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Evaluating the Effectiveness of a CDM ESD Control Program

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***Abstract*—Electric fields from charged semiconductor device packages or nearby charged insulators cause Charged Device Model (CDM) electrostatic discharge (ESD) events, when the device leads touch ground. Exposure to CDM ESD occurs primarily in the assembly, packaging, and test areas of semiconductor manufacturing, as well as in assembly areas of electronics contract manufacturing. Device design and proper handling methods, combined with static control methods, can prevent the rapid and damaging discharge to packaged devices. A complete static control program includes grounding methods, proper material selection, and ionization to neutralize charge on insulators. While this may be sufficient to prevent Human Body Model (HBM) ESD damage, more is needed to eliminate CDM ESD. Additional measurements to target the locations of CDM ESD, elimination of metal-to-metal contact, and monitoring to verify the effectiveness of the CDM ESD program are all required.**

I. INTRODUCTION

The physics of the Charged Device Model (CDM) electrostatic discharge (ESD) event is well understood. A semiconductor device package becomes charged and its electric field induces a charge on the device contacts. A nearby external electric field can induce charge on device contacts and cause ESD in the same way. This is known as a Field Induced Model (FIM) CDM ESD Event. In both cases, when the device contacts approach close enough to a ground, a discharge of sub-nanosecond duration occurs that damages the device (Figure 1). The source of the problem is charge accumulation on insulating material of the device package and/or the presence of nearby charged insulators. Device design for ESD protection can help to prevent ESD damage when a discharge occurs. However, current trends in IC design are making it increasingly more difficult to build effective ESD protection into a device.

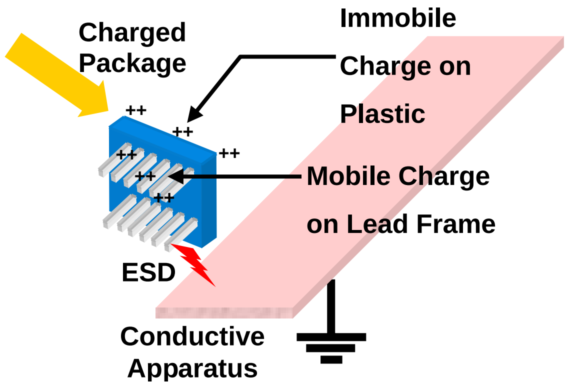

Fig. 1. CDM ESD Event caused by charged device package.

Smaller feature sizes, higher pin counts and higher operating speeds make designs that provide adequate protection against ESD significantly harder to achieve. [1] It is therefore unreasonable to depend solely on device design solutions to solve CDM ESD problems. More effective static control methods that prevent the buildup of static charge must also be implemented in the production environment.

II. Solving the CDM ESD Problem for Devices

Control of ESD is required in all stages of device manufacture, including when inserting devices in circuit boards, when inserting circuit boards in equipment and large systems, and anytime electronic systems need servicing. Indeed, triboelectric static charge generation is almost unavoidable during device or circuit board handling. Contact with other materials, regardless of whether those materials are insulators or conductors or whether or not they are grounded, will easily pass charge to the insulating material in a device package or circuit board.

Devices should not be placed in proximity to or pass near any charged objects. Ideally, insulators or ungrounded conductors should be kept at least 30 cm away from sensitive parts or they should be provided with electrostatic shielding. Devices can be affected by electric fields from charged parts previously placed on a circuit board. In fact, the additional parts that are connected to a device once it is placed in a circuit board increase the overall capacitance that determines the maximum static charge accumulation. If a lead of any component on the circuit board touches ground, a CDM-like discharge may occur.

This type of discharge, known as a Charged Board Event (CBE), is currently under study. The higher capacitance and greater accumulated charge involved in CBE-type discharges often results in much more severe device damage than that occurring in a CDM ESD event. It is easily mistaken for ESD damage accountable by other models. Device design for CDM-type discharge prevention cannot provide protection for the higher capacitance discharge of the CBE type. The same ESD mitigation methods used to prevent CDM ESD events are useful in preventing CBE.

Since CDM ESD events occur when a device lead contacts ground, a risk of CDM-type events begins in Wafer Probe at the end of semiconductor frontend processing and continues throughout the assembly, packaging and test processes in backend manufacturing. The device is thus at hazard to CDM ESD until it is contained in static-protective packaging for shipment to the customer. A further risk of CDM ESD damage exists when the customer removes the device from the static-protective packaging and places it in a circuit board or other location. Once a device is placed on the circuit board, ESD damage is rarely due to a CDM ESD event. ESD damage to circuit board mounted components may be CBE, or characterized by other ESD damage models.

Given the varied environments the device passes through, it is unreasonable to expect device design to provide complete protection from ESD. Indeed, protection alone, either through design or through static control grounding methods, is insufficient without charge elimination from the device environment.

III. STATIC CHARGE CONTROL

Since the late 1970's the understanding of prevention and protection from ESD events and ESD control through device design has been improving. However, functionality and feature size issues continue to challenge design for ESD control. Higher device operating speeds make the design of ESD protection networks more difficult and large pin count devices limit the die area available for the protection networks. Feature sizes keep rapidly shrinking to increase device functionality and increase manufacturing profitability, but the area needed to dissipate the energy of ESD events does not change accordingly. As the result, the ESD designers are asking to reduce user expectations for on-chip ESD protection, particularly due to significant improvements and wide acceptance of ESD control programs throughout the electronics industry. [1]

The understanding of ESD control is improving. This improvement was stimulated by the needs of hard disk drive (HDD) manufacturing in the late 1990's. Magneto-resistive (MR) read head technology introduced an essential electronic part that was sensitive to both Human Body Model (HBM) and CDM ESD events of 25 volts or less. Design improvements that increased the storage capacity of the HDD by several orders of magnitude lowered the voltage sensitivity for ESD even further. As a consequence, HDD factories now reliably control ESD levels below 5 volts and in some cases below 1 volt. Few semiconductors need ESD controls at this level at this time, but the HDD manufacturing results show that it is achievable.

The methods for strict control of electrostatic potential in HDD manufacturing developed because no design solution was available to mitigate CDM ESD problems. Once this was recognized the development of a complete static control program became an industry focus. Today, the production of disk drives without a complete static control program is not a possibility. As feature sizes shrink on semiconductor devices, HDD-style ESD control may be needed in the photolithography areas where reticles are handled. [2] Future design changes in semiconductor devices may also require more extensive static control programs.

IV. MODIFYING THE ESD CONTROL PROGRAM TO CONTROL CDM ESD

ESD control involves preventing the generation, storage, or rapid transfer of static charge. Properly designed static control programs, such as ANSI ESD S20.20 and IEC 61340-5-1, include all the elements needed to control static charge and to protect 100-volt HBM sensitive devices. [3][4] These programs focus on the devices and their environment, including the personnel that handle the devices. The focus of these programs is removing static charge from all objects in the work area, by connecting them through a resistive path to ground. Grounding of personnel, worksurfaces, furniture, flooring, transport methods, and packaging eliminates charge transfer to ESD sensitive devices and provides some shielding from electric fields. The static control program uses resistance measuring devices to verify the characteristics and grounding of the ESD control materials. An example of such a measuring device and different probes for worksurfaces is shown in Figure 2.

Fig. 2. Instruments for resistance measurement of worksurfaces

To stop CDM ESD damage in more sensitive devices, the static control program must expand its focus to include the device, the automated equipment used to handle the device, and the environment in which it is handled. As in all static control programs, grounding methods and static dissipative materials prevent the generation and storage of static charge. This approach, when applied to a device, uses conductive or dissipative carriers to maintain all device leads in contact with ground throughout the manufacture and handling of the device. Ground contact is often lost, however, when the device is removed from the carrier for different manufacturing steps or for insertion into circuit boards. Metal-to-metal contact between the exposed device leads and grounded surfaces must be avoided and dissipative contact surfaces must replace conductive surfaces whenever possible.

Final device test provides a good example of the difficulties experienced in protecting a device from CDM ESD damage. Even if all device leads remained connected to ground during all manufacturing steps leading up to final test, it is necessary that the device be removed from its carrier and inserted into a test socket during final test. At the moment of separation from the carrier, charge on the insulative device package is able to induce charge on the device leads. This charge on the package may have come from previous manufacturing steps or from the physical act of picking up the device from its carrier.

The device is next inserted into the metal contacts of the test socket. For testing purposes this is unavoidable and static dissipative contacts are not possible. CDM ESD events can occur at the instant of contact. Device damage may occur depending on the package size, package charge, and the level of device ESD protection built into the device. Similarly, removing the device from the socket after test may generate charge on the test socket itself. Left unneutralized this charge may present an increased CDM ESD hazard to the next device inserted in the test socket.

V. Ionization in the CDM ESD Static Control Program

Effective static control programs must also consider the charged insulators that are the source of the CDM ESD problem. Device packages, process essential insulating surfaces in test sockets, labeling equipment, circuit boards, packaging materials and other electronic components, all contribute to the CDM ESD problem. Properly designed air ionization, as a part of an overall static control program, is the key to removing any accumulated charge from these insulators. Leaving any static charge in the device environment will only increase the likelihood of device failure.

The proper application of ionizers requires that the ionized air come into contact with the charged surface long enough to assure charge neutralization. This consideration is especially important for ESD control in high-speed manufacturing equipment. Only the topside of a device package may be neutralized while the package is in its carrier. Only when the device is picked up can both sides be neutralized. Pickup and transport time needs to be long enough to assure sufficient device package neutralization.

Ionization removes static charge from the device package and all objects in their immediate area. The possibility of CDM ESD is all but eliminated if there is no static charge present. Thus, at a small incremental cost to a static control program, air ionization eliminates the static charge, complementing the protective effects of device design for ESD and other protective grounding measures. An example of an ionizer application in final test is shown in Figure 3.

Fig. 3. Ionizers in a test handler

VI. MONITORING THE CDM STATIC CONTROL PROGRAM

The ESD control programs previously mentioned contain technical requirements for assuring the performance of the static control methods. Periodic audits with resistance measurement techniques and a Charged Plate Monitor for measuring ionizer performance, assure that the static control methods are working correctly. However, the do not effectively demonstrate *the results* of the ESD control program. They do not demonstrate that ESD hazards to the device have been eliminated.

To verify ESD control for a CDM sensitive device, two measurements are needed. First, we must demonstrate that throughout the steps of the manufacturing process, a voltage measured on the device leads does not exceed the CDM voltage damage threshold. This voltage damage threshold is determined using industry standard CDM testers. [5] This assures that even in the case of metal-to-metal contact with ground, a damaging ESD event will not occur. Of course, metal-to-metal contact should have been eliminated by the proper design of the static control program. Second, we must demonstrate that throughtout the manufacturing operation, CDM ESD events (as well as other types) are not occurring, particularly in the areas where devices are transferred.

Measurements of device lead voltages require specially designed high input impedance voltmeters. We do not want the meter to change the voltage we are measuring. If we assume a device lead capacitance of approximately 1 picofarad (10^{-12} farads), we will need a measuring instrument input resistance of approximately 10^{14} ohms to give a time constant of 100 seconds. This will assure that the voltage does not change appreciably during a few seconds of measurement time. Additionally, we do not want appreciable charge transfer from the capacitance of the device lead to the capacitance of the measurement instrument. The input capacitance of the measurement instrument should be approximately 10^{-14} farads (10 femtofarads) to achieve this.

Using such an instrument, measurements may be made of the voltages present on device leads at any point in the manufacturing process, during device manufacture, as well as after the devices have been placed on circuit boards. The voltage measurements can then be compared to CDM damage thresholds established in CDM device testing. As long as the voltage measurements in the manufacturing area are kept reasonably below the CDM damage thresholds, it can be assumed that the manufacturing process can safely handle the CDM-sensitive devices. Analysis and testing of the manufacturing area needs to be carefully designed to locate all the areas where static charge may be generated on or near the devices. Consideration must also be given to the need to stop the process to make the measurements, and how this might change the voltage levels that are generated on the device. [6] Examples of contacting voltage measurements on a device and circuit board are shown in Figure 4.

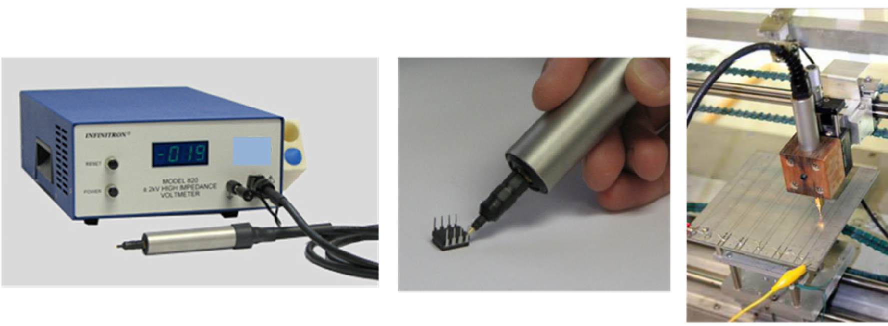

Fig. 4. Example of contacting voltmeter meaurement

To document the success of a CDM ESD control program, it is also necessary to demonstrate that potentially damaging ESD events have been eliminated. What is needed is as an ongoing process monitoring method that can be done without interrupting the process. Since an ESD event is characterized by a very rapid transfer of electric charges, a fast transient electromagnetic field having a fast risetime and a short duration is generated. This change in the field generates electromagnetic signals that can be used to characterize the ESD event that produced them. Measuring the electromagnetic signal can be a very effective tool in ESD management, as it is a signature that ESD events are occurring. [7] With a properly designed calibration method, the magnitude of the ESD event may be estimated.

There are several kinds of equipment available to detect and measure electromagnetic fields arising from ESD events. An oscilloscope equipped with proper antennae provides the most comprehensive information about waveform and magnitude of ESD-induced events. The minimum requirements for an oscilloscope used for this purpose are a 500 MHz bandwidth and a 5 gigasamples/s sampling rate. [7] The simplest kind of ESD Event

Detector (EED) provides both a visual and audible indication of the transient signal from an ESD event. It may not, however, give any information regarding the magnitude of the ESD event that produced the signal. A second type of EED is a general-purpose electromagnetic field strength meter with a bandwidth (up to 2 GHz) suitable for measuring signals from ESD events. It has a directional antenna to help identify sources of emission, and provides outputs for emission levels and the counting of ESD events, including time stamping. This tool can be very useful in correlating ESD events with device handling or equipment operations. Several different types of EEDs are shown in Figure 5.

Fig. 5. A sampling of available ESD Event Detectors (EED)

EEDs are essential elements of the CDM static control program. They are used to investigate the sources of CDM ESD events and to demonstrate the success of any mitigation techniques that are applied. They may be installed permanently in high-risk locations where manufacturing processes can put a device at risk to CDM ESD. For instance, the test socket location discussed above would be a good area to monitor continuously. EEDs are used as audit tools to demonstrate the ongoing success of the CDM static control program. It will be the task of standards making organizations to devise suitable calibration methods for these instruments to allow them to make accurate estimates of the magnitude of the ESD events occurring in the manufacturing process.

VII. CONCLUSION

Static charge control is a basic requirement in electronics manufacturing. Preventing CDM ESD damage requires attention to device design and a complete static control program. Such a program maintains device ground contact as much as possible, uses static dissipative materials to replace insulators and to prevent damaging device discharges, eliminates metal-to-metal contact, and uses air ionization to neutralize charge on device packages and other process-essential insulators.

Given the complexity of the device designs and the variety of manufacturing environments, device design for ESD control cannot, by itself, fully control CDM ESD problems. Only a complete static control program in all areas of manufacture and assembly can assure successful, high yield production of today's electronic devices. ANSI/ESD S20.20 and IEC 61340-5-1 static control standards provide guidance in the design and maintenance of a static control program. Fully solving the CDM ESD problem will require careful application of all the elements of these programs, but verifying the *operation* of the elements of the static control is not sufficient. It will also be necessary to verify the *results* of the static control program by demonstrating that there are no potentially damaging voltages on the devices themselves, and that there are no ESD events occurring in the manufacturing area.

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