SEMI E104-0302
SPECIFICATION FOR INTEGRATION AND GUIDELINE FOR CALIBRATION OF LOW-PRESSURE PARTICLE MONITOR

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1 Purpose

1.1 The use of in situ particle monitoring (ISPM; particle measurements performed while the wafer resides inside the processing chamber) in low-pressure and vacuum applications provides a number of advantages for defect, process, and equipment management such as:

- Reduction of particle test wafers used for off-line tests and saving operator time,
- Optimization and real-time characterization of the process,
- Advanced process control,
- Advanced equipment control,
- Monitoring process chamber conditions, and
- Optimization of cleaning procedures and maintenance.

1.1.1 Therefore, ISPM achieves more equipment availability and faster ramp-up of the production, reduces cost of ownership, improves quality and yield. To reach these goals, ISPM needs to be easily integrated into new or existing process equipment and the acquisition as well as the analysis of the particle data needs to be automated. The ISPM sensor should not have any negative influence on the process and the measurement has to represent the main particle flow. The sensor should be designed to have a minimum negative impact on the parameters defined in SEMI E10 for the whole semiconductor process equipment, to achieve an advantage in capacity.

1.2 This Standard is intended to stipulate operating conditions, mechanical, electrical, and communication interfaces for the use of low-pressure particle detectors integrated in semiconductor process equipment. A guideline for a reference calibration of those sensors is intended to support correlation between measurements with different sensors.

2 Scope

2.1 This Standard applies to particle measurement under low-pressure and vacuum conditions in semiconductor manufacturing equipment.

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 Referenced Standards and Documents

3.1 *SEMI Standards and Safety Guidelines*

SEMI C6.5 — Particle Specification for Grade 10/0.2 Nitrogen (N_2) and Argon (Ar) Delivered as Pipeline Gas

SEMI C6.6 — Particle Specification for Grade 10/0.1 Nitrogen (N_2) and Argon (Ar) Delivered as Pipeline Gas

SEMI E4 — SEMI Equipment Communications Standard 1 Message Transfer (SECS-I)

SEMI E5 — SEMI Equipment Communications Standard 2 Message Content (SECS-II)

SEMI E10 — Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM)

SEMI E33 — Specification for Semiconductor Manufacturing Facility Electromagnetic Compatibility

SEMI E37 — High-Speed SECS Message Services (HSMS) Generic Services

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SEMI E54 — Sensor/Actuator Network Standard

SEMI E54.10 — Specification for Sensor/Actuator Network Specific Device Model for an In-Situ Particle Monitor Device

SEMI F6 — Guide for Secondary Containment of Hazardous Gas Piping Systems

3.2 *ASTM Standards*[1]

ASTM D1193 — Standard Specification for Reagent Water

ASTM F328 — Standard Practice for Calibration of an Airborne Particle Counter Using Monodisperse Spherical Particles

ASTM F649 — Practice for Secondary Calibration of Airborne Particle Counter Using Comparison Procedures

3.3 *BSI Standard*[2]

BS 3406-7 — Determination of Particle Size Distribution – Recommendations for Single Particle Light Interaction Methods

3.4 *IEC Standards*[3]

IEC 60625-1 — Programmable Measuring Instruments – Interface System (Byte Serial, Bit Parallel) – Part 1: Functional, Electrical and Mechanical Specifications, System Applications, and Requirements for the Designer and User

IEC 60625-2 — Programmable Measuring Instruments – Interface System (Byte Serial, Bit Parallel) – Part 2: Codes, Formats, Protocols, and Common Commands

IEC 60654-1 — Operating Conditions for Industrial-Process Measurement and Control Equipment – Part 1: Climatic Conditions

IEC 60654-2 — Operating Conditions for Industrial-Process Measurement and Control Equipment – Part 2: Power

IEC 60654-3 — Operating Conditions for Industrial-Process Measurement and Control Equipment – Part 3: Mechanical Influences

IEC 60654-4 — Operating Conditions for Industrial-Process Measurement and Control Equipment – Part 4: Corrosive and Erosive Influences

IEC 60801-1 — Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment – Part 1: General Introduction

3.5 *IEEE Standards*[4]

IEEE 488.1 — IEEE Standard Digital Interface for Programmable Instrumentation

IEEE 488.2 — IEEE Standard Codes, Formats, Protocols, and Common Commands for use with IEEE 488.1, IEEE Standard Digital Interface for Programmable Instrumentation

3.6 *IEST Standard*[5]

IEST RP-011 — A Glossary of Terms and Definitions Related to Contamination Control

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[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA; Telephone: +1.610.832.9585, Fax: +1.610.832.9555, http://www.astm.org

[2] British Standards Institution, 389 Chiswick High Road, London, W4 4AL, UK; Telephone: +44.0.20.8996.9001, Fax: +44.0.20.8996.7001, http://www.bsigroup.com

[3] International Electrotechnical Commission, 3 rue de Varembé, Case Postale 131, CH-1211 Geneva 20, Switzerland; Telephone: +41.22.919.02.11, Fax: +41.22.919.03.00, http://www.iec.ch

[4] Institute of Electrical and Electronics Engineers, 3 Park Avenue, 17th Floor, New York, NY 10016-5997, USA; Telephone: +1.212.419.7900, Fax: +1.212.752.4929, http://www.ieee.org

[5] Institute of Environmental Sciences and Technology, 940 East Northwest Highway, Mount Prospect, IL 60056, USA.

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3.7 *ISO Standards*[6]

ISO 1609 — Vacuum Technology – Dimensions (ISO-K Style and ISO-F Style)

ISO 2861-1 — Vacuum Technology – Quick-Release Couplings – Dimensions – Part 1: Clamped Type (ISO-KF)

ISO 2861-2 — Vacuum Technology – Quick-Release Couplings – Dimensions – Part 2: Screwed Type (ISO-MF)

ISO 3669 — Vacuum Technology – Bakeable Flanges – Dimensions (ISO-K-CF)

ISO 9000 — Suite of International Quality Standards and Guidelines

ISO 13323-2 — Determination of Particle Size Distribution – Single Particle Light Interaction Methods Part 2: Light Scattering Single Particle Light Interaction Devices Design, Performance Specifications, and Operation Requirements

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

ISO 14644-5 — Cleanrooms and Associated Controlled Environments – Part 5: Operation of Cleanroom Systems

3.8 *JIS Standard*[7]

JIS B 9921 — Light Scattering Automatic Particle Counter

3.9 *VDI Standards*[8]

VDI-Richtlinie 3489-3 — Messen von Partikeln: Methoden zur Charakterisierung und Überwachung von Prüfaerosolen - Optischer Partikelzähler (Particulate Matter Measurement: Methods of Characterizing and Monitoring Test Aerosols – Optical Particle Counter)

VDI-Richtlinie 3491 — Messen von Partikeln: Herstellungsverfahren für Prüfaerosole, Verdünnungssysteme (Particulate Matter Measurement: Generation of Test Aerosols, Dilution Systems)

4 Terminology

4.1 *Abbreviations and Acronyms*

4.1.1 *COV* — coefficient of variation

4.1.2 *HEPA* — high-efficiency particulate air

4.1.3 *ISPM* — in situ particle monitor

4.1.4 *LDL* — lower detectable limit

4.1.5 *LPPD* — low-pressure particle detector

4.1.6 *PHA* — pulse height analyzer

4.1.7 *RPC* — reference particle counter

4.1.8 *ULPA* — ultra-low penetration air

4.2 *Definitions*

4.2.1 *accuracy of size* — the closeness of agreement between the ascertained size of the detected particle and its real size.

4.2.2 *coefficient of variation (COV)* — the width of a distribution (in %), obtained by dividing the standard deviation of the distribution by the mean of the distribution.

4.2.3 *coincidence* — the presence of two or more particles in the detection area of the particle detector at the same time, causing the particle detector to interpret the combined signal erroneously as resulting from one larger particle.

[6] 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

[7] Japanese Standards Association, 4-1-24 Akasaka, Minato-ku, Tokyo 107-8440, Japan; Telephone: +81.3.3583.8005, Fax: +81.3.3586.2014, http://www.jsa.or.jp

[8] Beuth Verlag GmbH, Burggrafenstrasse 6, D-10787 Berlin, Germany.

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4.2.4 *concentration* — the number of particles per unit volume, at ambient temperature T_A and pressure p.

4.2.5 *concentration limit* — the particle concentration specified by the manufacturer of the particle detector at which the error due to coincidence is 10% or less.

NOTE 1: Manufacturers may specify concentration limits at error levels other than 10%.

4.2.6 *counting efficiency* — the ratio (in %) of detected concentration divided by the actual concentration of particles of a given size or range of sizes (see Appendix 2).

4.2.7 *detection area* — the area, defined through the light beam and the detection optics, in which the particles are detected. Often this area is much smaller than the cross-section of the pump line or the process chamber.

4.2.8 *high-efficiency particulate air (HEPA) filter* — filter with a minimum particle-collection efficiency of 99.97% on all particles larger than 0.3 micrometer.

4.2.9 *in situ* — refers to processing steps or tests that are done without moving the wafer. Latin for 'in original position'.

4.2.10 *in situ particle monitor (ISPM)* — particle monitor used under atmospheric conditions or in low-pressure, vacuum or liquid applications to detect particles while a process is running.

4.2.11 *isokinetic sampling* — sampling of particles in a moving aerosol or fluid by matching the sample probe inlet velocity (flow speed and direction) to the velocity of the moving aerosol or fluid.

4.2.12 *lower detectable limit (LDL)* — in particle measurement: the smallest particle size that a particle detector can measure at a given flow rate with a signal-to-noise ratio of at least 3 dB and with a counting efficiency of 50% ± 10%.

NOTE 2: This is a general definition of LDL. Due to the special design of most of the LPPDs, a counting efficiency of 50% cannot be achieved.

4.2.13 *low-pressure particle detector (LPPD)* — optical particle sensor for use under low-pressure and vacuum conditions to measure particles or particle levels in semiconductor process equipment.

4.2.14 *monodisperse calibration particles* — particles with known optical properties, a sizing accuracy of at least 95%, and a size distribution in which the coefficient of variation is 5% or less.

4.2.15 *optical equivalent size* — the diameter of a monodisperse calibration particle that produces the same detected scattering intensity as the localized light scatterer (LLS) under investigation under identical test conditions.

4.2.16 *particle size* — for applications, size is the optical equivalent diameter of a reference sphere with known properties as detected by a given light-scattering particle counter [as defined in SEMI C6.5 and SEMI C6.6]. For calibration, size is the mean diameter of the monodisperse sphere.

4.2.17 *resolution* — the capability of the particle detector to differentiate between particles of similar size.

NOTE 3: The procedure to define resolution is discussed in § 9.2.3.5.

4.2.18 *sensitivity* — in particle measurement: the smallest standard particle size specified by the manufacturer that an instrument, method, or system is capable of measuring under specified conditions (with a counting efficiency of 50%; see Appendix 2). Also called minimum detectable particle size.

4.2.19 *ultrafine particle* — a particle with an equivalent diameter less than 0.1 µm [as defined in ISO 14644-1].

4.2.20 *ultra-low penetration air (ULPA) filter* — filter with a minimum particle-collection efficiency of 99.9995% on the most penetrating particle size.

4.2.21 *zero count* — the maximum particle count indicated by a particle counter, in a specified period of time, that is sampling particle-free air. This value is specified by the manufacturer, and is commonly also referred to as false call rate, false count, noise, or noise level.

4.2.22 *zero gas* — in determining contaminant contribution by gas distribution system components, a purified gas that has an insignificant particle concentration above the lower detectable limit (LDL) of the analytical instrument. This gas is used for both instrument calibration and component testing.

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4.3 *Symbols*

4.3.1 A_L — detection area (mm^2), defined through detector optics and light beam of the LPPD.

4.3.2 A_{RC} — opening area (mm^2) of the probe inlet of the reference particle counter.

4.3.3 C_L — number concentration (cm^{-3}) of particles in the line at the LPPD.

4.3.4 C_G — number concentration (cm^{-3}) of particles generated from aerosol generator at given V'_G.

4.3.5 D_L — diameter of the pump line (mm) at the LPPD.

4.3.6 d_p — diameter of the spherical particle (µm).

4.3.7 D_{RC} — diameter of the sample drawing line (mm) for the reference particle counter.

4.3.8 D_{VM} — diameter of the pump line (mm) at the velocity meter.

4.3.9 p — line pressure (torr or mbar).

4.3.10 RH — relative humidity (%).

4.3.11 T_A — ambient temperature (°C) around the measurement or calibration system.

4.3.12 T_G — gas temperature (°C).

4.3.13 v_L — velocity (m/s) of the aerosol at the LPPD.

4.3.14 $v_{L,\ min}$, $v_{L,\ max}$ — for applications, the velocity range (m/s) of the aerosol at the LPPD specified by the manufacturer.

4.3.15 V'_L — volume flow rate (l/min) in the line at the LPPD.

4.3.16 V'_G — volume flow rate (l/min) of the aerosol sample (measured directly behind the aerosol generator).

4.3.17 v_{VM} — velocity (m/s) of the aerosol at the velocity meter.

4.3.18 V'_{ZG} — volume flow rate (l/min) of the zero gas.

4.3.19 $\sigma_{V,LPPD}$ — standard deviation of the voltage sensor signal.

4.3.20 $\sigma_{p,LPPD}$ — standard deviation of the observed particle distribution.

4.3.21 $\sigma_{d,p}$ — standard deviation of the particles given by the particle supplier.

5 Mechanical Interfaces

5.1 *Flanges*

5.1.1 One of the following vacuum flanges should be used for mounting an LPPD into a pump line or on process equipment:

- ISO 2861-1 and ISO 2861-2 (ISO-KF/MF)
- ISO 1609 (ISO-K and ISO-F)
- ISO 3669 (ISO-K-CF)

5.2 *Space, Distances, and Installation*

5.2.1 The use of an LPPD should not have a negative impact on the process performance. The sensor location in the equipment shall ensure an optimum use of the sensor sensitivity in order to allow a measurement which is representative of the main particle flow. The influence of the process and the process equipment on the LPPD shall be minimized (thermal background radiation, vibrations, etc.).

5.2.2 The standard does not specify where an LPPD should be located in original equipment, or where space should be allowed for retro-fitting. It is recognized that the location is dependent on factors including transport behavior of particles, thermal background radiation etc. The designers of semiconductor process equipment should resort to the experience of application engineers of the LPPD suppliers and the end users. However, in either case designers shall

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take into account access requirements for maintenance and re-calibration. In the case of retro-fitting, the design should facilitate sensor installation rather than hinder it.

6 Electrical Interfaces

6.1 *Sensor/Controller Communication*

6.1.1 Depending on the choice of the LPPD supplier and the semiconductor equipment manufacturer, one of the following interfaces for data exchange between the LPPD and process equipment controller should be used.

6.1.2 *Sensor/Actuator Network (SAN)*

6.1.2.1 The electrical interfaces of the Sensor/Actuator Network are described in the suite of SEMI E54 Standards.

6.1.3 *Serial Communication*

6.1.3.1 RS 232 C (V.24/V.28)

6.1.3.2 RS 485

6.1.4 *Others*

6.1.4.1 IEEE 488 or IEC 60625

6.2 *Others*

6.2.1 Sensor calibration output (direct analog output).

6.2.1.1 The analog output for access to the sensor signal used for calibration purpose should be supported.

7 Communication Interfaces

7.1 *Sensor Bus Communication*

7.1.1 It is recommended to use a Sensor/Actuator Network (SAN) for the intra-tool communication between the LPPD controller and the controller of the process equipment. This communication is based on a suite of SEMI Standards including a Network Communication Standard, several Common Device Models (DeviceNet, SDS, Lonworks, ProfiBus etc.), and the specific device model for the sensor. The Network is described by the following suite of SEMI Standards: SEMI E54. The specific device model for ISPM is described by SEMI E54.10.

7.2 *SEMI Equipment Communication (SECS)*

7.2.1 If LPPD controllers provide the collected particle data to the process equipment controller, factory automation system, or SPC system, the SECS tool-to-host communication could be used. SECS is described in the following Standards:

- SEMI E5
- SEMI E4
- SEMI E37

7.3 *Attribute Definitions*

7.3.1 SEMI E54.10 addresses the minimum attributes, services and behavior an ISPM-device shall support. If any attributes and services are used by communication of the ISPM and the equipment controller via IEEE 488 (IEC 60625) or serial communication, they should be concurring.

8 Operating Conditions

8.1 To specify the operating conditions of an LPPD (temperature, humidity, electromagnetic compatibility, vibrations, etc.) refer to the following standards:

- IEC 60654-1
- IEC 60654-2
- IEC 60654-3

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- IEC 60654-4
- IEC 60801-1

8.2 *Temperature*

8.2.1 The LPPD should work correctly at an ambient temperature range T_A as specified in ISO 14644-5. If the use of an LPPD at an extended ambient temperature range is required, the specific LPPD should comply with these conditions.

8.2.2 The temperature T_G inside the pump line or inside the process equipment depends on the actual application. The application engineers shall check the use of LPPDs under these specific conditions. The temperature T_G is measured at the flange which the LPPD is mounted on.

8.3 *Humidity*

8.3.1 The LPPD should work correctly at an ambient humidity range RH as specified in ISO 14644-5. If the use of an LPPD at an extended ambient humidity range is required, the specific LPPD should comply with these conditions.

8.4 *Electromagnetic Compatibility*

8.4.1 The equipment should comply with SEMI E33.

8.4.2 Sensors will be incorporated into equipment either as original equipment or retro-fitted. In either case, the sensors or the equipment of which they are a part should comply with the current regulations covering EMC in the country or region where the equipment or sensor is used.

8.5 *Vibrations*

8.5.1 Process equipment designers are advised to consider the impact of vibration on the performance of the sensor while it is collecting data. Therefore, they should minimize vibrations. The designers of the LPPD sensors are also advised to consider the impact of vibrations on the equipment at a time the sensor is not collecting any data. It might be possible that these vibrations are stronger than those occurring while the sensor is collecting data.

9 Reference Calibration Procedure

9.1 The response of real contamination particles, typically with refractive indices and shapes different from calibration particles, will differ slightly from the results obtained by the procedures in this Document. It is known that LPPDs with different optical design may not produce the same data from identical aerosol samples. This may happen even with similar LPPDs if calibration differences have occurred. Therefore, before the first use the sensor should be calibrated by the manufacturer. This calibration should be compliant with or should be reviewed with the following reference calibration equipment and procedure. This reference calibration allows the characterization of the performance of the LPPD under test. The LPPD should be recalibrated at regular intervals and also in case of unusual measurement readings to ensure correct results.

9.1.1 The parameters calibrated for LPPDs with sizing capability are:

- Sizing calibration,
- Resolution,
- Zero counting,
- Counting efficiency, and
- Sensitivity.

9.1.2 The parameters calibrated for LPPDs with non-sizing capability are:

- Zero counting, and
- Counting efficiency.

9.1.3 Field calibration may not necessarily require the calibration of all parameters performed by calibration at the sensor manufacturer's site.

9.1.4 Due to the fact that different LPPDs might be working with different detection areas A_L, the number of counts should be printed out in counts per mm^2 detection area. Therefore, a comparison of the measurement results of different

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