Compliance Engineering®

Preventing Electrostatic Problems in Semiconductor Manufacturing

Arnold J. Steinman

Problems caused by electrostatic charge can be avoided in semiconductor manufacturing.

Standards contain performance requirements for equipment and systems and the measurement methods to ensure that the requirements are being met. Technology roadmaps detail the changes in performance requirements as industries evolve their products over time. This article discusses how problems caused by electrostatic charge can be avoided through the relationship between the *International Technology Roadmap for Semiconductors* (*ITRS*) and standards issued by Semiconductor Equipment and Materials International (SEMI) and the ESD Association (ESDA).

The problems caused by electrostatic charge in semiconductor manufacturing are well known, as those problems make it more difficult to maintain high levels of product quality and yield. Particle contamination, electrostatic discharge (ESD) damage, and equipment problems are the result of failing to control static charge. Electrostatic attraction (ESA) increases contamination of critical product and equipment surfaces, causing defects and increasing maintenance costs. Electrostatic discharge (ESD) damages semiconductors and the photomasks used to create them. ESD also produces unwanted electrical signals (electromagnetic interference [EMI]) that interfere with the operation of the production equipment.

These problems occur throughout the semiconductor process, including silicon wafer manufacturing, photomask manufacturing, front-end device manufacturing, and back-end assembly, packaging and test. Many of these static problems persist through the entire use cycle of the semiconductor device. Similar problems occur in the manufacture of disk drives, flat-panel displays, and medical electronic devices.

This article explores problems caused by static charge and methods used to control them. It discusses the recommendations of the new *ITRS 2003* document and its relationship to existing SEMI standards, E78 and E129, and ESDA standard ANSI ESD S20.20.

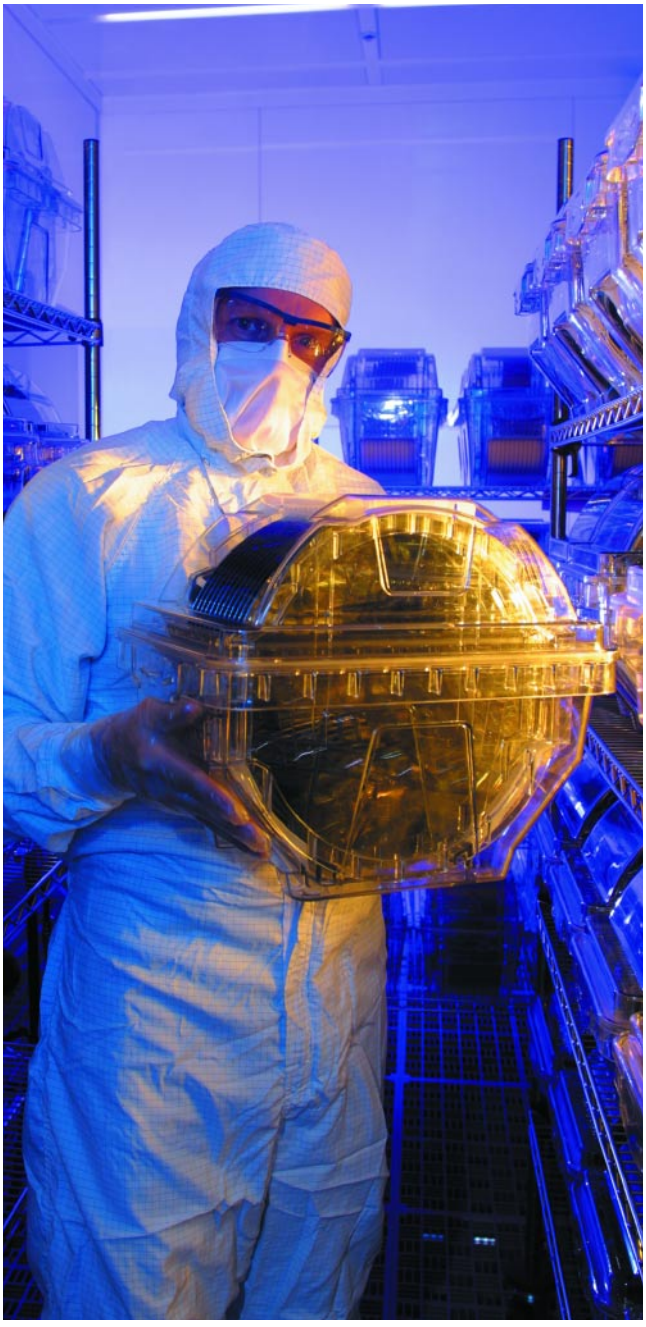

Photo courtesy of MEMC, St. Peters, MO.

Static Charge Problems

Modern cleanroom filtration keeps most external particles from entering the cleanroom. Particles are still produced *inside the cleanroom* by personnel, production equipment, and parts of the production process. Unfortunately, all of these particle sources are usually close to the product. If surfaces are charged, ESA attracts and holds particles that would otherwise remain airborne in the cleanroom laminar airflow. Sub-micron-sized

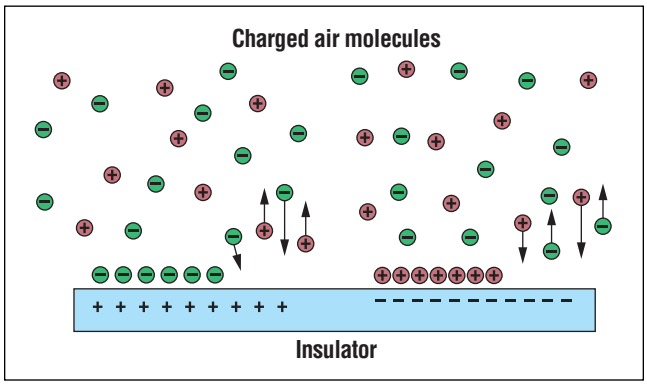

Figure 1. Neutralizing surface charges with bipolar air ionization.

particles cause defects in semiconductor production in much the same way that dust on a photographic negative or print paper causes a visual defect. As technology change leads to smaller feature sizes in semiconductor devices, the size of the killer particle also decreases. Smaller particles are more easily attracted and more difficult to remove because of static charge on surfaces.

Besides making the elimination of particles from the cleanroom more difficult, static charge causes other production problems as well. The uncontrolled transfer of static charge can damage product directly. This is an electrostatic discharge, or ESD event, typically occurring in 1–10 nanoseconds. One result of this rapid transfer of energy is local heating, sufficient to melt the silicon or metallization of the semiconductor device, causing a single device failure. If this occurs due to repetitive machine operations, multiple devices may be damaged. ESD on a photomask (the negative used to produce the device) can cause similar melting damage, which produces a repeating defect each time the photomask is exposed, transferring the device patterns onto the silicon wafer.

The energy from ESD events also appears as signals in the radio-frequency spectrum. Typically in the range of 100 MHz to 2 GHz, ESD events are in the same frequency range as the microprocessors that control the operations of most semiconductor production equipment. ESD events generate EMI that can cause a variety of equipment malfunctions from simple stoppages to erratic robot operations that destroy products. Because EMI propagates through both radiation and conduction, an ESD event in one piece of equipment may affect the operation of other nearby equipment, making the source of the problem difficult to locate.[1,2]

Charge Generation and Control

Whenever two surfaces in close contact are separated, one surface loses electrons and becomes positively charged, while the other surface gains electrons and becomes negatively charged. This is known as *triboelectric charging*. Whether the material remains charged depends on its conductivity and the availability of a path for the charge to flow to ground. Static charge is also generated by induction. Static charge on an object can create or induce opposite-polarity charges on the surface of another object.

Static charge generation is unavoidable. It is impossible to prevent the contact or friction between materials in most production areas. The presence of insulating materials in cleanrooms ensures that many charged objects will remain charged for a long period of time. Charge can be transferred to other

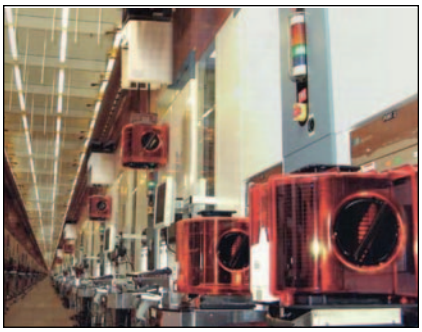

Figure 2. Ceiling air ionization in a 300-mm cleanroom. (Photo courtesy of Brooks Automation).

objects by contact (ESD) or induction. Solving most static problems requires one or more static control methods. Critical applications require a well-designed static control program.[2]

A variety of methods have been developed to deal with static charge.[3,4] Semiconductor production environments make extensive use of grounding with conductive and static-dissipative materials to methods that control charge on people and equipment, as well as on products. Grounding prevents the generation of static charge and removes it from isolated conductive materials that have become charged.

Unfortunately, semiconductor production uses many materials that are insulators, such as Teflon, various plastics, and glass. Often the insulating materials are an essential part of the product itself. Examples include oxide-coated semiconductor wafers, quartz photomask substrates, and the epoxy packages of the finished semiconductor devices. Most insulators are easily charged, retain their charge for long periods of time, and are close to, or part of, the product. It is not possible to remove the electrostatic charge on insulators by connecting them to ground, because charge will not move though insulators.

Neutralizing static charge on insulators (and isolated conductors) requires the use of some type of air ionization. Air ions are gas molecules in air that have either lost or gained an electron. Ionizing radiation from nuclear, x-ray, or ultraviolet (UV) sources may be used to create air ionization. The most common method used to create air ions is corona ionization, which uses a very high electric field to produce the air ions. When the ionized air comes in contact with a charged insulating surface, the charged surface attracts air ions of the opposite polarity. As a result, the static charge on the insulator is neutralized. Air ions of both polarities are required for neutralization, because both polarities of static charge are present in manufacturing areas. This is shown in Figure 1, while an example of an air ionizer installation in a 300-mm semiconductor cleanroom is shown in Figure 2.

Static Charge Control in Semiconductor Manufacturing

Defining production values to ensure profitability in semiconductor manufacturing is the charter of the *ITRS*.[5] Published annually in November, it communicates requirements for the construction and operation of semiconductor factories now and into the next 15 years. "The *ITRS* identifies the principal technology needs to guide the shared (semiconductor industry) research. It does this in the two following ways: showing the targets that need to be met by technology solutions currently under development, and indicating where there are no "known manufacturable solutions" (of reasonable confidence) to continued scaling of some aspect

Year	2000	2002	2003	2004	2005	2006	2007	2008	2009	2012	2015	2018
Technology Node	**180nm**	**130nm**	**100nm**	**90nm**	**80nm**	**70nm**	**65nm**	**55 nm**	**50nm**	**32nm**	**25nm**	**18nm**
Maximum allowable electrostatic field on facility surfaces	200 V/cm	150 V/cm	125 V/cm	100 V/cm	90 V/cm	80 V/cm	70 V/cm	60 V/cm	50 V/cm	35 V/cm	25 V/cm	18 V/cm
Maximum allowable static charge on devices	2.5–10 nC (250–1000 V)	2.0 nC (200 V)	1.5 nC (150 V)	1 nC (100 V)	0.8 nC (80 V)	0.65 nC (65 V)	0.5 nC (50 V)	0.35 nC (35 V)	0.25 nC (25 V)	0.125 nC (12.5 V)	0.10 nC (10 V)	0.08 nC (8 V)
Maximum allowable electrostatic field on wafer and photomask surfaces	200 V/cm	150 V/cm	125 V/cm	100 V/cm	90 V/cm	80 V/cm	70 V/cm	60 V/cm	50 V/cm	35 V/cm	25 V/cm	18 V/cm

Table I. Static control recommendations of *ITRS 2003*.

of semiconductor manufacturing."

Simply stated, the *ITRS* strives to ensure that problems are solved before they become technology barriers. Regarding static charge control, the *ITRS 2003* states, "Electrostatic charge adversely impacts every phase of semiconductor manufacturing, causing three basic problems. Electrostatic attracted (ESA) contamination increases as particle size decreases, making defect density targets more difficult to attain…. Electrostatic discharge (ESD) causes damage to both devices and photomasks. Shrinking device feature size means less energy is required in an ESD event to cause device or mask damage…. Equipment malfunctions due to ESD-related electromagnetic interference (EMI) reduce OEE (overall equipment efficiency), and have become more frequent as equipment microprocessor operating speeds increase.These three problems occur where bare wafers and photomasks are produced, where devices are produced in wafer fabs, and where individual devices are produced in back-end packaging, assembly, and test."

The *ITRS* contains recommendations to reduce static charge to levels that prevent static problems. Maximum levels are recommended for both the charge on devices (measured in nanoCoulombs [nC]), and electric fields (measured in volts/centimeter) produced by charge anywhere in the facility. These recommendations should be included in new facility construction and in new equipment, as well as in existing factories. Because static levels must go down as newer, smaller, technologies are introduced, it is critical that a static control program be implemented in every semiconductor factory.

The recommendations contained in *ITRS 2003* are shown in Table I. Gray indicates manufacturable static control solutions are known and being optimized.

Blue indicates that only solutions are known. Pink indicates those areas for which production uncertainties and other issues result in no known manufacturable solutions, pointing to areas where further research is needed. *ITRS 2003* is a roadmap document. As such it references existing industry standards for performance specifications and verification methods. *ITRS 2003* recommends the use of two SEMI standards in establishing and verifying a static control program in a semiconductor manufacturing facility. The first, E78-1102, "Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Semiconductor Equipment," makes recommendations for controlling static charge in production equipment, describing static-sensitivity levels of products and measurement methods to protect them.[3] Originally issued in 1998, it is currently being revised to encompass the rapid change in semiconductor technology requirements.

The latest document issued by SEMI is E129-1103: "Guide to Assess and Control Electrostatic Charge in a Semiconductor Manufacturing Facility."[4] This document is synchronized with the static control recommendations of *ITRS 2003*. It recommends static levels to prevent contamination and ESD damage from current 100-nm technology to the expected 25-nanometer technology of 2015. It contains measurement techniques, and it references other static control standards to verify that the recommendations are being met. Any company that is building, expanding, or updating a semiconductor factory needs to consider both present and future needs for static control. The recommendations from E129 are contained in Table II, and the similarities to the recommendations of *ITRS 2003* should be noted.

E129 contains an appendix and several related information sections. The appendix explains how the recommendations in the standard were developed to reduce or eliminate the various static problems. The explanation references earlier development work found in the E78 document. The related information sections provide additional information on device damage due to ESD, static control methods and standards, and ESD-related EMI generation and its measurement.

The Static Control Program

Referenced in the E129 document, one of the important static control programs is ANSI/ESD S20.20, "Development of an Electrostatic Discharge Control Program for the Protection of Electrical and Electronic Parts, Assemblies and Equipment."[6] The S20.20 program was developed using industry experiences with the ISO 9000 quality program. Rather than defining a single static control program that all must follow exactly, it specifies all the elements of the program and allows the user to define their implementation. The user of the program must determine:

- The static sensitivities of the products that are being protected.
- The program procedures and the static control methods in use.
- How performance of static control methods is being verified.
- How problems in the program are corrected.

Year Node	Electrostatic Discharge, nC	Electrostatic Field, V/cm	V/in.
2000 180 nm	2.5–10	200	500
2002 130 nm	2.0	150	375
2003 100 nm	1.5	125	300
2004 90 nm	1.0	100	250
2007 65 nm	0.5	70	175
2009 50 nm	0.25	50	125
2012 32 nm	0.125	35	88
2015 25 nm	0.1	25	63

Table II. E129—Recommended semiconductor facility electrostatic levels.

- How personnel are trained as part of the program.
- How to retain records of performance, corrective actions, and training.

S20.20 is a guidance document. It directs the user to existing industry standards for determining the ESD sensitivity of semiconductor devices. It lists both required and optional static control methods to protect 100-V human body model (HBM) sensitive devices. It provides specification limits for each static control method and allows the program to be modified for more- or less-ESD-sensitive devices (for example, silicon versus gallium arsenide semiconductors). It provides references to test methods for performance verification. S20.20 directs the user to establish and document the methods used for training and correction of program deficiencies. These methods should be familiar to any company that has an ISO 9000 certification.

ESDA has made the S20.20 standard available as a free download (including both Spanish and Chinese translations) from its Web site at http://www.esda.org. In addition, the association offers a handbook to assist users in implementing the S20.20 program.[7]

Cost—The Driver

As noted earlier, static problems are unavoidable in semiconductor production. Although both *ITRS* and SEMI recommend solving these problems while the factory is being built and before the equipment is installed, many users wait until an actual static problem occurs during production. It is easy to see, by describing the problem–solution discovery process, that this is a very costly approach.

A static problem is discovered when product losses occur, requiring engineering intervention to determine the cause of the product loss. Because the full manufacturing process can take 4–6 weeks, several months will be required to determine that the cause of the problem is static-charge related, determine the static control method that solves the problem, and install the static control method in the operating production facility.

It should be clear that a production shutdown (until the required static control method is installed) is not a realistic option. This means that during the entire process of discovery, product losses mount. In most cases, the costs of these product losses will be 10–100 times the cost of the static control method that eliminates the losses. Following the recommendations of the *ITRS* and SEMI standards is a cost-effective way to avoid static charge problems.

Conclusion

In semiconductor manufacturing, static charge control reduces product losses caused by contamination, ESD, and a variety of equipment-related problems. Grounding of conductors and air ionization for insulators are the primary methods available for controlling static charge. These methods should apply in all parts of the semiconductor manufacturing process, starting in the silicon foundry and mask house and extending through packaging and shipping of finished devices.

As noted by the *ITRS*, "Technology change assures that static charge problems will get worse…. As critical dimensions shrink, the presence of static charge becomes a technology barrier…. Limiting charge levels throughout the factory to protect devices will also avoid malfunctions due to ESD-related EMI in equipment and improve overall equipment efficiency.…" Eliminating static charge in semiconductor manufacturing has the clear benefits of improved yield and quality and lower costs for maintenance and rework. The result is higher profits. For the semiconductor industry to progress along its technology roadmap, static charge control is not an option, it is a requirement.

References

1. A Steinman, "Static-Charge—The Invisible Contaminant," in Cleanroom Management Forum, *Microcontamination* 10, no. 9 (1992): 46–512.
2. J Hamlin, "Controlling Static Charge in Cleanrooms, Why Should We?" *Semiconductor Fabtech*, 6th ed., (London: Henley Publishing, 1996).
3. SEMI E78-1102, "Guide to Assessing and Controlling Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) in Semiconductor Equipment," Semiconductor Equipment and Materials International (SEMI), San Jose, CA.
4. SEMI E129-1103, "Guide to Controlling Electrostatic Charge in a Semiconductor Manufacturing Facility," SEMI.
5. *International Technology Roadmap for Semiconductors* 2003 Ed., International SEMATECH, Austin.
6. ANSI/ESD S20.20–1999, "Development of an Electrostatic Discharge Control Program for the Protection of Electrical and Electronic Parts, Assemblies and Equipment," ESD Association, Rome NY.
7. ESD TR 20.20, "ESD Handbook," ESD Association, Rome NY.

Arnold J. Steinman is chief technology officer for Ion Systems Inc. (Berkeley, CA) He can be reached at 510-548-3640 or via e-mail at asteinman@ion.com. ■