Semiconductor Fab Electrostatic Charge Program Improvement Opportunities and Pitfalls

Introduction

As 300mm semiconductor front end (FEOL) wafer fabs move through the 14nm technology node, significant opportunities for improvement in micro-contamination and tool productivity can be realized by implementing an electrostatic charge control program. These opportunities extend to legacy 200mm fabs where, for minor investment, significant gains can be realized. This article highlights opportunities available by implementation of such a program in a FEOL fab, and details some of the potential pitfalls.

While the objectives of an ESD control program in the back end of line (BEOL) focus on eliminating damage to packaged parts, an electrostatic control program in the FEOL focuses on yield improvement from micro-contamination reduction, eliminating process interruptions from discharges near process controllers and controlling ESD damage to reticles which are extremely sensitive to electrostatic fields[i,ii] in the photolithographic bay. ESD damage to reticles results in printing defective dies.

FEOL Electrostatic Charge Control Program

ANSI/ESD S20.20-2014[iii] defines a BEOL electrostatic control program that is a model that can be also used in FEOL. The program includes two main principles:

- Ground/bond all conductors: it is important that all conductors in the FEOL are grounded; this includes static dissipative floors, tool frames, tool components and personnel.
- Control charge levels on all non-conductors: Static charge on all surfaces in proximity to wafers must be controlled. This is critical for control of micro-contamination.

In order to establish a meaningful FEOL electrostatic control program, initial and recurring audits are essential. The ANSI/ESD S20.20-2014 standard suggests "*If the field measured on the process required insulator is greater than 2000 volts/inch and the process required insulator is less than 30 cm (12 inches) from the ESDS item, steps shall be taken to* " move or ionize the object. This is intended to avoid ESD between product and nearby surfaces. While this is a good rule to follow for BEOL product protection, it is inadequate to minimize static–charge-enhanced micro-contamination in FEOL. In processes with sub-20 nm feature sizes, 10 nm particles can kill a die. The electrostatic forces on such small particles will overwhelm the intended cleansing action of Ultra Low Particle Adder filtered unidirectional air flow in a process tool.

In a calculation comparing particle deposition velocity versus size[iv] (Fig. 1), the electrostatic deposition velocity for 10 nm particles is ~2 cm/sec in a modest 2000 V/cm electric field (proportionally higher for higher fields). Compare that to typical laminar airflow speeds of ~25 cm/sec and there is a significant displacement of airborne particles from the trajectory engineered by the tool designer. This was empirically verified independently[v].

Figure 1 Deposition velocity for various effects as a function of particle size.

Per the SEMI E78-0912 standard[vi], a rule to follow for the control of FEOL micro-contamination is that no charged object within the process tool should have a field of >300 V/inch. A static audit measures insulating surfaces within each tool to confirm that no higher fields exist.

This rule is inadequate for a photolithographic bay where reticles are handled. Reticles are extremely sensitive to electric fields. Charged objects within 12 in of the reticle should be ≤ 100 V /in (20 V max on the reticle itself). To achieve an environment with minimal electric fields, insulators should be replaced by grounded conductors or dissipative material wherever possible.

Conducting a FEOL Electrostatic Audit

<u>Audit for charged surfaces</u>

Electrostatic charge is the source of electric fields which drive micro-contamination, transient electromagnetic interference (tEMI) from ESD, and reticle damage. Charged objects within the process environment must be identified. In a ballroom fab, look for charged objects near wafers.

A major cause of micro-contamination in legacy fabs is the Teflon™ cassettes, an excellent insulator and one of the most electronegative materials that exist. Any handling by either operators or robots generates large amounts of static surface charge. Teflon™ should be used only in processes involving caustic chemicals.

This audit employs an electrostatic fieldmeter which is an instrument for crude measurement of charge level on a surface by detecting the electric field (in Volts/inch) at each surface. The fieldmeter should be grounded either by a wire to ground or a grounded operator not wearing insulating gloves. The device is only calibrated at 1 inch from the surface it is measuring**.** Fieldmeters are often used incorrectly and therefore some training is desirable.

Figure 2. An electrostatic fieldmeter measuring at 1" from a surface. Photo courtesy of Prostat Corporation.

Most fieldmeters set the one inch distance either with spacer rods or a pair of concentric LED images which form a target when the meter is one inch from the surface. (Figure 2). Historically fieldmeters read in V/in, whereas fields are often specified in V/cm.

Audit of Ionizers

An electrostatic charge control program requires ionizers to control charge on insulators. Most corona ionizers are pulsed to efficiently deliver positive and negative ions to charged objects. Corona ionizers must be balanced at installation, and verified and cleaned regularly. This mandatory maintenance is typically done quarterly or semi-annually, but in wet process, cleaning and photolithography areas, ionizers acquire debris and require more frequent cleaning. After cleaning, ionizers must be calibrated and balanced[vii] using a Charge Plate Monitor (CPM). A significant pitfall is that frequently after installation the ionizers are not maintained. Note that corona ionizers do not work in pure nitrogen environments, a different ionization technology is required.

CPMs measure the voltage on an isolated conducting plate and determine the time to reduce the voltage from ±1000 V to ±100V, defined as the positive and negative discharge times[viii]. The CPM also measures maximum voltage excursions of the pulsing ionizer. The performance of an ionizer is specified by the discharge times and maximum offset voltages.

The CPM signal achieves equilibrium after several discharge times. Therefore better maximum excursions are obtained by delaying before recording. This delay is a new feature of CPMs manufactured this year and updated firmware is available for older CPMs[ix]. It will greatly simplify CPM measurements.

Ionizer measurements should be made with the CPM at the wafer location. Balance should be set so the maximum positive and negative excursions are similar. Discharge times should be much less than the time the wafer spends in in that location.

Audit for Continuous Grounding

Semiconductor tool manufacturers typically are rigorous at providing ground connections to conducting tool components. However older legacy tools can have ungrounded components. Also technicians occasionally fail to replace ground connections following tool maintenance. Tool component ground confirmation should be integrated into maintenance procedures. Resistance meters exist for measuring resistance to ground (RTG) that are capable of measuring resistances $\leq 10^{13}\ \Omega$.

Audit for EMI Transients

Electrostatic discharges create EMI transients (tEMI) that can cause misbehavior of microcontroller operating systems in tools, robotics, and factory automation resulting in process interruptions. An audit of tEMI signals should be undertaken, typically starting at each process tool and stocker. An electrostatic discharge can occur between conductors or dissipative materials. Conductor-to-conductor and conductor-to-dissipative material discharges are both important. Minute discharges to or from insulators are inconsequential. tEMI studies can employ an EMI locator or an oscilloscope and a wideband antenna.

Commercial EMI locators provide a crude amplitude measurement and a limited pulse shape discrimination. While this is a useful measurement, a 50 Ω antenna and a multi GHz bandwidth oscilloscope is the definitive technique.

Once tEMI signals are detected, the next challenge is determining their significance and whether they are responsible for bad behavior of a robot or tool OS interruptions. Signals are sometimes difficult to interpret, however if they occur in proximity to a tool with problems, the detected signal is likely an issue. Frequently tools with unexplained performance problems can be linked to a specific tEMI source.

Use of a digitizing oscilloscope and a wide bandwidth antenna allows the waveshape to be unambiguously identified. The oscilloscope trace on the left of Figure 3 shows an ESD event caused by handling of a wafer in a process tool. The discharge is extremely rapid, taking place in ~ 1 nanosecond with subsequent low amplitude ringing for another 1-2 ns. This is the signature of an ESD event. The trace on the right comes from a failing fluorescent light bulb. Both will trigger an EMI locator, however the oscilloscope differentiates them. The larger, faster waveform on the left is a candidate to be investigated. The slower, smaller waveform on the right is not.

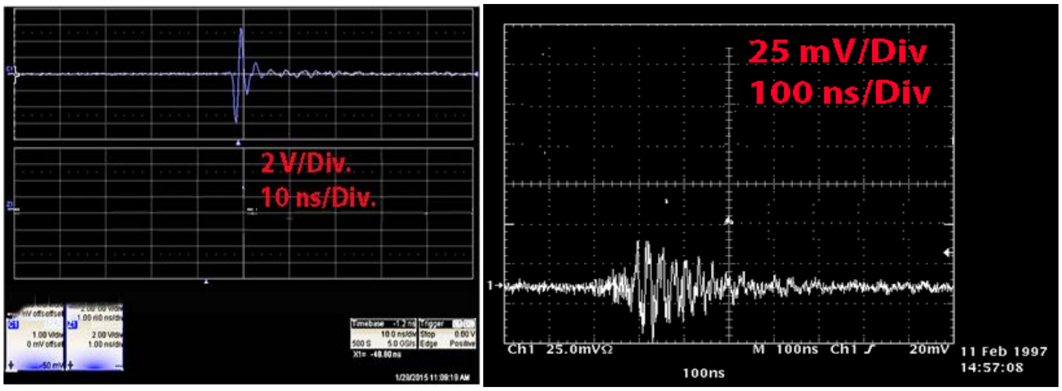

Figure 3. Discharge waveforms

The digitizing oscilloscope requires ≥1 GHz bandwidth and ≥4 GSamples/s of sampling rate. The antenna is quite simple, being a short whip on a ground plane.

Conclusion

Through the implementation of a comprehensive electrostatic control program in the FEOL facility with recurring audit procedures that serve to verify compliance, significant improvements can be realized in micro-contamination, reduction of tool interruptions due to tEMI and mitigation of ESD impacts to reticles. Overall FEOL improvements in wafer and process yield, tool availability and process variability can be realized.

[i] J. Montoya, LB. Levit, and A, Englisch, A Study of the Mechanisms for ESD Damage to Reticles, Proceedings of the 22nd Annual EOS/ESD Society, (Rome, NY: ESD Association, 2000), pp 394–405.

[ii] G. Rider, EFM- A Pernicious New Electric Field-Induced Damage Mechanism in Reticles, paper 2, SEMATECH Conference on ESD, Dec 2003.

[iii] ANSI/ESD S2020-2014, for the Development of an Electrostatic Discharge Control Program for – Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices), Electrostatic Discharge Association, Rome NY, p5.

[iv] Hogsett, Mark E., Electrostatic Effects on Particle Mobility, proceedings of the SEMATECH Workshop on Nanoparticle Defectivity Issues in Solutions, 9 July 2013.

[v] Long, C.W. Peterman, J., Levit L., Effects of Ionization on Airborne Particles in a Semiconductor Front-End Fab, 2007 Taiwan Electrostatic Discharge Conference November 2007, Hsinchu, Taiwan.

[vi] SEMI E78-0912, Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment, Semiconductor Equipment Manufacturers International.

[vii] ANSI/ESD STM 3.1-2015, ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Ionization, Rome NY, p6.

[viii] Ibid.

[ix] Lawrence Levit, William Vosteen, Geoffrey Weil, Analysis of Pulsed DC Ionizer Measurement Procedures with a CPM Using ESDA RP 3.11-2006, Proceedings of the 2015 37th Electrical Overstress/Electrostatic Discharge Symposium (EOS/ESD 2015), Reno, Nevada, USA 27 September – 2 October 2015.