

SEMI E78-0222

GUIDE TO ASSESS AND CONTROL ELECTROSTATIC DISCHARGE (ESD) AND ELECTROSTATIC ATTRACTION (ESA) FOR EQUIPMENT

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NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

1 Purpose

- 1.1 The purpose of this Guide is to minimize the negative impact on productivity caused by static charge and electric fields in semiconductor manufacturing equipment. It is a guide for establishing electrostatic compatibility of equipment used in semiconductor manufacturing. Electrostatic compatibility in the entire semiconductor factory is addressed in SEMI E129.
- 1.2 Electrostatic surface charge causes a number of undesirable effects in semiconductor manufacturing environments.
 - 1.2.1 Electrostatic discharge (ESD) damages both products and reticles. ESD events also cause electromagnetic interference (EMI), resulting in equipment malfunctions.
 - 1.2.2 Charged wafer and reticle surfaces attract particles (electrostatic attraction [ESA]) and increase the defect rate. Charge on products can also result in equipment malfunction or product breakage.
 - 1.2.3 Operating problems and additional product defects due to static charge can have a negative impact on the cost of ownership (COO) of semiconductor manufacturing equipment (refer to SEMI E35).
- 1.3 This Standard can be used as a guide for equipment manufacturers during the design and testing of their equipment. The test methods described can also be used by semiconductor manufacturers to check the performance of equipment and to verify its conformance with procurement specifications.
- 1.4 Semiconductor process technology continues to move toward smaller product geometries. Acceptable static charge levels continue to decrease with product feature size. This Guide provides recommendations for equipment static charge limits that are appropriate for the product being manufactured, referencing the feature sizes contained in the International Roadmap for Devices and Systems (IRDS).

2 Scope

- 2.1 The scope of this Guide is limited to providing recommended methods of measurement and guidance for the maximum recommended level of static charge on:
 - Product or reticles,
 - Carriers, and
 - Parts of the input/exit ports of equipment and minienvironments.
- 2.2 This Guide presents a table of maximum recommended levels of static charge on products, reticles, carriers, and the input and exit ports of production equipment or minienvironments. The purpose is to:
 - Reduce product, reticle, and equipment damage due to ESD;
 - Reduce equipment lock-up problems due to ESD events; and

- Reduce the attraction of particles to charged surfaces.

2.3 This Guide references SEMI E43 and other methods of measuring static charge.

2.4 Appendix 1 describes the methodology for determining the maximum recommended static charge levels that are shown in ¶ 12.7, Table 1. It includes both the original methodology contained in SEMI E78 and the updated information that harmonizes this Guide with the recommendations of SEMI E129.

NOTE 1: Related Information 1 of this Guide contains a theoretical investigation of particle ESA, as well as case histories from users and equipment manufacturers as to the static charge problems encountered and how they were solved. A bibliography of related technical papers is also included. Related Information 2 describes static-control methods commonly used in semiconductor manufacturing. A more detailed discussion of these static-control methods is found in SEMI E129. Related Information 3 contains an example for adding electrostatic-compatibility requirements to purchasing documents for semiconductor manufacturing equipment. Related Information 4 discusses the risk to reticles from electric fields. Revision Record describes the changes in this Guide from SEMI E78-0912.

2.5 For product and reticle protection or EMI control, the ESD risk of an area is defined by the presence and nature of the ESD events that occur.

2.6 For contamination control by reducing particle ESA, the static risk of an area is defined by the presence and level of static charges.

2.7 For damage to reticles, the risk is defined by the rate of change of static charge on a reticle or the electric field strength around a reticle.

2.8 An increasing amount of semiconductor production is done in minienvironments or within the production equipment. The majority of static-related problems occur while the product is in its carriers, or being transferred from them, by the production equipment.

2.9 Static-control methods can be incorporated in the equipment design to reduce static charge to acceptable levels. This Guide should be used primarily by equipment manufacturers during the design of their equipment.

2.10 There are test methods available (see §§ 6 and 7 of this Guide) to demonstrate the effectiveness of the static control methods. The end user should be able to use the same test methods to verify compliance with an equipment purchase specification. Testing should be done by persons qualified in the field of electrostatic measurements.

2.11 Increasingly, semiconductor production equipment is assembled using modules supplied by different manufacturers. While each module manufacturer may use the test methods in this Guide to demonstrate the effectiveness of their static-control methods, it is recommended that the same testing be applied to the complete system by the end user.

2.12 Static-control methods applied to equipment design cannot solve all static-related problems in the semiconductor manufacturing facility. Transport of product or reticles throughout the facility can be affected by and be the cause of static problems. Moving personnel in the manufacturing facility can also be a source of static charge problems. These facility issues are addressed in SEMI E129.

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 *Static Measurements* — Measurements of electrostatic quantities such as charge, electric field, voltage, and resistance to ground are difficult to make.

3.1.1 The nature of the object (insulator or conductor), its geometry, its surroundings, and the measuring equipment itself, are only a few of the factors affecting the accuracy of an electrostatic measurement.

3.1.2 In general, direct measurement of static charge is possible with small, moveable objects. Larger objects, and those fixed in position, should be characterized by the electric field that results from the static charge.

3.1.3 Similarly, it is difficult to relate the measurement of an electrostatic quantity to its effect on products or equipment.

3.1.3.1 For example, an ESD simulator produces a standardized discharge waveform when a capacitor is discharged at a known voltage. This instrument is used to establish the ESD damage threshold for semiconductor products, or the effect of ESD on equipment.

3.1.3.2 While the amount of charge transferred by the ESD simulator is known ($q = CV$, where q is charge, C is capacitance, and V is voltage), the maximum current that results is not. There is no guarantee that the same amount of charge would produce the same results if different values of capacitance and voltage were used.

3.2 *Location* — The test methods for static charge and maximum recommended levels of static charge on product, reticles, and carriers are meant to be applied at the input/exit ports of production equipment, and when possible for characterization within the equipment. This Guide is not meant to be applied in any way that affects the process within the equipment.

3.3 *Test Methods* — The test methods referenced in this Guide do not guarantee precise measurements of static charge levels. The maximum static charge levels recommended in this Guide have large tolerances (see ¶ 15.1).

3.4 *Static Charge Control* — There are a variety of static-related issues in a semiconductor manufacturing environment. The issues are complex due to the wide range of electrostatic problems, and device or equipment sensitivities to these problems. This Guide contains general recommendations. Users of this Guide are cautioned that specific static-related problems can require or allow different levels of static charge than are recommended in this Guide.

3.5 *Measurements*

3.5.1 *Measurements of Very High Static Potentials (>30,000 V)* — Measurements of very high static potentials (>30,000 V) should be done at large enough distances to avoid exceeding the measurement range of the meter and/or an ESD event to the meter.

3.5.2 Accuracy of measurements of static voltage on the object may vary depending on the size of the object, the distance from the object, and presence of other grounded or charged objects in the immediate proximity to the measured object. It is recommended to consult the measuring equipment manufacturer for information regarding measurements made at alternative distances.

3.5.3 *Measurements on Moving Objects or Surfaces* — Care should be taken, when attempting to read electrostatic charges on moving objects or surfaces, to maintain correct distance and avoid any contact; this is to ensure ‘good’ readings with no mechanical damage or personal injury.

3.5.3.1 Measurements made on moving objects should be done using measuring equipment with a response time fast enough for the speed of the moving object. It is recommended to consult the measuring equipment manufacturer for relevant information.

3.6 This Guide does not apply to semiconductor manufacturing equipment that does not handle or contain products or reticles, or their carriers.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI E33 — Guide for Semiconductor Manufacturing Equipment Electromagnetic Compatibility (EMC)

SEMI E35 — Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment

SEMI E43 — Guide for Electrostatic Measurements on Objects and Surfaces

SEMI E129 — Guide to Assess and Control Electrostatic Charge in a Semiconductor Manufacturing Facility

SEMI E163 — Guide for the Handling of Reticles and Other Extremely Electrostatic Sensitive (EES) Items Within Specially Designated Areas

4.2 ANSI¹/ESDA²/JEDEC³ Standards

ANSI/ESDA/JEDEC JS-001 — ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Human Body Model (HBM) – Component Level

ANSI/ESDA/JEDEC JS-002 — ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Charged Device Model (CDM) – Device Level

4.3 IEC Standards⁴

IEC 61000-4-2 — Electromagnetic Compatibility (EMC) – Part 4.2: Testing and Measurement Techniques – Electrostatic Discharge Immunity Test

4.4 United States Military Standards⁵

MIL-STD 883 — Department of Defense Test Method Standard: Microcircuits

4.5 Other Documents

EMC Directive 2014/30/EU⁶ — Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the Harmonisation of the Laws of the Member States Relating to Electromagnetic Compatibility

IRDS 2017 — International Roadmap for Devices and Systems⁷ (Formerly ITRS 1999, 2002, 2011 — International Technology Roadmap for Semiconductors – ITRS⁸)

White Paper 2: A Case for Lowering Component Level CDM ESD Specifications and Requirements⁹

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *CD* — critical dimension

5.1.2 *CDM* — charged device model

5.1.3 *COO* — cost of ownership

5.1.4 *EC* — European Commission

5.1.5 *EMI* — electromagnetic interference

5.1.6 *ESA* — electrostatic attraction

5.1.7 *ESD* — electrostatic discharge

5.1.8 *HBM* — human body model

5.1.9 *IC* — integrated circuit

5.1.10 *RH* — relative humidity

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² EOS/ESD Association, 218 W Court St., Rome, NY 13440-2069, USA; Telephone: +1.315.339.6937, <http://www.esda.org>

³ Joint Electron Device Engineering Council, 3103 North 10th Street, Suite 240-S, Arlington, VA 22201, USA; Telephone: +1.703.907.7560, Fax: +1.703.907.7583, <http://www.jedec.org>

⁴ International Electrotechnical Commission, 3 rue de Varembe, Case Postale 131, CH-1211 Geneva 20, Switzerland; Telephone: +41.22.919.02.11, Fax: +41.22.919.03.00, <http://www.iec.ch>

⁵ United States Military Standards, Available through <http://www.everyspec.com>

⁶ European Commission, Telephone: +00.800.67891011, https://ec.europa.eu/growth/sectors/electrical-engineering/emc-directive_en

⁷ Institute of Electrical and Electronics Engineers, IEEE Operations Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, New Jersey 08855-1331, USA. Telephone: +1.732.981.0060; Fax: +1.732.562.6380; <https://irds.ieee.org>

⁸ ITRS Worldwide Distribution Center; <http://public.itrs.net>

⁹ EOS/ESD Association, Inc., 218 W Court St., Rome, NY 13440-2069, USA; Telephone: +1.315.339.6937, <http://www.esda.org>

5.2 Definitions

5.2.1 *acceptable equipment-induced electrostatic levels* — acceptable static charge levels related to the major technology nodes of product and reticle feature sizes.

5.2.2 *carrier* — a device for holding wafers, dies, packaged integrated circuits (ICs), or reticles for various processing steps in semiconductor manufacturing.

5.2.3 *deposition rate* — particle flux to a surface (number of particles deposited per unit area per unit time) divided by the particle concentration adjacent to the surface boundary layer. Sometimes called the deposition velocity.

5.2.4 *electromagnetic interference (EMI)* — electromagnetic phenomena that can interrupt, obstruct, or otherwise degrade or limit the effective performance of electrical equipment. [SEMI E176]

5.2.5 *electrostatic attraction (ESA)* — the force between two or more oppositely charged objects.

NOTE 2: The result is increased deposition rate of particles onto charged surfaces, or movement of charged materials.

5.2.6 *electrostatic compatibility* — charge control adequate to allow the manufacturing of products and the interequipment transfer of products, reticles, and carriers without electrostatic problems. [SEMI E129]

5.2.7 *electrostatic discharge (ESD)* — the rapid spontaneous transfer of electrostatic charge induced by a high electrostatic field.

NOTE 3: Usually the charge flows in a spark between two objects at different electrostatic potentials.

5.2.8 *ESD simulator* — an instrument providing a specified electrostatic discharge current waveform when discharged directly to a product or equipment part.

5.2.9 *input and exit ports* — the locations where product and/or product carriers are placed to allow the equipment to process them, or where they are removed from the equipment after processing.

5.2.10 *minienvironment* — a localized environment created by an enclosure to isolate the product from contamination and people. [SEMI E45]

5.2.11 *product* — any unit intended to become a functional semiconductor device. This includes functional engineering devices.

5.2.12 *withstand voltage* — the highest voltage stress at which no device failures occur during discharge testing of integrated circuit (IC) devices.

5.3 Symbols

5.3.1 *N/A* — particle burden added to a wafer (number of particles per unit area)

5.3.2 *q* — charge

6 Establishing Requirements

6.1 The following sections contain test methods that can be used to establish static damage thresholds for product, reticles, or equipment. They also contain test methods to determine the levels of static charge and electrostatic fields that result on product, reticles, and equipment during the manufacturing process.

6.2 As an alternative to determining actual static charge sensitivity levels for product, reticles, and equipment, the end user may establish requirements based on the year and technology node of the manufacturing process. Recommendations for acceptable equipment static charge levels are found in ¶ 12.7, Table 1.

6.3 *Measurement Methods and Instrumentation* — No single method of testing for static charge can determine a ‘safe’ level. The amount of static charge, the distribution of static charge on an object, and the nature of the static discharge can all interact to determine if the charge level is safe.

6.3.1 It can be difficult to determine levels that *guarantee* static-related problems are totally eliminated.

6.3.2 Measurement methods described in this Guide can assist the user in identifying static charge or electric field levels likely to cause problems in process equipment. They can allow the user to evaluate the effectiveness of the methods used to control the static charge and electric field levels.

6.4 Testing for ESD Damage

6.4.1 When considering direct ESD damage to an object (i.e., product, reticle, equipment), the important parameter is the current accompanying the charge transfer to or from the object. Under a controlled set of test parameters, the damaging amount of current due to the charge transfer to or from the object can be determined.

6.4.2 When testing packaged devices, ESD simulators of various types are used for this purpose. Refer to ANSI/ESDA/JEDEC JS-001, ANSI/ESDA/JEDEC JS-002, or MIL-STD 883 standards listed in § 4 for further information concerning packaged device testing.

6.4.2.1 The above industry standards characterize the ESD sensitivity of packaged devices by the maximum voltage on the pins of the device that may be discharged without damage to the device. Suitable instrumentation can be used to measure the voltage on the pins of packaged devices as they are handled by production equipment.

6.4.3 There are no established standards for ESD simulator testing of wafers, reticles, or unpackaged semiconductor devices. ESD damage thresholds for these items may be different than for packaged devices.

6.4.4 Once the damaging current level for a product is determined using an appropriate ESD simulator (depending on the standard being used), the corresponding amount of charge is known from the ESD simulator operating parameters.

6.4.5 The end user should determine the damaging current level due to charge transfer to product or reticles, which can be handled in a particular piece of production equipment.

6.5 *Measuring Static Charge* — In the context of production equipment, it appears important to know the charge on the product, its carriers, and any other objects that might directly contact the product.

6.5.1 Charge is measured in coulombs (C), or more conveniently in nanocoulombs ($\text{nC} = 10^{-9}$ coulombs) for this purpose. Charge measurements are made with a Faraday Cup, as shown in § 7, Figure 1, or a coulombmeter as described in SEMI E43, for isolated conductors (including personnel), or small and moveable objects.

6.5.2 These measurement methods can be used to establish that the charge levels on these objects can pose a hazard to products or reticles from a direct ESD event.

6.5.3 A charged object, like an IC, is placed in the Faraday Cup (with a large enough cup for wafers, carriers, and other equipment parts to allow placing the objects into the cup without altering their charge levels) and a reading is taken of the charge on it. Further information on making these measurements should be available from the manufacturers of the measuring equipment.

6.5.4 The user should determine with an ESD simulator what levels of ESD cause product or reticle damage.

6.5.5 It should be the responsibility of the equipment manufacturer to demonstrate that equipment operation does not generate more than the allowable amount of charge on product, carriers, or equipment parts. This is shown in § 7, Figure 2.

6.6 *Measuring Electric Field* — Electric field measurements on large and fixed objects or insulators are less useful in estimating whether or not a damaging direct ESD event can occur. On objects that cannot be conveniently measured with a coulombmeter, electrostatic fieldmeter measurements can be useful in estimating the ESD threat from the object, even though the measurement may be less quantitative than the coulombmeter measurement. In some cases, an electrostatic voltmeter can be used to make measurements of electrostatic surface voltages that can be used to estimate electric fields.

6.7 *Measuring Voltage* — On packaged devices, the voltages on the pins can be measured directly using a contacting voltmeter. Since the individual pin capacitance is typically quite small, 1 pF or less, the contacting voltmeter should have the appropriate input impedance to make the measurement. To avoid discharging the packaged device pins, a resistance of at least $10^{14} \Omega$ and a capacitance of less than 10^{-2} pF should be used.

6.8 Testing for ESD Damage Caused by Induced Charge Separation

6.8.1 ESD damage may result from charge separation on an object. Part of a product (e.g., epoxy package) or reticle (e.g., quartz substrate) may become charged and induce charge separation to occur on another part of the product (e.g., lead pins) or reticle (e.g., chrome traces). ESD can occur if the lead pins or chrome traces are brought close enough to or make contact with a grounded surface.

6.8.1.1 Using a coulombmeter or Faraday Cup and the methods of SEMI E43, the end user should test product or reticles to determine the level of static charge at which ESD damage occurs from contact with ground.

6.8.2 Alternatively, either the product or reticles may be handled in proximity to another charged object. The field from this charged object induces charge separation on product or reticles, and ESD can result if the product or reticle is brought close enough to or contacts ground while in the presence of the field.

6.8.2.1 Using an electrostatic fieldmeter or voltmeter and the methods of SEMI E43, the end user should test products and reticles to determine the levels of electric field from static charge that cause ESD damage when there is contact with ground.

6.8.3 It has been shown that both a static and a changing electric field can cause ESD damage to reticles without ground contact occurring.

6.8.3.1 A static electric field occurs when the reticle or its packaging becomes charged during handling. A changing electric field can result at the reticle when an object in proximity to the reticle acquires a charge, the reticle or a charged object are in motion with respect to each other, or grounding conditions change the field between a charged object and the reticle (e.g., due to robot handling).

6.8.4 In equipment that produces or handles reticles, the electric field from any charged object should be limited to levels that do not cause reticle ESD damage. Test methods for electric field are contained in SEMI E43. There are currently no industry standards for determining the electric-field sensitivity of reticles, but test methods do exist.

NOTE 4: Refer to Related Information 2 and 4.

6.8.5 There is evidence that reticles can be damaged by electric fields without an ESD event occurring. Information concerning the handling of reticles and other extremely electrostatic sensitive items is contained in SEMI E163.

NOTE 5: Refer to Related Information 4.

6.8.6 Finally, there is increasing anecdotal evidence that the *presence* of static charge on wafer surfaces is becoming an ESD hazard as gate oxide thicknesses become thinner. In the future, further limits on allowable static charge on wafer surfaces should be evaluated to prevent ESD-related gate oxide damage during front-end semiconductor manufacturing. Further research should be performed in this area.

6.9 *Testing for Electrostatic Particle Attraction*

6.9.1 Electrostatic attraction (ESA) of particles can occur due to the electrostatic field created by the charge on the surface of an object.

6.9.1.1 Both the field strength and, usually to a lesser degree, the divergence of the field influence the electrostatic contribution to particle deposition rate (often referred to as the particle deposition velocity). Electrostatic particle deposition rate also depends on particle size and particle electrical charge.

6.9.1.2 Unfortunately, even under controlled laboratory conditions, accurate measurements of electric field strength, particle size distribution and especially, particle charge, are difficult. Of these three parameters, electric field measurements are the most likely to be available.

6.9.2 Measurements of electrostatic field are expressed in volts/m (volts/cm or volts/inch). Measurements should be made at a distance of 25.4 mm (1 in.) or as specified by the instrument manufacturer.

6.9.2.1 Precise measurements can be difficult as the presence of the measuring instrument changes the field characteristics and may overstate the actual level of electrostatic field. This is shown in § 7, Figure 3. SEMI E43 describes measurement techniques using an electrostatic fieldmeter, as well as alternate measurements using an electrostatic voltmeter.

6.9.3 Electrostatic particle deposition rate depends only on electric field, particle size, and particle charge. However, the number of particles deposited on a surface also depends on the particle concentration in the equipment area and the length of the exposure time during which particle deposition occurs.

6.9.3.1 Mechanisms other than electrostatic particle deposition, such as gravitational settling and diffusion, can also contribute to particle deposition. The number of particles deposited by these non-electrostatic mechanisms can also vary with particle concentration in the equipment ambient and exposure time.

6.9.3.2 Comparisons of the electrostatic particle deposition rate with the particle deposition rate associated with these other deposition mechanisms is the key for determining threshold values of allowed electrostatic field from the viewpoint of particle deposition. Such comparisons are the basis for estimating the allowed values of electrostatic field presented in Appendix 1, § A1-2.5.

6.9.3.3 Users and equipment manufacturers should determine and agree on ambient particle sizes and concentrations, and product exposure times.

NOTE 6: Additional information on the allowed values of electrostatic field affecting particle deposition are found in Related Information 1, § R1-3.

6.9.4 The measurement methods of § 7 and SEMI E43 can be used to establish that the electric field from any product, reticle, or equipment surface meets the recommendations of this Guide.

6.10 Equipment ESD

6.10.1 Equipment ESD immunity has been established at levels considerably higher than those that result in damage to product and reticles. If static charge limits shown in ¶ 12.7, Table 1 are used to protect product and reticles, they can provide sufficient protection for the equipment.

6.10.2 Equipment ESD immunity for manufacturing equipment is addressed, in general, through a number of international standards and directives including IEC 61000-4-2, EMC Directive 2014/30/EU for European Commission (EC) compliance, and the guidance in SEMI E33.

6.10.3 Measurements are made using an ESD simulator, which is described in these standards.

NOTE 7: A further discussion of ESD-related EMI issues can be found in Related Information 3 of SEMI E129.

7 Apparatus

7.1 *ESD Damage* — The apparatus for determining the ESD damage thresholds for products can depend on the test methods used. See § 4 for additional information. For measuring the charge generated on product, reticles, or carriers, the Faraday Cup test method is shown in Figure 1. Additional information on this test method and others are contained in SEMI E43.

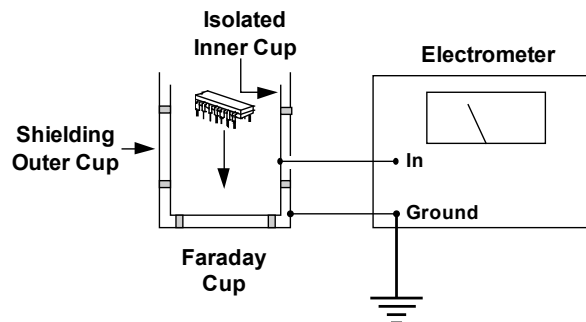


Figure 1
Faraday Cup Charge Measurement

7.1.1 Insulators are capable of simultaneously being charged to both polarities of static charge. Measurement with a Faraday cup can indicate the net charge rather than a separate amount of each polarity. An electrostatic fieldmeter or voltmeter should be used to determine whether this condition exists.

7.1.2 The relationship between ESD simulator testing for product damage and charge measurements using the Faraday Cup is shown in Figure 2.

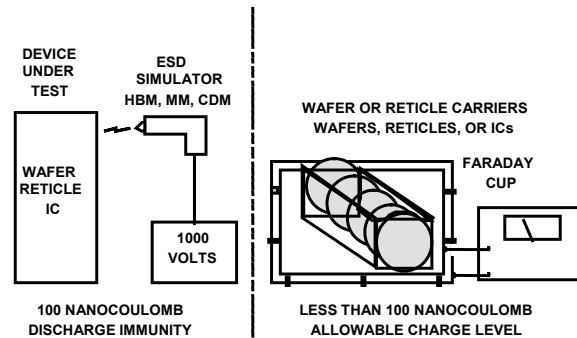


Figure 2
ESD Damage Testing

7.2 The instrument used for making electrostatic field measurements on large objects or surfaces is known as an electrostatic fieldmeter. Instructions concerning its use should be obtained from the instrument manufacturer and SEMI E43.

7.2.1 The measurement configuration shown in Figure 3 illustrates the effect of the instrument on the measurement. In most cases, the presence of the fieldmeter can increase both the flux from the charged surface and the convergence of the electric field lines. The fieldmeter can generally indicate a higher value of electric field than would be present without the fieldmeter.

7.3 An electrostatic voltmeter can be used as an alternative to the fieldmeter measurement. For small objects or surface areas, an electrostatic voltmeter is appropriate.

7.3.1 Under appropriate conditions, electrostatic voltmeters exhibit a high degree of accuracy and stability that is independent of the distance from the charged object. The electrostatic voltmeter probe can be located very close to a charged surface without arc-over, and it is able to resolve the field from a small-charged object.

7.4 A contacting, high-impedance voltmeter (resistance $>10^{14} \Omega$, capacitance $<10^{-2} \text{ pF}$) can be used to directly measure the voltage on packaged device pins. Even with the high impedance, measurements should be made as quickly as possible to avoid discharging the device pins and underestimating the voltage induced on the pins by static charge. The voltages measured on the pins of the packaged device, as it is handled in the production equipment, can be compared to the voltages used in ESD simulator testing to define packaged device ESD sensitivity (see ¶ 6.4.2).

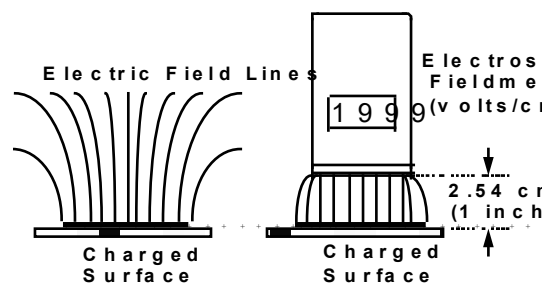


Figure 3
Electrostatic Field Measurement

8 Safety Precautions

8.1 *Personnel* — Static charges can create safety hazards during some semiconductor production processes.

8.1.1 ESA or ESD events that result in the jamming or breakage of product in high-speed equipment may create a personnel hazard.

8.1.2 ESD events that produce sparks should be prevented in areas that use flammable or explosive chemicals or gases.

8.1.3 ESD events to personnel are usually not harmful, but they may result in an unwanted reflex, or ‘startle’ reaction. This reflex may create a personnel hazard, particularly in the vicinity of moving equipment or where caustic chemicals are in use.

8.1.4 EMI resulting from ESD events may cause unpredictable behavior of robotics or other moving equipment that put personnel at risk.

8.1.5 It may be necessary to use additional static-control methods, beyond those used inside the equipment, to minimize these personnel hazards.

8.2 *Measurement Safety* — Users should exercise caution while making static charge measurements in the vicinity of moving parts of production equipment, or in areas where static potentials on ungrounded conductors may exceed 30,000 V. Refer to SEMI E43 for additional measurement safety considerations.

9 Test Specimen

9.1 The following are recommendations concerning the testing that can be performed. The user and equipment manufacturer should agree upon these recommendations and document them.

9.2 Measurements of electrostatic charge (in nC) should be performed using a nanocoulombmeter with a Faraday Cup.

9.3 Measurements of electrostatic field (in volts/m, volts/cm, or volts/inch) or electrostatic voltage (in volts) should be performed using an electrostatic fieldmeter or electrostatic voltmeter, respectively. Voltage measurements on the pins of packaged devices may be made with a contacting, high-impedance voltmeter.

9.4 The user and equipment manufacturer should agree on who can do the testing. Prior to such agreement, the equipment manufacturer may consider using a third party to make measurements on the production equipment.

9.5 Test samples should represent the materials that are handled by the equipment under actual use conditions. For example, testing with insulated and conductive wafers may produce significantly different results.

9.6 Measurements should be done with a minimum of 10 test samples of insulated or conductive wafers, reticles, packaged devices, or carriers, whichever are handled by the equipment. This may also be done in a minimum of 10 consecutive test cycles with a single sample that is handled by the equipment and then measured.

9.6.1 Electrostatic charge measurements should be made on each test sample. Electrostatic field measurements should be made at multiple locations on each test sample, or on the parts of the input/exit ports of the equipment. Refer to SEMI E43 for recommendations on making measurements on small objects.

9.6.2 The average of the electrostatic charge, field, or voltage measurements on each test sample, or of the electrostatic field or voltage measurements on parts of the equipment ports, should meet the recommendations of ¶ 12.7, Table 1. No individual measurement should exceed two times the table value selected. The standard error of the measurements should also be reported.

9.7 The user and/or equipment manufacturer should agree upon and document the operating history of the equipment prior to, or during testing (e.g., warm-up time, type of carrier, number of products processed, operating speed).

9.8 The user and/or equipment manufacturer should agree upon and document all appropriate environmental conditions (e.g., temperature, relative humidity [RH], dew point, airflow).

NOTE 8: § 12 provides guidance on test conditions prior to negotiation between the end user and equipment manufacturer.

10 Preparation of Apparatus and Sample

10.1 Depending on the type of testing to be done, consult the appropriate testing document for apparatus and sample preparation. See § 4 for additional information.

11 Calibration and Standardization

11.1 Depending on the type of testing to be done, consult the appropriate testing document for apparatus calibration and verification. See § 4 for additional information.

12 Procedures

12.1 End users may decide to follow the recommendations for acceptable electrostatic charge levels or electrostatic fields contained in ¶ 12.7, Table 1, which are based on product and reticle geometry. See Appendix 1 for more information.

12.2 Equipment manufacturers design their equipment to avoid producing damaging amounts of electrostatic charge or electrostatic field on products, reticles, or the surfaces of their equipment. Equipment manufacturers can use the test methods of § 9 and ¶¶ 12.4 to 12.5 below to qualify their equipment as following the recommendations for acceptable electrostatic charge or electrostatic field levels contained in ¶ 12.7, Table 1, which are based on product and reticle geometry.

12.3 Alternatively, end users can determine the levels of electrostatic discharge and electrostatic field their products and reticles can withstand without damage.

12.3.1 Measurement methods for ICs are described in the documents contained in § 4.

12.3.2 Appropriate measurement methods for ESD damage to wafers, reticles, and other items may be adapted from the instrumentation used in the test methods contained in the documents of § 4. Appendix 1, §§ A1-2.1 through A1-2.4 contains additional information to select an allowable electrostatic charge level to reduce ESD damage.

NOTE 9: Related Information 1, § R1-2 contains additional information to select an allowable electrostatic charge level to reduce ESD damage.

12.3.3 End users should work with equipment manufacturers and reticle suppliers to determine ambient particle levels, product exposure times during processing, and reticle damage levels due to electrostatic field. Appendix 1, § A1-2.5 contains information to select an appropriate electrostatic field level to reduce ESA of particles.

NOTE 10: Related Information 1, § R1-3 contains information to select an appropriate electrostatic field level to reduce ESA of particles.

12.4 ESD Damage

12.4.1 Measurement of ESD damage thresholds are made in units of coulombs (C), or more conveniently in nanocoulombs ($\text{nC} = 10^{-9} \text{ C}$). The recommendations in ¶ 12.7, Table 1 for packaged devices are based on a 10 pF packaged device, as explained in Appendix 1, § A1-2.5. The voltage levels in Table 1 are calculated from the formula $Q = CV$, where Q is the charge that may cause the ESD damage and $C = 10 \text{ pF}$.

12.4.2 The Faraday Cup method should be used to determine the static charge levels on products, product carriers, and equipment parts. Each item should be transported to the Faraday Cup in a way that does not alter its charge level. Consult the measurement equipment manufacturer's instructions for recommendations on how to achieve this.

12.4.3 The high-impedance contacting voltmeter can be used to measure the voltages on the pins of packaged devices as they are handled by production equipment. Particular attention should be paid to the locations just before the pins contact conductive surfaces within the equipment. The voltages can be compared to voltage sensitivity levels determined in industry standard device testing (see ¶ 6.4.2). At a given voltage level, discharges in equipment may not be as severe as discharges at the same voltage level in the controlled environment of the ESD simulator. Refer to White Paper 2 from the Industry Council on ESD Target Levels for a discussion of this issue.

12.4.4 Measurements should be made of products, carriers, and materials in the equipment input/exit ports after significant amounts of product have been handled under normal manufacturing conditions.

12.4.5 Measurements should be made of products and their carriers after they have undergone normal processing in the equipment under test. Typically five measurements of products and/or carriers should be sufficient to demonstrate compliance with the selected electrostatic charge level (see § 13).

12.4.6 Measurements should be made on each of two successive days after equipment has stabilized in its normal operating mode (e.g., after two hours). Equipment configuration (hardware and software) should not be changed for the duration the test period.

12.5 Electrostatic Field

12.5.1 Measurements of electrostatic field are expressed in volts/m (volts/cm or volts/inch). Measurement should be made at a distance of 25.4 mm (1 in.), or as specified by the instrument manufacturer.

12.5.2 Electrostatic field measurements should be made at a minimum on all surfaces within the equipment that can come within 30.5 cm (12 in.) of ESD sensitive items. Typical surfaces to measure would include products, reticles, carriers, robotics, and equipment surfaces.

12.5.3 Measurements should be made in five different locations on any item. Locations should be separated by approximately three times the distance between the measuring instrument and the measurement location. For most electrostatic fieldmeters measuring at 25.4 mm (1 in.), the measurement locations should be 76.2 mm (3 in.) apart. Refer to SEMI E43 for additional measurement considerations, as well as alternate measurement techniques using an electrostatic voltmeter.

12.5.4 Measurements should be made on products, reticles, carriers, and materials in the equipment input/exit ports after significant amounts of product or reticles have been handled under normal manufacturing conditions.

12.5.5 Measurements should be made of products, reticles, and their carriers after they have undergone normal processing in the equipment under test. Typically five measurements at each location should be sufficient to demonstrate compliance with the selected electrostatic level.

12.5.6 Measurements should be made on each of two successive days after equipment and process has stabilized in its normal operating mode (e.g., after two hours). Equipment configuration should not be changed during the test period.

12.6 SEMI E129 Recommendations

12.6.1 SEMI E129 ¶ 12.7, Table 1 contains recommendations for maximum electrostatic levels to prevent problems caused by static charge.

12.6.2 These levels apply to all elements of the semiconductor factory, including but not limited to construction materials, furniture, personnel, product, reticles, carriers, and transport and packaging materials. These levels should also apply to the equipment in the factory.

12.6.3 It is desirable in this Guide to harmonize with SEMI E129 recommended electrostatic levels, as well as to synchronize with the major changes in technology mapped in the International Roadmap for Devices and Systems (IRDS) (formerly International Technology Roadmap for Semiconductors [ITRS]).

12.7 Recommendations for acceptable equipment-induced electrostatic levels are listed in Table 1 and given for the major technology nodes of IRDS 2018 Table LITH-1, which relate to the size of the features on the wafer. Equipment used in semiconductor manufacturing should meet the following electrostatic levels shown in Table 1 for protection from problems caused by static charge.

12.7.1 Since many decisions to use static-control methods can result in the permanent installation of these methods in equipment, users may want to consider the expected lifetime of the equipment in their manufacturing process in selecting the acceptable electrostatic level.

NOTE 11: For example, at startup the equipment may be processing at 90 nm geometry, but can be capable of use down to 28 nm geometry. The equipment should be designed for the limits recommended for the 28 nm use.

Table 1 Recommended Acceptable Equipment-Induced Electrostatic Levels

Year Node	Wafers ^{#1} and Reticles ^{#2} Electrostatic Discharge, nC	10 pF Device ^{#1} Electrostatic Discharge, nC	10 pF Packaged Device ^{#1} Electrostatic Discharge, V	Electrostatic Field ^{#3} , V/cm V/m (V/inch)		
2000 180 nm	10.0	2.5 to 10	250 to 1000	200	20,000	(500)
2004 90 nm	10.0	1.0	100	100	10,000	(250)
2010 45 nm	2.5	0.25	25	50	5,000	(125)
2017 18 nm	0.40	0.04	4.0	20	2,000	(50)

Year Node	Wafers ^{#1} and Reticles ^{#2} Electrostatic Discharge, nC	10 pF Device ^{#1} Electrostatic Discharge, nC	10 pF Packaged Device ^{#1} Electrostatic Discharge, V	Electrostatic Field ^{#3} ,		
				V/cm	V/m	(V/inch)
2019 17.5 nm	0.38	0.038	3.8	19	1,900	(48)
2021 17.0 nm	0.36	0.036	3.6	18.5	1,850	(46)
2024 14.0 nm	0.24	0.024	2.4	15.5	1,550	(39)
2027 11.0 nm	0.14	0.014	1.4	12	1,200	(30)
2030 8.4 nm	0.09	0.009	0.9	9	900	(23)
2033 7.7 nm	0.07	0.007	0.7	8.5	850	(21)

#1 These table values for wafers and devices, taken from Table A1-4, are scaled from the values for 45 nm by the square of the feature size.

#2 These table values for reticles, taken from Table A1-6, are scaled from the values for 45 nm by the square of the feature size. Particle values are higher.

#3 These table values for reticles, taken from Table A1-6, are scaled from the values for 45 nm linearly with the feature size. Particle values are higher.

12.7.2 The levels in Table 1 assume that the equipment is processing silicon semiconductors. Equipment used for specialized components should use different levels as appropriate for that material.

NOTE 12: Examples are equipment used to process gallium arsenide semiconductors or magneto-resistive (MR) disk-drive read heads, or equipment experiencing significant losses due to contamination.

12.8 The levels listed in Table 1 have been determined as the result of analysis of working conditions, or experiments done in operating semiconductor facilities. Justifications for these levels are found in Appendix 1. The actual levels to be used for any production area may be decided by agreement between the user and designer/builder of the equipment.

12.9 Other levels may be appropriate under specific equipment conditions and for specific devices.

13 Calculations

13.1 The average of the five consecutive measurements should not exceed the recommended level.

13.2 No measurement should exceed two times the recommended level.

14 Reporting Results

14.1 Data records should contain the following information:

14.1.1 Description of equipment under test including model and serial numbers;

14.1.2 Description of the equipment operating conditions and environment;

14.1.3 Description of the measurement methodology;

14.1.4 Measurement equipment and last calibration date;

14.1.5 Description of objects measured and measurement locations;

14.1.6 RH, airflow, dew point, and temperature at measurement location when measurements were made;

14.1.7 Results of measurements;

14.1.8 Personnel making the measurements; and

14.1.9 Any other relevant comments.

15 Test Method Precision and Accuracy

15.1 The test methods referenced in this Guide do not guarantee precise measurements of static charge levels. Similarly, maximum static charge levels recommended in this Guide are not stated as precise requirements.

15.2 Accuracy of approximately $\pm 20\%$ is acceptable in all measuring instrumentation. At low static charge levels or for more accurate measurements, alternative instrumentation, and test methods should be considered.

15.3 To evaluate low levels of electric field strength or the voltage on an object, an electrostatic fieldmeter or electrostatic voltmeter with acceptable resolution and accuracy should be used.

16 Related Documents

16.1 IEC Standards⁴

IEC 61340-5-1 — Electrostatics – Part 5.1: Protection of Electronic Devices from Electrostatic Phenomena – General Requirements

IEC 61340-5-2 — Electrostatics – Part 5.2: Protection of Electronic Devices from Electrostatic Phenomena – Users' Guide – Elements of a Static Control Program