CLEANROOMS

Electrostatic management in cleanrooms

by Ted Dangelmayer and Arnold Steinman

STATIC-CHARGE CONTROL HAS BECOME ESSENTIAL TO PROTECTING PRESENT AND FUTURE CLEANROOMS FROM THE EFFECTS OF STATIC CHARGE.

It's hard to imagine a processing procedure in a cleanroom that doesn't involve contact and separation of materials; and, in turn, the resulting generation of static charge. Due to this inevitability, static-charge control in cleanrooms has become necessary to enhance the production of semiconductors, disk drives, flat panel displays, medical and optical devices and a wide range of other products.

Three basic results stem from not controlling static charge in a cleanroom: Product contamination due to electrostatic attraction and bonding of particulate to critical product surfaces; damage done directly to products by electrostatic discharge (ESD); and third, malfunction of production equipment caused by ESD-generated electromagnetic interference (EMI).

Managing a static-charge control program and steering clear of those unwanted results are difficult in a complex cleanroom environment due to a number of factors.

For example, surface cleanliness and low humidity present in cleanrooms encourages static-charge generation. Second, many static-charge problems are the result of interactions between personnel, product and the production environment—controlling static charge on personnel becomes especially difficult in rooms where activities are not limited to a single workstation.

Finally, management commitment to an ongoing static-control program in a cleanroom is difficult to secure when cleanroom operators have other problems that need to be solved.

The interaction of static charge in all aspects of cleanroom manufacturing is just beginning to be recognized, and there are a relatively small number of engineers and technicians possessing expertise in both areas.

Knowledge of electrostatics and ESD is not commonly taught at universities and there are few sources of impartial technical training[1, 2]. Rapid changes in the technology of products manufactured in cleanrooms worldwide makes the development of appropriate static-control knowledge even more challenging.

Electrostatic program management (EPM)

Many modern businesses recognize that some corporate skills aimed at controlling static charge need to be developed in-house, while others are more efficiently supplied by outsourcing. This is particularly true in the field of electrostatic program management, or EPM.

While we have only mentioned static-charge control, there are more activities required in managing a successful electrostatics program. Many times the difficulty in developing an in-house capability results in little or nothing being done. Outsourcing EPM may be the best method to rapidly eliminating the static-charge problem.

The process of successful EPM begins with diagnosis and analysis of the causes and magnitude of the static-charge problems.

Defective product or specialized test devices may be examined for evidence of ESD damage or contamination, static-charge levels in the cleanroom environment may be measured, and measuring equipment may detect the signature of ESD-related EMI. Trial methods of eliminating static charge need to be tested to determine their affects on the static-charge problems. At the end of this stage, management will be able to estimate the possible cost savings from implementing EPM, providing a justification for continuing the process.

Once the static problems have been identified and the associated costs quantified, the process of eliminating the problem can

12 critical factors of an ESD program

Management excellence

1. An effective implementation plan.
2. Management commitment.
3. A long-term process owner.
4. An active leadership team.
5. Realistic requirements.
6. Training for measurable goals.
7. Auditing using scientific measures.
8. ESD test facilities.
9. A communications program.
10. Systemic planning.
11. Human factors engineering.
12. Continuous improvement.

Figure 1. Critical factors of an ESD program.

Figure 2. Typical damage to semiconductors (Above) and disk drive heads (Below).

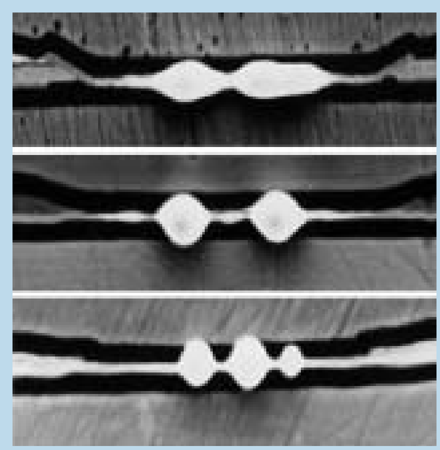

Table 1. Recommended sensitivity levels/SEMI E78-0998 static sensitivity table

	Electrostatic discharge (Nanocoulombs)	Particle attraction (Volts/CM)	Equipment malfunction (Nanocoulombs)
Level 4	100	4,000	1,200
Level 3	50	400	600
Level 2	10	200	300
Level 1	1	100	150

begin. There are many effective ways of controlling static charge for the manufacturing facility, the personnel and the production equipment. For each static-control problem and location, one or a combination of these methods will need to be selected. In most cases, some in-house personnel will need to be trained in the verification and maintenance of the static-control methods.

All through this process, the costs of implementing the static-control solutions will need to be tracked to assure that they are in line with the benefits anticipated—and remember, management is watching.

Effective static control is rarely a one-element, single-application event. Generally, EPM has many elements and they must be coordinated and managed over long periods of time with a total system approach. An example of such a system approach is shown in Figure 1.

In a cleanroom environment where products and processes are constantly changing, this systematic approach is highly effective and produces sustained results. ISO9000/14000 standards have defined the elements of a successful quality-control program. Many of the same elements are found in a successful static-control program.

A static-control program begins with the technical elements already discussed: problem definition and the static-control methods. Then the administrative portion of the program should be addressed. This includes the definition of the purpose of the program, job responsibilities for maintaining the program and the important factors noted in Figure 1. For example, an audit program to monitor performance and a database to record the results are critical elements of any effective program. Metrics from the auditing program can produce essential information to manage the program and leverage limited resources.

Problem analysis and solutions

Justification for EPM begins with a static audit. Instrumentation including an electrostatic fieldmeter is used to locate and determine the magnitude of static charges throughout the cleanroom. All facility surfaces, including building elements, furniture, equipment, product and personnel are monitored. Analysis of the data obtained provides insights into the probable locations of static problems, opportunities for the use of alternate materials and a baseline against which the subsequent success of the static-control program can be measured.

Defective product may need to be disassembled and analyzed to determine if failures are the result of static charge. Figure 2 shows evidence of ESD damage to both semiconductor and disk drive components.

Optical and scanning electron microscopes are used for this purpose, and there are a number of other instruments available for analyzing surface contamination levels. High frequency storage oscilloscopes (with a bandwidth greater than 500 MHz) coupled to directional antennas, or a variety of handheld EMI locators, may be used to detect the signature of ESD-related EMI. This type of testing is done when there is the possibility of equipment malfunctions due to ESD.

Another alternative method for verifying the existence of static hazards in the cleanroom is to take known good product—or something that simulates the product—pass it though all or a part of the cleanroom process.

An example of this method is the CanaryESD device from DuPont Photomasks (See *CleanRooms* July, 2001 Supplement, *ESD and Gas Handling*) used to look for ESD hazards for the photomasks used in semiconductor production[3]. This is a diagnostic device designed to have an increased ESD sensitivity that imitates the size and features of a production photomask. It has both a lower threshold for ESD events and experiences more catastrophic damage when an ESD event occurs. As a result, lower levels of static charge in the environment will do more damage to the CanaryESD than they would to production photomasks. The device catches ESD damage during abbreviated testing (days) that might only be reflected in actual production reticles over longer periods of time (weeks, months). Figure 3 shows typical damage to a photomask and the CanaryESD device[3, 4].

Once static problems have been identified, trial methods of eliminating static charge will need to be tested to determine their effects on the static-charge problems. Using the results of the original static audit as a baseline, static-charge levels may be measured after static-control methods have been installed. While this verifies that the static-control methods are lowering static-charge levels, additional testing may be needed to verify the impact on the actual static problem.

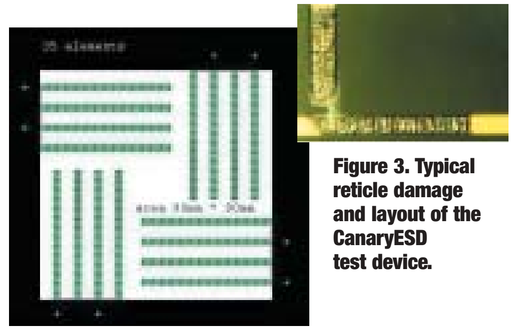

Figure 3. Typical reticle damage and layout of the CanaryESD test device.

Process yield records and other manufacturing data may need to be analyzed to determine that there are fewer damaged products or equipment operation problems due to ESD. Surface-analysis measurements should demonstrate that contamination levels on products have been reduced now that the static charge levels are lower. While this may only be done for a small part of the production area, it should be possible to provide a reasonable estimate of the cost savings from implementing EPM in the entire factory.

Static charge

Definition: Charge is a fundamental property of matter, dependent on the movement of electrons. When electrons flow through a conductor we have an electric current. Charge can also be transferred between objects. Whenever two materials are brought into contact, and then separated, a charge exchange occurs between the two materials. One material gains electrons and becomes negatively charged, the other material loses electrons and become positively charged. This is known as *triboelectric*, or *friction*, *charging*. If one or both materials are isolated from ground or an insulator, the charge will remain on the material. This is what we refer to as *static charge*. Charge on a material may be transferred to ground or another object. This transfer is an electrostatic discharge, or ESD.

Technical requirements

The technical requirements of the static-control program will be affected by the nature of the static problems, product sensitivities to these problems and any limitations for installing static-control methods in the cleanroom.

Each static-control method will need to be evaluated for its cleanroom compatibility. The first step in the process is always establishing grounding techniques. These are applied to all of the elements in the electrostatic protected area (EPA). This includes all building elements (ceilings, walls and floors), furniture (tables, chairs and carts), personnel, tools and equipment and product packaging and transport materials.

Each item will have a specification for its maximum resistance to ground. For items with too high a resistance, alternative materials may need to be selected. It may be necessary to isolate some materials—primarily insulators—from the static-sensitive products. When this is not possible, air ionization becomes necessary to neutralize charges on the insulators and isolated conductors. Finally, both the EPA and any static-sensitive product should be clearly marked to indicate their presence.

Each technical element in the program will have defined limits of acceptance, installation requirements, maintenance requirements and a periodic verification interval. In designing the program, these will all be connected to the severity of the static problem. As noted, each element connected to the ESD ground system will have maximum resistance to ground associated with it. Personnel grounding methods will also have a minimum resistance to ground specification as well (for electrical safety). Air ionizers will have a balance requirement and often a requirement for maximum allowable static neutralization time.

Selection of the technical elements will involve laboratory testing to make sure that they meet program requirements. Testing may also need to be repeated after installation to assure that the required performance is obtained under actual use conditions and provide a baseline for future audit measurements.

Maintenance requirements, such as cleaning procedures, will need to be determined and each element will have a periodic verification interval. All, or a sample of each static-control method, should be measured periodically to assure that it is still functioning as originally installed. This will be a part of the audit program.

Static-control program development

There is no doubt that the careful selection of a few static-control methods can have an immediate positive effect on manufacturing results. However, you're looking to maximize and sustain the positive results in the complex, rapidly changing environment of cleanroom manufacturing, more is required.

Administrative elements and a total system approach must be added to the static-control program[8]. In creating these administrative elements, pay attention to the requirements of existing quality-control standards, such as ISO 9000/14000. The static-control program must conform to existing quality plan requirements and infrastructure.

A number of years ago, the ESD Association was asked to develop a static-control standard to replace the existing U.S. Military, MIL STD 1686C. Pursuant to this request, and recognizing the need for compatibility with existing industry static-control programs, the ESD Association released ANSI ESD S20.20-1999 "Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment."

This new standard defines the basic elements of a static-control program and is compatible with the requirements of ISO 9000/14000 quality programs (See *CleanRooms* July, 2001 Supplement, *ESD and Gas Handling*). The ESD Association has also trained ISO auditors to provide third-party certification of the S20.20 program[7].

Define the scope of the program: Why is there a need for static control, what areas will be included and what are the intended results? Testing or other types of analysis should establish the static-charge sensitivity of the products being manufactured in the cleanroom. This is important in defining the extent and complexity of the static-control program. Anyone looking at the program documentation should immediately understand why the program exists.

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Program tasks, activities and procedures: These elements will need to be clearly defined. Definition of the technical elements and selection of the materials for static control falls into this category. For example, a decision needs to be made whether to accept vendor material specifications, or to do in-house laboratory or *in situ* testing. Appropriate instrumentation and test procedures need to be part of the plan. Installation methods and employee operating procedures are included. How often will employees check the effectiveness of their wrist strap grounders, monthly, daily or continuously?

Audit procedures: A static-control program without adequate auditing is doomed to fail, usually placing considerable amounts of product at risk before the failure of the static control is noted. Auditing is also considered the binding force behind sound ESD program management, and a list of items requiring verification to be developed. For each item, define the required measurement and its limits, as well as the measuring instrument and its calibration interval. Also important is to define the frequency of audit for each item, as this may vary greatly. For instance, while you may only check equipment grounds once every six months, you may want to check ionizer performance bimonthly and wrist strap grounds daily.

Preventive and corrective action procedures: These procedures also need to be a part of the administrative plan to deal with deficiencies uncovered in the auditing process and are usually an integral part of any existing ISO 9000/14000 quality plan. Some problems are simply corrected by procedural changes, but in the worst case, may require the isolation of product or product recalls. Management may be very concerned about the possibility of selling product to customers that has been damaged by ESD in the period between audits.

Employee training: Training is essential to the success of any process in a manufacturing area. All manufacturing personnel need to understand the goals, procedures and technical elements of the static-control program. Training will need to be done at the start of the program, and in response to audit findings. Regular refresher courses will also need to be scheduled, typically within two years of the initial training. The administrative section of the static-control plan should define who needs to be trained, when the training should occur and the type of training to be offered. Evaluation testing or certification needs to be included to demonstrate that the employee has the required knowledge of the static-control program.

Support documents: These documents, usually industry standards, are the final administrative element. When specifying or developing these documents, it is essential that they be realistic requirements for the production area. These documents support all aspects of the static-control program, but particularly the technical elements and their audit procedures. Test methods, instrument calibration and specification limits are typically contained in these documents. In the general field of static-charge control, the ESD Association (www.esda.org) has an extensive range of documents addressing the testing of static-control methods. Specialized documents on static-charge control in the semiconductor industry are available from Semiconductor Equipment and Materials International (SEMI www.semi.org) and JEDEC (www.jedec.org). Static-control standards for the disk drive industry are available from IDEMA (www.idema.org). Static-control programs used in cleanrooms will likely have support documents that relate to contamination-control aspects as well.

Getting it certified

A successful static-control program will include a certification program, such as ESDA S20.20, for two basic reasons. First, management may desire assurance that the program, as defined, conforms to the requirements of the in-house quality system, and is continuing to supply the benefits of increased productivity and quality.

Second, the static-control program must satisfy customer requirements that the product has been protected from static charge during its manufacture. Particularly in the electronics industry, there is a growing knowledge that product damaged by static charge may pass component or subassembly testing yet fail prematurely in a completed product sold to a customer. Eliminating static hazards and certifying the static-control program become important elements of both the quality and reliability of the product—just saying you have a static-control program is no longer sufficient.

In setting up a static-control program, you will define those items that require certification. You will have to decide who will perform the certification—in-house personnel, industry experts or perhaps a third party to do this type of certification. For example, third-party certification is required for ISO 9000/14000. Administrative documentation will need to record the results of the certification, and include procedures for corrective action if some activity in the cleanroom does not pass certification.

SEMI has released E78-0998 "Electrostatic Compatibility: Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment." This document contains test procedures and acceptance limits for static-charge generation in production equipment.

While the limits are set for semiconductor components, they are easily changed to meet the needs of other cleanroom production. A companion document, E43-0301 "Recommended Practice for Measuring Static Charge on Objects and Surfaces," discusses measurement techniques and instrument calibration in more detail. These documents can be combined with certification procedures to assure static-safe production equipment.[5, 6]

The complexity of modern cleanroom operations requires a well thought out electrostatic management program, designed and executed by experts in the field.

The ESD Association released ANSI ESD S20.20-1999, which defines the basic elements of a static-control program. Designed to protect electronic devices sensitive to ESD at a specified 100 volt level, it contains descriptions and guidance to create the administrative elements of the program, required and optional technical elements, specification limits, audit procedures and intervals, testing procedures to establish actual product sensitivity and document references. It is available as a free download from the ESD Association website (www.esda.org).

Wrapping it all up

Static-charge control has become essential to protecting present and future cleanrooms from the effects of static charge. Damaged or defective product and inefficiencies in the production process are the result of a failure to control static. These show up as manufacturing yield losses, but even more serious are the impacts of static charge on long term reliability of the product. Most advances in the technology of products produced in cleanrooms will tend to make the static problems worse.

The complexity of modern cleanroom operations requires a well thought out electrostatic management program, designed and executed by experts in the field. While some standards have begun to appear in this field, the dissemination of electrostatic knowledge is in general, very slow. For companies with multiple manufacturing sites, the possibility of outsourcing EPM may be a cost-effective alternative.

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