Test Methodologies for Detecting ESD Events in Automated Processing Equipment

ESD Association Standards - Automated Handler Workgroup WG10
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Abstract - ESD events cause device damage and equipment malfunctions in automated processing equipment. This paper surveys the problems caused by static charges in automated processing equipment. It looks at a number of test methods that detect those charges and the ESD events that occur in this equipment. It also provides examples of using these techniques to solve factory problems.

Introduction

The laws of physics are the same everywhere. Static charge generation is unavoidable whenever materials come in contact. Without a static control program, the problems caused by static charge are also unavoidable. The most common problem caused by static charge is electrostatic discharge (ESD).

ESD is the rapid, uncontrolled transfer of charge between objects at different potentials. This results in damaged semiconductor ICs, photomask defects, magneto-resistive (MR) read head defects in disk drives, and failures of the drive circuits for flat panel displays (FPD). ESD also creates a significant amount of electromagnetic interference (EMI). Often mistaken for software errors, EMI resulting from ESD interrupts the operation of production equipment. This is particularly true of equipment depending on high-speed microprocessors for control. Results include unscheduled downtime, increased maintenance requirements, and frequently, product scrap. Technology trends to smaller device geometries, faster operating speeds, and increased circuit density make ESD problems worse. [1]

Solving the ESD problem has become essential to achieving high production yields in modern electronics manufacturing. Static control programs exist from the silicon factory to printed circuit board assembly and test. Consumers are often instructed in static safe handling procedures as they set up their newly purchased electronic equipment. In circuits designed to operate at lower and lower voltages, charges resulting in voltages as low as 50 volts can damage or destroy an electronic device—paving the way for product failure.

For many years static control programs concentrated on protecting components from the charge generated on the personnel that handled them. Many static control methods were devised to control the charge on people including wrist and heel straps, dissipative shoes and flooring, and garments. Increasingly, however, the production of electronic components is done by automated equipment, and personnel never come into contact with the static-sensitive devices. Solving the ESD problem means assuring that ESD events do not occur in the equipment used to manufacture and test electronic components.

ESD Hazards in Equipment

The primary method of static charge generation is triboelectric charging which occurs when materials are in contact and in motion with respect to each other. It is hard to imagine how this might be prevented in automated equipment, where both the equipment parts and the product are constantly in motion. ESD occurs when charged equipment parts contact the product, or when charged product contacts grounded equipment parts. A successful static control program for equipment must prevent both of these types of events from occurring. Additionally, once an object is charged it can induce charge on other nearby conductive objects. This is most obvious when charge is generated on the insulating material of the component package. Charge is then induced on the component leads attached to the internal circuitry. If the leads touch a grounded surface, an ESD event will occur that could damage the component.

Test methods exist to determine sensitivity of components to ESD events that may happen in equipment. Machine Model (MM) ESD testing measures the sensitivity to discharges that might occur from ungrounded conductive equipment parts. A 200pF capacitor is charged to a known voltage and then discharged through a zero resistance path into the leads of the component being tested. Charged Device Model (CDM) testing simulates the ESD event that occurs when the device package becomes charged, and then the device leads contact a conductive equipment part. In this case the device itself is charged to a known voltage, and the device leads are connected through a one ohm path to ground. While there is no correlation between the safe discharge levels of these test methods, or with any other common ESD related component tests, in most cases modern components are not sensitive below 200 volt discharges. There are, of course, occasional exceptions to this level. [2,3]

Static Control in Equipment

An effective static control program in equipment is designed to prevent both MM and CDM ESD events. As with any static control program it starts with grounding all materials that might come close to, or in contact with the static sensitive components. This prevents the generation of static charge on machine components and eliminates them as a source of the charge creating ESD events. Care must be taken in a grounding program to assure that moving equipment parts remain grounded when they are in motion. In some cases, static dissipative materials may be substituted for conductive materials where flexibility, thermal insulation, or other properties not available in conductive materials are needed. If charging of components is unavoidable, static dissipative materials may be used to slow the resulting discharges and prevent component damage.

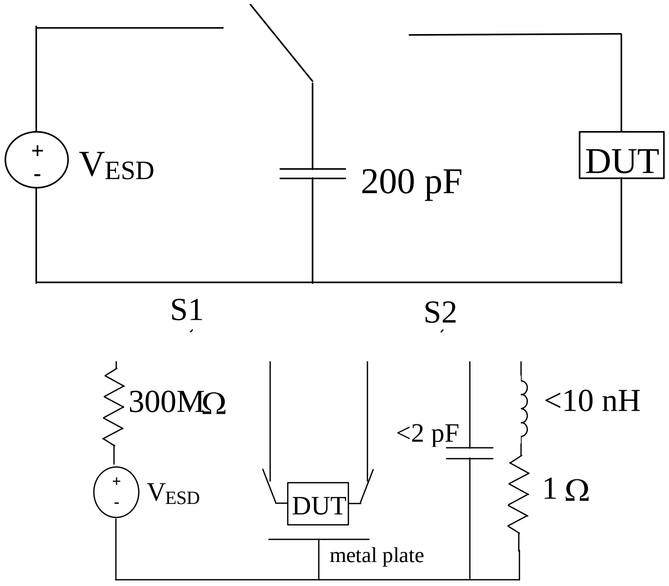


Figure 1 - Machine Model and Charged Device Model Schematics

In fact, component charging that results in CDM ESD events is the more difficult problem to solve. Most electronic components contain insulators that are part of their design or packaging. Epoxy packages of integrated circuits and the substrates of printed circuit boards are the most obvious examples. Handling these insulating materials inevitably generates static charge, and this charge cannot be removed by grounding the materials. If charge generation is unavoidable, the only effective method of neutralizing the charge on insulators or isolated conductors is to use air ionization. Ionizers are typically mounted in the load stations and process chambers of the automated equipment to neutralize the charge that causes CDM ESD damage.

Verifying Equipment Static Control

A static control program begins when the automated equipment is designed by the OEM, and then continues throughout the lifetime of the equipment. Two basic issues need to be demonstrated. First, are all components in the product-handling path connected to ground? Second, as the product passes through the equipment, is it handled in a way that does not generate static charge above an acceptable level on the component? Assistance in answering these questions is provided by an ESD Association Standard Practice, EOS/ESD DSP 10.1-1998[4]. This document contains test methods to verify the integrity of the ground path to equipment parts, as well as to determine if the product is being charged during its passage through the equipment. The test methods are applicable during the original design of the equipment and during acceptance testing by the end user.

While the test methods of DSP10.1 can also be used for periodic verification of the equipment performance, they have one drawback. The automated equipment must be taken off-line to do the testing. This means that there is lost production time, and often the periodic testing is eliminated to maintain product throughput. The only time testing occurs is when product losses reach a level that causes concern. In today’s high speed manufacturing environment, product losses caused by ESD hazards can quickly become very expensive. What is clearly needed are test methods that can be performed with the equipment operating on-line, without altering or disturbing its operation.

ESD and EMI

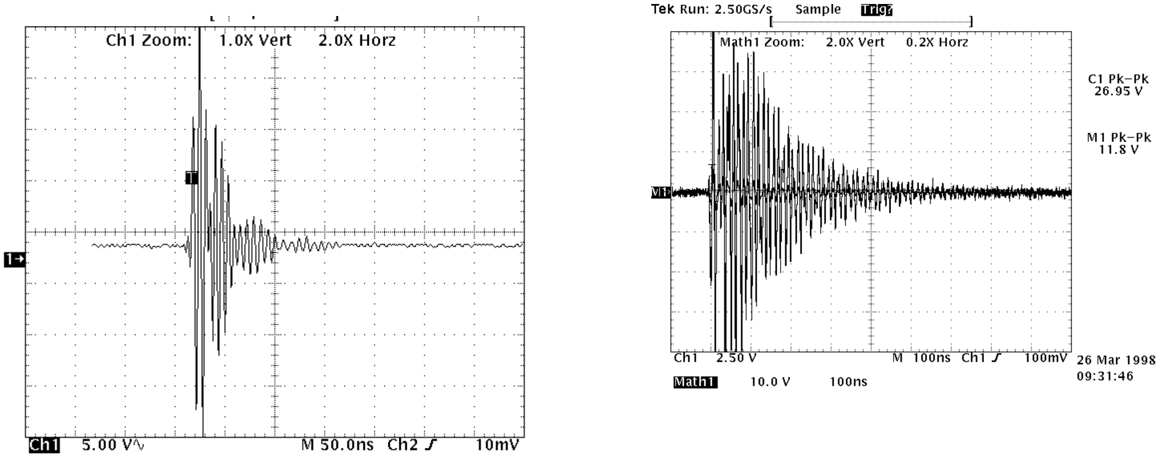
When ESD occurs, the discharge time is usually 10 nanoseconds or less. Discharging energy in this short time interval results in the generation of electromagnetic radiation in the 10MHz to 2GHz frequency range, as well as the heat that damages electronic components. This electromagnetic radiation is the EMI that can affect the operation of production equipment. Today’s complex equipment is increasingly operated by microprocessors whose operating frequency is in the same range as the EMI from ESD events. ESD events cause a variety of equipment operating problems including stoppages, software errors, testing and calibration inaccuracies, and mishandling causing physical component damage. Since the EMI can be either radiated or conducted over long distances, identifying the source of the EMI is often difficult. It may not occur in the equipment that is experiencing the operating problem, and it tends to be random in nature.

Component damage due to ESD is a more serious problem because it tends to be repetitive, rather than random. A machine action that charges a component will generally charge all components that are being handled. At some later point in the equipment operation, the component contacts ground, and an ESD event occurs. As with any ESD event, EMI is generated, and this EMI can be detected with appropriate instrumentation.

EMI Locators

When component damage or equipment problems due to ESD are suspected, it may be useful to detect the electromagnetic interference (EMI) generated by the ESD event. This type of testing is both a starting point for determining that static charge has been generated, and it is a measurement point to ascertain that any static control methods have been successful. Such testing will often prevent wasted man-hours trying to find the cause of random machine stoppages or ESD damaged components. It is a measure of dynamic operating conditions because it is usually not necessary to interrupt equipment operations to make measurements.

An EMI Locator can be used for this testing. It is available in a number of different forms. In its simplest form, it consists of an AM radio tuned off station. A popping noise will be heard when an ESD event occurs. At the most complex it consists of a wideband (greater than 1GHz) digital storage oscilloscope with a set of appropriate antennas, probes, and software. Measurements of radiated interference can be made using antennas while probes can be connected to equipment parts or electronics and power lines. A number of methods have been devised to use multiple locations of this equipment to assist in pinpointing the actual location of the ESD event. Figure 2 shows typical waveforms of signals detected from both radiated and conducted EMI that was caused by ESD events.



Conducted EMI measured at 10 meters on an oscilloscope on the power line.

Radiated EMI detected on an antenna at 3 meters.

Figure 2 – Conducted and Radiated EMI Waveforms

Several papers have been published detailing how an antenna, typically a monopole antenna in the range of 5-50 mm in length, can be used to detect the presence of ESD pulses in a local area.[5,6,7,8] A set of antennas can be used to not only detect the presence of an ESD event, but to determine the location of the pulse in 3 dimensions.[9,10] Using the same concept as a global positioning system (GPS), the difference in the arrival times of the signal is directly related to the difference in the distance of each antenna from the ESD source. With the time deltas and the locations of the antennas known, the location of the spark can be uniquely identified. Waveforms from a set of three antennas are shown in Figure 3. Employing the appropriate analysis program enables locating in space where the CDM ESD event that produced theses waveforms occurred.

Many other types of EMI locating equipment are currently in use. Most consist of high frequency receiving circuitry followed by level detectors to determine the magnitude of the signal. For the purpose of detecting EMI from ESD events, the equipment should have some way of differentiating the short impulse of EMI from the ESD event from the continuous high frequency radiation of other EMI sources. Two different EMI locators are shown in Figure 4.

The Lucent Technologies Model T100 ESD Event Detector provides detection levels of 20 millivolts and 2 volts using a small loop antenna attached to the instrument. It contains a counter to total the number of ESD events above the threshold, and alarms to indicate when the number of ESD events exceeds a preset number. The instrument can be placed near a piece of equipment that is suspected of causing ESD events and left in place to monitor.

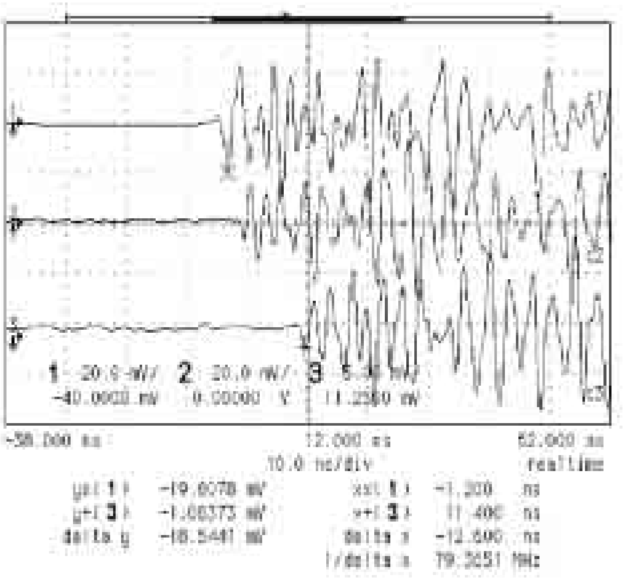


Figure 3 – Example of radiated EMI from a CDM ESD event detected by a set of three antennas

Sanki Model ES-81V

Lucent Model T-100

Figure 4. EMI Locators

The Sanki Model ES-81V is a small, handheld device using a short monopole antenna to detect the high frequency impulses generated during an ESD event. It provides sensitivity levels of 5 and 120 millivolts, and separate alarm indicators for each level. Optional longer antennas can extend the device sensitivity to lower levels. Since it is a battery operated device, it is suitable for surveying an entire production facility for the occurrence of ESD events.

The small size of this EMI Locator allows it to be placed directly inside operating equipment to detect signals that might otherwise be shielded by the equipment's cover panels. (Note that EMI shielding is usually an important part of the design of most production equipment to prevent radiation from the equipment. This makes the detection of ESD events outside the equipment more difficult.) It allows pinpointing of the location of an ESD event, which can then be correlated to particular machine operations. This allows the identification of ESD events that cause equipment malfunctions as well as those that potentially can cause damage to components. [5,11,12]

The Credence Technologies, Inc. EM Eye® CTM041 and CTM045 are small, hand-held devices using directional antennas to help locate sources of ESD events, not only by proximity, but also by focusing on the direction of maximum signal strength. Both models include ESD event counters and log the magnitude of these events into memory. An audio speaker or headphones allow listening to the discharges to simplify location of their sources. The CTM045DL also provides data logging of ESD events with time/date stamping, and a computer interface for data retrieval.

Some equipment is suitable for continuous monitoring. The advantage here is that changes in static discharge characteristics can be detected quickly and thus reacted to in shorter time frames. Computer logging of monitor results can help in isolating the sources by correlating the times of discharges with, for example, a new tester setup or a new operator beginning a shift. The Credence Technologies, Inc. AWARE™ are low-cost ESD event monitors for continuous monitoring of workstations and equipment. Each monitor features sensitivity adjustment, audio event indicator, LED event indicator, and networking capability for use as remote ESD event sensors in a monitoring system. An analog output indicates the magnitude of ESD events.

One caution needs to be observed when using EMI locators to detect ESD events that cause component damage. The signal received by these devices is generated in areas usually surrounded by grounded metal components. It may have to pass through equipment panels and travel some distance through the air before it reaches the detector. There may be other radio frequency sources and reflecting or absorbing materials in the area. It will be difficult to establish any correlation between the amplitude of the signal received by the EMI locator and the energy in the ESD event that produced the signal. The EMI locator primarily indicates the occurrence of an ESD

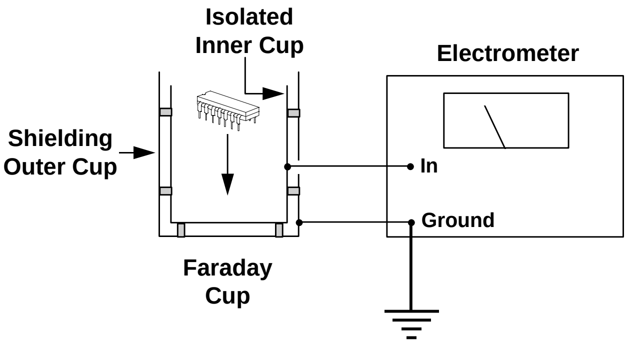


Figure 5. Faraday Cup for Charge Measurement

event and can be used to illustrate that a particular static control method has eliminated it. It should not be assumed that every ESD event detected results in damage to components or equipment problems. Additional testing will be needed to establish that connection.

Detecting Static Charge and ESD

Hopefully, the EMI locator was useful in pinpointing the location of the ESD event. If not, it still has demonstrated that an ESD event is occurring in the process equipment. In either circumstance, the next step is to begin searching for the location where the charge is generated, and then to apply countermeasures that prevent charge generation or charge retention.

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 instrumentation for detecting or measuring charge accumulation. Of these, only the Coulombmeter with Faraday Cup (shown in Figure 5) measures the charge directly. The other instruments locate charges indirectly by detecting or measuring their electrostatic fields (fieldmeter shown in Figure 6).

The Coulombmeter with Faraday cup is used to measure the charge on small objects directly. 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 stopping the equipment. It is difficult to accomplish when large objects like printed circuit boards are involved.

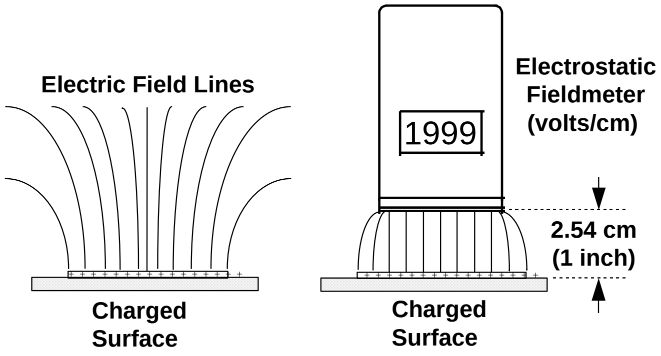


Figure 6. Indirect Charge Measurement Methods
(Fieldmeter, Static Sensor, Voltmeter with Probes)

Many fieldmeters are handheld instruments. Handheld instruments are usually not appropriate for locating charged surfaces in equipment that is operating unless the handheld instrument can be suitably fixtured in the equipment. It should be remembered that fieldmeters installed close to a charge surface will alter the field from the charge on that surface, and may give an inaccurate measurement. Particularly when they are used to measure the field on a moving object, an appropriate calibration procedure will need to be followed (see EOS/ESD DSP 10.1). Considerable errors may be introduced when measuring fields from charges on insulating materials.

Electrostatic voltmeters 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 of the charged surface and more accurately reports the potential on the charged surface. Since the sensor probe housing will be at some non-zero voltage, some care must be taken in mounting these probes in equipment.

Electrostatic voltmeters and electrostatic fieldmeters featuring small probes can be mounted in critical locations in the 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.

Static Event Detectors

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, and it may be reused until the ESD level is achieved, and the SED fails. This type of SED requires additional instrumentation to determine its status.

Motorola has also developed a similar device based on another historically ESD susceptible device, the Metal Oxide Capacitor (MOSCAP). The 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 have to be removed from the assembly and inserted into a readout unit in order to determine whether the sensor had recorded an ESD event.

Another type of SED is referred to as the ExMOD (Exotic Magneto-Optical Detector)[13]. 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.

The device can be simply read using a microscope equipped with a polarizing element (see Figure 7). Since the device does not need to be removed from the circuit to be read, high volume production applications are feasible using pattern recognition readers which can transmit the ESD event trip level

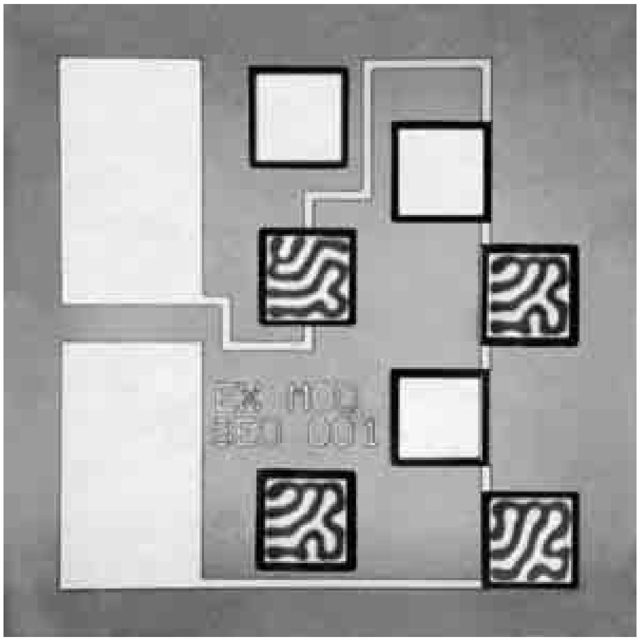


Figure 7 - ExMOD with several sites indicating ESD events

back to the process tool for acceptance or rejection. The unit can be reset without contact using a very strong magnet.

This SED is extremely small, 20x20x20 mils in size, and can be installed on circuit boards, in a multichip package, or directly to device leads. It requires no power; and can be used with one lead attached to the circuit to be monitored and the other to ground. With the device connected in series with a circuit, it can also be used as a fuse for both monitoring and protecting sensitive circuits. The device can indicate ESD events, and if they exceed a predetermined current level, the internal conductor will open to protect the circuit downstream.

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.

Case Histories

Case #1 - A semiconductor photomask inspection instrument was reporting surface particles which did not exist. The “particles” were traced to discharges in the ungrounded ceiling of the facility that were producing conducted EMI. The signal from the photodetector within the instrument was viewed with an oscilloscope triggered by a signal from a passive antenna within the room. Phantom photodetector signals were seen with 100% efficiency when the oscilloscope was triggered. The EMI from the ESD events was produced over 10 meters from the instrument and was conducted to it via the neutral line of the power source. Grounding of the ceiling components solved this problem. The rate of oscilloscope triggers dropped to near zero (less than 1 per hour as compared with over 10 per minute) and the incidence of coincident signals from the photodetector was eliminated.

Case #2 – Yield losses on a particular semiconductor device were experienced due to the burn-in process. This was determined by testing parts before and after burn-in. Individual device tests did not indicate any particular thermal sensitivity. Suspecting that there might be an ESD issue, an EMI Locator was used to survey the automated handler removing devices from the burn-in carriers. ESD events were noted when the device was placed on an alignment stage after removal from the carrier. It was noted that the ionizer in the equipment was not directed at the burn-in carriers as they came out of the burn-in oven. The ionizer was redirected so that it ionized the devices in the burn-in carriers as soon as they exited the burn-in oven, before the pick-and-place robot removed the devices from the carriers. When this was done, the EMI Locator stopped indicating ESD events and the yield loss also ceased. Subsequent device testing confirmed that the ESD was responsible for the yield losses.

Case #3 – 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 50 V 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 of 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, where ionizers were not in use.[14]

Conclusion

There is little question that static charge problems continue to result in significant losses in high technology manufacturing. Static control programs are successful in minimizing these losses when they are implemented properly. Increasingly, static control methods must be applied in the automated equipment that produces the product. In the future, equipment static-related problems will increase while personnel related static problems will tend to decrease. It will be important to develop new diagnostic methods and measurement equipment for ESD in automated equipment. This paper has attempted to present some of the methods that are currently available.

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