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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Determining the Positional Accuracy Capabilities of a Scanning Surface Inspection System¹

This standard is issued under the fixed designation F 1621; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the determination of the accuracy with which a scanning surface inspection system (SSIS) reports the positions of localized light scatterers on a silicon wafer surface.

NOTE 1—This practice was developed primarily for use with laser-based SSISs. Although it may also be applicable for determining the positional accuracy capabilities of other types of SSISs, the conditions for which this extension of the practice might be valid have not been determined.

1.2 This practice includes procedures to separate the influences of wafer handling and wafer orientation on the precision and bias of the positions reported.

1.3 The procedure must be carried out on an SSIS that is located in a Class M2.5 (Class 10) or better environment as defined in Federal Standard 209E.

1.4 This practice relies on a fabricated silicon reference wafer that contains a prescribed pattern of multiple etched feature fields on its polished (front) surface.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method²

F 1241 Terminology of Silicon Technology³

F 1618 Practice for Determination of Uniformity of Thin Films on Silicon Wafers³

F 1620 Practice for Calibrating a Scanning Surface Inspection System Using Monodisperse Polystyrene Latex Spheres Deposited on Polished or Epitaxial Wafer Surfaces³

2.2 SEMI Standard:

M1 Specification for Polished Monocrystalline Silicon Wafers⁴

2.3 Federal Standard:

Fed Std 209E Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones⁵

2.4 ISO Standard:

ISO/TAG 4/WG 3 Guide to the Expression of Uncertainty in Measurement⁶

3. Terminology

3.1 Definitions:

3.1.1 *accuracy*—the closeness of agreement between a test result or the mean of a group of test results and the accepted reference value.

3.1.1.1 Discussion—Accuracy depends on both precision and bias of the measurement process. Since in routine use, random components of error (resulting in imprecision) and systematic components of error (resulting in bias) cannot be completely separated, the reported accuracy must be interpreted as a combination of these two elements. In part because of the inability to separate the random and systematic components of error, the ISO Guide to the Expression of Uncertainty in Measurement⁶ separates uncertainty components of a measurement result into two categories (Type A and Type B) based on their method of evaluation. Type A uncertainties are those that are evaluated by the statistical analysis of a series of observations. Type B uncertainties are those that are evaluated by other (nonstatistical) means.

3.1.2 *bias*—the systematic difference between the population mean of the test results from a measurement process and the accepted reference value of the property being measured.

3.1.2.1 Discussion—One or more systematic error components may contribute to the bias. Because the population mean involves the totality of all possible test results, it cannot be determined directly. The sample mean, $\bar{x}$, is an estimator of the population mean:

¹ This practice is under the jurisdiction of ASTM Committee F-1 on Electronics and is the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

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² Annual Book of ASTM Standards, Vol 14.02.

³ Annual Book of ASTM Standards, Vol 10.05.

⁴ Available from Semiconductor Equipment and Materials International, 805 E. Middlefield Rd., Mountain View, CA 94043.

⁵ Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

⁶ Available from ISO Central Secretariat, C. P. 56, CH-1211 Genève 20, Switzerland, or (in the U.S.A.) from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (1)$$

3.1.3 *coefficient of variation (CV)*—the standard deviation expressed as a percentage of the estimated value.

3.1.3.1 Discussion—CV can be estimated from the sample standard deviation, s , and the mean value, $\bar{x}$, of a distribution as follows:

$$CV = \frac{s}{\bar{x}} \times 100$$

where CV is an appropriate measure of variability only when the sample standard deviation is proportional to the mean; otherwise it varies with the value of the measurand. If the sample standard deviation is independent of the value of the measurand, it is more appropriate to use it directly rather than CV.

3.1.4 *dynamic repeatability*—repeatability as determined from a series of measurements made with removal and replacement of the test wafer between each measurement.

3.1.4.1 Discussion—Dynamic repeatability includes contributions from load-unload and other handling operations. It may be influenced by test wafer nonuniformity as well as lateral and rotational positioning variations.

3.1.5 *etched feature*—a localized light scatterer of specified size photolithographically defined on or in a silicon wafer surface to simulate a particle or surface topography.

3.1.5.1 Discussion—Wafers with etched features may serve as calibration artifacts for both scanning surface inspection systems and surface topography instruments.

3.1.6 *etched feature array*—a group of etched feature fields on a silicon wafer that have defined spatial relationships with one another.

3.1.7 *etched feature field*—a group of etched features on a silicon wafer that have defined spatial relationships with one another.

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

3.1.8.1 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.

3.1.9 *laser-light scattering event*—a signal pulse that exceeds a preset threshold, generated by the interaction of a laser beam with a localized light scatterer (LLS) at a wafer surface as sensed by a detector; see also **haze**.

3.1.9.1 Discussion—The amplitude of the signal, as measured by 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, the background signal due to haze and laser-light scattering events together comprise the signal due to light scattering from a wafer surface.

3.1.10 *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; sometimes called **light point defect**.

3.1.10.1 Discussion—Localized light scatterers of sufficient size appear as points of light under high intensity optical illumination; these points of light can be observed visually, but the observation is a qualitative one. 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 "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 amplitude data. Also, the observer cannot deduce the size, shape, or composition of the LLS from the signal amplitude alone. The presence of LLSs does not necessarily decrease the utility of the wafer.

3.1.11 *missing count*—the case in which a localized light scatterer does not produce a laser-light scattering event; also called **false negative**.

3.1.12 *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**.

3.1.12.1 Discussion—The presence of nuisance counts may be a function of the optical configuration of the scanning surface inspection system, the orientation of the wafer surface, or both.

3.1.13 *positional accuracy*—deviation of the location of a localized light scatterer (LLS) on a wafer surface as reported by the scanning surface inspection system from the true position of the LLS on the wafer.

3.1.14 *precision*—a measure of the variability of a measurement process about the mean value of the test results obtained.

3.1.14.1 Discussion—Unless the measurement process is in a state of statistical control, the precision of the process has no meaning. Since the precision is poorer for greater dispersion of the test results, measures of variability (such as repeatability and reproducibility) are actually direct measures of the imprecision of the measurement process.

3.1.15 *repeatability*—the closeness of agreement between test results obtained under repeatability conditions.

3.1.15.1 Discussion—Repeatability can be quantified as the repeatability standard deviation, σ_r , or the repeatability limit, r . In either case, repeatability is determined from a series of measurements made either with (dynamic repeatability) or without (static repeatability) removing the test wafer between each measurement. In the context of particle counting, the use of σ_r is preferred; the repeatability limit is included because the repeatability of fully evaluated ASTM test methods is reported in terms of this quantity.

3.1.16 *repeatability conditions, for evaluation of scanning surface inspection systems*—test conditions involving acquisition of a series of test results with the same test protocol

and instrument set up in the same laboratory by the same operator on the same equipment in the shortest practical period of time on the same test wafer without explicit recalibration.

3.1.16.1 Discussion—The acquisition of test data under repeatability conditions is intended to avoid influences of long-term drift, operator or instrument differences, material variability, and the like. Recalibration of the instrument would be expected to cause discontinuous differences in test results. However, if recalibration is required by the test protocol or is internal to the instrument, it is considered to be an allowable variation in determination of repeatability.

3.1.17 *repeatability limit (r)*—the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with some specified probability.

3.1.17.1 Discussion—The repeatability limit is given as follows:

$$r = k\sigma_r$$

where σ_r is the repeatability standard deviation. Both m , the number of repetitions used in determining σ_r , and k must be reported together with r . Typically, r is the value below which the absolute difference between two individual test results may be expected to occur with a probability of approximately 95 %. For the case of normally distributed data, $k \approx 1.96\sqrt{2} \approx 2.77$; although this factor is strictly accurate if the population standard deviation, σ , is used, it has become customary to use it even when the population standard deviation is estimated by the sample standard deviation, s .⁷

3.1.18 *repeatability standard deviation (σ_r)*—the standard deviation of m repeated measurements made under repeatability conditions (static or dynamic).

3.1.18.1 Discussion—The repeatability standard deviation can be estimated from (1) the sample standard deviation of a set of m determinations on a single day ($m \geq 2$), (2) the pooled sample standard deviation of multiple sets of m determinations made on different days by the same or different operators, or (3) the pooled, single instrument, single operator within-laboratory sample standard deviation of m measurements made in several laboratories as described in Practice E 691. In some cases, σ_r is simply called "repeatability."

3.1.19 *reproducibility*—the closeness of agreement between the means of test results obtained with the same test method on the same test wafer (or a lot of "identical" test wafers) under different (specified) conditions.

3.1.19.1 Discussion—Among the different conditions that can be used are operator, set-up procedures, recalibration, environmental conditions, test instrumentation, measurement location, and long time period; conditions varied for a particular determination of reproducibility must be reported together with the reproducibility. If q different conditions introduce variability into the measurement independently from one another, the variances add directly as follows:

$$\sigma_R = (\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \dots + \sigma_q^2)^{1/2}$$

and they may be separated by the use of judiciously designed experiments.

Reproducibility can be quantified as the reproducibility standard deviation, σ_R , or the reproducibility limit, R . In the context of particle counting, the use of σ_R is preferred; the reproducibility limit is included because the reproducibility of fully evaluated ASTM test methods is reported in terms of this quantity; however, it should be noted that the reproducibility standard deviation used in this context is not identical with the quantity defined here. (Refer to Practice E 691 for a more complete discussion of this issue.)

3.1.20 *reproducibility limit (R)*—the value below which the absolute difference between two individual test results obtained with the same test method on the same test wafer (or a lot of "identical" test wafers) under different conditions may be expected to occur with some probability.

3.1.20.1 Discussion—The reproducibility limit is given as follows:

$$R = k\sigma_R$$

where σ_R is reproducibility standard deviation obtained with a specified set of measurement conditions. Typically, R is the value below which the absolute difference between two test results obtained under different (specified) conditions may be expected to occur with a probability of approximately 95 %. For the case of normally distributed data, $k \approx 1.96\sqrt{2} \approx 2.77$; although this factor is strictly accurate if the population standard deviation, σ , is used, it has become customary to use it even when the population standard deviation is estimated by the sample standard deviation, s .⁷

3.1.21 *reproducibility standard deviation (σ_R)*—the standard deviation of the population of the means of test results obtained with the same test method on the same test wafer (or a lot of "identical" test results obtained with the same test method on the same test wafer (or a lot of "identical" test wafers) under a specified set of p different test conditions.

3.1.21.1 Discussion—If the number of replications, n , made with each test condition is large, the sample standard deviation, $s_{\bar{x}_i}$, of the means, $\bar{x}_i$, is as follows:

$$s_{\bar{x}_i} = \left[\frac{1}{p-1} \sum_{i=1}^p (\bar{x}_i - \bar{x}_{\text{grand}})^2 \right]^{1/2}$$

where $\bar{x}_{\text{grand}}$ is the average of the $\bar{x}_i$, is an unbiased estimate of σ_R . However, if, as is usually the case, n is relatively small (4 to 10), each $\bar{x}_i$ contains a contribution from the uncertainty of the average of n measurements so that $s_{\bar{x}_i}^2$ is actually the unbiased estimator of the sum $\sigma_R^2 + m\sigma_r^2$, where m is the number of replications used in determining σ_r . Therefore the reproducibility standard deviation for a given set of test conditions can be estimated as follows:

$$s_R = \left[s_{\bar{x}_i}^2 - \frac{ms_r^2}{n} \right]^{1/2}$$

where s_r is the estimator for the repeatability standard deviation of m measurements.

3.1.22 *sample standard deviation (s)*—the positive square root of the sum of the squares of the deviations of a sample of n observations, x_i , from the sample average, $\bar{x}$, divided by the number of degrees of freedom.

⁷ Mandel, John, "Repeatability and Reproducibility," *Materials Research and Standards*, Vol 11, No. 8, August 1971, pp. 8-15, 52.