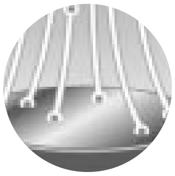
Education Series

Developing a Static Budget for Capital Equipment:

Understanding and Applying SEMI's E78 Guide



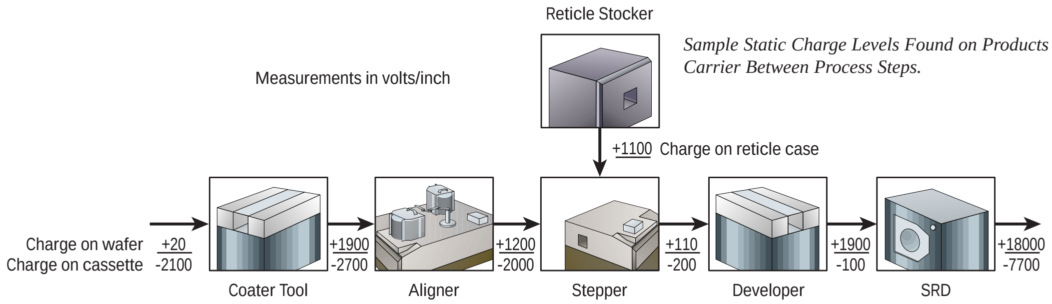
I. Introduction to SEMI's E78-0998 Guide

Industry Impact

In 1995 SEMI established a SEMI standards task force made up of professionals in the semiconductor industry. Their mission was to create a guide to "minimize the impact on capital productivity due to the presence of static charge in semiconductor manufacturing environments." The result of this group's efforts is document E78-0998 "Electrostatic Compatibility: Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment," also referred to as the Static Budget Guide for Capital Equipment.

> *The Static Budget Guide promotes a partnership between tool manufacturers and end users to create products, processes, and cleanroom environments that moderate the effects of static charge.*

The Static Budget Guide identifies static charge as a factor that can be detrimental to semiconductor manufacturing processes. To combat it, the Guide promotes implementing electrostatic compatibility (ESC), which would limit the amount of static charge generated during the handling and processing of product and reticles, and the handling of their carriers. A *static budget* sets a limit on charge levels, so that they are not great enough to cause product or reticle damage, attract significantly more particles to surfaces, or cause equipment malfunctions due to ESD-induced electromagnetic interference (EMI). The Static Budget Guide provides a matrix of recommended charge values, measured in nanocoulombs, and electric field values, measured in volts/cm, depending on the sensitivities of the products and equipment involved.



Sample Static Charge Levels Found on Products and Carrier Between Process Steps.

With the publication of the Guide, tool manufacturers and end users will have a common document to work from when developing their electrostatic management programs. Historically, the costs of static charge problems were absorbed by end users. The Static Budget Guide promotes a partnership between tool manufacturers and end users to create products, processes, and cleanroom environments that moderate the effects of static charge. In the partnership, equipment manufacturers design in static control to meet specified sensitivity levels. Awareness of the problem on both sides is the best way to determine an acceptable level of static charge that will not affect yield or throughput.

Implementing the Guide should minimize the negative impact on productivity caused by static charge in semiconductor manufacturing environments. While it will be difficult to determine charge and electric field levels that guarantee static-related problems are eliminated, with perseverance, a significant reduction in these problems is achievable.

With the cost of equipment making up approximately 90% of a semiconductor wafer fab, the Static Budget Guide provides an opportunity for the industry to achieve a lower overall cost and accelerate overall fab effectiveness (OFE).

The more efficiently equipment runs, the better the industry is able to perform as a whole. Defeating problems caused by static charge is a hurdle that can be overcome if both tool manufacturers and end users know the issues surrounding static charge and work together to solve them.

Static Budget Guide: What's Inside?

To help toolmakers and end users ensure that equipment and processes are not adversely affected by the levels of static charge created during semiconductor manufacturing, the Static Budget Guide presents a methodology for measuring and managing this problem. The Guide recommends acceptable levels of charge and electrostatic field for the differing sensitivity levels of semiconductor manufacturing processes. It also recommends instruments to be used for measuring charge and electric field. The Guide's greatest value, however, is that it develops a common language for dealing with ESD, particle attraction, and equipment malfunction caused by ESD-induced EMI.

The Guide assists in identifying static charge levels likely to cause problems in process equipment. The effects these problems have on product and equipment are defined and discussed in detail in the Related Information and Appendix sections of the document. Instruments are introduced for defining critical static levels or measuring electrostatic charge or field. These instruments include the electrostatic fieldmeter, ESD simulator, and Faraday Cup. The Guide should provide the user with enough insight to define a test methodology for each static problem and understand its limitations.

The Guide does not attempt to provide any new test methodologies. Rather, it references existing standards and test methods already used to establish critical static charge levels on products and process equipment. The Guide then relates these critical charge levels to measurements made on products, reticles, and carriers handled within the process equipment. The Guide's recommended testing procedures include definition of both end user and equipment manufacturer responsibilities for controlling static charge, where and when charge and electric field measurements should be made, safety precautions when testing equipment, and what data records for reporting results should contain.

Items for which the Guide provides maximum recommended levels of static charge include the following:

- Product or reticles
- Carriers
- Parts of the input/exit ports of equipment and mini-environments

The task force developed four different sensitivity levels by which to measure ESD (maximum charge), particle attraction (maximum electric field in volts/cm), and equipment ESD (maximum charge). Once a sensitivity level for a given process is defined, the amount of charge, measured in coulombs, generated in equipment should not exceed the maximum limit given for that level. The levels were determined as the result of analyses of working conditions and experiments performed in operating semiconductor facilities. They are justified by common test methods, typical formulae, and international standards described in the Appendix and Related Information sections of the Guide.

To determine compliance with a selected sensitivity level, the Guide recommends that a number of measurements be made at specified times in a tool's operating cycle. The average of the measurements taken should not exceed the recommended sensitivity level. The sensitivity levels range from 1 to 4. Level 4 should be used for processes that have no significant problems handling charged product, while level 1 is applicable for manufacturers of ultra-sensitive components, such as gallium arsenide semiconductors or those using specialized equipment with low immunity to ESD or EMI. The level to be employed for any given process should be decided by agreement between the user and manufacturer of equipment.

The Guide assists in identifying static charge levels likely to cause problems in process equipment.

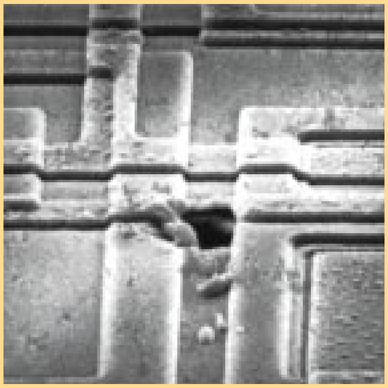
In addition to the main part of the Guide and its Appendix there is also a Related Information section. This section includes information on static charge problems, Related Information 1, and static control methods, Related Information 2. Related Information 1 was contributed by industry experts from Advanced Micro Devices, TheTexwipe Company, Sandia National Laboratories, and Intel Corporation. Theoretical justifications for the Guide's sensitivity levels can be found here, as well as a valuable assessment of the impacts of ESD in semiconductor equipment. Related Information 2 references the common methods for reducing static charge, after charge sensitivity levels have been determined by the end user.

II. Problems caused by ESD, EMI, and ESA

Uncontrolled electrostatic charge is a significant and growing problem in semiconductor manufacturing and many other industries. When a static charge builds up on sensitive products, work surfaces, equipment or personnel, the result can be destructive. Products may be damaged, processes may become degraded and a long list of other problems may ensue.

Decreased Product Quality and Yield

Static charge damages manufactured products through ESD and electrostatic attraction (ESA), which attracts airborne contaminants (particles and AMCs). Product damage from static charge can cost manufacturers millions of dollars in scrapped materials and loss of potential revenue.



A magnified view depicting how a single ESD event can cause fatal damage to sensitive electronic devices. Photo courtesy of Lockheed Martin.

Damage from Electrostatic Discharge (ESD)

An ESD event is the uncontrolled transfer of static charge from one object to another. Although the amount of static charge transferred is usually small and measured in nanocoulombs, a discharge deposits its energy into a very small area of the device in a very short time, typically measured in nanoseconds. This energy deposit vaporizes the metal lines or silicon, punches through the oxide layers and causes other damage. ESD events can also damage production tools, such as photomasks and reticles, and occasionally production equipment itself. While ESD events to products cause random defects, in the case of reticles and photomasks the defects are repeatedly patterned onto multiple wafers.

> *As line widths get smaller, the killer particle size needed to create a defect has decreased proportionally and high-tech manufacturers must concern themselves with controlling increasingly smaller particles.*

ESD can also cause latent failures where it weakens but does not completely destroy device functionality. Damaged products may initially pass quality tests and then fail prematurely in the field.

Contamination through Electrostatic Attraction (ESA)

When a wafer or cassette becomes charged, the resulting electric field attracts airborne particulate and AMCs through ESA in much the same way that a television screen attracts dust. Once bonded to a charged surface, it is very difficult to remove the contamination. As line widths get smaller, the “killer particle” size needed to create a defect has decreased proportionally and high-tech manufacturers must concern themselves with controlling increasingly smaller particles. The electrostatic attraction of particles also increases as particle sizes become smaller, which magnifies the problem.

Airborne Molecular Contaminants (AMCs)

AMCs are a type of contaminant that is becoming more of a concern in semiconductor fabs. AMCs come from both organic and inorganic sources, and cannot be removed by HEPA or ULPA filters. Problems with AMCs include poisoning Deep UV photoresist processes, roughening the silicon at the pre-gate clean and breaking down HEPA filter media, which causes the release of dopant AMCs such as Boron. There are indications that electrostatic charge increases the attraction of AMCs to product surfaces although direct correlations to yield still need to be established. As device damage from AMCs becomes more of a concern, controlling static charge will be even more crucial.

Decreased Production Rates

Static charge can also decrease production rates by causing equipment malfunctions. Manufacturing line shut-downs due to problems caused by static charge means decreased throughput and loss of potential revenue.

Tool Lock-up from Electromagnetic Interference (EMI)

The subtlest effect of static charge is the interruption of a process due to ESD-induced EMI. Although ESD was once thought to be only a threat to devices, it is now clear that the EMI associated with ESD can be just as serious a problem for equipment since most modern equipment is controlled by microprocessors. EMI can cause unpredictable behavior in high-speed microprocessors, often mimicking random software errors. In worst-case scenarios robotic arms have broken wafers on the side of a process chamber or dropped an entire wafer boat. Usually the process is interrupted, requiring a manual reset, and sometimes the product must be removed and reprocessed or scrapped. All of the above scenarios result in costly downtime and decreased throughput.

Equipment lock-up occurs when an ESD event produces EMI. The charge associated with static electricity is quite small, but an ESD event happens in just a few nanoseconds. The resulting ESD current can be over 10 Amps, and can produce EMI over a wide frequency band, from 10 megahertz up to 2 gigahertz. Such high intensities and high frequencies affect microprocessors operating in the same frequency range—corrupting instructions as they are read from memory or changing the data being analyzed. As microprocessor clock speeds increase, the microprocessors become more susceptible to EMI, which means fabs today are experiencing lock-up on a much larger scale than they were just a few years ago.

Radiated EMI

An ESD event can cause EMI to be radiated through the environment. As the disturbance moves away from the source it spreads its energy over an ever-increasing area and the power density drops off as the square of the distance ($1/r^2$). This radiated emission is a source of process tool interruption up to a distance of about one meter.

Conducted EMI

A second way that the disturbance can find its way into equipment is through conducted emission. If a discharge is generated near a conductor such as electrical wiring or a large ungrounded metal panel, the EMI can induce a voltage signal within the conductor. Once the signal is in the conductor, it does not experience the $1/r^2$ attenuation. This characteristic means that ESD events located as far as 10 meters away can cause lock-ups.

Equipment lock-up is often misdiagnosed as a software or hardware problem, when ESD-induced EMI may be the true culprit. The ESD event may not be occurring in the equipment experiencing the problem, making the ESD event even more difficult to locate.

Relevant Instrumentation

The instruments outlined below and in the Guide will be important during various phases of an electrostatic management program for equipment.

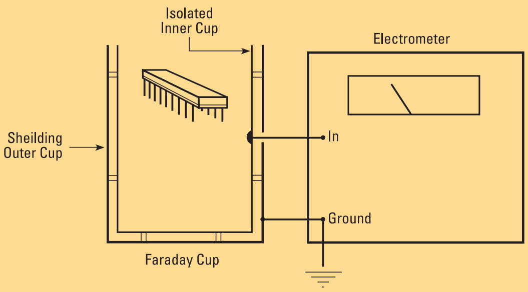
Electrostatic Fieldmeter

Measurements of an electrostatic field can be made with a commonly available electrostatic fieldmeter and expressed in units of volts per inch or volts per centimeter. Precise measurements are difficult because the presence of the measuring instrument and nearby grounded objects changes the electrostatic field. Precise measurements are not required to meet the recommendations of the SEMI E78-0998 Guide.

Faraday Cup

Charge can be measured directly with a Faraday cup, depicted below. A charged object, such as a wafer, is placed in the cup and a reading is taken of the charge on it. The cup must be large enough to accommodate wafers, cassettes, and other equipment parts. In order to avoid altering the charge levels, these items must not come into contact with other objects as they are placed in the cup.

Faraday Cup Charge Measurement



ESD Simulator for Product ESD Damage Testing

ESD simulators generate electrostatic discharges in a reliable, reproducible way. They consist of a defined value of capacitance that is charged to a known voltage. The capacitor is then discharged into the device through controlled values of resistance and inductance to produce a standardized discharge waveform. Simulators are commonly used by device manufacturers to establish ESD sensitivities for their products.

ESD Simulator for Equipment ESD Immunity Testing

An ESD simulator for equipment ESD testing works in a similar manner to the one above, but is used to test equipment susceptibility to ESD-induced EMI. Two tests are normally performed, one using a direct discharge to the equipment surfaces, and a second discharge to a metal surface located 10 cm away from the equipment. This test shows ESD immunity to both radiated and conducted EMI and establishes the charge level at which these problems occur. For true electrostatic compatibility, ESD events should not be produced in equipment, nor should the equipment be affected by ESD events occurring elsewhere in the fab. Testing equipment for ESD immunity using an ESD simulator begins the process of ensuring that the facility is systematically protected from the hazards of static charge.

EMI Locator

While not specified for making measurements in the Static Budget Guide, another useful instrument is the EMI Locator, which notifies the user through a series of beeps when it detects the spontaneous EMI generated by ESD events. This handheld instrument is particularly useful when it is impractical to get close enough to a charged object to use a fieldmeter, or when the charged object is on a ground plane that suppresses the electric field extending from the object.

The EMI Locator indicates when the charge level on an object is sufficient to produce an ESD event.

III. Why Electrostatics Management is Rapidly Becoming Imperative

Table 1. Wafer Size

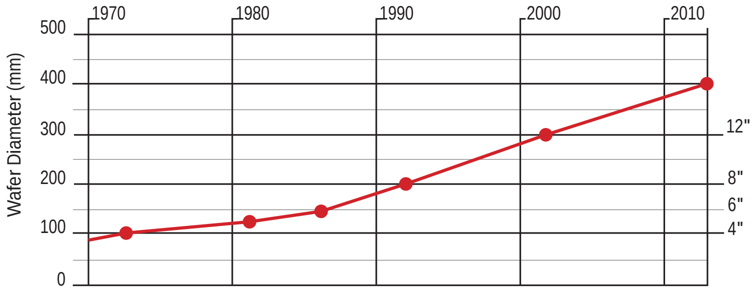


Table 2. Total Charge on Wafer at an Electrostatic Potential of 10kv

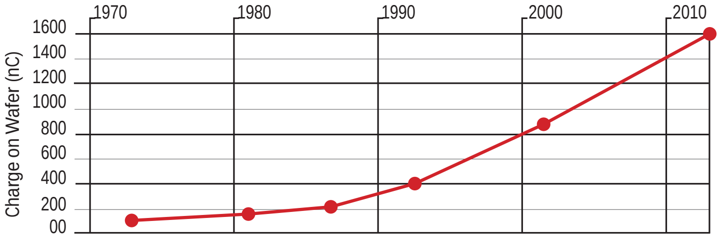
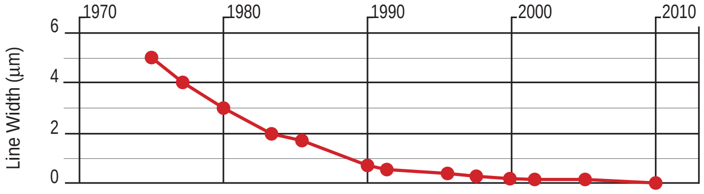


Table 3. Feature Size



Semiconductor Industry Trends

As various technology trends converge, electrostatics management becomes an enabling technology for the manufacture of semiconductors. Technology trends include smaller feature sizes, increased die size, 300-mm wafers, shrinking gate oxide thickness, and the increased use of high-speed microprocessors in equipment. ESD issues take on increased importance because larger wafers hold more charge and shrinking features and gate oxides can be destroyed by smaller ESD events. Diminishing line widths also influence the wafer's vulnerability to particles. The size of a "killer" particle decreases in step with the shrinking size of features. Defects now include molecular level contaminants and residues.

Table 4. Required Operational Effectivness for Future Technology Generations

Year of First Product Shipment	1997	1999	2001
Technology Generation	250 nm	180 nm	150 nm
Average Tool OEE(%)	45	52	59

One of the goals of the fab management team is to maximize factory productivity as measured by overall fab effectiveness (OFE). A subset of OFE is overall equipment effectiveness (OEE) measured by yield, throughput, and tool availability. With average tool OEE hovering just above 50% (see Table 4) it is imperative that the semiconductor industry work as a whole to maintain historic 25-30% levels of productivity growth per year.

The technology road map for the semiconductor industry has been accelerated from approximately three to two years in order to meet these productivity goals and decrease cost-per-function (see Table 10). The faster technology trends converge, the greater challenge it is for wafer manufacturers to contend with ESD-related problems.

2003	2006	2009	2012
130 nm	100 nm	70 nm	50 nm
65	71	76	80

Unification of Tools in Fab

As the components of the fab unify into a system and automate, there is a greater need to boost the integration of hardware and software for the fab to eventually operate as a single, continuous data processing system. The fundamental infrastructure of the semiconductor manufacturing environment is changed as it moves from being a series of discrete manufacturing steps to a continuous manufacturing process. In an environment increasingly controlled by centralized computer systems, ESD events can result in bad data transfers that affect operations throughout the fab. Tool functionality is of the utmost importance to fab profitability, because the cost of tool capital equipment is approaching 90% of the cost of the total factory investment. Currently, as much as 30% of new tool equipment failures are software related. Possibly as much as 40% of software-related downtime is attributable to unexplained software errors. A sizeable percentage of these “unexplained software errors” is due to ESD-induced EMI.

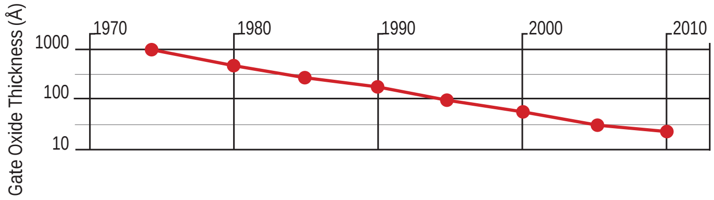


Table 5. Gate Oxide Thickness

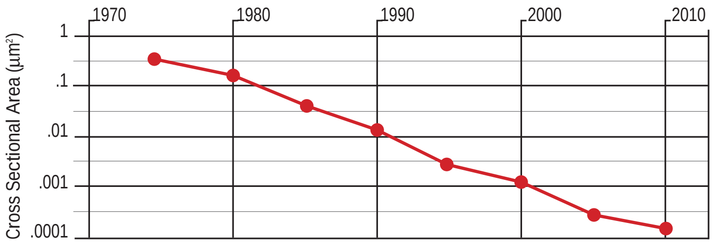


Table 6. Cross Sectional Area of Gate Oxide

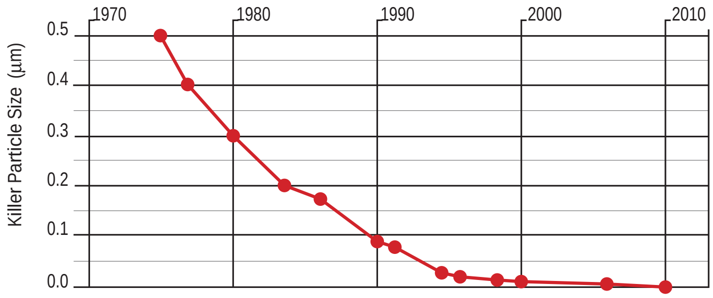


Table 7. Killer Particle Size

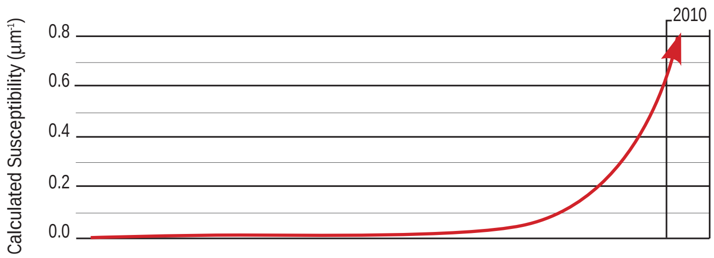
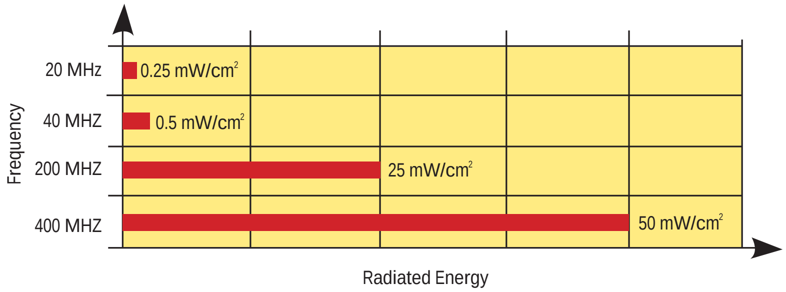


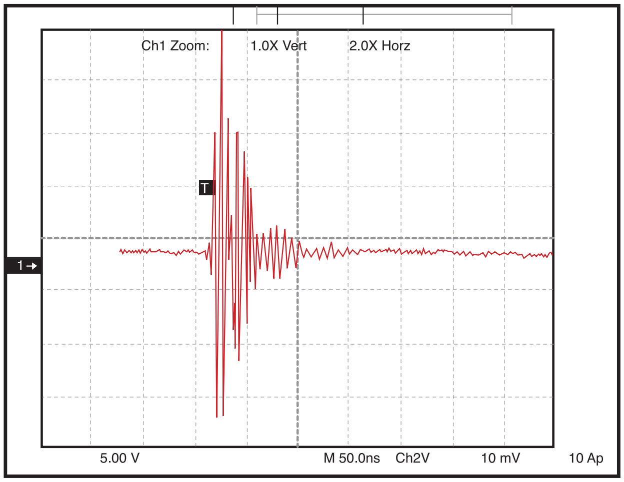
Table 8. ESD Susceptibility (1/cross sectional area)

Table 9. Amount of Energy Seen by Microprocessors of Different Bandwidths



As microprocessors accelerate to higher speeds and cover more bandwidth, they are able to see greater levels of noise in the environment.

ESD-Induced EMI



A signal caused by an ESD event recorded on a neutral power line of a semiconductor fab. This signal, with an amplitude of nearly 40 V and a bandwidth in excess of 100 MHz, was large enough to interfere with the operation of the microprocessor controlling one of the robotic handlers within the fab.

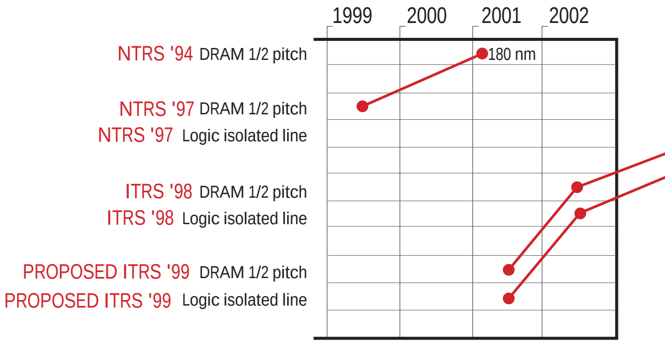
Faster Microprocessors: A Challenge to New Infrastructure

The move toward tool linkage and automation in the fab is affected by the susceptibility of faster microprocessors to EMI. As microprocessors accelerate to higher speeds and cover more bandwidth, they are able to see greater levels of noise in the environment (see Table 9). This change increases the likelihood of exposure to EMI, which can confuse circuitry and cause unscheduled tool downtime.

In a qualitative sense, bandwidth is proportional to the complexity of the data for a given level of system performance. The market demand for higher performance products creates the need for processing electrical signals at a progressively faster rate. In 1990, the Intel 8088, common in many computers at the time, ran at 4.77 MHz. Now the speed of microprocessors is roughly doubling every year, with industry giants and

Table 10. Technology Cycle Accelerates from 3 to 2 Years

National Technology Road Map for Semiconductors (ITRS) and
International Technology Road Map for Semiconductors (ITRS)



upstarts alike planning to release new microprocessors in the next 18 months which will push speeds of 700 MHz and beyond (see Table 11). With successive process generations, devices are smaller, power supply voltages are lower, and devices are more noise sensitive. The progression to higher operational frequencies in conjunction with fabs' functioning as a single data processing system necessitates greater protection against random noise in the environment.

While the current, prevalent manufacturing trends will ultimately serve to bring the semiconductor industry to a more efficient level of operation, there is an immediate challenge to counter obstacles on the road to that goal. Awareness of EMI and other static-related issues is a step towards controlling the effects of static charge in the fabs of the future. The Static Budget Guide can serve as a tool to leverage fab productivity from a systemic point of view.

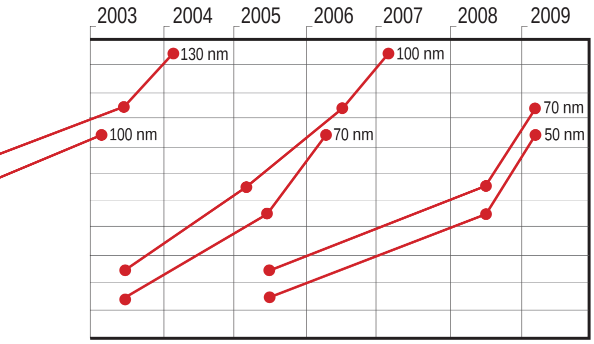
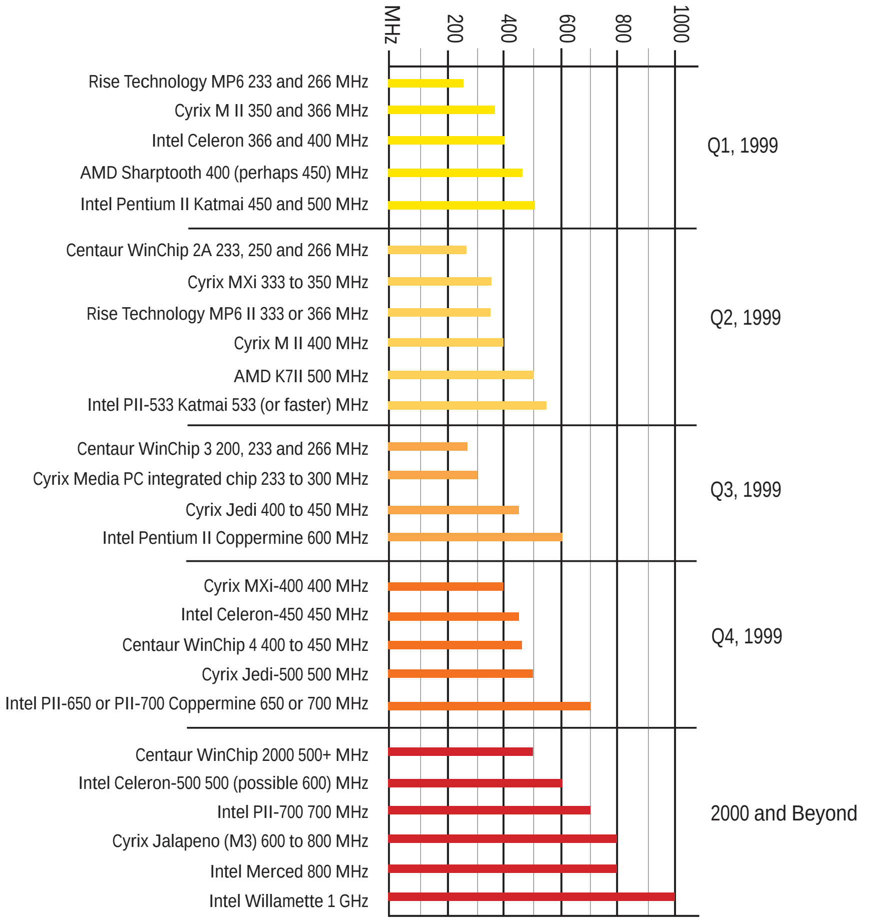


Table 11. Microprocessor Road Map: Outlook for 1999 and Beyond

All dates and chip speeds are approximate



Source: *PC World*, February 1999

IV. Electrostatics Management in Tools

If ESD is not controlled in equipment from the beginning, it can damage tools in operation and be a major cause of customer field returns. Equipment suppliers have a choice: they can recognize that static charge generation is unavoidable, or they can spend a great deal of time and money trying to find work-arounds. The manner in which a company chooses to handle static charge issues will ultimately reflect on its image and reliability within the industry.

One of the most serious obstacles to profitable operation of the fab is ESD-induced EMI, as it reduces equipment availability and product throughput.

While end users have traditionally taken the responsibility for static charge management by ionizing cleanrooms, room ionizers cannot eliminate static charge generated during wafer processing inside mini-environments or production tools. The increasing use of mini-environments also serves to isolate the product and equipment from the positive effects of room ionization. To effectively manage static charge throughout the manufacturing process, additional point-of-use static control is required.

The following factors in tools and mini-environments increase the likelihood of contamination and ESD damage of products:

- The product is in close proximity to charged wall surfaces and is being removed from, and inserted into, charged insulative (usually Teflon™) carriers

- The product is inductively charged by nearby static charges and triboelectrically charged by contact with other materials
- Moving parts generate particles, and there is often no laminar airflow to prevent particles from being attracted and bonded to the charged product surface
- Contact of charged product with grounded surfaces causes ESD damage to the product as well as random lock-ups of production equipment

These impediments to productivity can be controlled by well-established static control techniques, such as the use of static dissipative materials, grounding, and ionization. The goal of achieving ESC means that equipment manufacturers must ensure that product and product carriers will not exceed certain agreed-upon static charge levels as they exit the equipment.

To achieve ESC, the cleanroom where the tool resides must be conducive to achieving the desired levels of static charge neutralization. No piece of equipment is an island, and for equipment manufacturers' static control measures to work, a proper static control program should be in place throughout the cleanroom.

V.

Electrostatics Management in Cleanrooms

End users also have a choice: they can continue to spend expensive production time in search of solutions to a static problem, or they can work with equipment suppliers and cleanroom designers to ensure that static charge problems have been solved before first product comes out of the factory.

The dry, minimal-contamination atmosphere of a cleanroom is a unique environment that requires a comprehensive static control program. The cleanroom is especially prone to developing static charge because it is maintained at a low humidity, typically 40 ±10% relative humidity, which is conducive to the generation of high levels of static charge. As humidity levels drop below 30%, insulative materials hold increasing amounts of charge. As humidity rises above 50%, the environment becomes more conductive, but high humidity may create other process problems. Another factor that causes electrostatic problems in a cleanroom is the HEPA filtration system, which strips air of its normal ion content, causing it to lose its natural static-dissipative qualities.

The cleanroom is especially prone to developing static charge because it is maintained at a low humidity.

Controlling static charge has become vital to world-class semiconductor factories. A fab-wide static control program should include grounding personnel and conductive materials, avoiding insulative materials whenever possible, and the creation of a conductive environment using air ionization to neutralize charge on the remaining insulators and isolated conductors. While static control measures are always beneficial to a fab's operation, they are most cost-effective to implement during construction of the factory. Attempting to solve static charge problems while simultaneously trying to ramp up production is relatively expensive.

To achieve electrostatic compatibility, both equipment and the cleanroom must be protected from static charge.

VI. A Systemic Environment Requires Systemic Solutions

The best way to implement the Static Budget Guide is to have tool manufacturers and end users work together to develop viable static budgets for equipment that will ensure electrostatic compatibility. The following is a hypothetical example of how the process of arriving at an agreed upon maximum voltage level for tools might work.

If they do not yet have an electric field specification for equipment, tool manufacturers can work with their customers to develop one according to the particular sensitivity levels of the process and the fab environment.

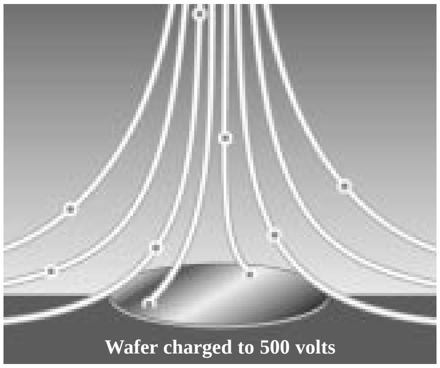
Chemical vapor deposition (CVD) in semiconductor manufacturing is a process that is particularly sensitive to electrostatic attraction (ESA), because wafers are very susceptible to particles during this stage of manufacture. Because particles on wafers directly impact yield, particle control is of the utmost importance. The presence of excess electrical charge on a wafer can create electrostatic field that will lead to accelerated deposition of particles onto the wafer (see figures below). Electrostatic field is measured in volts/cm, so the number of particles on a wafer will in part be influenced by the amount of electric field the wafer carries.

Traditionally, end users have called for a particle specification when purchasing equipment. With the publication of the Static Budget Guide, the relationship between electric field and particle count is evident. To control for electric field, end users can include electric field measurements in their purchase specification. While general levels of acceptable electric field on products can be defined at varying sensitivity levels, particles and particle size on wafers is customer-specific and should be determined with consideration of the operating environment.

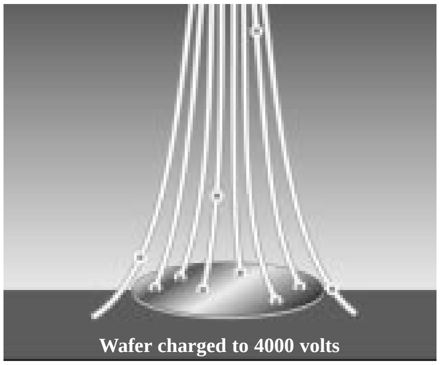
Manufacturers of CVD equipment will most likely already have a standard equipment specification for particles. If they do not yet have an electric field specification for their equipment, the tool manufacturers can work with their customers to develop one according to the particular sensitivity levels of the process and the fab environment itself.

The end user has a line static budget just as they have a line thermal budget. For example, the engineer directing the CVD process may stipulate that no more than a 500 volt/cm charge on wafers is acceptable in the equipment under purchase consideration. The tool manufacturer accepts this proposition, but only if products enter his piece of equipment charged to 500 volts/cm or less.

At this point, the end user may need to set specifications between different tool suppliers. For example, if the CVD tool manufacturer has indicated he cannot accept wafers charged with more than 500 volt/cm charge in order to meet the end user's particle specification, then the tool upstream from the CVD tool cannot pass a wafer charged over 500 volts. In this case, if the device manufacturer is



The aerodynamic behavior of particles is strongly affected by excess electrical charge which can create electrostatic field, measured in volts/cm.



A wafer with a higher level of charge pulls more particles out of a laminar airflow to the surface of the charged wafer.

working with the spin rinser dryer (SRD) supplier, that tool's exit charge specification must be 500 volts or less. To arrive at the specification, the SRD manufacturer can build in static control, such as grounding and ionization.

As each player works to define a specification that is reasonable, it may be necessary to stipulate static charge protection within the cleanroom, since the product will be exposed during wafer transfer. Supplying a cleanroom environment that is favorable to tool manufacturers' achieving their specifications is the responsibility of the end user. Issues at hand would be provision of temperature and humidity control, grounding of conductive materials, class of cleanroom environment and ion density.

Mini-environments

In the case where a chemical mechanical polishing (CMP) tool manufacturer places an SRD system in a mini-environment within the CMP equipment, the negotiation becomes a two-way discourse between the two tool suppliers.

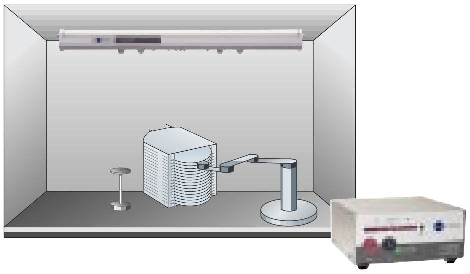
The close working relationship formed by all parties will most likely continue through the installation and system qualification phases of the purchase. End users will not authorize tool shipment unless compliance with the E78 Guide's recommendations has been demonstrated as part of the source inspection.

ESD

Another negotiating point could involve ESD, which can lockup equipment. The majority of toolmakers have set their spec to the CE requirement of 8kV. However, wafer manufacturers may demand a tighter spec than this, say 3kV, so that their tools do not lockup any other equipment in their vicinity. In this instance, the same process of negotiation would take place.

As each player works to define a specification that is reasonable, it may be necessary to stipulate static charge protection within the cleanroom, since the product will be exposed during wafer transfer.

Sensing



Wafer manufacturers produce products that are often extremely sensitive, with multiple chips and circuits existing on a single wafer. They may specify to a tool maker, such as an SRD manufacturer, that at no time during their process can the charge on the wafer exceed 5kV. Such a spec would be designed to prevent ESD damage to devices. Therefore, the SRD manufacturer may be required to sense the charge level throughout his process or maintain a minimum ion density to reduce charge. Sensing will alert the tool manufacturer to actual charge levels and in-situ static controls will actively work to reduce charge and combat product loss.

To learn more about SEMI's E78-0998 Guide or purchase a copy, visit the standards section of SEMI's online bookstore (www.semi.org) or contact SEMI in Mountain View, California at 1-650-964-5111.

VII. Glossary

Balance The production of an equal ratio of positive and negative ions by ionizers.

Charge An excess or absence of electrons on the surface of an object. An excess of electrons causes the object to be negatively charged relative to ground. An absence of electrons causes an object to be positively charged.

Conductor A material that has low resistivity and conducts current easily. Materials that are conductors distribute charge over the entire conductive surface, even if charge is generated at a localized area.

Discharge Time The time required to reduce the static charge on a surface, also referred to as decay rate.

Electromagnetic Compatibility (EMC) The electromagnetic radiation generated from a tool can propagate from place to place, possibly causing other tools in its vicinity to malfunction. The electromagnetic disturbance generated by any equipment must not exceed a level that allows radio, telecommunications, and other apparatus to operate as intended.

Electrostatic Attraction (ESA) The accelerated deposition of particles onto a surface due to the presence of electric field created by excess electrical charge on a surface. Once bonded to a charged surface, it is very difficult to remove the contamination.

Electrostatic Compatibility (ESC) Static charge generated in equipment is kept below a level at which it affects product or any part of the production process adversely. Inter-equipment transfer of products, reticles, and carriers should take place without affecting product or other nearby equipment.

Electrostatic Discharge (ESD) ESD is the uncontrolled transfer of static charge from one object to another.

Electrostatic Field An attractive or repulsive force in space that originates from the presence of electric charge.

Electromagnetic Interference (EMI) EMI is any energy that interferes with the normal operation of equipment.

Electrostatics Management The control of charge in manufacturing processes and cleanroom environments through grounding, static-dissipative materials, and ionization.

Grounding When charge can be conducted through a material, the solution to static charge problems is to provide a path for the charge to flow to ground. This solution works only on conductors and static-dissipative materials. While charge is mobile on a conductor or static-dissipative material, charge is not mobile on insulators. The only effective means of neutralizing static charge on insulators is through air ionization.

Inductive Charging This type of charging occurs when a charged object creates a stationary electrostatic field. The electrostatic field from the original object attracts opposite polarity charge to the surface of the new object placed within the field. If that object is grounded, then isolated from ground and removed from the field, it will hold an electrostatic charge.

Insulators Materials such as plastic, quartz, ceramics, glass and silicon that do not conduct current. Charge on an insulator will not distribute itself over the material’s entire surface, but will stay fixed at the generating site.

Ionization Ions are molecules of the gases in air (nitrogen, oxygen, water vapor, and carbon dioxide) that have lost or gained electrons. Ionization systems work by increasing the conductivity of the air with the charged gas molecules. When ionized air comes in contact with a charged surface, the surface attracts ions of the opposite polarity. As a result, the static electricity is neutralized.

Static Dissipative Materials Insulative materials, usually plastics, that are made conductive with the addition of carbon or metal fillings. The conductive dispersion can be adjusted depending on the amount of fillings added to provide resistivity ranging from fully conductive to dissipative.

Triboelectric Charging Also known as friction charging, this event takes place whenever two surfaces in close contact are separated. One surface loses electrons and becomes positively charged while the other surface gains the same electrons and becomes negatively charged. After separation, each surface retains its positive or negative charge, unless the surface is conductive and a path to ground is provided.

Voltage The force applied between two points causing charged particles (and hence current) to flow.

VIII. Bibliography

Bruchez, J. and G. Kelm, “European Suppliers Focus on Tool Productivity,” *Semiconductor International*, April 1999.

Desmond, M. “Your PC in the New Millenium,” *PC World*, February 1999.

Air Ionization: Theory and Practice, Ion Systems, Berkeley, CA, 1996.

Levit, L. and Menear, J. “Measuring and quantifying static charge in cleanrooms and process tools,” *Solid State Technology*, February 1998.

Montoya, J., Steinman, A. "Developing an Exit Charge Specification for Semiconductor Production Equipment," *Micro*, April 1997.

Peters, L. "Clean Processing," *Semiconductor International*, September, 1997.

SEMI Standard E78-0998 *Electrostatic Compatibility: Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment*, September 1998, SEMI.

National Technology Roadmap for Semiconductors, Semiconductor Industry Association, 1997.

Spanbauer, S. “Pentium III Hits 500 MHz!” *PC World*, April 1999.

Van Zant, P. *Microchip Fabrication: A Practical Guide to Semiconductor Manufacturing*, McGraw-Hill, New York, 1997.

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