of the LLS (including the directional dependence of the scattering) and the geometry of the collection optics of the SSIS. For a given wavelength of incident radiation and SSIS geometry, regular objects of certain sizes exhibit non-linearities, in the form of response curve oscillations, so that the curve of scattering amplitude as a function of physical size of the scatterer may not be monotonic. Thus, similar objects with modest variations in physical size can scatter the same amount of light into a given detector. Different materials may exhibit response curve oscillations at different sizes. Response curve oscillations occur for PSL sphere diameters greater than about half of the wavelength.

5.2.2.24 *scanning surface inspection system (SSIS)* — an instrument for rapid examination of the entire quality area of a wafer to detect the presence of localized light scatterers or haze or both; also called *particle counter* and *laser surface scanner*.

5.2.2.25 *threshold* — the level set on a scanning surface inspection system (SSIS) to discriminate between signal pulses of different size.

5.2.2.25.1 *Discussion* — Thresholds may be set to discriminate between true counts and surface or electrical noise (nuisance or false counts, respectively) or between different sizes of light scatterers. Because of spatial non-uniformity of the intensity of the scanning beam and the general use of overlapping scans in an SSIS, a localized light scatterer with equivalent size near the threshold may generate a signal greater than or less than the threshold depending on its