Advanced Electrostatic Charge (ESC) Programs

Focus on 300mm Processing Equipment

It has been over 25 years since CMOS products brought the issue of Electrostatic Discharge (ESD) in semiconductor manufacturing to our attention. Since then, many industries have realized the importance of understanding ESD and protecting their products from its effects. However, as we enter the new Millennium, technology has advanced to the point that ESD programs need to be re-evaluated. Organizations including the Electrostatic Discharge Association (ESDA), IDEMA and SEMI have recently addressed the need for more stringent ESD control within their industries. Existing technologies such as Semiconductors, Flat Panel and Disc Drive as well as new technologies including MEMS, DNA and Gaas products such as Db gain amplifiers now require control of Electrostatic Charge (ESC) and ESD to levels well below 100 volts. Some of the newer technologies require control to levels of less than 10 volts!

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1. Introduction

Electrostatic phenomena in semiconductor manufacturing manifest themselves in many ways. These may include increased particle deposition due to electrostatic-induced particle attraction; damage to product, reticles (photo masks), and equipment from direct contact or induction from a charged object; and equipment malfunctions caused by electromagnetic interference (EMI) generated by the electrostatic discharge (ESD) event itself.

Until recently, there was no documentation to guide the end-user or the equipment manufacturer in minimizing the impacts associated with electrostatic phenomena. The Semiconductor Equipment and Materials International (SEMI) organization's committee on ESD produced a document last year to address these issues. The document, titled Electrostatic Compatibility-Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment, is referenced as E78-0998 and is available through SEMI.

The purpose of E78-0998 is to minimize the negative impact on productivity caused by static charge in semiconductor manufacturing environments. It is a guide for establishing electrostatic compatibility of equipment used in semiconductor production so the manufacturer can:

- Reduce product, reticle and equipment damage due to ESD
- Reduce equipment lock-up problems due to ESD events
- Reduce the attraction of particles to charged wafers

The scope of the document is limited to methods of measurement and guides for the maximum recommended level of static charge on product, reticles, carriers and parts of the input/exit ports of equipment and mini-environments. The later portion of the document deals with particle attraction due to ESA. Section R1-2 of the document deals with "Enhanced Particle Deposition Attributable to Electrical Charge on a Wafer". It is in this section that the potential for yield loss to static charge really comes into play.

Typically, the level of static charge required to physically damage a die or create a machine lock-up during a discharge event is fairly high. This has created a false sense of security about the level of static charge that is acceptable. But as semiconductor manufacturing migrates to 300mm and beyond, it is essential that these beliefs be re-examined. Larger wafer sizes coupled with decreased device dimensions and increased use of automated processing will challenge both the end-user and manufacturer of semiconductor equipment from an electrostatic standpoint. It is hoped that SEMI E78-0998 will provide a vehicle for the end-user and equipment manufacturer to achieve effective electrostatic control within the process environment.

Though primarily designed for equipment manufacturers as a guideline for design and test of new equipment and verification of the effectiveness of static control methods, it is also a valuable tool for implementing and testing ESD programs in other areas of the fab.

2. Electrostatic Testing Techniques for 300mm Semiconductor Manufacturing

The introduction of new electrostatic detection and test equipment has greatly improved the ability to provide cost effective and timely characterization of materials, equipment and environments. These new methods include the use of wide bandwidth oscilloscopes coupled with broad band antennas, and electrometers coupled with a laptop and data acquisition software.

ESD events by their nature occur very quickly, but emit electromagnetic waves that can be detected if the proper equipment is used. Due to the speed of an ESD event, one must use a calibrated wide bandwidth oscilloscope capable of accurately

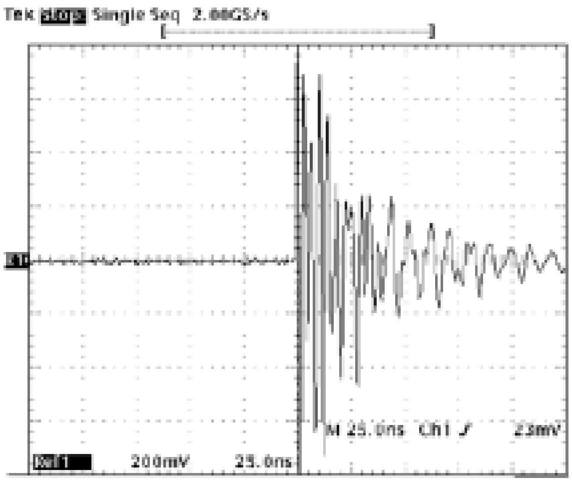

Figure 1. A Charged 300mm Wafer Contacting a Conductive-Grounded Surface

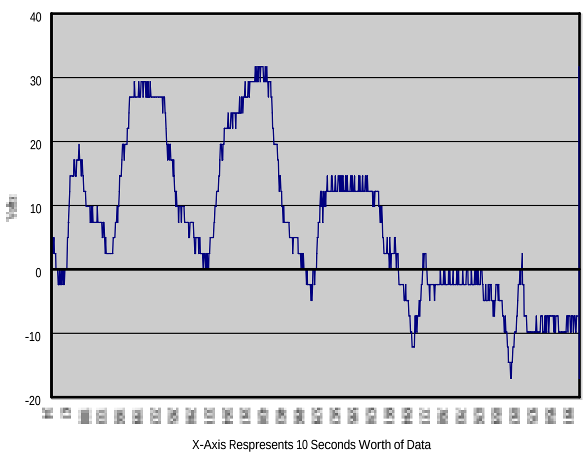

Figure 2. Electrostatic Voltage Induced on Bare Wafer Held within Sealed Static Dissipative Carrier when being Manually Handled with Cleanroom Gloves

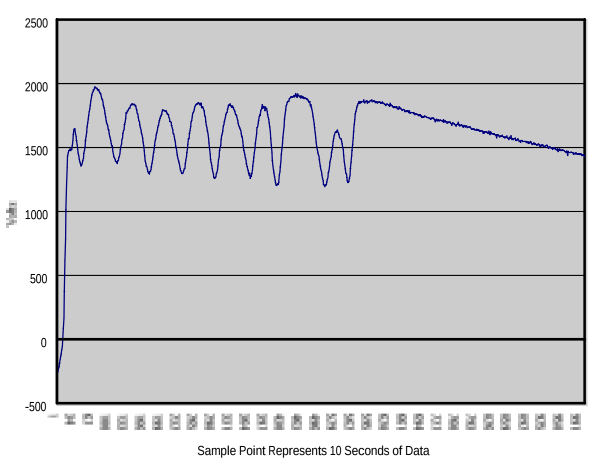

Figure 3. Voltage Induced by Personnel Walking on Carpet

resolving time domain events in the nano second range. At a minimum, a 1 GHz oscilloscope is required. Also the antenna/transducer used to absorb the electromagnetic energy associated with an ESD event must have sufficient bandwidth to resolve the ESD event. Ideally a calibrated antenna with a minimum of 2 GHz should be used. This technology is currently used in the 300mm semiconductor manufacturing environment, including process equipment, to detect ESD events. Figure 1 illustrates a typical ESD event captured using this method. The event was created by a charged 300mm wafer contacting a conductive-grounded surface. Preferably the antenna/transducer should be placed near the area suspected of generating the ESD event, but this may not always be possible, so an amplifier should be used to amplify the ESD signal absorbed by the antenna/transducer. This non-contact method of ESD event detection can be cost effective, and provides accurate data needed to drive changes within equipment and the environment.

The electrometer is another very useful instrument for detecting electrostatic charge within the semiconductor manufacturing environment. This instrument can be used as a direct contact electrostatic detector, or induced electric field detector, and when coupled with data acquisition software provides a cost-effective means of characterizing materials, equipment, personnel, and environments. This technology can be applied in "real world" scenarios to aid in material and equipment evaluations, or as a trouble-shooting tool. Figures 2 and 3 are examples of how this technology is implemented in a fab environment.

Identifying the presence of static charge in automated equipment presents significant difficulties. Coulombmeters with Faraday cups, ESD indicators, electrostatic fieldmeters, and electrostatic voltmeters, are the most commonly used instruments for detecting and/or measuring charge accumulation. Of these, only the Coulombmeter with Faraday cup measures the charge directly. Other instruments locate charges indirectly by detecting or measuring their electrostatic fields.

The Coulombmeter with Faraday cup is normally used to measure the charge on small objects. The part to be measured is carefully transferred (without generating additional charge) to the interior of the Faraday cup. The problem in using the Faraday cup is that the part must be removed from the equipment to make the measurement. This often involves disassembly of the equipment, or at the very least shutting the equipment down. It is also very difficult to accomplish when large objects like printed circuit boards are involved.

Many fieldmeters are hand-held instruments that measure the strength of an electric field produced by charge on a surface. Hand-held instruments are usually not appropriate for locating charged surfaces in equipment that is operating, unless the hand-held instrument can be suitably fixtured in the equipment. It should be remembered that fieldmeters installed close to a charged surface will alter the field from the charge on that surface, and may give an inaccurate measurement. Figure 4 shows the electric field lines both with and without the fieldmeter in place. Particularly when these instruments are used to measure the field on a moving object, an appropriate calibration procedure will be crucial (see EOS/ESD DSP 10.1). Also, substantial errors may be introduced when measuring fields from charges on insulating materials.

Static sensors such as the one shown in Figure 5, incorporate very high input impedance circuitry. They can be used to sense the field generated by a charged part as it moves through the process tool. The sensor should be mounted as close as practical to the part and should be no wider than the part being measured, to eliminate the effects of field suppression by nearby grounds.

As the part moves in the vicinity of the sensor, the measuring circuit will indicate any change in the electric field amplitude, indicating whether the part is charged or not. While this is a relative measurement, it can be calibrated by making a contact measurement on the charged part and comparing it to the field strength measured. Variations in humidity and temperature can also affect the level of the electric field measurement and should be taken into account.

This technology is useful for indicating charge on parts in high throughput machines, since nulling the field is not required as it is with fieldmeters. Mounted permanently, static sensors provide continuous monitoring and possibilities for closed loop control of static within the equipment.

Electrostatic voltmeters (see Figure 5) use voltage feedback to their sensor probe housing to null the electric field between the charged surface and the probe. As compared with fieldmeters, this method minimizes capacitive loading and more accurately reports the potential on the charged surface. Since the sensor probe housing will be at some nonzero voltage, care must be taken in mounting these probes in equipment.

Electrostatic voltmeters and electrostatic fieldmeters featuring small probes can be mounted in critical locations within automatic handling equipment to monitor the charge on parts as they pass by the probe. The probes are small enough to be useful in the small confines of the equipment.

In-situ calibration of these probes is often necessary as their measurements are affected by the field suppression effect of grounded surfaces; the size, speed, and distance of the part from the probe; and the orientation of the charged surface with respect to the probe. Care must be taken in locating the probes so that they make measurements in the appropriate locations without interfering with the movement of equipment parts.

For years, the Semiconductor industry has used Statistical Process Control (SPC) to optimize production. Now equipment and software programs are available to allow real-time Electrostatic Charge (ESC) monitoring and SPC programs (Figure 6) that will not only monitor the process tool but also control its operating environment to ensure charge will not reach unacceptable levels. The system can constantly monitor operators for charge and ground, and can also monitor field charge in critical locations in the tooling. This technology not only ensures that high levels of electrostatic charge will not damage the product or equipment from ESD events, but can also be used to control the charge at much lower levels to reduce defects caused by static-induced particle deposition on the wafers. The data acquisition capability allows for yield tracking in relation to static charge.

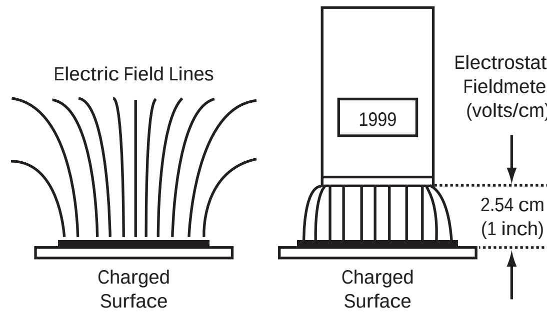

Figure 4. Fieldmeter Suppression of Electrostatic Field

Figure 5. Electrostatic Voltmeter

Figure 6. Real-time ESC/SPC Monitoring and Control Systems

3. Static Event Detectors (ExMOD) and Intel Case Example

The first static event detector (SED) was invented by Zero Static Systems in the late 1980's. The detector is small enough to be placed on circuit boards, and detects the current pulse in an ESD event through an antenna or external clip. The signal is amplified and processed to produce a reflectance change in the built-in Liquid Crystal Display (LCD). The SED is designed to trip at a predetermined threshold voltage, detects ESD transients above the selected amplitude, and is not polarity sensitive. The device is reset with a magnet, making it reusable. Unfortunately, the threshold setting does not directly relate to ESD damage in electronic circuits.

A second-generation device was introduced by Electrostatic Designs and is called "The Static Bug". It employs the well-understood ESD susceptibility of Metal Oxide Semiconductor Field Effect Transistors (MOSFET). The test methodology is to amplify an ESD transient to create sufficient energy to destroy the gate oxide. The standard configuration has a 300 volt ESD failure threshold. The device may be reused until the ESD level is reached, then the SED fails and is no longer usable. This type of SED requires additional instrumentation to determine its status.

Motorola developed a similar device based on another historically ESD susceptible device, the Metal Oxide Capacitor (MOSCAP). Current leakage through the device significantly increases if the ESD amplitude is sufficient to damage the Metal Oxide Semiconductor (MOS) structure. Both Electrostatic Design and Motorola SEDs must be removed from the assembly and inserted into a readout unit to determine whether the sensor has recorded an ESD event.

Another type of SED is referred to as the ExMOD (Exotic Magneto-Optical Detector). The detector employs the Faraday Effect to detect and optically record an ESD current transient onto a magneto-optic thin film detector. The magnetic field from the ESD current alters the film's magnetic state and affects the degree of polarization of visible light reflected from the film. Different thresholds are indicated by varying the distance between the film and the ESD current-carrying conductor.

This device (see Figure 7) can be simply read using a microscope equipped with a polarizing element and does not need to be removed from the circuitry to be read. It can be reset without contact using a very strong magnet.

SEDs can be useful in determining the occurrence of ESD events in operating production equipment. The SED has the ability to indicate ESD events of a known level, aiding in the design and performance verification of automated equipment. While costly analysis of failed devices can also provide this information, correlation to machine operations is usually difficult. An SED that can be monitored optically as it passes through operating equipment provides a convenient method to verify that automated equipment is not generating levels of static charge that result in ESD damage. Intel uses a series of component handlers to automate the testing process. These handlers use insulative vacuum cups to transfer devices, and in the process generate a substantial amount of charge on the device. To counteract this charging, the handler is equipped with ionizers to dissipate any charge on the device. In the past, devices have been damaged as a result of ESD even with the ionizers operating within their specification. It was unclear whether the devices were damaged during the assembly process or at test. A metrology tool was needed to evaluate the component handlers and determine if they were the cause of the ESD damage.

Intel used multilevel SED devices to evaluate the ESD performance of these component handlers. Ten SED devices were assembled in 50mm SPGA packages with the I/O pads of the SED connected to the outermost pins. These test vehicles were then cycled through the component handler five times with the ionizers turned on and again with the ionizers turned off. Results showed that with the ionizers on, only the 50V domain on four of the devices had tripped. This was below the threshold of ESD damage for the device. With the ionizers off, however, the SED devices detected voltages up to 500V, a potential source of damage. This test pointed out that the ESD damage to the devices was likely occurring in some other part of the assembly process.

4. Current ESD Requirements for Sensitive ESD Technologies

Flooring

A high quality static dissipative or conductive floor may be one of the most significant capital investments in the factory. If problems arise with a poorly selected or incorrectly installed floor, the cost of changing the floor may far exceed the original installation cost. While the cost of materials and labor related to replacement may be borne by the supplier of the defective floor, manufacturing downtime and the legal costs to recover may be significant. For this reason, the flooring used in cleanroom fabrication and assembly areas must be evaluated and chosen carefully to provide the desired long-term results.

In many cases, the flooring and footwear provide the primary path for grounding of personnel. Evaluation of flooring should include a qualification of the floor in conjunction with the footwear that will actually be worn by personnel working in the area. Qualification testing for static control properties would include

Figure 7. Static Event Detector (ExMOD)

point-to-point resistance and resistance to groundable point testing using the ESD Association's test methods (ESD-S7.1, ESD-STM 97.1), and characterization of voltage generation on the operator using ESD-STM 97.2. Carefully, laboratory-based testing can be performed using these test methods to compare different suppliers and installations. If the user cannot perform this testing in-house, several independent laboratories offer a testing service.

Part of the decision in choosing a supplier of flooring must also include the installation. Many excellent dissipative or conductive floors have been ruined by poor installation. Ask the proposed supplier if they have qualified installers who have been trained in proper installation techniques. If possible, use the vendor's own trained installers to prevent "finger-pointing" later if there is a problem with the floor. After the floor is installed, careful evaluation should be carried out to ensure that it was installed properly and the user received the materials that were originally qualified. Again, use the "installed floor" sections of ESD Association test methods 7.1, 97.1 and 97.2 to carry out this evaluation.

The cost of ownership of a static control floor must include long-term maintenance costs. Some floors only require damp mopping on a daily (or less frequent) basis, combined with a "once-in-a-while" polishing to retain the original sheen of the installed floor. Other flooring requires the application of sophisticated and expensive coatings to maintain their electrical and cosmetic properties. Long-term maintenance costs should be included with the original installation cost when choosing a floor system.

Garments

Garments for class 10 or better cleanrooms that also provide sufficient static control protection for ultra sensitive products have been the subject of much controversy. In many cases, the materials needed for high filtration do not allow enough contact between the conductive elements of the material to obtain conduction between the different panels of the garment. Some users and garment manufacturers claim that conductivity across the panels is not necessary, while others require conduction across the panels. If the end-user decides that conductivity across the panels is a requirement, the test methods called out in ANSI/ESD-S2.1 can be applied to evaluate the garments. Many garments will pass these tests initially, but fail after just a few wearing/laundering cycles. A careful evaluation of new and used garments should be undertaken to ensure proper long-term performance.

Part of the garment that is commonly ignored in these evaluations is the footwear. Many suppliers specify a static dissipative or conductive sole, but then ignore the issue of how they are going to get a connection between the operator and the sole. Many cleanroom operations include one or more shoe covers that must go on the operator's feet prior to placement of the cleanroom boot onto their foot. Most of these shoe covers are insulative and will prevent connection of the operator to the boot sole. A method must be implemented that will allow the operator to contact the sole electrically. Some companies are utilizing a grounding strap on the outside of the shoe covers that make contact with the operators "sweat layer" and the inside surface of the sole (similar to heel or toe grounders). Others are investigating making the connection through the garment itself.

Voltage generation of the boot was addressed in the discussion on flooring, but the garment itself must also be evaluated for voltage generation.

Chairs

Several well-built "ESD chairs" are available on the market. Many are also compatible with class 10 or better cleanrooms. Considerations for chairs used in static control work areas include the surface resistance of the material and its voltage generation on the operator while they are sitting in the chair. The ability of the chair to conduct charge off the operator is dependent not only on the resistance of the fabric/seat material, but also on the quality of the electrical connection between the chair and the floor. All components of the chair should be connected electrically, and should be reliable so that the chair remains conductive throughout its useful life. The casters/wheels in particular often have reliability problems. Casters/wheels on chairs should be tested frequently until reliability of the design is established. Evaluation of chairs can be performed using the test method outlined in ESD-S12.1.

Worksurfaces

Worksurfaces can pose an interesting tradeoff between cleanroom considerations and ESD control considerations. Most companies are not only specifying a maximum resistance/resistivity for worksurfaces, they are also specifying a minimum. The minimum resistance/resistivity is important, particularly in assembly factories, to prevent charge-device-model (CDM) damage to components. On the other hand, ultra clean facilities and facilities using caustic chemicals typically require stainless steel worksurfaces. Careful evaluation of the process must be undertaken to ensure that charge can be removed from the device before it contacts metal tooling/worksurfaces to prevent charge-device-model damage. In areas where the product is easily charged, i.e. assembly factories where potting compounds and substrates are made of insulators, it may be necessary to install static dissipative worksurfaces rather than conductive worksurfaces (see grounding section for more details).

Wrist-Straps

The wrist-strap is the most visible and obvious static control tool available. While in many instances it may be possible to ground personnel through other means (footwear, chairs, etc.), the most reliable and visible method is via a wrist-strap. Another benefit of the wrist-strap is to remind personnel that they are in a special area, and must follow certain protocols while they are in the area. Like an air shower, the wrist-strap can serve as a reminder that the environment the person is entering is different from the one they were in before.

Ionizers

Ionization is used to remove charge from items that cannot be grounded due to their material properties (insulators), or because they cannot be physically grounded (spinning metal end-effectors etc.). Typical applications for ionizers would be to remove charge from materials like wafer boats, encapsulant molding, and printed circuit substrates.

A critical thing to remember is that ionization takes time to work. In many cases, components are moving so fast along a conveyor or in a process that the part is only in the ionized air stream for a few hundred milliseconds before it is touched or picked up by a handler. In these cases, very little charge is removed from the part, and the ionization system is of minimal value. The process must be carefully evaluated to determine if the right ionization is installed, if the ionization can be moved or changed to provide better coverage and/or discharge times, or if the process needs to be modified to allow the ionizer to work.

Qualification of an ionizer should begin with applying the test methods outlined in ESD-S3.1, and then evaluating the ionizer in the actual work environment with the actual parts being handled.

Monitors

Workstation monitors developed for the extremely static-sensitive Disc Drive Industry have found many applications in the newer, more sensitive and highly automated Semiconducter manufacturing lines. They provide the ability to monitor charge on the operator rather than simply measuring the resistance of the operator. The charge measurement is a true measure of the ability of the grounding to dissipate charge accumulation on the operator. The monitors also incorporate the ability to constantly measure the resistance to ground of sensitive mobile ground systems such as robots or shuttle systems. The units incorporate the ability to measure field charge and can also be interfaced to some ionizers to control balance at the product location and reduce large charge build-up on wafers. The monitors can also be incorporated into facility monitoring and control systems, which will then interface with the controller of the process tool to ensure product is processed in an optimum environment.

Packaging/Material Handling

Evaluation of product movement should be performed to determine the correct packaging for that product. For instance, if the product is moving between workstations within an ESD-protected work area, the packaging should be antistatic, or dissipative. If the product is moving out of the ESD-protected work area, but through a controlled environment into another ESD-protected area, then a dissipative package with some field shielding properties would be sufficient. However, if the product will be moved through an uncontrolled environment, the packaging should provide static discharge shielding properties.

A common problem in the semiconductor industry today is the use of insulative wafer boats and wafer jars. Some of the most sensitive devices ever produced are being placed into standard polyethylene, polypropylene, or Teflon containers. Visible sparks between personnel, tooling, and wafers inside these containers have been observed in assembly houses. While it may appear that the devices are not ESD sensitive since they are still in wafer form, this may not be the case. In addition, electrostatic attraction of particles to these wafers is a serious problem. A wafer charged to 20KV makes an effective electrostatic cleaner for the assembly area.

The industry must begin to develop better packaging for wafer products. Although they are more expensive, dissipative containers will provide reduced fields for inducing large charges onto wafers, thereby reducing ESD event damage and contamination-induced damage. In addition, these containers are more cleanable and can probably be re-used.

Facility Grounding

Another common mistake found in many facilities, particularly older ones, is the installation of separate ESD grounds from the power supply ground. Particular problems exist in overseas facilities where multiple power types are installed. Sometimes, there is the 220V, 50Hz power from the standard power distribution, then a split to provide 110V, 50Hz, and then a generator that provides 110V, 60Hz power. In many cases, each of these has its own grounding system. To make matters worse, there is frequently an additional "ESD Ground" run that provides yet another place to ground items. In this example, there are possibly four different grounds, each having its own potential. Since they are all tied to the earth at some point, it would seem that they should be at the same potential, but this is not the case. In some factories, several volts may be present between the grounds, with sufficient energy to damage electronics and potentially injure personnel.

There should be only one ground for the facility. In operations where a "quiet ground" is necessary for some equipment, all of the ESD grounding for that tool should be tied to the same ground to ensure that the ESD ground and tool ground are one and the same (see workstation grounding, below). Ground-Fault-Circuit-Interruption (GFCI) equipment should be installed whenever practical to ensure personnel safety.

Workstation Grounding

Each workstation should have a common point ground installed. Everything on the workstation should be tied to that common point ground, then the common point tied to the same ground as any power equipment on the workstation. In this way it is possible ensure that no potential exists between any of the grounds on the workstation.

Workstations should also never be connected together, with one then being tied to the facility ground (daisy-chained). Each workstation should have an independent connection to ground. This helps prevent ground loops, and the catastrophic situation of having one ground wire open, resulting in an entire row of workstations becoming ungrounded.

5. Closing

ESC/ESD Programs are here to stay. Many companies, especially in the Disk Drive Industry, have realized that although ESD monitoring and controls may be costly; they are a requirement to produce quality products. They have also accepted the fact that technology advancements will continue to require lower ESD control limits.

To stay ahead of the current and projected limits, the leading companies have adopted ESD control programs that far exceed the requirements for today's products. They have set control limits to meet the needs of the forecasted technologies 3 to 5 years in advance. This strategy forces the process equipment, monitoring instrumentation and the training of personnel to exceed present considerations and be prepared for the requirements of the foreseeable future. This attitude minimizes the risk of ESD-related issues, resulting in maximum yield on today's products as well as minimizing time-to-market with new products in an industry with product life cycles of 90 to 180 days. By following this strategy, the cost of ESD protection products can also be capitalized over a number of years rather than meeting only the present requirements. ESD protection with associated cost and control will become a strategic part of a dynamic overall manufacturing program. This requirement will not decrease but will become mandatory to remain competitive in the 21st century.

Biographies

Carl Newberg is the president and owner of River's Edge Technical Service, an independent testing laboratory and consulting service to the ESD and contamination control industries. He has held positions as the ESD Program Manager for Western Digital Corporation, and has been actively involved in the corporate ESD program at Seagate Technology and IBM Corporation. He is the co-chairman of the ESD subcommittee of IDEMA and is a member of the ESD Association. Carl is an active member of the ESD Association Standards Committee, participating in the standards writing and review committees..

Don Boehm is the Executive Vice President of Novx Corporation, a manufacturer of leading-edge ESC monitoring instruments and has more than twenty-five years experience in the semiconductor industry. Don is currently a member of the National ESD Association, sitting on several working committees, and also serves as liaison to the U.S. Display Consortium (USDC). He has also co-authored technical papers for the International EOS/ESD Symposium and was awarded "Best Presentation" for the ExMOD Paper.

Julian A. Montoya is the Program Manager for Electromagnetic Compatibility and Telecommunications Infrastructure where he is responsible for the selection, design, and implementation of electromagnetic interference controls, electrostatic discharge controls, and telecommunications infrastructures for Intel's facilities worldwide. Montoya is also a member of the ESD Association, SEMI Exit Charge Work Group, and SEMI Regulatory Compliance Work Group. Montoya has written or co-written papers in IEEE, Micro, SEMI, and Intel publications on the subjects of electromagnetic compatibility, electrostatic compatibility, and regulatory compliance.