PROPOSED ESD TESTS FOR FRONT-END WAFER FAB TOOLS

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Abstract
This article serves to provide an insight into the types of ESD related tests that should be performed when commissioning front end wafer fab tools and follow-up periodic verification tests that need to be conducted with reference to industry standards, guidelines and practices. This article also makes reference to the electrostatic limits recommended for production equipment as part of the Semi E78 guideline and proposes new (advanced) tools available that can continuously monitor the static potential (or charge) levels in the tools as part of the continuous, real-time verification plan.

Basic ESD Tests
When commissioning any tool with respect to ESD safety and compliance, there are a few basic tests that need to be done like resistance measurements of parts, tribocharging propensity measurement of parts (basically static voltage measurements), grounding measurements and the verification of common point grounds, workstation monitors and ionizers (if present).

a. Resistance measurements (in ohms)
Resistance measurements are basically done using a wide range resistance meter with 2.27kg (5 lbs) electrodes with conductive rubber, alligator clips and/or 2-pin probes for measuring small areas or parts. All materials like enclosure walls, surfaces and parts that make contact with the reticles or wafers need to be verified. The test involves the application of a 100V DC voltage across the relevant parts and then measuring the resistance in ohms *(refer to Fig 1 for an example of resistance and tribocharging propensity values for a robotic arm in a metrology tool).* For small parts, a 2-pin electrode should be used for the resistance measurement. However, this 2 pin probe has to be correlated to a similar measurement using the 5lbs electrodes to have consistency in the reporting. A 2 pin probe will normally measure slightly lower than a 2.27 kg (5 lbs) electrode because of the small surface area. This is the reason why correlation has to be done based on a known repeatable surface like a wall/floor panel or worksurface. Once the factor has been established all measurements made by the 2 pins probe has to be multiplied by this factor. Take

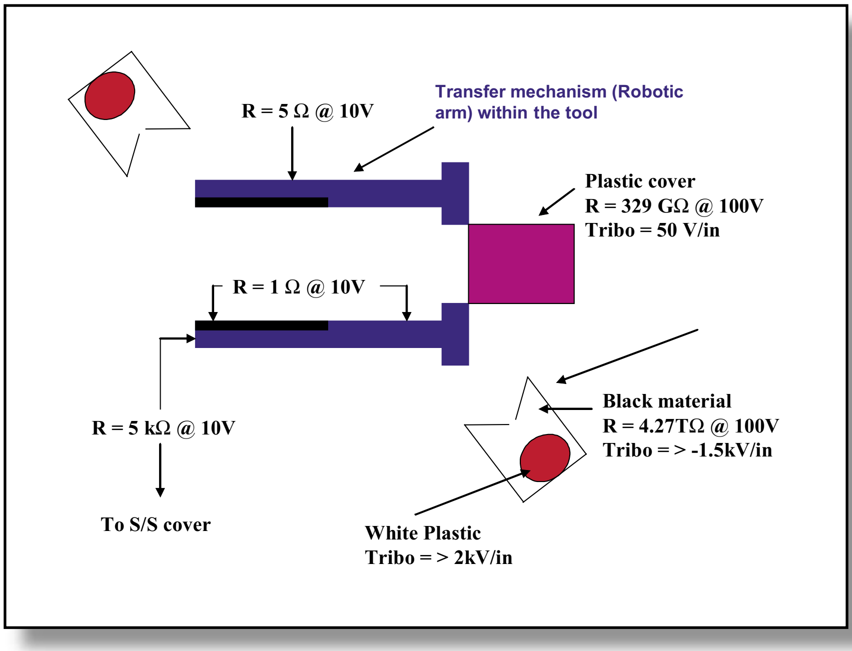

Figure 1 :
Resistance / Tribocharging propensity data for a Robotic arm in a Metrology tool

note that there are also other probes with more than 2 pins available which can be used for measurement of small parts and again similar correlation factors have to be established for each type of probe. *Conductive surfaces or parts should normally have resistance values of between 10^4 to 10^6 ohms and static dissipative parts should have values of between 10^6 to 10^9 ohms. It is not advisable to have specifications that stretch across the conductive to static dissipative ranges. The following standards should be referenced as guidelines when testing :*

- ANSI/ESD S4.1-2006:
  Worksurfaces – Resistance Measurements
- ANSI/ESD S7.1-2005:
  Resistive Characterisation of Materials – Floor Materials
- ESD ADV53.1-1995:
  ESD Protective Workstations
- ESD TR53-01-06:
  Technical Report on Compliance Verification of ESD Protective Equipment & Materials *(FOR REFERENCE ONLY)*

b. Tribocharging Propensity (in volts/in)

This involves the rubbing of the same parts within the tool using a gloved finger and then measuring the voltage developed in volts/in using an electrostatic fieldmeter or an electrostatic voltmeter for very small parts. This test is necessary as it provides information on the ability of the parts to develop a charge through tribocharging (rubbing / friction). *The recommended safe value should be based on the technology node and as a guide, table 1 can be referenced (this table is extracted from the Semi E78 guideline). The following standard should be referenced as a guideline when testing :*

- SEMI E43-0301:
  Guide for Measuring Static Charge on Objects & Surfaces

c. Grounding Measurement (in ohms)

One of the most important parameters, the grounding of the tool should be measured. Poor or faulty grounding may result in personnel exposure to dangerous voltages, equipment malfunction or lockup, damage to sensitive components, high resistance and slow charge dissipation. There are tools available like ground integrity meters that can measure AC impedance which the standards like the ANSI/ESD S6.1-2005 : Grounding call for. Using regular volmeters or multimeters do not give accurate measurements because of the presence of ground currents. Some impedance monitors or ground integrity meters also measure the EMI or voltage on ground connections and if specified these have to be reported in millivolts or in dBm – this readings give you an indication of the noise on your ground lines and this could lead to equipment malfunction. *The measured resistance value should be less than 10ohms (with tool operational). If a common point ground is available and designated, ensure that the connection from the common point ground to electrical ground is measured and reported – same specifications will apply. Ensure also that the common point ground is marked with a label or sticker and distinctly noticeable to maintenance personnel. The following standards can be referenced as guidelines when testing :*

- ANSI/ESD S6.1-2005:
  Grounding
- ANSI/ESD S20.20-2007:
  Protection of Electrical & Electronic Parts, Assemblies & Equipment (Excluding Electrically Initiated Explosive Devices)

d. Ionizer Performance measurements (in volts for offset voltage, in secs for decay time)

If there are ionizers present, these should be adjusted and calibrated to meet with the ionization specifications. Depending on the type of ionizer (AC, Steady-State DC or Pulsed DC), the offset (balance or swing voltage) voltage and decay time (from 1000V to 100V, 90% decay) should be measured using a charged plate monitor. It should also be confirmed that the ionizer is mounted at the correct distance and at the appropriate location so as to provide optimal ionization coverage which will result in quick charge decay and an ESD-safe environment. The recommend offset voltage can be derived from table 1 as well as a guide. *For example, if the fab is operating at a technology node of 65nm where the allowable electrostatic field limit is 175volts/in – this implies that your swing voltage in the case of pulsed DC ionizers should not be higher than ±175V (for Steady–State DC ionizers, the balance voltage should be limited to within ±50V to prevent charging up of worksurfaces or products). As for the decay time, depending on the particular tool, this should be between 15secs to 60secs, and depending again on the available exposure time of the wafer or reticle to ionization. The following standard / (recommended practice should be referenced as guidelines when testing :*

- ANSI/ESD STM3.1-2006:
  Ionization
- IEST-RP-CC-022.2:
  Electrostatic Charge in Cleanrooms & Other Controlled Environments

Refer also to article *"Ionization in Clean Environments" by Inderjit Singh, Technology Digest, Dec 2005 Issue* for more information on ionization.

e. Ground / ESD Workstation Monitors

If there are other equipment ground monitors or workstation monitors available, ensure that these are tested according to the manufacturers instructions for operator resistance, soft / hard ground resistance, body voltage and EMI on ground, if available . Normally handheld testers are available from the manufacturers which test these different parameters and ensure through "Pass/Fail" indicators that the monitors are within specifications. *Can refer to the S20.20 ESD Standard on recommended acceptance criteria. The following standards should be referenced as guidelines when testing/verifying :*

- ESD TR53-01-06:
  Technical Report on Compliance Verification of ESD Protective Equipment & Materials
  (FOR REFERENCE ONLY)
- ANSI/ESD S6.1-2005:
  Grounding
- ANSI/ESD S20.20-2007:
  Protection of Electrical & Electronic Parts, Assemblies & Equipment (Excluding Electrically Initiated Explosive Devices)

Intermediate (Optional) Test

Besides these basic ESD tests, it is recommended that more advanced tools like ESD monitors with data acquisition software (with analysis features) be used to establish and report the number of ESD events (discharges) clocked over a period of time and within the critical processing chamber of the tool (refer to Figure 2). This gives information on possible lockups due to EMI generated within the environment from ESD events or discharges occurring nearby. Knowing the Charged Device Model (CDM) threshold of the device (may it be the reticle or wafer or IC) in volts, the antenna of the ESD monitor can be placed at a certain distance (say within 1ft or 300mm) from the area of interest or process chamber and the number of discharges exceeding the CDM threshold be counted over a period of time with the tool operational and running. This can be repeated about 5 times, for a period of 2 to 3 hours over a 5 days period and then the data analysed graphically through the analytical software. If during these 5 days and during the measurement period the tool works well without any lockups or damage to the product, then the number of ESD events clocked over the daily measurement period (of 2 or 3 hrs), averaged over the 5 days, can be used as the specification for periodic verification of this specific tool or also for the commissioning of other similar tools within the fab. It is recommended that another ESD monitor be placed in the general cleanroom environment outside the tool, as well, to clock the number of ESD events over the same period. This will give the number of ESD events for the background or ambient environment. This data will help in the future if there are equipment lockup issues. For example, when troubleshooting a particular tool for lockup due to EMI from possible high ESD events, the increase in the background number of ESD events

Figure 2 : Example of ESD Monitors & Antenna that can not only look at ESD events but static voltage and EMI as well

will help to give an indication that the lockup is probably due to EMI from other nearby tools or environmental devices rather than the particular tool that is locking up.

Advanced Testing : ESD Compliance testing for Semiconductor Equipment (Semi E78)
For a more comprehensive ESD compliance testing and verification of semiconductor equipment, the "Semi E78 : Guide to Assess and Control Electrostatic Discharge(ESD) and Electrostatic Attraction (ESA) for Equipment" guideline can be used to ascertain whether the equipment is ESD safe and fit for production. The guideline recommends the measurement of *charge* in coulombs using a Faraday cup method and the *electrostatic field* in volts/cm (or volts/in) using an electrostatic fieldmeter or voltmeter, of the product (or reticles, wafers, carriers and materials) in the equipment input/output ports, after significant amounts of product(s) have been processed and handled under normal manufacturing conditions. For the measurement of charge in coulombs, the guide recommends that at least five measurements of products and/or carriers should be made over two successive days after the equipment has stabilized in its normal operating mode. As for measurement of the *electrostatic field* in volts/cm (or volts/in), the guide recommends measuring any surface within the equipment that comes within 30.5cm (or 12") of ESD sensitive items or devices and recommends that surfaces such as products, reticles, carriers, robotics and equipment surfaces be measured. Similarly the guide recommends that at least 3 locations per surface be tested and at least five sets of readings per location/surface be made over two successive days after the equipment has stabilized in its normal operating mode. For both types of measurement, the equipment configuration should not be changed during the test period. The data obtained should then be compared against the recommended values in *table 1*, depending on the year and technology node and then a conclusion made as to whether the tool or equipment is ESD complaint per Semi E78. More data should be taken if the 5 sets of readings or measurements prove inconclusive. If the data shows that the tool is non-compliant based on the year and technology node, then changes will have to be made to the materials or surfaces used and a re-test done after the changes have been implemented. Prior to performing the re-test, the basic tests as recommended under the paragraph "Basic ESD tests" should be carried out for the new materials or surfaces.

Periodic Verification
It is recommended to re-test the tool or equipment at least on an annual basis by performing the basic ESD tests (except for the ionizers within the tool which should be maintained and calibrated at least semi-annually or twice a year). If, however, there is a change in the configuration of the tool or if the tool is modified somehow, then the basic tests as well as the Semi E78 compliance testing should be carried out as though the tool was new. The intermediate testing of ESD events is optional and left to the discretion of the user but it is recommended that this be verified at

Year Node	Electrostatic Discharge ηC	Electrostatic Field	
		V/cm	V/in
2000 180 ηm	2.5 - 10	200	500
2002 130 ηm	2.0	150	375
2004 90 ηm	1.0	100	250
2006 70 ηm	0.6	80	200
2007 65 ηm	0.5	70	175
2009 50 ηm	0.3	55	140
2010 45 ηm	0.25	50	125
2013 32 ηm	0.125	35	88
2015 25 ηm	0.08	28	70
2018 18 ηm	0.04	20	50

Table 1 : Recommended Equipment Electrostatic levels based on production year and technology node *(Extracted from Semi E78 Guideline – Table 1, Pg 10)*

least annually as well or if continuous ESD monitors are installed then this intermediate testing can be dispensed with.

Continuous ESD Monitoring

After proper and successful commissioning of the tool or equipment, it is encouraged that some kind of continuous monitoring of the critical ESD parameters be incorporated within the tool to give a real-time alert to the user as soon as any of the critical ESD parameters is violated or exceeded. This could even involve shutting down the tool if the set points are far exceeded via interfacing of the monitors / sensors with the tool's control system. The following are some of the latest ESD monitors and sensors available that help keep the tool ESD safe :

a. Ionization Feedback sensors / controllers

If the tool has ionizers, it is advisable to monitor or control the offset voltage and decay time to ensure a safe and optimal ionized environment. There are feedback sensors and/or controllers available that can be used to connect up to ionizers to form a continuous closed loop feedback as shown in Figure 3 OR ionization sensors that just continuously monitor the ionization voltage / decay times only (without feedback to ionizer) and then alert the user when the ionizer has exceeded the alarm thresholds. Real time feedback sensors are preferred as this ensure that the critical environment is always optimally ionized through a closed loop feedback which either produces more positive or negative ions to keep the environment balanced. Also as the emitter points get dirty, the offset voltage tends to drift and through this feedback sensors the integrity of the environment is optimally maintained upto a point when the emitter points get too dirty such that cleaning is required. In another way it helps to alert the user when cleaning of the emitter points is required. Monitors on the other hand just look at the offset or swing voltages and then alert the user when the ionizer goes out of balance. Both of these feedback sensors or monitors do have external outputs that permit them to be interfaced with the tools control system if real time alerts/alarms are required. *Refer to article "Maintenance & Monitoring of Ionizers" by Inderjit Singh, Technology Digest, 2006 Issue for more information on these sensors / monitors.*

b. ESD Monitors

To ensure that the tool or equipment is always kept within ESD safe limits, an ESD monitor *(refer to Figure 2)* can be installed within the tool. This ESD monitor comes with a remote antenna that is small enough to be located close to the area of concern and calibrated to monitor the number of ESD events happening within a certain radius of the area of concern. This ESD monitor usually comes with it's own software for stand alone operation or can be integrated with the user's own facility monitoring software so that the user is able to capture real time data as it happens, thereby allowing shut down of the tool, if required. Alternatively, the ESD monitor, which usually comes with an output connectivity (like 4-20mA or 0 to 5V output or something similar) can be interfaced with the tool's control system or

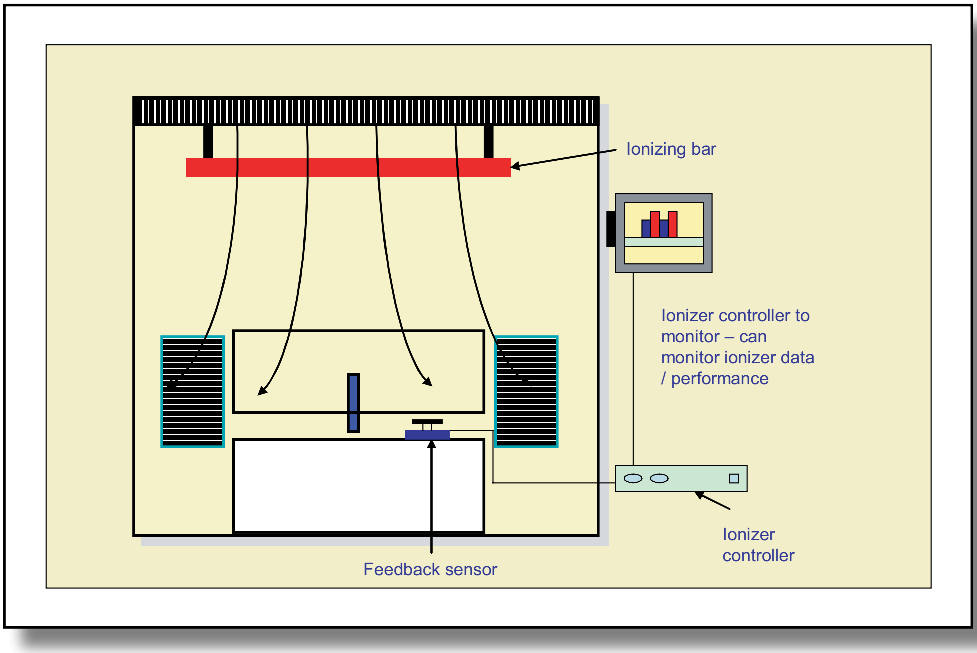

Figure 3 : Schematic of Closed Loop Feedback in an ionized minienvironment - sensor connected directly to an ionizer controller with output (via software) to a monitor displaying ionizer data / performance

operating software, thereby shutting down the tool or alerting the maintenance personnel if pre-set alarms or excursions are exceeded.

c. Static Charge / Voltage Monitors

In line with the recommended electrostatic field measurements of the Semi E78 guideline, there are now voltage sensors available that can be installed within tools and equipment that can continuously measure the surface potential (electrostatic field) in volts on products or surfaces. These sensors can be located a distance away (unlike handheld electrostatic fieldmeters or volmeters which need to take measurements at 1" or 2.54cm from the surface) from the area of concern such that there is no obstruction to the movement of robotic arms, transfer mechanisms, pick and place operations and general product flow. Multiple sensors can be mounted within the tool to look at the different surface potential on surfaces, products like reticles or wafers and critical transfer mechanisms. These sensors will be integrated to a microprocessor based monitor or monitors depending on the number of sensors used and generally located outside the tool. The monitor comes with digital displays showing the value of the surface potential (electrostatic field). As with ESD monitors, these voltage monitors come with their own software and have output connectivity which can be integrated with the tools control system / software or integrated into the existing facility monitoring software. *Refer to Figure 4* for a diagram showing how the sensor can be located within the tool.

Conclusion

Proper qualification of the production equipment or tool, with reference to ESD-safety and compliance is mandatory and not an option. Such testing ensures that the equipment or tool is safe from ESD related discharges or zaps and this in turn keeps the product safe and improves yield. Such ESD measurements should form an integral part of a tool's commissioning and buy-off tests. It is highly recommended to incorporate ESD monitoring and management tools like ESD monitors, Ionization feedback sensors (if ionizers are present) and static voltage real-time monitoring sensors within the tool to reduce tool downtime, when performing manual periodic verification tool-intrusion measurements. This increases tool uptime, gives predictive maintenance information (for example when the emitter points of the ionizer need to be cleaned or replaced) and ensures that alerts are sent when there is an immediate problem through integration of these monitors to the tool's control system / software.

Editor's Note :

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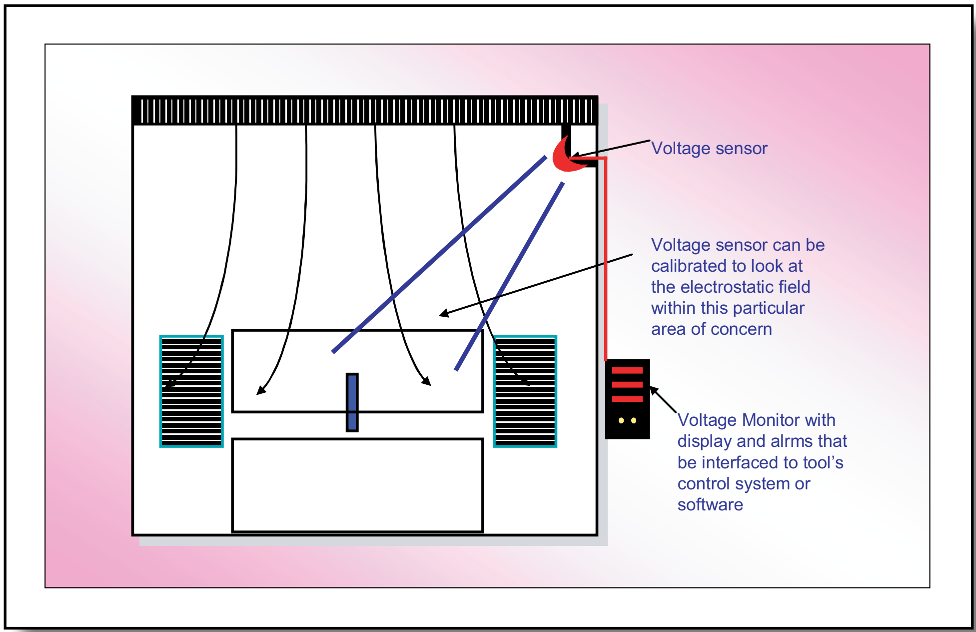

Figure 4 : Example of a static voltage sensor mounted within a tool that is capable of measuring the electrostatic field on the wafer or reticle, even at a distance away