# APPENDIX 1
# DETERMINING STATIC SENSITIVITY LEVELS

NOTE: This appendix was approved as an official part of SEMI E78 by full letter ballot procedure. This appendix offers information related to the Sensitivity Levels contained in Section 12.5.

## A1-1 Recommended Levels

A1-1.1 The recommended charge and electrostatic field levels in this guide are not based on specific protection thresholds for individual devices or process tools. Rather, their aim is to classify the types of ESD events or static levels that are likely to be of concern. Tool manufacturers and users should determine the type of events that are of most concern to their products and process, so as to apply this guide to their needs. Information on specific device damage thresholds and tool sensitivities is best determined on an individual basis.

## A1-2 Justification of Guide Recommendations in Section 12.5 and Table 1

A1-2.1 *Recommendations for ESD Damage*

A1-2.1.1 Related Information R1-1 discusses test methods for determining ESD damage thresholds for semiconductor devices. Devices are qualified according to the highest ESD stresses they can withstand without measurable change in their operating parameters. This section attempts to develop guide recommendations for minimizing ESD damage based on that discussion.

A1-2.1.2 *Industry Device Damage Levels* — Each of the test methods, HBM, MM, and CDM have a set of qualification levels defined. These are contained below.

*HBM Classification Levels*

| *Class* | *Voltage* |
|---|---|
| 0 | < 250 |
| 1A | 250–499 |
| 1B | 500–999 |
| 1C | 1000–1999 |
| 2 | 2000–3999 |
| 3A | 4000–7999 |
| 3B | ≥ 8000 |

*MM Classification Levels*

| *Class* | *Voltage* |
|---|---|
| M1 | < 100 |
| M2 | 100–199 |
| M3 | 200–399 |
| M4 | ≥ 400 |

*CDM Classification Levels*

| *Class* | *Voltage* |
|---|---|
| C1 | < 125 |
| C2 | 125–249 |
| C3 | 250–499 |
| C4 | 500–999 |
| C5 | 1000–1499 |
| C6 | 1500–1999 |
| C7 | ≥ 2000 |

A1-2.1.3 *Charge Levels for ESD Damage* — As discussed in Related Information R1-1.4, ESD Simulator testing uses different capacitances for each model. For HBM it is 100 picofarads, for MM it is 200 picofarads, and for CDM it depends on the capacitance of the actual device being tested. In any case, it is charge (charge = voltage × capacitance) that damages the device. It would seem appropriate, therefore, that the guide recommendations in Table 1 Section 12.5 be stated in units of charges (e.g. nanocoulombs).

A1-2.1.4 *Guide Recommendations* — Based on industry testing reflected in device data sheets, there appears to be a wide range for ESD immunity in semiconductor devices. This document deals primarily with ESD occurring within equipment. HBM type ESD discharges are the least likely to occur within equipment. Charged equipment parts contacting devices (MM) and charged devices contacting machine parts (CDM) are the most likely causes of ESD damage to devices in equipment. The following sensitivity levels are defined with respect to the existing industry MM and CDM classifications.

A1-2.1.4.1 *Level 4* — Devices are essentially unaffected by any reasonable level of ESD encountered in equipment. Devices pass testing at levels higher than MM Class M4 (400 volts × 200 picofarads = 80 nanocoulombs). Equipment should not create or store charge on itself or on devices in excess of the guide recommendation. Guide recommendation (table 1 in Section 12.5) – 100 nanocoulombs.

A1-2.1.4.2 *Level 3* — Devices are affected by moderate levels of static charge in equipment. Devices pass testing for MM Class M4 (400 V × 200 picofarads = 80 nanocoulombs) and most of MM Class M3 (over 250 volts × 200 picofarads = 50 nanocoulombs). Guide recommendation (Table 1 in Section 12.5) – 50 nanocoulombs.

A1-2.1.4.3 *Level 2* — Devices are damaged by lower levels of static charge in equipment. Devices pass testing at MM Class M1 (100 V × 200 picofarads = 20 nanocoulombs) and CDM Class C4 (1 kV × 10 picofarad device = 10 nanocoulombs). Guide recommendation (Table 1 in Section 12.5) – 10 nanocoulombs.

A1-2.1.4.4 *Level 1* — Devices are easily damaged by even low levels of static charge in equipment. Devices pass testing at CDM Class 1 (125 V × 10 picofarads device = 1.25 nanocoulombs). In most cases simulator equipment is not designed to do testing at these very low levels for MM. Guide recommendation (Table 1 in Section 12.5) – 1 nanocoulombs.

A1-2.2 *Recommendations for Particle Deposition*

A1-2.2.1 Related Information R1-2 discusses the enhancement of particle deposition due to electrostatic fields from charges on the wafer surface. This section attempts to develop the guideline recommendations for minimizing particle deposition based on that discussion.

A1-2.2.1.1 From Equation 3 of Related Information R1-2.2,

$$N/A = c v_{elect} t \qquad (12)$$

where $N/A$ equals the particulate burden added to a wafer during exposure time $t$, exposed to a particle concentration $c$, in an environment characterized by an electrostatic particle deposition velocity, $v_{elect}$.

A1-2.2.1.2 Target values for $N/A$ are given in the National Technology Roadmap for Semiconductors (NTRS, 1994). These target values vary from 0.02–0.01 defects/cm$^2$, depending on the critical dimensions of the technology, and represent an upper value of the acceptable particulate concentration on a wafer at the conclusion of the fabrication sequence. For individual processing steps making up the fabrication sequence the target values are lower yet.

A1-2.2.1.3 The variables $c$ and $t$ are process step dependent and may or may not be controllable. Clearly minimizing both of these variables is desirable in order to minimize particle deposition on a wafer in any environment.

A1-2.2.1.4 The only variable in Equation 12 that depends on electrical forces is $v_{elect}$. Both the particle charge and the electric field in the vicinity of the wafer affect the magnitude of $v_{elect}$. Particle charge is generally unknown unless it is deliberately controlled by a neutralizing action, such as flooding the environment with both positive and negative charges. Under these conditions a Fuchs type charge distribution is a reasonable assumption for the particle charge. This assumption was used to calculate the values of $E_0$ in Table R1-2 of Related Information R1-2.3.2.

A1-2.2.1.5 When the environmental electric field is less than $E_0$, deposition of electrically “neutralized” particles is dominated by diffusion. When the environmental electric field is greater than $E_0$, electrostatic forces dominate particle deposition even when particle charge has been “neutralized.” Values of $E_0$ for a Fuchs charge distribution can be calculated from Related Information R1-2.3.2 Equation 10. For particle charge greater than the Fuchs charge, $v_{elect}$ increases by a factor of $q/q_{Fuchs}$. Unfortunately, the actual particle charge $q$ is generally unknown.

A1-2.2.1.6 Using the process step values of $c$ and $t$ and the value of $v_{elect}$ calculated from Equation 10, the value of $N/A$ for any process step can be estimated. Alternatively, having a target value of $N/A$ and estimating the value of $v_{elect}$ as outlined in the previous paragraphs, allows one to calculate the tolerable value of $ct$:

$$ct = [N/A]/v_{elect} \qquad (13)$$

A1-2.2.1.7 Setting $N/A = 0.01/\text{cm}^2$ and using Equation 10 to calculate $v_{elect}$ for a 0.1 µm particle at various values of electric field and particle charge, target values of $ct$ can be calculated from Equation 13. The allowed exposure times in an ISO Class 1 environment ($c \leq 10^{-5}$ particles/cm$^3$) can be deduced as shown in the following table:

**Table A1-1 Allowed Exposure Times in an ISO Class 1 Environment**

| *E V/cm at One Wafer Radius* | $q/q_{Fuchs}$ | $v_{elect}$ cm/sec | *ct sec/cm$^3$* | *max t in ISO Class 1 sec* |
|---|---|---|---|---|
| 4000 | 1 | 0.8 | 0.01250 | 1250 |
| | 2 | 1.6 | 0.00625 | 625 |
| | 10 | 8.0 | 0.00125 | 125 |
| 400 | 1 | 0.08 | 0.1250 | 12500 |
| | 2 | 0.16 | 0.0625 | 6250 |
| | 10 | 0.8 | 0.0125 | 1250 |
| 200 | 1 | 0.04 | 0.250 | 25000 |
| | 2 | 0.08 | 0.125 | 12500 |
| | 10 | 0.4 | 0.025 | 2500 |
| 100 | 1 | 0.02 | 0.50 | 50000 |
| | 2 | 0.04 | 0.25 | 25000 |
| | 10 | 0.2 | 0.05 | 5000 |

A1-2.2.1.8 Using higher values of *N/A* in Equation 13 will increase the acceptable values of *ct* and max *t*. Accepting higher values of *c* will reduce max *t*. The guideline table provides an order of magnitude assessment of the degree of electric field and charge control needed in specific operations. Minimum field and minimum particle charge are always the goal but usually not practically achievable. This guideline table provides background estimates of envelopes for acceptable operation in electrically charged environments.

A1-2.2.2 The following simplified table is offered as an alternative to Table A1-2 based on the following assumptions:

1. Calculations made for Federal Standard 209E Class 1 ($c \leq 0.00124$ particles/cm$^3$).
2. The value of the electrostatic field is referenced at a distance of one wafer radius from the wafer. While electrostatic field measurements can certainly be made at this distance, they are typically made at 2.5 cm (1 inch) with common instrumentation. This is described in SEMI E43. Measurements made at this smaller distance will be proportionally higher, but under varying measurement conditions, it is difficult to determine a precise relationship between electric field and measurement distance. To provide a suitable safety factor, assume a linear relationship, rather than one proportional to the square of the distance. For example, with a 200 mm wafer, 4000 Volts/cm at 2.5 cm would result in 1000 Volts/cm at 10 cm, rather than 250 Volts/cm.
3. The proportionality effect of $q/q_{Fuchs}$ has been explained, as has the difficulty in actually determining any value for it. For simplicity, the table includes only the $q = q_{Fuchs}$ condition.
4. *N/A* = 0.016 defects/cm$^2$ as specified for 0.25 µm technology in the National Technology Roadmap for Semiconductors.

**Table A1-2.1 Alternative to Allowed Exposure Times in an ISO Class 1 Environment**

| *EV/cm at 2.5 cm* | *N/A defects per cm$^2$* | $v_{elect}$ cm/sec | *ct* sec/cm$^3$ | *max t in Class 1 sec* |
|---|---|---|---|---|
| 4000 | 0.016 | 0.21 | 0.0762 | 61 |
| 400 | 0.016 | 0.021 | 0.762 | 610 |
| 200 | 0.016 | 0.0105 | 1.524 | 1220 |
| 100 | 0.016 | 0.00525 | 3.048 | 2440 |

A1-2.3 *Guide Recommendations for Equipment Malfunctions*

A1-2.3.1 *Equipment Survey* — Most semiconductor production equipment should comply with the ESD immunity requirements of the European Economic Community (EEC). The testing mandated by the EEC uses the test methods and ESD immunity levels specified in IEC 6100-4-2. A recent survey of 262 semiconductor equipment suppliers revealed that 71% were compliant with the EEC requirements. There is an expectation that all equipment to be used in future 300 mm wafer fabrication will meet or exceed the ESD immunity requirements of IEC 6100-4-2.

A1-2.3.1.1 To test for compliance, measurements were made with the ESD simulator described by IEC 6100-4-2 on a representative sample of semiconductor equipment. The results were as follows:

*ESD Simulator Testing Direct Contact Discharge*

| *Equipment* | *Test Voltage Level 1 (2 kV)* | *Test Voltage Level 2 (4 kV)* | *Test Voltage Level 3 (6 kV)* | *Test Voltage Level 4 (8 kV)* | *Test Voltage Level X (NOTE 1)* |
|---|---|---|---|---|---|
| A | | X | | | |
| B | | X | | | |
| C | | | | X | |
| D | | X | | | |
| E | | | | X | |
| F | | X | | | |
| G | | X | | | |
| H | | X | | | |
| I | | X | | | |
| J | | X | | | |

*ESD Simulator TestingAir Discharge at 10 cm*

| *Equipment* | *Test Voltage Level 1 (2 kV)* | *Test Voltage Level 2 (4 kV)* | *Test Voltage Level 3 (8 kV)* | *Test Voltage Level 4 (15 kV)* | *Test Voltage Level X (NOTE 1)* |
|---|---|---|---|---|---|
| A | | | X | | |
| B | | | X | | |
| C | | | | | X |
| D | | | X | | |
| E | | | | | X |
| F | | X | | | |
| G | | | X | | |
| H | | | X | | |
| I | | | X | | |
| J | | | X | | |

"X" indicates that the equipment passes ESD simulator testing at this level.

NOTE 1: This level is subject to negotiation and has to be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.

A1-2.3.2 *Static Audit* — While equipment may meet the ESD immunity levels specified in IEC 6100-4-2, it should be remembered that static charge levels in manufacturing environments may be substantially higher. Direct measurements of static charge are difficult, and the presence of a charge does not always imply that an ESD event causing an equipment malfunction will occur. Some information may be gained by using a fieldmeter to measure the electrostatic field created by the surface charge. Instruments known as EMI locators may also be used in some cases to determine if ESD-related EMI is occurring. Some representative measurements of electric fields from objects in various areas of a semiconductor wafer fab are as follows:

- *Wet Etch* — 0.1 kV/inch to 30 kV/inch
- *Planarization* — 0.1 kV/inch to 20 kV/inch
- *Lithography* — 0.1 kV/inch to 20 kV/inch
- *Dry Etch* — 0.1 kV/inch to 15 kV/inch
- *Thin Film* — 0.1 kV/inch to 15 kV/inch
- *Diffusion* — 0.1 kV/inch to 30 kV/inch
- *Implant* — 0.1 kV/inch to 15 kV/inch

A1-2.3.2.1 A knowledge of object capacitance and other physical properties is needed to determine if any of the above measurements indicate an equipment hazard due to ESD events. However, the range of the measurements strongly indicate that such ESD events can occur. The examples in Related Information R1-3.3 support this conclusion.

A1-2.3.3 *Guide Recommendations* — Based on the static audits and equipment test data, there appears to be a wide range of static immunity in equipment as well as in the static charge levels in work environments. As stated previously, it is difficult to establish a direct correlation between ESD events and fieldmeter measurements made on products, carriers, or any other objects in the work environment. The following sensitivity levels are defined with recommended test levels for each.

A1-2.3.3.1 *Level 4* — Field measurements of static charge at input/exit ports are expected to exceed 10 kV/inch. Equipment should pass ESD simulator testing at 8 kV direct contact discharge, 18 kV air discharge. Guide recommendation (Section 12.5) - 1200 nanocoulombs (8 kV × 150 picofarads).

A1-2.3.3.2 *Level 3* — Field measurements of static charge at input/exit ports are expected to exceed 4 kV/inch, but are less than 10 kV/inch. Equipment should pass ESD simulator testing at 4 kV direct contact discharge, 8 kV air discharge. Guide recommendation (Section 12.5) - 600 nanocoulombs (4 kV × 150 picofarads).

A1-2.3.3.3 *Level 2* — Field measurements of static charge at input/exit ports are expected to exceed 500 V/inch, but are less than 4 kV/inch. Equipment should pass ESD simulator testing at 2 kV direct contact discharge, 4 kV air discharge. Guide recommendation (Section 12.5) - 300 nanocoulombs (2 kV × 150 picofarads).

A1-2.3.3.4 *Level 1* — Field measurements of static charge at input/exit ports are expected to exceed zero, but are less than 500 V/inch. Equipment should pass ESD simulator testing at 1 kV direct contact, 2 kV air discharge. Guide recommendation (Section 12.5) - 150 nanocoulombs (1 kV × 150 picofarads).

# RELATED INFORMATION 1
# STATIC CHARGE PROBLEMS

NOTE: The material contained in this related information is not an official part of SEMI E78 and is not intended to modify or supersede the guide in any way. These notes are provided as a source of information to aid in the application of the guide, and are to be considered reference material. Determination of the suitability of the material is solely the responsibility of the user.

## R1-1 ESD Damage

Contributed by Leo G. Henry, Ph.D., Advanced Micro Devices, EOS/ESD/LU/EMC Department, Sunnyvale, CA 94538, leogesd@pacbell.net.

R1-1.1 *Introduction* — ESD damage to devices occurs when they come into contact with personnel and equipment. Either may store a residual charge large enough to destroy the device if a discharge occurs. In the semiconductor industry, it has been established that a significant proportion of customer field returns are attributed to damage resulting from ESD.

R1-1.2 *Description of ESD Damage Mechanisms* — ESD failures are the result of either a current-induced phenomenon or a charge-induced phenomenon, and the damage can either be junction, contact, dielectric or oxide related. The apparent similarity in current-induced damage resulting from ESD due to human body model discharges (HBM) or machine model discharges (MM) results from the thermal nature of both of these process. The HBM and MM damages result when the temperature (joule heating) of the region dissipating the ESD pulse energy reaches a critical value and melting occurs.

R1-1.2.1 Charge-induced phenomena are predicted by the charged device model (CDM). For CDM type discharges, oxide punch through occurs when the ESD voltage applied across the oxide creates a high enough field to break down the oxide. Excessive current flow results, causing an oxide short, but there is no heat transfer (adiabatic process).

R1-1.2.2 It should be noted here that the time duration for typical ESD events from charged objects and personnel ranges from 10 to 100 nanoseconds, while CDM type events occur in less than 1 nanosecond.

R1-1.3 *Device Testing Models*

R1-1.3.1 *Human Body Model (HBM)* — The Human Body Model is the oldest and the most widely used of the three ESD models. The model attempts to replicate the discharge from a real human when the latter touches a device that is at a lower potential. The human capacitance and resistance have been ideally chosen to be 100 picofarads and 1500 ohms respectively. The values were chosen after measurements were made on humans in varying positions with respect to their surroundings. The resulting discharge waveform has a double exponential shape with risetime range of 2–10 nsec and a decay constant (1/e position) of 150 ± 20 nsecs. The typical peak currents range from 0.67 Amps at 1000 volts to 2.67 Amps at 4000 volts.

R1-1.3.2 *Machine Model (MM)* — The Machine Model is described by Electronic Industries Association of Japan (EIAJ) as a worst case HBM. The model attempts to replicate the discharge from a metallic arm of an automatic handler coming into contact with the metallic leads of a semiconductor device which is at a lower potential. A capacitance of 200 picofarads and ideally zero resistance produces a sinusoidal decaying waveform with an effective pulse duration of 200 nsec. The typical peak currents range from 1.75 Amps at 100 volts to 14.0 Amps at 800 volts. Note that MM failures occur at 5–10 times lower voltage than HBM.

R1-1.3.3 *Charged Device Model (CDM)* — The Charged Device Model in its purest form is actually a field induced model because the device is actually part of model. This model attempts to describe a device which itself becomes charged due to an external field, or due to triboelectric charging of the device surfaces. During discharge, the parasitics (capacitance, inductance and impedance) in the device play a significant role in the resulting failure. The discharge pulse is a sinusoidal waveform with an extremely fast risetime of less than 500 picoseconds. The waveform decays rapidly with a total pulse duration of less than 5 nano-seconds. The peak currents range from 2.0 Amps at 250 volts charging voltage, to 18.0 Amps at 2000 volts charging voltage.

R1-1.3.4 *Correlation Between Models* — There is much debate on whether or not there is any type of correlation between HBM and MM. While some companies report a correlation of roughly 10:1 between the two models, other companies have seen anywhere from 5–20:1 differences in passing voltages between the two models. There is also no established voltage correlation between CDM damage and HBM or MM ESD events. In equipment, ESD damage events will be related to the MM or CDM types of ESD. Users will need to determine the type of ESD hazard to their devices and choose the test method accordingly.

R1-1.4 *ESD Laboratory Simulation Testing*

R1-1.4.1 *Description of Test Methods* — Test procedures discussed here for ESD simulation conform to those established by the ESD Association Standards ESD STM 5.1 (for HBM), ESD S5.2 (for MM), and MIL-STD-883, C/3015.7-method 8. The ESD Association is presently considering two documents related to CDM Testing. Details are to be found in these standards.

R1-1.4.1.1 Devices are qualified at a level corresponding to the highest ESD stress they are able to withstand. These levels are discussed in more detail in Appendix A1-2.1.

R1-1.4.2 *Simulation Test Results* — In general all units must be data-logged both pre- and post-stress test. Any leakage current equal to or greater than a specific amount (company dependent — typically 10 micro-amps or less) is "flagged" as a failure, and any current shift greater than about 200 nano-Amp is marked on the record.

R1-1.4.3 *HBM Stress Testing* — An R-C network is used to simulate the ESD event. In an HBM ESD Simulator, a high voltage is used to charge the capacitor (100 pF) which discharges through the resistor (1500 ohms) into the device under test. The present draft standard (1997) requires a minimum of two discharges (1 positive and 1 negative) per voltage level.

R1-1.4.4 *MM Stress Testing* — An R-C network is also used in the MM ESD Simulator for ESD testing. High voltage charges the capacitor (200 pF) which discharges through the short wire (zero ohm) into the device under test. The present standard requires a minimum of six discharges (3 positive and 3 negative).

R1-1.4.5 *CDM Stress Testing* — The package and leadframe of the device are charged by direct charging or field induction. For the Direct Charging Method, direct contact is made to one of the device leads connected to the substrate or bulk material of the device. The device is then discharged via a one ohm resistor to ground.

R1-1.4.5.1 For the Field Induced Method, the device is placed on a metallic charging plate with the device packaging material touching the plate. The potential of the device is raised by applying a voltage to the charging plate. The induced voltage on the device is discharged to ground through a 1 ohm resistor that contacts each device lead. The present draft standard (1996) requires a minimum of 6 discharges (3 positive and 3 negative) from each device lead.

R1-1.5 *Examples of Damage from Device Testing*

R1-1.5.1 *HBM ESD Damage*

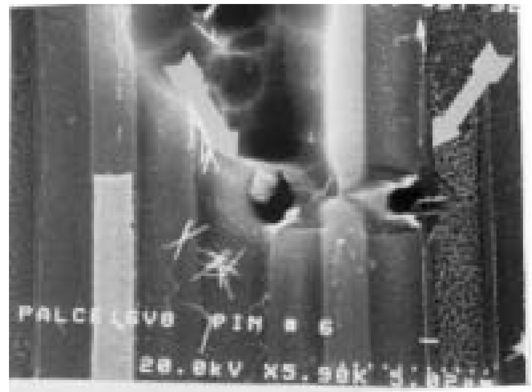

**Figure R1-1**
**Example of HBM Damage**

R1-1.5.1.1 In this example of HBM damage (refer to Figure R1-1), de-processing (removal of the processed layers) down to the poly level and very high magnification (SEM) examination were required in order to see the failure site morphology of arcing from source to drain within the ESD protective structures. The electrical characteristics found were: resistive shorts, leakages, low breakdown voltages and Icc failures.

R1-1.5.2 *MM ESD Damage*

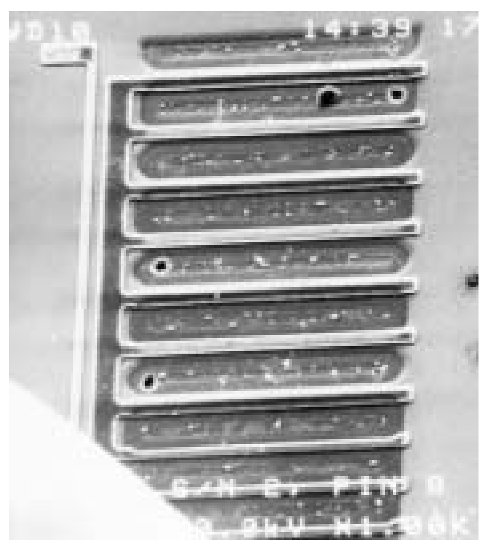

**Figure R1-2**
**Example of MM Damage**

R1-1.5.2.1 In the above MM example (refer to Figure R1-2), the damage was more severe than for HBM. De-processing down to the poly level and the SEM examination showed the failure site morphology of large deep pits occurring at the contact(s) suggesting high current parasitic bipolar action deep in the substrate and also within the ESD protective structures. The electrical characteristics found also resistive shorts, leakages, low breakdown voltages and Icc failures.

R1-1.5.3 *CDM ESD Damage*

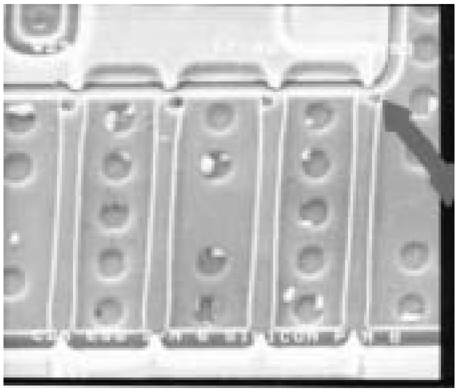

**Figure R1-3**
**Example of CDM Damage**

R1-1.5.3.1 In the above CDM example (refer to Figure R1-3), the gate oxide damage is seen as a unique failure signature beyond the input protection structures at an internal location of the die. Most often the oxide failure is located beneath the poly at the field oxide edge, or is located at the poly edge adjacent to the source/drain junction. To date all CDM ESD damage has been found in the gate oxide at the input buffer circuitry.

R1-1.6 *References*

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## R1-2 Enhanced Particle Deposition Attributable to Electrical Charge on a Wafer

Contributed by Douglas W. Cooper, Ph.D., The Texwipe Company, Upper Saddle River, NJ 07458.

R1-2.1 *Introduction* — The presence of excess electrical charge on a wafer can create an electrostatic field that will lead to accelerated deposition of particles onto the wafer. This undesirable consequence is but one of several threats to product yield posed by the presence of excess electrical charge on a wafer. Sections R1-1 and R1-3 of this related information discuss two other important and potentially damaging consequences of surface charge.

R1-2.1.1 The purpose of the discussion in this section is to estimate the magnitude of electrostatic field that can be tolerated before electrostatically enhanced particle deposition becomes the dominant particle deposition mechanism. Over the particle size range 0.01 to 0.3 µm, diffusion is the dominant, non-electrostatic mechanism of particle deposition. Thus, values of electrostatic fields that do not produce particle deposition velocities greater than those attributable to particle diffusion will be deemed tolerable. A set of such values calculated under a specific and very restrictive set of conditions are presented in this section.

R1-2.2 *Theoretical Background* — Although there are numerous electrostatic interactions between particles and surfaces, the dominant one is almost always the "Coulombic" interaction: the attraction (or repulsion) of a charged particle by a charged surface. This is the only electrostatic effect considered here.

For particles of one diameter, $d$, and one charge, $q$, the particle deposition flux, $j$, (the number of particles deposited per unit area per unit time) is the product of aerosol particle number concentration, $c$; particle charge, $q$; the electric field created by the charged wafer, $E$; and particle mechanical mobility, $B$ (terminal velocity per unit external force):

$$j = cqEB \qquad (1)$$

The group qEB is the "electrostatic deposition velocity", $v_{elect}$

$$v_{elect} = qEB = j/c \qquad (2)$$

The variables $q$ and $E$ are those containing the electrical parameters that affect the magnitude of $v_{elect}$; $B$ depends on particle diameter but not electrical properties.

It is the $v_{elect}$ values that will be calculated for comparison with those of $v_{diff}$ , the particle deposition velocity attributable to particle diffusion. Values of $E$ for which $v_{elect} < v_{diff}$ will be those deemed tolerable in wafer manufacturing.

Note that the total number of particles, $N$, deposited on a wafer, obtained by integrating Equation (1) over the wafer area, $A$, and the time of exposure, $t$, depends on $c$ as well as the deposition velocity:

$$N = cqEBAt \text{ or } N/A = ctv_{elect} \qquad (3)$$

Reducing $c$ obviously reduces $N$, but the relative importance of the differing deposition mechanisms and the values of the deposition velocities associated with these mechanisms are assumed to not depend upon $c$, at least to a first-order approximation (see, for example, Peters and Cooper, 1991).

R1-2.2.1 *Effect of the Particle Charge, q* — There are many charging and discharging mechanisms for particles, so $q$ is hard to predict and likely to be highly variable. In a normal atmosphere the positive and negative air ions tend to have roughly equal effectiveness in charging particles, so that the number of positively charged particles is roughly equal to the number of negatively charged particles. Thus, about half the particles will be attracted and half repelled by a net charge on the wafer. Special circumstances, such as corona discharge ionizers that are not balanced, could alter this conclusion. Without ionizers, cleanrooms tend to have relatively low levels of ions compared to the outdoor or other indoor atmospheres, because the HEPA/ULPA filters efficiently remove ions from the recirculating air.

R1-2.2.1.1 A Boltzmann charge equilibrium, the charge distribution approximated by aerosol particles exiting a radioactive neutralizer, is a plausible *lower limit* for particle charge and will be assumed in the calculations of $v_{elect}$, using an improved version of this distribution developed by Fuchs (1964). *Upper limits* on particle charge are determined by ion emission limits or, in the case of water droplets, the Rayleigh limit. However, assuming higher particle charge distributions usually means that $v_{elect} > v_{diff}$ for virtually any value of $E > 0$ and that the only method for avoiding electrostatically enhanced particle deposition is to reduce wafer charge to zero. Thus, the Fuchs charge distribution will be assumed in calculating $v_{elect}$ even though it represents the most favorable particle charge distribution for minimizing electrostatically enhanced particle deposition. Under many practical circumstances the particle charge will be greater and the maximum tolerable electrostatic field will be lower than that calculated for the Fuchs charge levels.

R1-2.2.2 *The Electrostatic Field, E, Induced by the Wafer Surface Charge* — The electrostatic field will depend on the charge on the wafer divided by a quantity with the units of length squared; either a distance squared (far from the wafer) or an area (close to the wafer) or some combination at intermediate distances. While field is not properly measured as a voltage, measuring the voltage, $V$, at a fixed distance, $s$, from the wafer allows inferring the field from $V/s$ and the appropriate geometric and dimensional factors. The electrostatic field to be used in Equation (2) can be estimated from the ratio of the wafer charge to the wafer surface area, or the average field near the surface at the center, $E_0$.

R1-2.2.2.1 Very far from the wafer, many wafer diameters away, the field created by the net wafer charge, $Q$, will be similar to that from a point charge:

$$E_1 = k_1 \; Q/r^2 \qquad (4)$$

where $k_1$ depends on the system of units used; and $r$ is the distance from the center of the wafer to the particle.

R1-2.2.2.2 Very close to the wafer, a fraction of a wafer diameter away, the field created by the net wafer charge is:

$$E_2 = k_2 \; Q'/r^2 \qquad (5)$$

where $Q'$ is the net wafer charge, assumed to be uniformly distributed, contained within the intersection of a sphere of radius, $r$, and centered on the point of the wafer closest to the particle.

R1-2.2.2.3 This equation indicates that the charge distribution on the wafer can make a difference close to the wafer. For an insulating wafer with a uniform charge and a radius, $R$:

$$E_2 = E_0 = k_2 \; Q/\pi R^2 \qquad (6)$$

at a distance $r = R$ from the center of the wafer.

R1-2.2.2.4 For a conductive wafer, or for a wafer with localized regions of charge, the electric field will vary over the surface, causing greater and lesser deposition velocities. A conductive wafer will have the charge concentrated near the edges, producing a relatively high field there and much lower fields as the center is approached.

R1-2.2.2.5 Note that both $E_1$ and $E_2$ are proportional to $Q$ and therefore, other variables being equal, electrostatic deposition is expected to be proportional to $Q$. Thus, the criterion to be specified is not the tolerable charge on the wafer but the tolerable electrostatic field near the wafer surface (such as that evaluated at a distance of one radius perpendicular to the wafer surface above its center), $E_0$. A maximum tolerable value of $E_0$ will be estimated by calculating the maximum $E_0$ values for which $v_{elect} < v_{diff}$, assuming a Fuchs distribution for the particle charge.

R1-2.3 *Tolerable Electrostatic Field*

R1-2.3.1 *Particle Deposition Velocity Attributable to Convective Diffusion (vdiff)* — In a microelectronics cleanroom, airflow is generally laminar ("unidirectional") downward at about 50 cm/sec (100 ft/min). If the flow is perpendicular to a surface, such as a wafer of diameter, *Dw*, a boundary layer forms across which particles diffuse to the surface. Liu and Ahn (1987) adapted the correlation of Sparrow and Geiger (1985) and obtained a correlation for the average diffusive deposition velocity as:

$$v_{diff} = 1.08\, Sc^{1/3} Re^{1/2} D^{*}/D_w \qquad (7)$$

where $Sc = \mu/\rho D^{*}$ is the Schmidt Number

$\mu$ is the gas viscosity

$\rho$ is the gas density

and $D^{*} = kTB$ is the particle diffusivity

$k$ is the Boltzmann constant

$T$ is the absolute temperature and

$B$ is the particle mobility

and $Re = \rho U D_w / \mu$ is the Reynolds number

$U$ is the gas velocity and

$D_w$ is the wafer diameter

Bae et al. (1994) reviewed the experimental work of others and presented their own, supporting this correlation; Cooper et al. (1990) obtained a similar equation by a somewhat different method. Oh et al. (1996) summarized prior experimental and theoretical work and extended the numerical analysis with a turbulent transport properties model, finding a small increase in deposition for the conditions modeled. These authors' publications support the approximation that the diffusional deposition velocity is about 0.006 cm/sec at particle diameter of 0.25 µm and about 0.03 cm/sec at particle diameter of 0.01 µm, or:

$$v_{diff} = (0.03\ cm/sec)/(d/0.01\ \mu m)^{1/2} \quad (8)$$

for $0.01\ \mu m \le d \le 0.3\ \mu m$ in cleanroom air.

R1-2.3.2 *Particle Deposition Velocity Attributable to Electrostatic Forces ($v_{elect}$)* — Using a power law to approximate the Fuchs particle charge distribution yields the following approximation for electrical mobility (Cooper et al., 1990):

$$Z = qB = (0.002\ cm/s)/(d/0.01\ \mu m)(1\ V/cm) \quad (9)$$

from which the deposition velocity attributable to electrostatic forces becomes:

$$v_{elect} = (0.002\ cm/s)[E_0/(V/cm)]/(d/0.01\ \mu m) \quad (10)$$

Setting $v_{elect}/v_{diff} = 1$ results in the following expression for tolerable $E_0$:

$$[(E_0/(V/cm)] = 15\ [d/(0.01\ \mu m)]^{1/2} \quad (11)$$

Table R1-2 lists the values of tolerable electrostatic field adjacent to a wafer surface as calculated from Equation (11). Note that the electrostatic fields are calculated at a distance of one wafer radius from the center of the wafer. $E_0$ is the value of electric field at which electrostatically enhanced particle deposition is estimated to match the particle deposition velocity attributable to diffusion, assuming a Fuchs charge distribution on the particles. This charge distribution represents a minimal particle charge. With most particle charge distributions to be encountered in practice, even lower values of electrostatic fields will produce enhanced deposition. A safe conclusion is that there is no safe value of electrostatic field that will avoid enhanced particle deposition unless neutralization of particle charge has been achieved, in which case the very modest values of electrostatic fields calculated from Equation (11) and tabulated in Table Rl-2 should be tolerable.

**Table R1-2 Tolerable Levels of Electrostatic Field at a Distance of One Radius from the Center of a Wafer, Assuming a Fuchs Charge Distribution on the Particles**

| *Minimum Particle Diameter d in µm* | *Tolerable Field $E_0$, in Volts/cm* |
|---|---|
| 0.01 | 15 |
| 0.02 | 21 |
| 0.03 | 26 |
| 0.05 | 34 |
| 0.10 | 47 |
| 0.20 | 67 |
| 0.30 | 82 |

R1-2.4 *Conclusions* — As indicated in Table R1-2, the calculated value of tolerable electrostatic field (the value of electrostatic field above which electrostatic particle deposition becomes the dominant mechanism of particle deposition) is just 47 V/cm for particles of 0.1 µm diameter when the particle electrical charge is that described by the Fuchs charge distribution, a minimum value of particle charge that is normally exceeded in most environments. In most realistic environments the particle charge will be greater and the tolerable electrostatic field, even lower. Hence the conclusion that in all practical processing environments electrical forces will be the dominant mechanism of particle deposition on wafers.

R1-2.4.1 In a Federal Standard 209E Class 1 environment ($c \leq 0.00124$ particles/cm$^3$) with $v_{elect}$, ~ 0.01 cm/s (the value predicted by Equation 10 for a 0.1 µm particle in an electric field of 47 Volts/cm) the target areal particle densities ($N/A = 0.016$ particles/cm$^2$ for the 0.25 µm technology of 1998) specified in the National Technology Roadmap for Semiconductors (NTRS, 1994) will be reached after an exposure time of about 1300 seconds, assuming $c$ is at its maximum allowed concentration.

R1-2.4.2 With less favorable electrical conditions, or higher particle concentration, the maximum allowed exposure time becomes shorter. In addition, the target values for $N/A$ continue to decrease with each technology generation. Fortunately, one or more of the parameters, particle concentration in the ambient, the charge level on a surface, or the time a charged surface is exposed to a given particle ambient, can be controlled.

R1-2.4.3 *Charge Neutralization* — Achieving the Fuchs charge distribution by means of radioactive isotopes or balanced corona neutralizers — is the first step in controlling particle deposition on wafers. This step, while clearly necessary, is unlikely to be sufficient to guarantee meeting the NTRS requirements of the future. Steps to minimize environmental particle concentration, $c$, and time of exposure, $t$, will have to be part of the strategy for creating acceptable processing environments. Minimizing these variables reduces particle deposition attributable to all mechanisms, not just electrostatic deposition.

R1-2.4.4 Contemporary standards recognize the need for reduced particle concentrations in wafer environments. For example, the classification ISO Class 1 (of the proposed international standard for classifying cleanrooms according to concentration of airborne particulate cleanliness) describes an environment in which the concentration of particles > 0.1 µm is $10^{-5}$ particles/cm$^3$ or less. In an environment of this quality, wafer exposure can be as long as $10^5$ seconds at the deposition velocity predicted for neutralized 0.1 µm particles (~0.01 cm/s) and still meet the target defect density that the NTRS recommends for the 0.1 µm technology anticipated in 2007. Fractional increases in the electric field above 47 Volts/cm will decrease the allowed exposure time by that same fraction (Equations 10, 12) — an electric field of 94 Volts/cm reduces the allowed exposure time to $5 \times 10^4$ seconds, etc.

R1-2.5 *References*

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Cooper, D. W., Miller, R. J., Wu, J. J., and Peters, M. H., "Deposition of Submicron Aerosol Particles During Integrated Circuit Manufacturing: Theory", *Particulate Science Technology 8 (3 and 4)*: p. 209–224 (1990)

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Peters, M. H., and Cooper, D. W., "Approximate Analytical Solutions for Particle Deposition in Viscous Stagnation-Point Flow in the Inertial-Diffusion Regime with External Forces", *J. Colloid Interface Science* 142(1): p. 140–148 (1991)

Sparrow, E. M. and Geiger, G. T., "Local and Average Heat Transfer Characteristics for a Disk Situated Perpendicular to a Uniform Plow", J. Heat Transfer 127: p. 321–326 (1985)

*Federal Standard 209E* — "Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones"

R1-2.6 *Experimental Reference*

R1-2.6.1 Deposition of 0.1 to 1.0 Micron Particles, Including Electrostatic Effects, onto Silicon Monitor Wafers (Experimental)

R1-2.6.2 William J. Fosnight, Vaughn P. Gross, Kenneth D. Murray, Richard D. Wang, IBM Corporation published in 1993 Microcontamination Conference proceedings

R1-2.6.3 Summary: Submicron particle contamination continues to be a concern in the manufacture of integrated circuits. Quantifying particle deposition velocity (the ratio of particle deposition rate to airborne particle concentration) is of fundamental importance in understanding the defect-density impact of airborne contamination.

R1.2.6.4 As particle size decreases, the effect of electrostatic charge plays an increasing role in the deposition of particles onto surfaces. This four-trial study examines the deposition of 0.1 to 1.0 micron particles onto horizontal, grounded and electrostatically charged, silicon monitor wafers in an 80 feet per minute vertical unidirectional airflow. The experimental deposition velocity results were compared to theoretical predictions found in the literature.

R1-2.6.5 Three primary observations were obtained from this study. First, measured values of deposition velocity agreed reasonably well with predicted values. However, deposition velocity was not observed to increase below 0.2 micron. Secondly, particles less than 0.5 micron were observed to deposit onto charged wafers approximately three to ten times faster than onto grounded (not charged) wafers. Finally, settling monitor wafers may be a time consuming (and expensive) means of certifying the cleanliness of a "clean" (less than 10 ppcf at scanner threshold particle size) environment. However, settling-monitor studies should not be confused with particles-per-wafer-pass (PWP) measurements; PWP measurements often provide useful information regarding the performance of the automation and/or process of a tool, even if it is in a very clean environment.

## R1-3 ESD Impacts in Semiconductor Equipment

Contributed by Julian A. Montoya, Intel Corporation, 5200 NE Elam Young Parkway, Hillsboro OR, 97124-6497.

R1-3.1 *Introduction* — Electrostatic phenomena impact semiconductor manufacturing in many ways. These range from increased particle accumulation on wafer surfaces to electrostatic discharge (ESD) events which impact equipment performance, and in some cases impact factory yields and throughput.

R1-3.1.1 All areas within a semiconductor manufacturing environment must be concerned with electrostatic control. This encompasses initial wafer receiving to shipping of final product. In addition, the equipment which will be housed within that environment must also be concerned with electrostatic control and electrostatic immunity.

R1-3.1.2 This section highlights issues associated with static charge and ESD in a semiconductor manufacturing environment and its effects on production equipment.

R1-3.2 *Overview* — Static charge issues in semiconductor manufacturing manifest themselves in many ways. Problems occur by direct contact with charged items, by induction from electrostatic fields, and indirectly by radiated and conducted electromagnetic interference (EMI) emitted into the environment as a result of the ESD event.

R1-3.3 *Equipment ESD Examples* — The following section presents real world examples of the cause and impacts associated with electrostatic discharge and semiconductor manufacturing equipment.

R1-3.3.1 Charged operators came into direct contact with diffusion furnace control panel. Process aborted on many occasions resulting in loss of product and reduced equipment utilization.

R1-3.3.2 Numerous instances where charged reticles (photomasks) came into direct contact with a grounded object. This caused damage to reticles and impacted factory throughput. Costs were associated with replacing damaged reticles and requalifying reticle sets.

R1-3.3.3 Charged operators came into direct contact with electronic card cage of chemical vapor deposition tool. This resulted in process abort, loss of product, and reduced equipment availability.

R1-3.3.4 Charged wafer cassette induced charge onto robot arm on wafer transfer tool. Robot arm came into contact with grounded screw creating an ESD event. This resulted in data corruption which caused robot arms to open, dropping fully loaded wafer cassettes to the floor. Costs were associated with loss of product.

R1-3.3.5 Automated material handling system "car" became charged while coming in close proximity to ionizer. Car came into contact with grounded object during charging; creating data corruption which resulted in system downtime, impact to factory throughput, and cost associated with the replacement of control electronics.

R1-3.3.6 Wafer taping/detaping tool generated charge during normal operation. Chassis ground of the tool was inadvertently removed, causing high charge to be developed within the tool. Electrostatic Discharge occurred at random time intervals within the tool. Impact to equipment availability, and long solution time.

R1-3.3.7 Wafers became charged during spin rinse process. During transfer to wafer metrology tool electrostatic discharge occurred, causing data corruption. This resulted in unexpected tool lockups, and reduced equipment availability.

R1-3.3.8 Ungrounded wall panels became charged and generated ESD events. EMI produced from ESD events coupled into photolithography equipment and created data corruption. This resulted in impacts to equipment utilization. Long solution time.

R1-3.3.9 Insulative ceiling panels became charged and generated ESD events which produced high levels of radiated and conducted EMI in a test area. EMI coupled into tester/handler and produced data scramble. This resulted in reduced equipment availability.

R1-3.3.10 Finished product became charged during manual handling. Product came into direct contact with test/handler equipment. This resulted in damaged circuit cards which needed to be replaced, and decreased equipment availability.

R1-3.3.11 Wafer transfer cart became charged while rolling over temporary "insulative" floor. Cart came into contact with plasma etcher control cabinet. Resulting ESD event caused product loss and reduced equipment availability.

R1-3.3.12 Wafer polisher robot arm became charged during normal operation. Chassis ground wire for robot left off. ESD event occurred causing data scramble which resulted in process being aborted.

R1-3.4 *Conclusion* — Electrostatic Discharge (ESD) affects semiconductor manufacturing equipment in many ways. The issues are wide ranging from trivial lock-ups and aborts of process equipment to factory throughput and yields impacts. The scope of the ESD problem is very broad and encompasses every aspect of semiconductor manufacturing.

# RELATED INFORMATION 2
# STATIC CONTROL METHODS

NOTE: This related information is not an official part of SEMI E78 and is not intended to modify or supercede the official standard. Determination of the suitability of the material is solely the responsibility of the user.

## R2-1 Static Charge Control

R2-1.1 It is usually impossible to totally eliminate static electricity from work areas, but with proper use of equipment and remedial procedures, most static problems can be controlled. Many approaches to controlling static charge have been tried over the years and it is clear that there exists no single method for controlling all static charge problems.

## R2-2 Grounding Conductors and Static Dissipative Materials

R2-2.1 An important consideration in selecting a method is whether the charged material is a conductor or an insulator. Static dissipative materials are created by lowering the resistivity of insulating materials through the addition of metal or carbon particles, or other chemical additives. Static charge on a conductive or static dissipative object can be easily controlled if the object is provided with a path for the charge to flow to earth ground. While charge is mobile in a conductor (or in a static dissipative material), in insulators charge is not mobile, and earth grounding is not an effective means of eliminating the static charge.

R2-2.2 Equipment manufacturers can use both conductive and static dissipative materials to reduce the presence of static charge. If there is a path for the charge to flow to earth ground, the static charge on equipment, and materials handled by the equipment, can be rapidly, and harmlessly, neutralized. Obviously, the success of earth grounding depends on maintaining the integrity of the ground path. This is sometimes a problem when high-speed, moving parts of equipment must be connected to earth ground.

R2-2.3 Static dissipative materials will need to retain their dissipative properties over the range of temperature and humidity conditions they will encounter, and not change significantly over time. In cleanrooms they must also meet requirements for avoiding micro-particle production and outgassing. As long as the ground connection is maintained, these “passive” procedures offer reasonable protection to the equipment and product from sources of static charge.

R2-2.4 Unfortunately, these methods do not provide complete protection from static-related problems. Even when earth grounding is an option, it is subject to human error. In applications where contamination is an issue, additives and carbon particles used in static-dissipative materials may become sources of contamination themselves. When earth grounding or the use of dissipative materials is either inappropriate or not cost effective, ionization can be used.

## R2-3 Ionization

R2-3.1 More often than not, the product itself uses insulating materials, making earth grounding unavailable as an option. While silicon is a semiconductor, its oxide coating transforms it into an insulator. Teflon is used in many chemical processes, and quartz in high temperature processes. Epoxy and ceramic packages are used for integrated circuits. Insulators are easily charged, retain their charge for long periods of time, and are often close to the product. Dealing with static charge on insulators and isolated conductors will often require the use of some type of ionization. Ionizers are the most effective means of dealing with static charges on insulators and isolated conductors.

R2-3.2 For purposes of static charge control, ions are molecules of the gases in air (nitrogen, oxygen, water vapor, and carbon dioxide) that have lost or gained an electron. Ions are present in normal outside air but are removed when air is subjected to filtration and air conditioning. Ionization systems work by increasing the conductivity of the air with the ionized gas molecules. When ionized air comes in contact with a charged surface, the charged surface attracts ions of the opposite polarity. As a result, the static electricity that has built up on products, equipment and surfaces is neutralized.

R2-3.3 The most common methods of producing air ions are radioisotopes and “corona discharge” resulting from the electric field created when high voltage is applied to a sharp point.

R2-3.4 The radioisotope most commonly used to produce ionization is Polonium$^{210}$, an alpha particle emitter. The alpha particle collides with the surrounding gas molecules, dislodging electrons, which results in pairs of positive and negative ions.

R2-3.5 The corona discharge method produces a very high electric field that interacts with the electrons in the surrounding gas. The polarity of the ions depends on the polarity of the high voltage on the emitter point. Ions of opposite polarity to the charged surface are required. Either polarity of static charge may be created in the equipment or on the product.

R2-3.6 Ionizers in equipment must deliver ionization over a wide range of humidity and temperature conditions. Back-end assembly and test areas often do not have the level of temperature and humidity control found in front-end wafer production. Ionizers installed in the cramped spaces of production equipment will be close to the product, in areas surrounded by grounded metal parts. Ionizers should isolate the emitter points from both the product and adjacent grounded surfaces. Ionizers should produce sufficient ions to discharge static on surfaces and products moving at high speeds despite losses to ground. Most ionizers require maintenance and periodic verification of their performance.

## R2-4 Problem of Controlling Static Charge in Manufacturing Equipment

R2-4.1 The interior of high speed production equipment presents a challenge to most static control methods. The cost of production space is high and requires that equipment occupying the space be compact and operate at as high a speed as practical. Product is moved through small spaces at high speed by a variety of robotic and other mechanisms. Triboelectric charging (charge generation due to friction or contact and separation of dissimilar materials) and contact with ground are almost unavoidable. Grounding of equipment parts that contact the product presents added difficulties when the equipment parts are moving at high speeds. Dissipating charge from insulating surfaces and integrated circuit (IC) packages may be difficult if the charged surfaces are not accessible. Using ionizers in these confined spaces presents challenges.

RELATED INFORMATION 3

# EXAMPLE FOR ADDING ELECTROSTATIC COMPATABILITY REQUIREMENTS TO PURCHASING DOCUMENTS FOR SEMICONDUCTOR MANUFACTURING EQUIPMENT

NOTE: This related information is not an official part of SEMI E78 and is not intended to modify or supercede the official standard. Determination of the suitability of the material is solely the responsibility of the user.

## R3-1 Purpose

Purchasing semiconductor manufacturing equipment that meets SEMI E78 Electrostatic Compatibility requirements can reduce the cost of ownership of the equipment by reducing operating problems and product defects, by eliminating costly equipment modifications after delivery, and by making the equipment available for use more quickly after delivery.

The purpose of this Related Information 3 is only to describe an example of specifications for electrostatic compatibility that are meant to form part of a general purchasing document for production equipment or minienvironments.

R3-1.1 *Limitations* — Related Information 3 is only one possible example of defining E78 compliance requirements for equipment. Users may include all, or any part of it, modifying it as necessary in their purchase documents. Users are responsible for determining the appropriate level of static control protection depending on their specific circumstances.

## R3-2 Terminology (Reference: ESD Association Glossary ADV1.0)

R3-2.1 *conductive material* — electrostatic conductive materials have a surface resistance of $< 1 \times 10^4\ \Omega$ or a surface resistivity of $< 1 \times 10^5\ \Omega$/square when tested according to ESD Association ESD STM11.11, or a volume resistance of $< 1 \times 10^4\ \Omega$ or a volume resistivity of $< 1 \times 10^4\ \Omega$-cm when tested according to ESD Association ANSI/ESD STM11.12. (Other national or international (IEC) standards may be substituted).

R3-2.2 *static dissipative material* — electrostatic dissipative materials have a surface resistance between $1 \times 10^4\ \Omega$ and $< 1 \times 10^{11}\ \Omega$ or a surface resistivity of between $1 \times 10^5\ \Omega$/square and $< 1 \times 10^{12}\ \Omega$/square when tested using ESD Association ESD STM11.11, or a volume resistance of between $1 \times 10^4\ \Omega$ and $< 1 \times 10^{11}\ \Omega$ or volume resistivity between $1 \times 10^4\ \Omega$-cm and $< 1 \times 10^{11}\ \Omega$-cm when tested using ESD Association ESD STM 11.12. (Other national or international (IEC) standards may be substituted)

## R3-3 General Static Control System Description

R3-3.1 The static control system shall provide electrostatic charge and ESD control to meet the recommendations for Level 2 (or 1, 3, or 4 as agreed upon) contained in SEMI standard E78 Electrostatic Compatibility: Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment. These recommendations are defined in Section 12.5 Table 1.

R3-3.2 The static control system shall consist of the following items, applied as needed to assure compliance.

R3-3.2.1 Grounding of conductive equipment parts when feasible.

R3-3.2.2 Static dissipative materials to replace insulators when feasible.

R3-3.2.3 Ionization sources to control static charge on process essential insulators or isolated conductors, particularly when they are part of the product (e.g., oxide-coated silicon, epoxy-packaged devices, reticles).

## R3-4 General Static Control System Design Requirements

R3-4.1 *Grounding*

R3-4.1.1 Conductive equipment parts shall maintain a resistance to chassis ground or to electrical ground of less than 1 ohm. (Reference – ESD Association standards ANSI EOS/ESD S6.1 Grounding -- Recommended Practice and ESD SP10.1 Automated Handling Equipment. Other national or international (IEC) standards may be substituted)

R3-4.1.2 In critical applications, as determined by the user, constant monitoring of equipment grounding shall be required. In some cases, local electrical safety regulations may prohibit the use of this method. A suitable test method to capture short interruptions of ground connections may need to be used.

R3-4.1.3 Resistance measurements for moving equipment parts shall be made with the equipment in operation.

NOTE 3: Grounding methods to prevent the generation and accumulation of static charge are not necessarily sufficient for conduction at high frequencies, or to provide electrical safety.

R3-4.2 *Static Dissipative Materials*

R3-4.2.1 Insulators shall be replaced with grounded static dissipative materials when feasible.

R3-4.3 *Ionizers*

R3-4.3.1 Charge on insulators or isolated conductors in the product handling path, product, or reticles (if used by the equipment to produce product) shall be controlled with ionizers.

R3-4.3.2 Ionizer performance shall be measured using ESD Association standard ANSI ESD STM3.1 Ionization. (Other national or international [IEC] standards may be used.)

R3-4.4 *Cleanroom Compatibility*

If equipment or materials are to be installed in a cleanroom, all static control system components shall demonstrate compatibility with cleanroom class requirements.

NOTE 4: The user may need to define cleanroom compatibility requirements for static control materials here (such as, particle shedding, outgassing, and chemical compatibility) if such requirements are not defined elsewhere in the purchasing document. (Reference ESD TR11-01 – Electrostatic Guidelines and Considerations for Cleanrooms and Clean Manufacturing)

## R3-5 Compliance Testing

R3-5.1 Compliance testing shall be done by:

a) a capable independent third party, or

b) the equipment manufacturer, or

c) the end user

to demonstrate that the equipment meets the recommendations for Level 2 (or 1, 3, or 4 as agreed upon) contained in SEMI standard E78.

R3-5.2 Acceptance testing of the static control system performance shall be performed at the actual equipment use location.

## R3-6 Referenced Standards

(The following ESD Association Standards and Advisories[4] are referenced above. The may be other equivalent national or international standards covering these areas.)

ESD ADV1.0 — Glossary of Terms

ANSI ESD STM3.1 — Ionization

ANSI/ESD S6.1 — Grounding – Recommended Practice

ESD SP10.1 — Automated Handling Equipment

ESD STM11.11 — Surface Resistance Measurement of Static Dissipative Planar Materials

ANSI/ESD STM11.12 — Volume Resistance Measurement of Static Dissipative Planar Materials

ESD TR11-01 — Electrostatic Guidelines and Considerations for Cleanrooms and Clean Manufacturing

4 ESD Association, 7900 Turin Road, Rome, NY 13440 USA.

# SEMI E79-0304
# SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT PRODUCTIVITY

This specification was technically approved by the Global Metrics Committee and is the direct responsibility of the North American Metrics Committee. Current edition approved by the North American Regional Standards Committee on October 15, 2003 and December 4, 2003. Initially available at www.semi.org February 2004; to be published March 2004. Originally published February 1999; last published February 2000.

## 1 Purpose

1.1 The document provides metrics for measuring equipment productivity.

## 2 Scope

2.1 The document defines metrics and calculations for measurement of equipment productivity.

2.2 In the context of this document, it is important to note that “equipment productivity” is impacted greatly by factors far beyond the equipment itself, including operator, recipe, facilities, material availability, scheduling requirements, etc.

2.3 Effective application of this specification requires that equipment performance is tracked using the metrics for Equipment Reliability, Availability, and Maintainability (RAM) established in SEMI E10. Additionally, the Automated Reliability, Availability, and Maintainability Standard (ARAMS) SEMI E58 can be used for equipment with ARAMS capability. Productivity metrics for flexible-sequence cluster tools require tracking of SEMI E10 equipment states and recipes at the level of individual processing modules. The Equipment Performance Tracking (EPT) Standard SEMI E116 assists SEMI E79 by providing the status of the major modules of the equipment allowing performance metrics to be tracked at the module level. SEMI E116 also assists SEMI E79 by providing task-level detail of the equipment or module’s current activity, allowing performance metrics to be tracked at the task level. Productivity performance of a flexible-sequence cluster tool is then calculated as the aggregate productivity performance of its individual processing modules.

2.4 This document is currently limited to measuring equipment productivity using Overall Equipment Efficiency (OEE) as the metric, and does not address the impact of productivity changes on cost, cycle time, or other measures. This document does not address any RAM issues over and above those in SEMI E10.

**NOTICE:** This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

## 3 Referenced Standards

3.1 *SEMI Standards*

SEMI E10 — Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM)

SEMI E38 — Cluster Tool Module Communications (CTMC)

SEMI E58 — Automated Reliability, Availability, and Maintainability Standard (ARAMS): Concepts, Behavior, and Services

SEMI E116 — Provisional Specification for Equipment Performance Tracking

**NOTICE:** Unless otherwise indicated, all documents cited shall be the latest published versions.

## 4 Terminology

4.1 *Terminology Applicable to Computation of the OEE Metric*

4.1.1 *actual unit output* (units) — the number of units processed by the equipment during production time.

4.1.2 *availability efficiency* (time divided by time) — the fraction of total time that the equipment is in a condition to perform its intended function.

4.1.3 *cluster tool* — a manufacturing system made up of integrated processing modules mechanically linked together (the modules may or may not come from the same supplier) (SEMI E10).

4.1.4 *downtime (equipment downtime)* (time) — the time when the equipment is not in a condition, or is not available, to perform its intended function. It does not include any portion of non-scheduled time (SEMI E10).

4.1.5 *effective unit output* (units) — the number of units processed by the equipment during production time that were of acceptable quality, i.e., actual unit output less equipment assignable rework and equipment assignable scrap.

4.1.6 *equipment-assignable rework* (units) — any units being reworked due to a fault or defect assignable to the subject equipment. The units may be reworked at the equipment where the fault or defect occurred, or at other equipment.

4.1.7 *equipment-assignable scrap* (units) — any units that are permanently removed from production due to a fault or defect assignable to the subject equipment. The units may be removed from production at the operation where the fault or defect occurred, or at a subsequent operation.

4.1.8 *equipment module —* an indivisible entity within a system.

4.1.9 *fixed-sequence cluster tool* — a cluster tool in which all units of production visit all processing modules making up the tool in a fixed sequence. [1]

4.1.10 *flexible-sequence cluster tool* — a cluster tool in which the units of production visit a subset of the processing modules of the tool in sequences that may vary from unit to unit. In such tools, the processing modules that are engaged in processing activity vary from unit to unit according to dispatching decisions made by software internal to the tool (CSM 42).

4.1.11 *non-processing module* — an equipment entity that supports the movement or conditioning of units through the system, such as,

- robotic handler
- load/unload lock
- pre-aligner

4.1.12 *non-scheduled time* (time) — time when the equipment is not scheduled to be used in production (SEMI E10).

4.1.13 *operational efficiency* (time divided by time) — the fraction of equipment uptime that the equipment is processing actual units.

4.1.14 *operations time* (time) — total time minus non-scheduled time (SEMI E10).

4.1.15 *overall equipment efficiency (OEE)* (time divided by time) — a metric of equipment performance, expressing the theoretical production time for the effective unit output divided by the total time. [2].

NOTE 1: The overall equipment efficiency metric accounts for all losses that reduce equipment performance from its maximum potential performance taking the existing equipment design and recipe specifications as given.

4.1.16 *performance efficiency* (time divided by time) — the fraction of equipment uptime that the equipment is processing actual units at theoretically efficient rates.

4.1.17 *processing module —* an indivisible production entity within an equipment system, e.g., a processing chamber or station within a cluster tool.

4.1.18 *processing module recipe* — all processing steps of a recipe performed within a single processing module without requiring reloading of that processing module (CSM 42).

4.1.19 *production time* (time) — sum of all periods of time in which a processing module is performing its intended function.

- For a non-cluster tool, a fixed-sequence cluster tool, or an individual processing module within a flexible-sequence cluster tool, production time is equivalent to the SEMI E10 productive time for that entity.
- For a flexible-sequence cluster tool, production time is the sum of the productive times of all processing modules encompassed by the cluster tool (CSM 42).

4.1.20 *productive state* — a period of time (*productive time*) when the equipment is performing its intended function (SEMI E10).

4.1.21 *quality efficiency* (time divided by time) — the theoretical production time for Effective Units divided by the theoretical production time for Actual Units.

4.1.22 *rate efficiency* (time divided by time) — the fraction of production time that equipment is processing actual units at theoretically efficient rates.

4.1.23 *recipe* — the pre-planned and reusable portion of the set of instructions, settings, and parameters under control of a processing agent that determines the processing environment seen by the material. *Recipes* may be subject to change between runs or processing cycles (SEMI E38).

4.1.24 *system* — an integrated structure of components and subsystems capable of performing, in aggregate, one or more specific functions. For the purpose of this specification, a system consists of one or more processing or non-processing modules.

1 CSM 42: Productivity Metrics for Flexible-Sequence Cluster Tools, Engineering Systems Research Center, University of California, Berkeley, 1998

2 CSM 21: Closed-Loop Measurement of Equipment Efficiency and Equipment Capacity, Engineering Systems Research Center, University of California, Berkeley, 1997.

4.1.25 *theoretical production time per unit (THT)* (time per unit) — the minimum rate of time per unit to complete processing, given:

- the specified recipe
- the equipment design
- continuous operation
- no efficiency losses

NOTE 2: Recipe specifications and settings for THT are the ones actually used in production and are not idealized. Equipment of the same design (e.g., same make and model) are expected to have the same THTs, whereas equipment of a different design may have different THTs even if they perform the same intended function. Continuous operation requires that equipment loading is optimized for throughput and there are no internal or external interruptions or delays to processing. Given the constraints of specified recipe, equipment design, and continuous operation, THTs shall not include allowances for any other efficiency losses (e.g., slower than ideal changes in temperature or pressure, longer than ideal reaction times for valves or moving parts, different moments within a maintenance cycle or the life-cycle of a consumable, etc.).

4.1.26 *theoretical production time* (time) — production time during a period that is theoretically required to complete the unit quantities of the production recipes undertaken during the period. Theoretical production time is computed as the aggregation over all recipes of the theoretical production time per unit for the recipe applied to the unit quantity of that recipe (CSM 21, CSM 42). For flexible-sequence cluster tools, theoretical production time is the sum of the theoretical production times for the set of virtual machines.

4.1.27 *theoretical unit throughput by recipe* (units per time) — for a given production recipe, the number of units per period of time that theoretically could be processed by the equipment. For each recipe, theoretical unit throughput is equal to the reciprocal of theoretical production time per unit.

4.1.28 *total time* (time) — all time (at the rate of 24 hours per day, seven days per week) during the period being measured. In order to have a valid representation of *total time* all six basic equipment states shall be accounted for and tracked accurately (SEMI E10). For a flexible-sequence cluster tool, total time is defined as the aggregate total time of the set of virtual machines encompassed by the cluster tool (CSM 42).

4.1.29 *unit* — any wafer, die, packaged device, or piece part thereof (includes product and non-product units) (SEMI E10).

4.1.30 *uptime (equipment uptime)* (time) — the time when the equipment is in a condition to perform its intended function. It includes *productive, standby, and engineering time*, and does not include any portion of *non-scheduled time* (SEMI E10). For a flexible-sequence cluster tool, uptime is defined as the aggregate uptime of the set of virtual machines encompassed by the cluster tool (CSM 42).

4.1.31 *virtual machine* — an individual processing module within a flexible-sequence cluster tool, in combination with the transport module(s) serving that processing module. A flexible-sequence cluster tool has one virtual machine defined for each of its processing modules (CSM 42).

4.2 *Terminology Applicable to Computation of Additional Productivity Metrics Defined in Appendix 2*

4.2.1 *demand equipment efficiency (DEE)* (time divided by time) — a measure of equipment productivity during the time that products are planned to be available to process at the equipment.

4.2.2 *engineering overall equipment efficiency (E-OEE)* (time divided by time) — a measure of equipment productivity assuming process specifications are optimized for minimum production time.

4.2.3 *engineering theoretical production time per unit (ETHT)* – (time per unit) — the theoretical time required to process a given recipe assuming the recipe specification is optimized for minimum production time. *ETHT* is based on minimum durations for the objective processing steps, e.g., implant time for ion implant systems, plus minimum allowances for any additional supporting process steps, e.g., heating, cooling, gas stabilization, that are deemed absolutely necessary. *ETHT* shall be defined to be less than or equal to the corresponding *theoretical time per unit (THT)* used in calculating *OEE*.

4.2.4 *equipment down no product time* (time) — the period of *equipment downtime* during which there are no units available at the equipment to process.

4.2.5 *intrinsic equipment efficiency (IEE)* (time divided by time) — a measure of equipment productivity that considers the combined effect of rate efficiency losses, recipe design, and equipment design.

4.2.6 *no product time* (time) — the period of *standby time* that the equipment is idle because there are no units available at the equipment to process.

4.2.7 *planned no product time* (time) — the period of *operations time* that the factory model or production schedule expects the equipment to be idle because there are no units available to process at the equipment.

4.2.8 *production equipment efficiency (PEE)* (time divided by time) — a measure of equipment productivity during the time that products are available to process at the tool.

NOTE 3: One application of *PEE* is to measure the productivity of non-constraint tools that are expected to have periods of idle time due to lack of available work.

4.2.9 *reference overall equipment efficiency (R-OEE)* (time divided by time) — a measure of equipment productivity relative to a benchmark theoretical production time.

4.2.10 *reference theoretical production time per unit (RTHT)* (time per unit) — the theoretical time required to process a given recipe on benchmark equipment (i.e., the fastest equipment model of similar type), for a benchmark product and process design. *RTHT* shall be defined to be less than or equal to the corresponding *theoretical time per unit* (*THT*) used in calculating *OEE*.

4.2.11 *value-added in-process overall equipment efficiency (VA-OEE)* (time divided by time) — a measure of equipment productivity assuming all time except the value-added portion of processing cycles is wasted equipment time.

4.2.12 *value-added in-process theoretical production time per unit (VTHT)* (time per unit) — theoretical production time per unit that credits only the objective processing steps that add value to products. *VTHT* shall be defined to be less than or equal to *engineering theoretical production time per unit* (*ETHT*) used in calculating engineering OEE (*E-OEE)*.

## 5 Equipment Productivity Measurement

5.1 The OEE calculation has been stated in terms that are consistent with SEMI E10. Reference may be made to Figure 1.

5.1.1 Figure 2 indicates how total time may be divided into portions representing theoretical production time for effective units and various sources of productivity loss. The domain for productivity improvement of all losses except operational efficiency is shared between the equipment supplier and equipment user. Productivity improvement of operational efficiency is the exclusive domain of the equipment user.

5.1.2 The formulas introduced in this section require as inputs the following fundamental quantities: total time, equipment uptime, production time, and theoretical production time. Sample calculations for each of the formulas are provided in Appendix 1.

5.1.3 For efficiency measurement of individual processing modules or of fixed-sequence cluster tools, the fundamental quantities may be tallied in a straightforward manner, and consequently the formulas of this section may be applied in a straightforward fashion.

5.1.4 For efficiency measurement of flexible-sequence cluster tools, determination of the fundamental quantities requires more involved calculations. Formulas are provided in Section 6 for computing the fundamental quantities for flexible-sequence cluster tools. These fundamental quantities then may be used as inputs to the formulas of this section to compute the efficiency of a flexible-sequence cluster tool.

5.1.5 Additional supplemental efficiency metrics that will enable users to assess more specific aspects of equipment productivity are:

- Reference OEE,
- Engineering OEE,
- Value-Added In-Process OEE,
- Demand Equipment Efficiency,
- Production Equipment Efficiency, and
- Intrinsic Equipment Efficiency.

Definitions and formulas for these metrics are presented in Appendix 2.

5.2 *Overall Equipment Efficiency (OEE)* — The fraction of total time that equipment is producing effective units at theoretically efficient rates.

*Overall Equipment Efficiency (OEE)*
*= (Theoretical Production Time for Effective Units)*
*/(Total Time)*
*= (Availability Efficiency) × (Performance Efficiency)*
*× (Quality Efficiency)*

5.2.1 *Availability Efficiency* — The fraction of total time that the equipment is in a condition to perform its intended function.

*Availability Efficiency =*
*(Equipment Uptime)/(Total Time)*

5.2.2 *Performance Efficiency* — The fraction of equipment uptime that the equipment is processing actual units at theoretically efficient rates.

*Performance Efficiency =*
*(Operational Efficiency) × (Rate Efficiency)*

5.2.2.1 *Operational Efficiency* — The fraction of equipment uptime that the equipment is processing actual units.

*Operational Efficiency =*
*(Production Time)/(Equipment Uptime)*

5.2.2.2 *Rate Efficiency* — The fraction of production time that equipment is processing actual units at theoretically efficient rates.

*Rate Efficiency =*
*= (Theoretical Production Time for Actual Units)*
*/(Production Time)*

5.2.2.3 *Theoretical Production Time (for Actual Units or for Effective Units)* — Production time (for actual units or for effective units) during a period of observation that is earned at strictly theoretically efficient rates and assumes no efficiency losses.

*Theoretical Production Time for Actual Units =*
$\Sigma_i$ *(Actual Units of Recipe i × $THT_i$)*

*Theoretical Production Time for Effective Units =*
$\Sigma_i$ *(Effective Units of Recipe i × $THT_i$)*
*where*

$THT_i$ = *theoretical production time per unit of recipe$_i$*

NOTE 4: Theoretical Production Time (for actual units or for effective units) may be calculated in terms of theoretical unit throughput by recipe.

*Theoretical Production Time for Actual Units =*
$\Sigma_i$ *(Actual Units of Recipe i/$UPH_i$)*

*Theoretical Production Time for Effective Units =*
$\Sigma_i$ *(Effective Units of Recipe i/$UPH_i$)*

*where*

$UPH_i$ = *theoretical unit throughput by recipe of recipe i*

5.2.3 *Quality Efficiency* — The theoretical production time for Effective Units divided by the theoretical production time for Actual Units.

*Quality Efficiency =*
*(Theoretical Production Time for Effective Units)*
*/(Theoretical Production Time for Actual Units)*

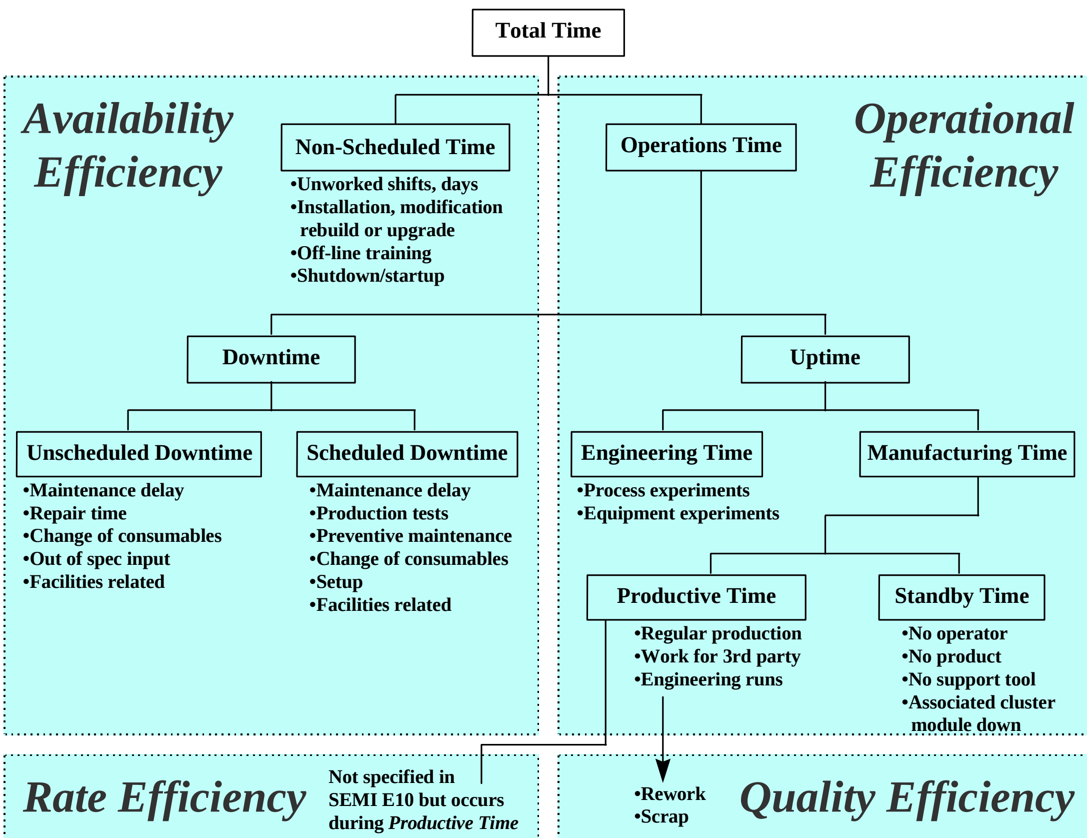


**Figure 1**
**The Relationship Between SEMI E10 and OEE**

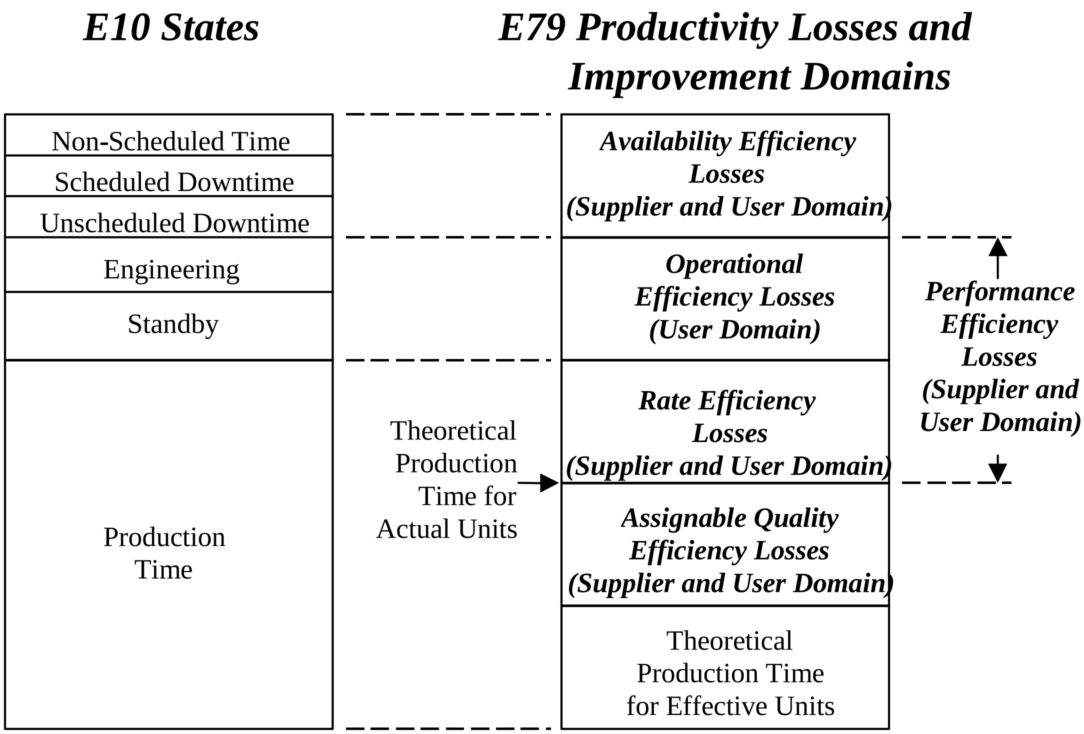


**Figure 2**
**Stack Chart of Productivity Losses and Improvement Domains**

## 6 Flexible-Sequence Cluster Tools

6.1 This section provides definitions and formulas applicable to flexible-sequence cluster tools for computing the following fundamental quantities: theoretical production time, production time, equipment uptime and total time. These quantities serve as inputs to the formulas of Section 5 for efficiency measurement.

6.1.1 Flexible-sequence cluster tool productivity is measured at the individual processing module level of detail according to a virtual machine model described in this section. Productivity performance for the entire flexible-sequence cluster tool is then calculated as the aggregate productivity performance of its individual processing modules.

NOTE 5: Evaluation of flexible-sequence cluster tool productivity does not necessarily apply to the evaluation of flexible-sequence cluster tool RAM.

6.2 *Virtual Machine Model*

6.2.1 A virtual machine is an individual processing module in combination with the transport mechanisms that serve that processing module. When a transport mechanism is engaged in a material handling operation that does not involve a particular processing module, it is not considered to be operating as part of the virtual machine defined for that processing module.

6.2.2 Theoretical production time per unit for a recipe is the sum of theoretical times for all required operational elements:

- Wafer loading,
- Elements occurring within a process module, and
- Wafer unloading.

6.2.2.1 Where appropriate, a combined loading and unloading time may be replaced with a single theoretical value for a *wafer exchange*.

6.3 *Fundamental Quantities for Virtual Machines and Flexible-Sequence Cluster Tools* — This section defines fundamental quantities that are evaluated for individual virtual machines and flexible-sequence cluster tools as inputs to the formulas presented in Section 5. In each case, the fundamental quantity is determined for each individual virtual machine within a flexible-sequence cluster tool. The equivalent fundamental quantity for the flexible-sequence cluster tool is the sum of the quantities for the individual virtual machine.

NOTE 6: It is recognized that application-specific interactions between virtual machines within flexible-sequence cluster tools may impose varying amounts of standby time on the individual virtual machines. This approach treats these interactions as standby losses for the flexible-sequence cluster tool and does not make any allowances for them in either production time or theoretical production time.

6.3.1 *Theoretical Production Time (for Actual Units and for Effective Units)*

6.3.1.1 *Virtual Machine Theoretical Production Time (for Actual Units and for Effective Units)* — Theoretical production time earned by an individual virtual machine according to the virtual machine model.

*Virtual Machine*
*Theoretical Production Time for Actual Units =*
$\Sigma_i$ *[(Theoretical Production Time Per Unit*
*for Virtual Machine Recipe i)*
× *(Actual Units of Virtual Machine Recipe i)]*

*Virtual Machine*
*Theoretical Production Time for Effective Units*
= $\Sigma_i$ *[(Theoretical Production Time Per Unit*
*for Virtual Machine Recipe i)*
× *(Effective Units of Virtual Machine Recipe i)]*

6.3.1.2 *Flexible-Sequence Cluster Tool Theoretical Production Time (for Actual Units and for Effective Units)* — Aggregate theoretical production time earned by all virtual machines according to the virtual machine model.

*Flexible-Sequence Cluster Tool*
*Theoretical Production Time for Actual Units*
= $\Sigma_j$ *(Theoretical Production Time*
*for Actual Units for Virtual Machine j)*

*Flexible-Sequence Cluster Tool*
*Theoretical Production Time for Effective Units*
= $\Sigma_j$ *(Theoretical Production Time*
*for Effective Units for Virtual Machine j)*

6.3.2 *Production Time*

6.3.2.1 *Virtual Machine Production Time* — The sum of all periods of manufacturing time in which a virtual machine is performing operations according to the virtual machine model. When SEMI E10 equipment states are tracked at the virtual machine level, processing module production time is equivalent to *E10 productive time*. Automated tracking is required for accurate results.

6.3.2.2 *Flexible-Sequence Cluster Tool Production Time* — Aggregate production time for all virtual machines tracked according to the virtual machine model.

*Flexible-Sequence Cluster Tool Production Time =*
=$\Sigma_j$*(Production Time for Virtual Machine j)*

NOTE 7: In this quantity, elapsed times for transport operations that reposition units from one virtual machine to another are intentionally credited to both modules. Also note that this aggregate measure may be larger than the elapsed time observed and can only be compared with similar aggregate flexible-sequence cluster tool metrics.

6.3.3 *Equipment Uptime*

6.3.3.1 Equipment uptime is defined to measure the total time, during a period of observation, that a virtual machine or a flexible-sequence cluster tool is in a condition to perform processing in some form.

6.3.3.2 SEMI E10 defines equipment uptime as including E10 productive time, engineering time, and standby time. This definition applies to individual virtual machines of a flexible-sequence cluster tool. For the flexible sequence cluster tool as a whole, production time is the sum of production times for the individual virtual machines. This production time is used in lieu of productive time.

6.3.3.3 *Virtual Machine Equipment Uptime*

*Virtual Machine Equipment Uptime =*
*Virtual Machine Production Time*
*+ Virtual Machine Engineering Time*
*+ Virtual Machine Standby Time*

6.3.3.3.1 *Virtual Machine Engineering Time* — The sum of all periods of time in which a virtual machine is user-selected for the exclusive use of engineering product, process, and/or equipment experiments. Engineering time may be declared for one virtual machine without having to declare engineering time for all virtual machines.

6.3.3.3.2 *Virtual Machine Standby Time* — The sum of all periods of manufacturing time not counted in production time, when the virtual machine is *capable* of starting new work.

6.3.3.4 *Flexible-Sequence Cluster Tool Equipment Uptime*

*Flexible-Sequence Cluster Tool Equipment Uptime =*
$\Sigma_j$ *(Virtual Machine Equipment Uptime*
*for Virtual Machine j)*

6.3.4 *Total Time*

6.3.4.1 *Virtual Machine Total Time* — For individual virtual machines, virtual machine total time is trivially defined as all time observed (at the rate of 24 hours per day and seven days per week).

6.3.4.2 *Flexible-Sequence Cluster Tool Total Time*

*Flexible-Sequence Cluster Tool Total Time =*
$\Sigma_j$*(Virtual Machine Total Time*
*for Virtual Machine j) =*
*(Total Time Observed)* × *(Number of Virtual Machines)*

## 7 Related Reference Material

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# APPENDIX 1
# CALCULATING PRODUCTIVITY METRICS

**NOTICE**: The material in this appendix is an official part of SEMI E79 and was approved by full letter ballot procedures on December 15, 1999 by the North American Regional Standards Committee.

## A1-1 Example Calculations for an Individual Processing Module or a Fixed-Sequence Cluster Tool

A1-1.1 *Sample Data* — The calculations in this section are based on the following sample data. The sample data is for a seven-day period.

| | |
|---|---|
| *Non-Scheduled Time* | *0.00 hours* |
| *Unscheduled Downtime* | *4.00 hours* |
| *Scheduled Downtime* | *8.00 hours* |
| *Engineering Time* | *3.00 hours* |
| *Standby Time* | *6.00 hours* |
| *Production Time* | *147.00 hours* |
| *Total Time* | *168.00 hours* |

| *Recipe* | *Theoretical Production Time Per Unit* | *Theoretical Units Per Hour* | *Actual Units of Recipe* | *Effective Units of Recipe* |
|---|---|---|---|---|
| A | 0.03333 hr/unit | 30.00 units/hr | 1420 | 1400 |
| B | 0.04000 hr/unit | 25.00 units/hr | 600 | 600 |
| C | 0.05000 hr/unit | 20.00 units/hr | 800 | 800 |
| D | 0.06667 hr/unit | 15.00 units/hr | 500 | 480 |

A1-1.2 *Fundamental Quantities*

*Equipment Uptime*
*= (Production Time) + (Standby Time) + (Engineering Time)*
*= (147.00 hours) + (6.00 hours) + (3.00 hours)*
*= 156.00 hours*

*Production Time (given)*

*Theoretical Production Time for Actual Units*
$= \sum_i$ *(Actual Units of Recipe i* $\times$ $THT_i$*)*
*= [(1420 units × 0.03333 hr/unit)*
*+ (600 units × 0.04000 hr/unit)*
*+ (800 units × 0.05000 hr/unit)*
*+ (500 units × 0 .06667 hr/unit)]*
*= 144.66 hours*

*Theoretical Production Time for Effective Units*
$= \sum_i$ *(Effective Units of Recipe i* $\times$ $THT_i$*)*
*= [(1400 units × 0.03333 hr/unit)*
*+ (600 units × 0.04000 hr/unit)*
*+ (800 units × 0.05000 hr/unit)*
*+ (480 units × 0.06667 hr/unit)]*
*= 142.67 hours*

A1-1.3 *Productivity Metrics*

*Availability Efficiency*
*= (Equipment Uptime)/(Total Time)*
*= (156.00 hours)/(168.00 hours)*
*= 0.9286*

*Operational Efficiency*
*= (Production Time)/(Equipment Uptime)*
*= (147.00 hours)/(156.00 hours)*
*= 0.9423*

*Rate Efficiency*
*= (Theoretical Production Time for Actual Units) /(Production Time)*
*= (144.66 hours)/(147.00 hours)*
*= 0.9840*

*Performance Efficiency*
*= (Operational Efficiency) × (Rate Efficiency)*
*= (0.9423) × (0.9840)*
*= 0.9272*

*Quality Efficiency*
*= (Theoretical Production Time for Effective Units) /(Theoretical Production Time for Actual Units)*
*= (142.67 hours)/(144.66 hours)*
*= 0.9862*

*Overall Equipment Efficiency (OEE)*
*= (Theoretical Production Time for Effective Units) /(Total Time)*
*= (142.67 hours)/(168.00 hours)*
*= 0.8492*

## A1-2 Example Calculations for a Flexible-Sequence Cluster Tool

A1-2.1 *Sample Data* — The calculations in this section are based on the following sample data. The sample data is over a seven-day period for a flexible-sequence cluster tool encompassing three virtual machines. This example will calculate the theoretical OEE for the cluster tool without consideration of OEE degrading module interactions.

| | *Virtual Machine A* | *Virtual Machine B* | *Virtual Machine C* |
|---|---|---|---|
| *Non-Scheduled Time* | *0.00 hours* | *0.00 hours* | *0.00 hours* |
| *Unscheduled Downtime* | *5.00 hours* | *5.00 hours* | *0.00 hours* |
| *Scheduled Downtime* | *0.00 hours* | *5.00 hours* | *0.00 hours* |
| *Engineering Time* | *3.00 hours* | *5.00 hours* | *0.00 hours* |
| *Standby Time* | *10.00 hours* | *5.00 hours* | *88.00 hours* |
| *Production Time* | *150.00 hours* | *148.00 hours* | *80.00 hours* |
| *Total Time* | *168.00 hours* | *168.00 hours* | *168.00 hours* |

| *Process Sequence for Flexible-Sequence Cluster Tool* | *Virtual Machine A Recipe* | *Virtual Machine B Recipe* | *Virtual Machine C Recipe* | *Actual Units of Sequence* | *Effective Units of Sequence* |
|---|---|---|---|---|---|
| S1 | R1 | R2 | | 300 | 275 |
| S2 | | R2 | R4 | 100 | 100 |
| S3 | R2 | R3 | | 250 | 240 |
| S4 | | R3 | R4 | 400 | 400 |

| *Virtual Machine Recipe* | *Theoretical Production Time Per Unit ($THT_i$) including Load/Unload Time* |
|---|---|
| R1 | *0.3000 hr/wafer* |
| R2 | *0.2000 hr/wafer* |
| R3 | *0.1000 hr/wafer* |
| R4 | *0.1500 hr/wafer* |

A1-2.2 *Fundamental Quantities*

*Virtual Machine Theoretical Production Time for Actual Units*

$= \sum_i$ *(Actual Units of Recipe i* $\times$ $THT_i$*)*

| *Sequence* | *Actual Units* | *Virtual Machine A* | *Virtual Machine B* | *Virtual Machine C* |
|---|---|---|---|---|
| S1 | 300 | *300 units × 0.3000 hr/unit* | *300 units × 0.2000 hr/unit* | |
| S2 | 100 | | *100 units × 0.2000 hr/unit* | *100 units × 0.1500 hr/unit* |
| S3 | 250 | *250 units × 0.2000 hr/unit* | *250 units × 0.1000 hr/unit* | |
| S4 | 400 | | *400 units × 0.1000 hr/unit* | *400 units × 0.1500 hr/unit* |
| *Virtual Machine Theoretical Production Time for Actual Units =* | | *Σ = 140.00 hours* | *Σ = 145.00 hours* | *Σ = 75.00 hours* |

*Flexible-Sequence Cluster Tool Theoretical Production Time for Actual Units*

*= $\sum_j$ (Theoretical Production Time for Actual Units for Virtual Machine j)*

*= (140.00 hours) + (145.00 hours) + (75.00 hours)*

*= 360.00 hours*

*Virtual Machine Theoretical Production Time for Effective Units*
*= $\sum_i$ (Effective Units of Recipe i × $THT_i$ )*

| Sequence | Effective Units | Virtual Machine A | VirtualMachine B | Virtual Machine C |
|---|---|---|---|---|
| S1 | 275 | *275 units × 0.3000 hr/unit* | *275 units × 0.2000 hr/unit* | |
| S2 | 100 | | *100 units × 0.2000 hr/unit* | *100 units × 0.1500 hr/unit* |
| S3 | 240 | *240 units × 0.2000 hr/unit* | *240 units × 0.1000 hr/unit* | |
| S4 | 400 | | *400 units × 0.1000 hr/unit* | *400 units × 0.1500 hr/unit* |
| *Virtual Machine Theoretical Production Time for Actual Units =* | | *Σ = 130.50 hours* | *Σ = 139.00 hours* | *Σ = 75.00 hours* |

*Flexible-Sequence Cluster Tool Theoretical Production Time for Effective Units*
*= $\sum_j$ (Theoretical Production Time for Effective Units for Virtual Machine j)*
*= (130.50 hours) + (139.00 hours) + (75.00 hours) = 344.50 hours*

*Virtual Machine Production Time (given)*

*Flexible-Sequence Cluster Tool Production Time*
*= $\sum_j$ (Production Time for Virtual Machine i)*
*= (150.00 hours) + (148.00 hours) + (80.00 hours) = 378.00 hours*

*Virtual Machine Equipment Uptime*
*= (Virtual Machine Production Time) + (Virtual Machine Standby Time)*
*+ (Virtual Machine Engineering Time)*

| | Virtual Machine A | Virtual Machine B | Virtual Machine C |
|---|---|---|---|
| *Engineering Time* | *3.00 hours* | *5.00 hours* | *0.00 hours* |
| *Standby Time* | *10.00 hours* | *5.00 hours* | *88.00 hours* |
| *Production Time* | *+150.00 hours* | *+148.00 hours* | *+80.00 hours* |
| *Equipment Uptime* | *163.00 hours* | *158.00 hours* | *168.00 hours* |

*Flexible-Sequence Cluster Tool Equipment Uptime = $\sum_j$ (Equipment Uptime for Virtual Machine j)*
*= (163.00 hours) + (158.00 hours) + (168.00 hours) = 489.00 hours*

*Virtual Machine Total Time (given)*

*Flexible-Sequence Cluster Tool Total Time = (Number of Virtual Machines) × (Total Time Observed)*
*= (3 Virtual Machines) × (168 hours) = 504 hours*

### A1-2.3 *Productivity Metrics*

*Virtual Machine Availability Efficiency = (Virtual Machine Equipment Uptime)/(Total Time)*

| Virtual Machine A | Virtual Machine B | Virtual Machine C |
|---|---|---|
| *= (163.00 hours)/(168.00 hours)* | *= (158.00 hours)/(168.00 hours)* | *= (168.00 hours)/(168.00 hours)* |
| *= 0.9702* | *= 0.9405* | *= 1.000* |

*Flexible-Sequence Cluster Tool Availability Efficiency*
*= (Flexible-Sequence Cluster Tool Equipment Uptime)/(Flexible-Sequence Cluster Tool Total Time)*
*= (489.00 hours)/(504.00 hours)*
*= 0.9702*

*Virtual Machine Operational Efficiency*
*= (Virtual Machine Production Time) ÷ (Virtual Machine Equipment Uptime)*

| Virtual Machine A | Virtual Machine B | Virtual Machine C |
|---|---|---|
| *= (150.00 hours)/(163.00 hours)* | *= (148.00 hours)/(158.00 hours)* | *= (80.00 hours)/(168.00 hours)* |
| *= 0.9202* | *= 0.9367* | *= 0.4762* |

*Flexible-Sequence Cluster Tool Operational Efficiency*
*= (Flexible-Sequence Cluster Tool Production Time)/(Flexible-Sequence Cluster Tool Equipment Uptime)*
*= (378.00 hours)/(489.00 hours)*
*= 0.7730*

*Virtual Machine Rate Efficiency*
*= (Virtual Machine Theoretical Production Time for Actual Units)/(Virtual Machine Production Time)*

| Virtual Machine A | Virtual Machine B | Virtual Machine C |
|---|---|---|
| = (140.00 hours)/(150.00 hours) | = (145.00 hours)/(148.00 hours) | = (75.00 hours)/(80.00 hours) |
| = 0.9333 | = 0.9797 | = 0.9375 |

*Flexible-Sequence Cluster Tool Rate Efficiency*
*= (Flexible-Sequence Cluster Tool Theoretical Production Time for Actual Units)*
*/(Flexible-Sequence Cluster Tool Production Time)*
*= (360.00 hours)/(378.00 hours)*
*= 0.9524*

*Virtual Machine Quality Efficiency*
*= (Virtual Machine Theoretical Production Time for Effective Units)*
*/(Virtual Machine Theoretical Production Time for Actual Units)*

| Virtual Machine A | Virtual Machine B | Virtual Machine C |
|---|---|---|
| = (130.50 hours)/(140.00 hours) | = (139.00 hours)/(145.00 hours) | = (75.00 hours)/(75.00 hours) |
| = 0.9321 | = 0.9586 | = 1.0000 |

*Flexible-Sequence Cluster Tool Quality Efficiency*
*=(Flexible-Sequence Cluster Tool Theoretical Production Time for Effective Units)*
*/(Flexible-Sequence Cluster Tool Theoretical Production Time for Actual Units)*
*= (344.50 hours)/(360.00 hours)*
*= 0.9569*

*Virtual Machine Overall Equipment Efficiency (OEE)*
*= (Virtual Machine Theoretical Production Time for Effective Units)/(Virtual Machine Total Time)*

| Virtual Machine A | Virtual Machine B | Virtual Machine C |
|---|---|---|
| = (130.5 hours)/(168.00 hours) | = (139.00 hours)/(168.00 hours) | = (75.00 hours)/(168.00 hours) |
| = 0.7768 | = 0.8274 | = 0.4464 |

*Flexible-Sequence Cluster Tool Overall Equipment Efficiency (OEE)*
*=(Flexible-Sequence Cluster Tool Theoretical Production Time for Effective Units)*
*/(Flexible-Sequence Cluster Tool Total Time)*
*= (344.50 hours)/(504.00 hours)*
*= 0.6835*

# APPENDIX 2
# SUPPLEMENTAL PRODUCTIVITY METRICS FOR FOCUSED PRODUCTIVITY STUDIES

**NOTICE**: The material in this appendix is an official part of SEMI E79 and was approved by full letter ballot procedures on December 15, 1999 by the North American Regional Standards Committee.

### A2-1 Supplemental Productivity Metrics with Total Time as the Denominator

A2-1.1 OEE is based on "as-is" assumptions with respect to process specifications (recipes), equipment type, and equipment design. In this way, OEE measures the performance of the organizations of the manufacturer and the equipment supplier as they attempt to drive equipment performance to a potential defined by given process specifications and a given equipment type and design.

A2-1.2 This section presents three variations on the OEE calculation that additionally measure the performance of engineering and design organizations as they attempt to improve equipment selection, process specifications and equipment design. These three variants are each based on more discriminating definitions of the theoretical production time per unit, as shown in Figure A2-1. Total time is the denominator for each metric.

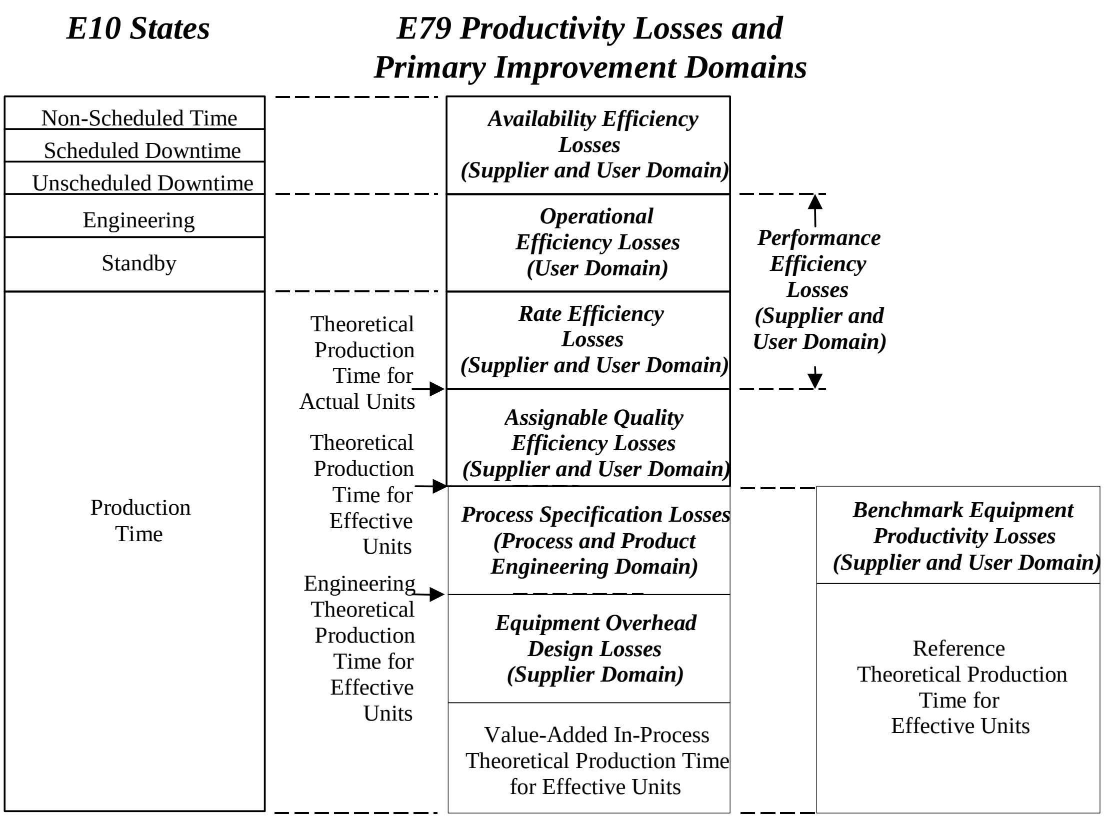


**Figure A2-1**
**Incompatibility of R-OEE with E-OEE and VA-OEE**
**(Data for sample calculations are given on the following page.)**

*Operations Time = 168 hours*
*Theoretical Production Time*
*for Effective Units = 146 hours*
*No Product Time = 6 hours*
*Equipment Unavailable No Product Time = 4 hours*
*Planned No Product Time = 8 hours*

| *Recipe* | *Theoretical Production Time Per Unit ($THT_i$)* | *Reference Theoretical Production Time Per Unit ($RTHT_i$)* | *Engineering Theoretical Production Time Per Unit ($ETHT_i$)* | *Value-Added In-Process Theoretical Production Time Per Unit ($VTHT_i$)* | *Actual Units of Recipe* | *Effective Units of Recipe* |
|---|---|---|---|---|---|---|
| A | 0.03333 hr/unit | 0.03333 hr/unit | 0.02500 hr/unit | 0.01000 hr/unit | 1500 | 1500 |
| B | 0.04000 hr/unit | 0.03333 hr/unit | 0.02000 hr/unit | 0.00500 hr/unit | 600 | 600 |
| C | 0.05000 hr/unit | 0.03333 hr/unit | 0.01500 hr/unit | 0.00500 hr/unit | 800 | 800 |
| D | 0.06667 hr/unit | 0.03333 hr/unit | 0.03250 hr/unit | 0.01000 hr/unit | 500 | 480 |

### A2-1.3 *Reference OEE (R-OEE)*

A2-1.3.1 Reference OEE provides a measure of equipment productivity relative to a benchmark theoretical production time. The reference theoretical production time per unit for a given recipe is the time required by the benchmark equipment (i.e., the fastest equipment model of similar type), running the comparable recipe for a benchmark product and process design. Reference theoretical production time per unit (RTHT) shall be defined to be less than or equal to theoretical time per unit (THT) used in calculating standard OEE. The *R-OEE* score may be compared against the standard *OEE* score to assess the productivity loss arising from the application of inferior equipment.

$$\text{Reference OEE (R-OEE)} = [\textstyle\sum_i (\text{Effective Units of Recipe } i \times RTHT_i)] / (\text{Total Time})$$

*where $RTHT_i$* = reference theoretical production time per unit of recipe *i* (based on the benchmark equipment performing a comparable recipe for a benchmark product and process design). Reference OEE utilizes an incompatible definition of theoretical production time for effective units compared to that utilized in Engineering OEE and Value-Added In-Process OEE. Productivity losses indicated by R-OEE and by E-OEE and VA-OEE may overlap. (See Figure A2-1.)

A2-1.3.2 *Sample Reference OEE (R-OEE) Calculation*

*Reference OEE (R-OEE)*
$= [\sum_i (\text{Effective Units of Recipe } i \times RTHT_i)] / (\text{Total Time})$
$= [(1500 \text{ units} \times 0.03333 \text{ hr/unit})$
$+ (600 \text{ units} \times 0.03333 \text{ hr/unit})$
$+ (800 \text{ units} \times 0.03333 \text{ hr/unit})$
$+ (480 \text{ units} \times 0.03333 \text{ hr/unit})] / (168.00 \text{ hours})$
$= 0.6706$

### A2-1.4 *Engineering OEE (E-OEE)*

A2-1.4.1 Engineering OEE provides a measure of equipment productivity assuming process specifications are optimized for minimum production time. Engineering theoretical production time per unit (ETHT) shall be defined to be less than or equal to theoretical time per unit (THT) used in calculating standard OEE. Engineering theoretical production time per unit may include minimum durations for the objective processing steps, e.g., implant time for ion implant systems, and minimum allowances for any additional supporting process steps, e.g., heating, cooling, gas stabilization, only if those steps are deemed absolutely necessary. Time to perform test wafers, sample wafers, send-aheads, clean cycles, seasoning cycles, and allowances for non-continuous cascading of lots through tools are to be specifically excluded.

$$\text{Engineering OEE (E-OEE)} = [\textstyle\sum_i (\text{Effective Units of Recipe } i \times ETHT_i)] / (\text{Total Time})$$

where $ETHT_i$ = engineering theoretical production time per unit of recipe *i*.

A2-1.4.2 *Sample Engineering OEE (E-OEE) Calculation*

*Engineering OEE (E-OEE)*
$= [\sum_i (\text{Effective Units of Recipe } i \times ETHT_i)] / (\text{Total Time})$
$= [(1500 \text{ units} \times 0.02500 \text{ hr/unit})$
$+ (600 \text{ units} \times 0.02000 \text{ hr/unit})$
$+ (800 \text{ units} \times 0.01500 \text{ hr/unit})$
$+ (480 \text{ units} \times 0.03250 \text{ hr/unit})] / (168 \text{ hours})$
$= 0.4589$

### A2-1.5 *Value-added In-Process OEE (VA-OEE)*

A2-1.5.1 Value-added In-Process OEE provides a measure of equipment productivity assuming the non-value-added portion of processing cycles is wasted equipment time. The non-value-added time should be the focus of efforts by the equipment supplier to reduce or eliminate it through improved equipment design. Value-added In-Process theoretical production time per unit (*VTHT*) shall be defined to be less than or equal to engineering theoretical production time per unit (*ETHT*) used in calculating engineering E-OEE (OEE).

$$\text{Value-Added In-Process OEE (VA-OEE)} = [\textstyle\sum_i (\text{Effective Units of Recipe } i \times VTHT_i)] / (\text{Total Time})$$

where $VTHT_i$ = value-added in-process theoretical production time per unit of recipe *i*.

A2-1.5.2 Value-added in-process theoretical production time per unit credits time only for the objective processing steps. The objective processing steps for recipes performed by major types of wafer fabrication equipment are indicated in Table A2-1.

A2-1.5.3 Value-added in-process theoretical production time per unit specifically excludes the following items (partial list):

- All wafer handling time,
- All load-lock time,
- Pre-etch and pre-deposition time,
- Thermal stabilization time,
- Gas stabilization time,
- Wafer heating and cooling time,
- Time for clean cycles, and
- High-etch and seasoning time.

A2-1.5.4 *Sample Value-Added In-Process OEE (VA-OEE) Calculation*

$$\begin{aligned}\text{Value-added In-Process OEE (VA-OEE)} &= [\textstyle\sum_i (\text{Effective Units of Recipe } i \times VTHT_i)] / (\text{Total Time}) \\ &= [(1500 \text{ units} \times 0.01000 \text{ hr/unit}) \\ &\quad + (600 \text{ units} \times 0.00500 \text{ hr/unit}) \\ &\quad + (800 \text{ units} \times 0.01000 \text{ hr/unit}) \\ &\quad + (480 \text{ units} \times 0.0050 \text{ hr/unit})] / (168 \text{ hours}) \\ &= 0.1690\end{aligned}$$

**Table A2-1 Identification of Objective Process Steps for Value-Added In-Process Theoretical Time Per Unit**

| *Equipment Type* | *$VTHT_i$ Includes* | *$VTHT_i$ Excludes* |
|---|---|---|
| Resist Processing | Coat, Develop, Bake, Cool Time at Process Temperature | Temp. Ramp Up/Down |
| Photolithography Exposure | Exposure Time | Pre-Alignment, Align, Stepping Time |
| Etch, Oxide, Metal, Poly | Flood Expose Time | Chamber Clean Time |
| Asher, Dry | Ashing Time | |
| Clean Wet Processing Station | Acid, Rinse and Dry Time | Robot Transport Time |
| Furnace Atmospheric Process, Furnace LPCVD Process, and Rapid Thermal Processing | Main Oxidation, Anneal Time at Defined Fixed Process Temperatures Resulting in Thermal (Film) Treatment | Ramp Up/Down, Boat Push/Pull |
| Implanter HC, MC, HE … | Implant Time | Beam Setup Time |
| Metal Deposition - PVD, CVD | Metal Deposition Time | Chambers Clean Time |
| Dielectric - CVD | Dielectric Deposition Time | Chambers Clean Time |
| CMP Planarization | Polishing Time | Pad Dressing Dedicated Time |
| Measure CD SEM | Measurement Time | Pattern Recognition Time |
| Measure Overlay | Measurement Time | Pattern Recognition Time |
| Defect Detection Patterned Wafers | Scanning Measurement Time | Pattern Recognition Time |
| Defect Detection Unpatterned Wafers | Scanning Measurement Time | |
| Measure Film Thickness | Measurement Time | Pattern Recognition Time |

## A2-2 Additional Productivity Metrics Involving Denominators Other Than Total Time

A2-2.1 This section presents three productivity metrics for assessing efficiency of the equipment resource relative to a time frame less than total time.

A2-2.2 *Production Equipment Efficiency* and *Demand Equipment Efficiency* exclude portions of *no product time* from productivity losses, as depicted in Figure A2-2. While the idle time due to no product is excluded from the operational losses in these particular measures of equipment efficiency, the user should be aware that the additional productivity losses due to sub-optimal load or batch sizes may also be present as rate efficiency losses. Such losses, which result from fluctuations in product flow or tool loading policies, are considered in any equipment efficiency calculation that uses theoretical time per unit.

A2-2.3 *Production Equipment Efficiency (PEE)* — A measure of equipment productivity during the time that work is available to process at the tool. One application of *PEE* is to measure the productivity of non-constraint tools, which are expected to have periods of idle time due to lack of available work.

*Production Equipment Efficiency (PEE)*
*= (Theoretical Production Time for Effective Units)*
*/[(Operations Time) - (No Product Time)*
*- (Equipment Down No Product Time)]*

*= Overall Equipment Efficiency × Total Time*
*/[(Operations Time) - (No Product Time)*
*- (Equipment DownNo Product Time)]*

A2-2.3.1 *Sample Production Equipment Efficiency (PEE) Calculation*

*Production Equipment Efficiency (PEE)*
*= (146 hours)/[(168 hours) - (6 hours) - (4 hours)]*
*= 0.9241*

A2-2.4 *Demand Equipment Efficiency* (DEE) — A measure of equipment productivity during the time that work is planned to be available to process at the equipment. A factory model or production schedule that defines the expected or planned idle time at the equipment is required to calculate *Demand Equipment Efficiency*. *DEE* measures the productivity of the equipment relative to the requirements of the factory model or production schedule.

*Demand Equipment Efficiency (DEE)*
*= (Theoretical Production Time for Effective Units)*
*/[(Operations Time) - (Planned No Product Time)]*

*= Overall Equipment Efficiency × Total Time*
*/[(Operations Time) - (Planned No Product Time)]*

A2-2.4.1 *Sample Demand Equipment Efficiency (DEE) Calculation*

*Demand Equipment Efficiency (DEE)*
*= (146 hours)/[(168 hours) - (8 hours)]*
*= 0.9125*

A2-2.5 *Intrinsic Equipment Efficiency (IEE)* — A measure of equipment productivity that compares value-added, in-process theoretical production time to the actual production time. IEE measures the combined productivity losses due to rate efficiency losses, recipe design, and equipment design.

*Intrinsic Equipment Efficiency (IEE)*
$= [\sum_i (\text{Actual Units of Recipe } i \times VTHT_i)]$
*/(Production Time)*

where $VTHT_i$ = value-added in-process theoretical production time per unit for recipe *i*. See Section A2-1.3.

A2-2.5.1 *Sample Intrinsic Equipment Efficiency (IEE) Calculation*

*Production Time = 155.00 hours*

*Intrinsic Equipment Efficiency (IEE)*
$= [\sum_i (\text{Actual Units of Recipe } i \times VTHT_i)]$
*/(Production Time)*
*= [(1500 units × 0.01000 hr/unit)*
*+ (600 units × 0.00500 hr/unit)*
*+ (800 units × 0.01000 hr/unit)*
*+ (500 units × 0.0050 hr/unit)]/(155 hours)*
*= 0.1839*

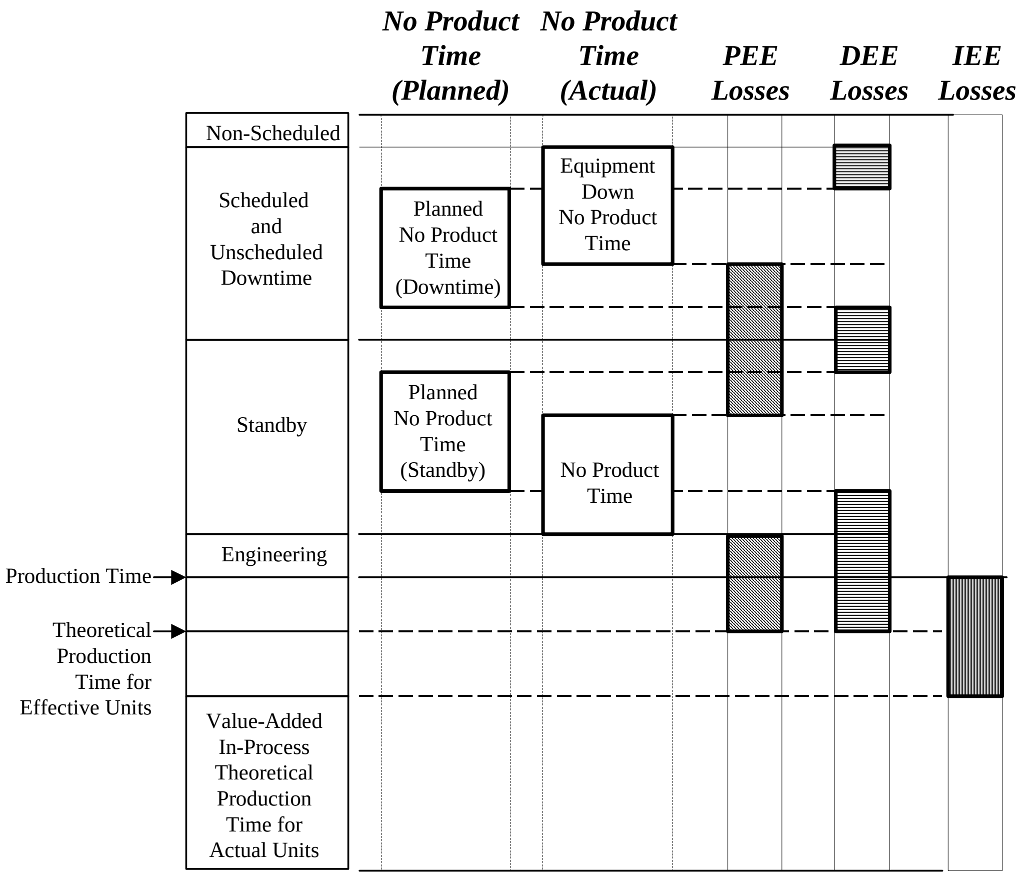


**Figure A2-2**
**Productivity Losses Included in PEE and DEE, and IEE Metrics (shaded regions)**

**NOTICE:** SEMI makes no warranties or representations as to the suitability of the standard set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature respecting any materials mentioned herein. These standards are subject to change without notice.

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# RELATED INFORMATION 1
# GUIDELINES FOR DETERMINING THEORETICAL PRODUCTION TIME PER UNIT

**NOTICE**: This related information is not an official part of SEMI E79. This related information was approved for publication by vote of the responsible committee on December 15, 1999.

## R1-1 Background

R1-1.1 Overall Equipment Efficiency (OEE) is computed in terms of the theoretical production time per unit for each recipe performed. This theoretical time per unit is based on the actual recipe, the actual equipment design in use, and an assumed load size that optimizes equipment throughput (expressed in units of output per hour) for that recipe.

R1-1.2 OEE is intended to express the true efficiency of the equipment resource. A score of 50% OEE indicates that exactly half of the maximum productive potential of the equipment resource is being realized; a score of 100% indicates that no further increase in productivity is feasible, taking the existing process recipes and equipment design as given.

R1-1.3 To accurately calculate OEE in turn requires that theoretical production times per unit be accurately defined. In particular, theoretical production times per unit shall be defined so that the speed losses are always non-negative, i.e.,

$$\begin{aligned}&\textit{Speed Losses}\\&= \textit{(Production Time) - (Theoretical Production Time for Actual Units)} \geq 0\end{aligned}$$

R1-1.4 According to now-classical industrial engineering practice, standards for ideal performance are determined by application of the following:

- Break work methods down into their *operational elements* (hereafter simply referred to as *elements)*.
- Study each of these elements separately to determine its ideal duration.
- Design a new ideal method offering the shortest sequence of only the necessary elements (where the term “sequence” as used herein may involve parallel performance of some or all elements).

R1-1.5 It is remarked that even when the durations of all elements are ideal, if the sequence of elements is not ideal, ideal overall performance cannot be achieved. Based on this understanding, theoretical processing time for an equipment recipe shall be based on both an ideal element sequence as well as ideal durations for all elements.

## R1-2 Modeling Operational Element Sequences

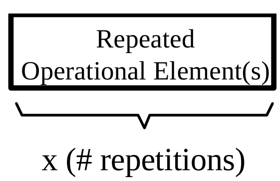
R1-2.1 A graphical model of the sequence of operational elements comprising the performance of an equipment recipe can be helpful for determining theoretical production time per unit. This model has the following components:

R1-2.2 *Resource Utilization Chart* — a Gantt chart displaying a separate timeline for each primary resource within the equipment. Utilization sequences displayed for each primary resource may be used to show how each resource within an equipment system is utilized, and how resources may interact.

R1-2.3 *Operational Element* — An operational element occurring within a utilization sequence is depicted by a box-shaped bar with a label. The time for this element to execute may be fixed, recipe-dependent, or calculated from parameters. Operational elements that are not related to material handling operations have a thick outline.


R1-2.3.1 Material handling elements have a thin outline.


R1-2.4 *Repeated Groups* — A bracket underneath a group of operational elements indicates that the group repeats multiple times based on the parameter shown. For elements that occur conditionally, the number of repetitions may be zero. These repetitions apply to all elements in all timelines positioned in the vertical range of the bracket.




R1-2.5 *Sub-Sequences* — A number in front of an element label indicates that the element represents a group of elements defined elsewhere. This group is referred to as a sub-sequence.

| 1.1 Sub-Sequence Operational Element |
|---|

R1-2.6 *Calculating Theoretical Production Time Per Unit* — Any element sequence may be modeled as an activity-on-node network derived from precedence constraints on the operational elements and precedence constraints on the allocation of equipment resources to the elements. Using the network model, the duration of the element sequence is simply the duration of the critical path through the network.

R1-2.6.1 Theoretical production time per unit is then the theoretical duration for the element sequence divided by the number of units processed during the sequence.

*Theoretical Production Time Per Unit for recipe i [THT$_i$] =*
*= (Theoretical Duration for the Element Sequence)*
*/(Number of Units Processed During Sequence)*

R1-2.7 *Allowances for Non-Steady-State Processing* — For complicated batch-load equipment models, it is useful to divide resource sequences into a beginning phase, a steady-state-phase, and an ending phase. For modeling theoretical time, it is important to determine what allowances to make, if any, for the beginning and ending phases. For machines that are limited in the number of lots that can be processed in a continuous cascade, appropriate allowances shall be made for beginning and ending phases. However, for machines that are capable of running continuously, the beginning and ending phases should not be considered in determining theoretical production time.

R1-2.7.1 Under certain conditions, setup type operations that are not tracked as part of downtime shall be considered as part of the theoretical resource sequence for a tool. These conditions include operations that shall occur in every machine cycle, e.g. recipe download, as well as operations that occur on other regular intervals, e.g., one clean cycle every 75 wafers. In general, any activity that occurs on predictable intervals and is a necessary part of a recipe specification should be considered in the equipment sequence for determining theoretical production time.

R1-2.7.2 Operations that occur at irregular intervals or that apply to an unpredictable quantity of wafers, lots, or loads are not counted. An example of an unpredictable frequency setup is a recipe changeover, when the machine is changed from the requirements of one process recipe to meet the needs of another, e.g., a species change as on an ion implant system. The ideal frequency of these events is taken as zero.

R1-2.8 *Optimality* — Theoretical sequences shall be designed so as to optimize equipment throughput by using only the best configuration of elements and an optimal load size. Optimal sequences may differ for different recipes performed on the same machine. Optimal load sizes are not necessarily maximum load sizes.

R1-2.9 *Error-Checking Element Sequences* — Once a theoretical sequence is specified for a piece of equipment, it can be compared against actual equipment operations to check for errors. If discrepancies are found, three possibilities to investigate are:

- The sequence contains extraneous elements.
- The sequence is missing necessary elements.
- The series and parallel relationships between elements are not correctly specified.

R1-2.9.1 What may at first appear to be sequence specification errors may in fact be undiscovered rate efficiency losses embedded in the equipment sequence. Because sequences are fundamental to overall performance, it is important to rule out sequence specification errors to preclude erroneous assignment of rate efficiency losses to individual elements.

R1-2.10 *Example Resource Utilization Sequence* — An example of a resource utilization sequence is given in Figure R1-1. This example represents a particular instance of a photolithography stepper that exposes patterns from a reticle onto a wafer. This example assumes that the stepper receives individual unexposed wafers from a linked coat track and transfers individual exposed wafers to a linked develop track.

R1-2.10.1 First, a reticle box shall be loaded into the stepper reticle handling system (“load box”). Before a wafer may be exposed, the reticle shall be set and aligned. A wafer shall also be loaded onto the pre-align chuck, pre-aligned, and transferred to the exposure stage. Each wafer is exposed then transferred to a post processing relay chuck. The transfer operation simultaneously removes an exposed wafer and replaces it with an unexposed wafer.

R1-2.10.2 The expose operation is represented by the sub-sequence shown in Figure R1-2. Depending on the recipe to be executed, the expose sub-sequence may consist of several different reticle images requiring changes of “blade” positioning. For each image, there is one “align” operation. For each individual exposure, there is a “step” operation, a “level” operation, and the “expose” operation itself. Within the same image, different exposures may require different leveling times, as well as different stepping times.

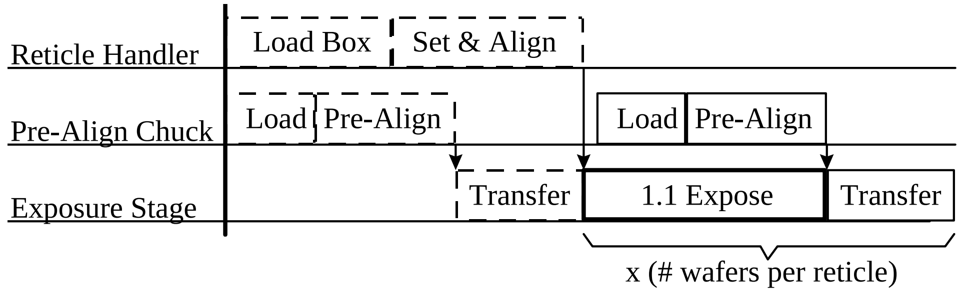



**Figure R1-1**
**Example Resource Utilization Sequence**

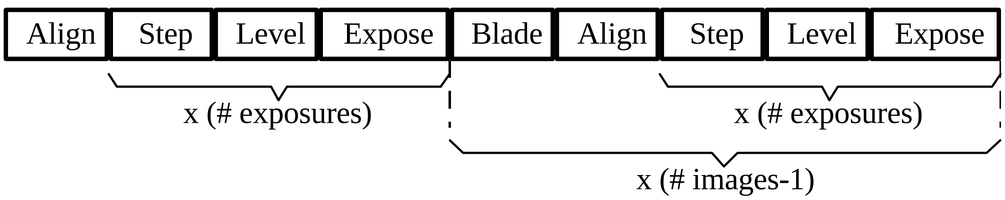



**Figure R1-2**
**Example of Equipment Sub-Sequence**

R1-2.10.3 The operations indicated by dashed boxes represent the beginning phase of the main equipment sequence. If the stepper is capable of processing wafers of the same reticle indefinitely, then the beginning phase is not included in theoretical production time. If, however, there is a hardware and/or software limit to the number of wafers that may be run consecutively, then the beginning phase shall be counted in theoretical production time.

## R1-3 Modeling Theoretical Durations for Operational Elements

R1-3.1 Once a theoretical equipment sequence is defined, the next step is to measure and/or model theoretical durations for each operational element in the sequence. As a rule, it is preferable to acknowledge in the model an elemental speed loss that can never be recovered in lieu of inadvertently overlooking another loss that could be reduced or eliminated.

R1-3.2 *Legitimate Observations* — Each theoretical element duration should always be less than or equal to any *legitimate observation* for that element, where a legitimate observation is a traceable instance of an operational element that does not result in a loss of quality. The time for any legitimate observation that is less than the existing theoretical element duration should become the new theoretical element duration. For legitimate instances of the same operational element on different instances of identically configured equipment, the best time observed among all equipment of that type should be used as the theoretical element duration.

R1-3.3 *Basis for Theoretical Element Durations* — Theoretical element durations may be based on time studies, nominal parameters, and/or parametric modeling.

R1-3.3.1 *Time Studies* — Most mechanical operational elements that have fixed execution times, like transport and load lock operations, can be accurately determined by time studies using either stopwatches, equipment data acquisition systems, timing systems built into the equipment, or stand-alone data acquisition systems that use sensors to detect equipment events and/or state changes.

R1-3.3.1.1 When it is difficult to directly measure individual elements, collections of elements may be observed and timed instead. On systems where a number of consecutive identical elements occur too fast to be measured individually, a set of elements should be timed, and the time should be divided by the number of elements in the set. For even more complicated situations, element times may be derived algebraically from observations of several linearly independent sets of operational elements.

R1-3.3.2 *Nominal Parameters* — There are instances where it is desirable to use nominal parameters to represent theoretical conditions rather than using direct observations, such as when:

- Nominal parameters are more representative of the physical systems being studied.
- Nominal parameters are more representative of the desired system performance.
- It is not practical to obtain reliable data.

R1-3.3.3 *Parametric Models* — For cases where the time for an operational element may have a range of values that are dependent on recipe specifications, theoretical time is best represented by a parametric model. Parametric models for representing semiconductor operations may be based on mathematical formulas, e.g., implant time versus beam current, and/or "lookup" tables, e.g., best observed etch time vs. etch end point.

R1-3.3.3.1 For the photolithography example, one of the recipe parameters is the exposure energy (EE). Given the ideal or theoretical lamp intensity (LI) of the stepper, the theoretical duration per exposure ($THT_{EX}$) for the recipe may be calculated as $THT_{EX} = EE / LI$ .

# RELATED INFORMATION 2
# RAPID CHARACTERIZATION OF INTRINSIC EQUIPMENT EFFICIENCY (IEE) AND THE PRODUCTIVITY EFFICIENCY PLANE

**NOTICE**: This related information is not an official part of SEMI E79. This related information was approved for publication by vote of the responsible committee on December 15, 1999.

## R2-1 Rapid Characterization of Intrinsic Equipment Efficiency

R2-1.1 IEE may be rapidly characterized as follows using a limited number of production experiments.

R2-1.2 *Step 1: Design Production Experiments* — Select a limited number of scenarios to execute as equipment experiments. It may be of interest to characterize IEE according to either operating modes, processing diversity, or a combination of operating modes and process diversity.

R2-1.2.1 Determine the value-added in-process theoretical production time per unit (VTHT) – (time per unit) for all recipes involved. This information is required for determining IEE. See Table A2-1.

R2-1.2.2 For assessment of operating modes, experiments should examine only a single typical recipe that is likely to be used most frequently. Each experiment should examine a separate operating mode, where examples of various equipment operational modes may be as follows:

One wafer at a time mode (production monitor wafer).

One batch is run, then the tool stops.

Two batches are run, then the tool stops.

Three batches are run, then the tool stops.

Continuous (cascade) mode. A larger number of batches is run, then the tool stops.

R2-1.2.3 For assessment of process diversity, select a limited number of representative recipes that will be processed by a tool. This population should include at least one recipe representing the minimum expected processing duration and one representing the maximum.

R2-1.2.4 Each experiment should be designed and executed to eliminate rate efficiency losses to the greatest extent possible. It is further assumed that quality efficiency losses are zero. Under this approximation, (VA-OEE) = (OEE) × (IEE).

R2-1.3 *Step 2: Execute Process Experiments* — Perform process experiments recording all relevant input variables including the configuration of lots and wafers, and recipes. For each experiment, record the elapsed production time using convenient means, e.g., stopwatch or existing data acquisition system.

R2-1.4 *Step 3: Calculate Results* — Calculate IEE and throughput for each experiment. IEE may be used to measure the effect of *non-value-added overhead time* during equipment processing. Approximately:

*Intrinsic Equipment Efficiency (IEE)*
*= (Value-Added In-Process Theoretical Time)*
*/(Non-Value-Added Overhead Time*
*+ Value-Added In-Process Theoretical Time)*

R2-1.4.1 Hence, *non-value-added overhead time* for each experiment may be calculated as:

*Non-Value-Added Overhead Time*
*= [(Production Time)*
*- ( Value-Added In-Process Theoretical Time)]*

R2-1.4.2 It should be the focus of efforts by the equipment supplier and the end-user to reduce or eliminate non-value-added overhead time through improved equipment design, including scheduling software, as well as hardware components (carrier and wafer handling systems, valves, pumps, heaters, coolers, etc.).

R2-1.4.3 Results may be shown in either tabular form or plotted graphically on a Productivity Effectiveness Plane. See Section R2-2.

*Sample Rapid Characterization of Intrinsic Equipment Efficiency (IEE)*

*Four experiments were designed and executed with the following results:*

| *Exp.* | *Units of Recipe i Per Experiment* | *Value-Added In-Process Theoretical Production Time Per Unit ($VTHT_i$)* | *Production Time Per Experiment* |
|---|---|---|---|
| *1* | *50 of recipe A* | *0.00670 hr/unit* | *3.3333 hr* |
| *2* | *100 of recipe B* | *0.00550 hr/unit* | *5.0000 hr* |
| *3* | *150 of recipe B* | *0.00550 hr/unit* | *6.0000 hr* |
| *4* | *300 of recipe A* | *0.00670 hr/unit* | *10.0000 hr* |

*Effective Unit Throughput Per Experiment*
*= (Total Units Per Experiment)*
*/(Production Time Per Experiment)*

*Intrinsic Equipment Efficiency (IEE) Per Experiment*
*= [$\Sigma_i$ (Units of Recipe i Per Experiment × $VTHT_i$)*
*/(Production Time Per Experiment)] × 100%*

*Non-Value-Added Overhead Time Per Experiment*
*= [(Production Time Per Experiment)*
*- $\Sigma_i$ (Units of Recipe i Per Experiment × $VTHT_i$)]*

| *Experiment* | *Effective Unit Throughput* | *Intrinsic Equipment Efficiency* | *Non-Value-Added Time in Hours* |
|---|---|---|---|
| *1* | *15 units/hr* | *10.05%* | *2.9983 hr* |
| *2* | *20 units/hr* | *11.00%* | *4.4500 hr* |
| *3* | *25 units/hr* | *13.75%* | *5.1750 hr* |
| *4* | *30 units/hr* | *20.10%* | *7.9900 hr* |

## R2-2 Productivity Efficiency Plane (PEP)

R2-2.1 It is recognized that OEE and throughput are separate metrics whose relationship may not be straightforward. Because theoretical production time per unit may vary widely by recipe, good throughput performance may not indicate correspondingly good performance in terms of overall equipment efficiency. Similarly, a high OEE score may not be indicative of high throughput. Given this disparity, it is essential that both metrics be analyzed and compared as separate entities.

R2-2.2 Data from rapid characterization experiments may be displayed graphically on a Productivity Effectiveness Plane (PEP) diagram, Figure R2-1.

R2-2.3 In PEP diagrams, IEE is plotted as a function of throughput. Points that appear further to the right have higher throughput and points that appear higher up have higher IEE. It is desired to have combined equipment and process designs whose performance would appear in the upper right quadrant of the plane for the entire operating range of the tool.

R2-2.4 The four experimental data points from the sample problem are plotted in Figure R2-1 and, when connected, appear to approximate an upward sloping curve. This curve is referred to as a *tool signature*.

R2-2.5 Tool signatures may be used to describe tool performance relative to isolated variables. This representation helps equipment suppliers and users visualize the effects of tool operating modes on IEE and throughput. For more complex multi-dimensional experiment sets, the tool signature would appear as a hyper-surface.

R2-2.6 OEE can be plotted for comparison against tool signatures. In Figure R2-1, an OEE measurement of a typical week is plotted. For the known throughput corresponding to this OEE score, the value of IEE on the tool signature for the same throughput may be used to approximate the IEE score for the week without calculating IEE explicitly.

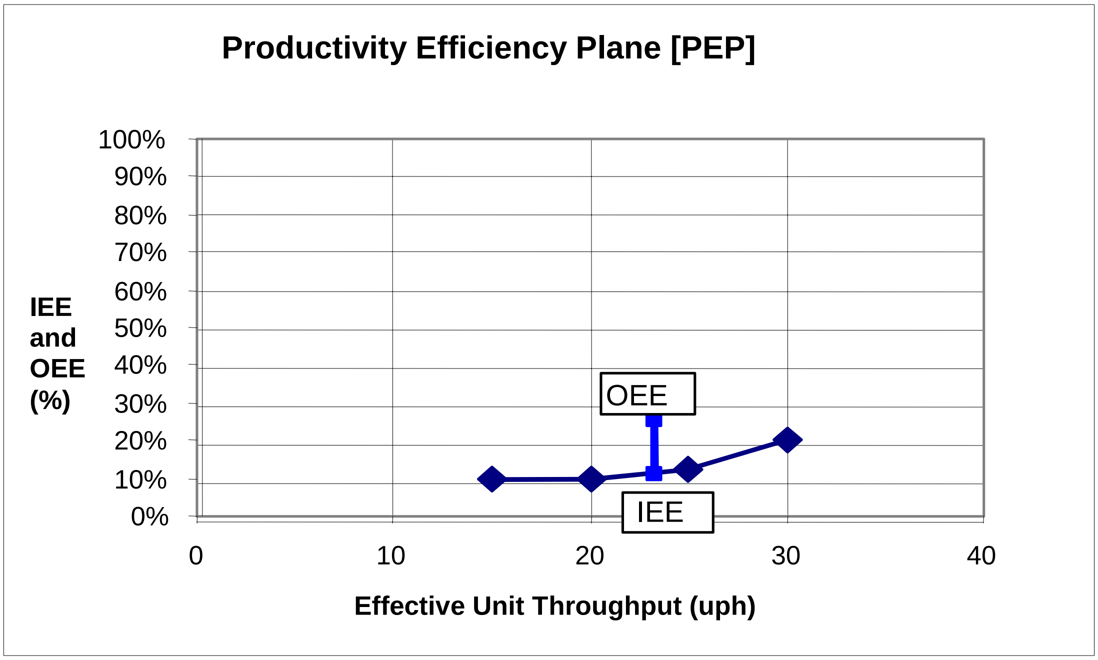



**Figure R2-1**
**Productivity Efficiency Plane**

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The user's attention is called to the possibility that compliance with this standard may require use of copy-righted material or of an invention covered by patent rights. By publication of this standard, SEMI takes no position respecting the validity of any patent rights or copyrights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of any such patent rights or copyrights, and the risk of infringement of such rights, are entirely their own responsibility.

# SEMI E80-0299 (Reapproved 1104)
# TEST METHOD FOR DETERMINING ATTITUDE SENSITIVITY OF MASS FLOW CONTROLLERS (MOUNTING POSITION)

This test method was technically approved by the Global Gases Committee and is the direct responsibility of the North American Gases Committee. Current edition approved by the North American Regional Standards Committee on July 11, 2004. Initially available at www.semi.org September 2004; to be published November 2004. Originally published in 1999; last published November 2004.

## 1 Purpose

1.1 The purpose of this test method is to provide a standardized method for quantifying the effect of mounting attitude on an MFC.

1.2 This document provides a common basis for communication between manufacturers and users regarding testing and describing MFC mounting effects.

## 2 Scope

2.1 This procedure describes a method to determine the effect of attitude (mounting position) of a Mass Flow Controller on flow span and zero.

2.2 The intent of this document is not to suggest any specific testing program but to specify the test method to be used when testing for parameters covered by this method. Reference operating conditions represent the environmental conditions where the "best" performance can be expected.

2.3 The minimum test described in this document is to test one MFC in 5 common mounting positions using Nitrogen gas at 135.8 kPa (19.7 psia) and 308 kPa (44.7 psia). This test method can be used to evaluate additional gases, pressures or mounting attitudes.

**NOTICE:** This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

## 3 Limitations

3.1 It is not practical to evaluate performance under all possible combinations of operating conditions. This test procedure should be applied under laboratory (reference) conditions; its intent is to collect sufficient data to form a judgment of the field performance of the MFC being tested.

3.2 The results from this test represent the performance of the specific device tested i.e., make, model, full scale flow and operating conditions. The results may not apply to devices of different manufacture, model, full scale flow or under different operating conditions.

3.3 Due to manufacturing variability, attitude sensitivity may vary for the same model of MFC. To statistically quantify attitude sensitivity for a particular model of MFC, multiple samples should be tested.

## 4 Referenced Standards

None.

## 5 Terminology

5.1 *Acronyms and Abbreviations*

5.1.1 *% F.S.* — Percent Full Scale

5.1.2 *DUT* — Device Under Test

5.1.3 *HBD* — Horizontal Base Down. Mounting attitude 1, as shown in Figure 1.

5.1.4 *HED* — Horizontal Either side Down. Mounting attitude 3, as shown in Figure 1.

5.1.5 *HUD* — Horizontal Upside Down. Mounting attitude 5, as shown in Figure 1.

5.1.6 *kPa* — KiloPascal

5.1.7 *MFC* — Mass Flow Controller

5.1.8 *psia* — Pounds per Square Inch Absolute

5.1.9 $SAS_{max}$ — the maximum Span Attitude Sensitivity between two attitudes

5.1.10 $SAS_{nm}$ — Span Attitude Sensitivity between attitudes n and m

5.1.11 *Sccm* — Standard cubic centimeters per minute

5.1.12 *Slm* — Standard liters per minute

5.1.13 *VFD* — Vertical Flow Down. Mounting attitude 2, as shown in Figure 1.

5.1.14 *VFU* — Vertical Flow Up. Mounting attitude 4, as shown in Figure 1.

5.1.15 *VID* — Vertical Inlet Down. Mounting attitude 4, as shown in Figure 1.

5.1.16 *VIU* — Vertical Inlet Up. Mounting attitude 2, as shown in Figure 1.

5.1.17 *$ZAS_{max}$* — the maximum Zero Attitude Sensitivity between two attitudes.

5.1.18 *$ZAS_{nm}$* — Zero Attitude Sensitivity between attitudes n and m.

5.2 *Definitions*

5.2.1 *actual flow* — the flow rate as determined by the flow standard used in the test procedure.

5.2.2 *attitude* — the mounting position of the MFC with respect to the surface of the earth, as shown in Figure 1.

5.2.3 *indicated flow* — the flow rate as determined by the output of the DUT.

5.2.4 *measured value* — the actual flow through a DUT, expressed in sccm or slm.

5.2.5 *nameplate gas* — the gas intended to be controlled by the MFC in operation.

5.2.6 *setpoint* — the input signal provided to achieve a desired flow, reported as sccm, slm, or percent full scale.

5.2.7 *span* — the full scale range of the DUT.

5.2.8 *zero drift* — the undesired change in electrical output (i.e., indicated flow), at a no-flow condition, over a specified time period, reported in sccm or slm.

5.2.9 *zero offset* — the deviation from zero at a "no-flow" condition reported in sccm, slm, % F.S. or mV.

## 6 Summary of Test Method

6.1 Gas flow, indicated flow and setpoint data are collected for an MFC. This data is reduced to quantify the relationship between the flow control by the MFC and its relationship to the attitude of the MFC.

6.2 This method allows the user to determine the effect of different mounting attitudes on MFC zero and span.

6.3 The standard test is determining the effect of changing between attitudes 1 and 2 on Nitrogen. Other typical MFC attitudes and gases may also be tested (see Figure 1).

## 7 Interferences

7.1 The accuracy rating of the measuring equipment shall be superior to that of the DUT. Preferably, the measuring equipment will have an accuracy that is four times better than the DUT. Calibration equipment must have a valid calibration certificate.

7.2 Take care when using test instruments with a specified accuracy expressed in percent of full scale.

7.3 Installation effects on the flow should be minimized. Monitor pressure upstream of the DUT to ensure that flow variations due to pressure are minimized.

7.4 Verify electrical signals directly at the DUT connector to ensure that the signals at the DUT and standard agree with the signals at the data recording equipment.

7.5 All electrical measurements should be read on devices with at least 4.5 digits of resolution. These devices must have valid calibration certifications.

7.6 All instrumentation in the test apparatus must remain in a constant orientation except the device under test.

## 8 Significance and Use

8.1 The data generated by this method is used to estimate the effect-mounting attitude will have on the performance of a mass flow controller. It would typically be used to estimate the potential flow error caused by using an MFC in attitude, other than the one it was calibrated for.

## 9 Apparatus (see Figure 2)

9.1 *Flow Standard* — A device or system that accurately measures the flow and reports the actual flow.

9.2 *Data Acquisition System* — The system that measures the electrical signals from the device under test. The data acquisition system may also read the signals from the flow standard, record test data and control the test sequence.

9.3 *Isolation Valves* — Valves that will positively shut off the gas line.

9.4 *Pressure Regulator* — A device that regulates gas pressure to a set value.

9.5 *Pressure Transducer* — An instrument to measure the gas pressure and report it as an electrical signal.

9.6 *Flexible Gas Line* — Flexible tubing that will allow the DUT to be moved to the various test attitudes while the other components can remain in a fixed position.

## 10 Materials

10.1 Clean, Dry $N_2$, with 99.9% minimum purity.

10.2 MFC Calibration Test Gas as desired.

## 11 Safety Precautions

11.1 Follow the manufacturer's specifications and instructions for installation and operation whenever possible. Note any exceptions in the test report.

## 12 Test Specimen

12.1 Allow all components in the test apparatus to warm up following the manufacturer's specification.

12.2 Take necessary steps when switching gases to ensure that only the desired gas is in the DUT and flow standard at the time the test is performed.

## 13 Preparation of Apparatus

13.1 Locate the DUT in the test environment to stabilize temperature prior to warm up.

13.2 The reference operating conditions shall be as follows:

13.2.1 *Ambient temperature* — 21 ± 4 °C

13.2.2 *Ambient Temperature Stability* — Ambient temperature to stay constant within ± 1 °C during data acquisition period.

13.2.3 *Gas temperature* — Same as ambient.

13.2.4 *Gas pressure, Outlet* — Ambient Pressure

13.3 Following the conditioning period (Section 12.1) warm up the device according to manufacturer's specifications.

13.4 Perform an adequate purge to ensure all previous gases and atmospheric moisture has been removed from the system.

13.5 Leak check the test set up, using available methodologies to verify the test system leak integrity.

13.6 The power supply must be sufficiently rated for the device under test.

## 14 Procedure

14.1 Open V1 and V2. DUT and allow the flow to stabilize. Adjust the inlet pressure to 135.8 kPa (19.7 psia).

14.2 Close the downstream isolation valve (V2); then close the upstream isolation valve (V1), (see Figure 2).

14.3 With both isolation valves closed, and a 100% setpoint wait until the pressure drop across the MFC is dissipated, ensuring a “no flow” condition through the MFC. Dissipation of the pressure across the MFC is indicated when the indicated flow drops to a steady state value near zero.

14.4 Once the indicated flow has dropped to a steady value set the MFC setpoint so there is no power being dissipated by the control valve. For a normally closed valve this is 0% and for a normally open control valve it is 100%.

14.5 After the electrical output signal has stabilized for at least three minutes, record the MFC indicated zero in Table 1.

14.6 Open V1 and V2, command 100%.

14.7 After the electrical output signal has stabilized for at least three minutes, record the actual flow as reported by the flow standard and the indicated flow in Table 1.

14.8 Change the attitude of the DUT to the next desired attitude.

14.9 Close the downstream isolation valve (V2); then close the upstream isolation valve (V1) (see Figure 2).

14.10 With both isolation valves closed, and a 100% setpoint wait until the pressure drop across the MFC is dissipated, ensuring a “no flow” condition through the MFC. Dissipation of the pressure across the MFC is indicated when the indicated flow drops to a steady state value near zero.

14.11 Once the indicated flow has dropped to a steady value set the MFC setpoint so there is no power being dissipated by the control valve. For a normally closed valve this is 0% and for a normally open control valve it is 100%.

14.12 After the electrical output signal has stabilized for at least three minutes, record the MFC indicated zero in Table 1.

14.13 Open V1 and V2, command 100%.

14.14 After the electrical output signal has stabilized for at least three minutes, record the actual flow as reported by the flow standard and the indicated flow in Table 1.

14.15 Repeat Sections 14.8 to 14.14 for each of the desired attitudes.

14.16 Return the DUT to attitude 1.

14.17 Adjust the inlet pressure to 308 kPa (44.7 psia).

14.18 Repeat Sections 14.8 to 14.14.

## 15 Calculations or Interpretation of Results

15.1 Attitude sensitivity between two mounting positions is calculated as follows:

$ZAS_{nm} = Z_m - Z_n$

Where,

$ZAS_{nm}$ = Zero attitude Sensitivity between attitude n and attitude m

$Z_n$= zero indication at attitude n

$Z_m$= zero indication at attitude m

$SAS_{nm} = S_n - S_m$

Where,

$SAS_{nm}$ = Span attitude Sensitivity between attitude n and attitude m
$S_n$= Actual flow in attitude n

$S_m$= Actual flow in attitude m$ZAS_{max}$ = The maximum zero attitude sensitivity for all attitudes.
$SAS_{max}$ = The maximum span attitude sensitivity for all attitudes

15.2 *Interpretation*

15.2.1 Table 2 shows examples of raw and reduced data. For the MFC tested, the maximum zero shift was 0.3% F.S. and the maximum span shift was 0.4% F.S.

**Table 1 Attitude Test Data**

MFC Mfg/Model/Serial # ______________________________________________
Name Plate Gas/Range ______________________________________________
Test Gas ______________________________________________
Temp ______________________________ Date __________________
Factory Calibration Gas ______________________________________________

| *Attitude* | *Pressure (kPa)* | *Indicated Flow by DUT with Zero Actual Flow (% F.S.)* | *Zero Attitude Sensitivity Compared to Attitude 1 (% F.S.)* | *Actual Flow by Flow Standard at 100% DUT Setpoint (% F.S.)* | *Span Attitude Sensitivity Compared to Attitude 1 (% F.S.)* |
|---|---|---|---|---|---|
| **1** | **135.8** | | 0 | | 0 |
| **2** | **135.8** | | | | |
| **3** | **135.8** | | | | |
| **4** | **135.8** | | | | |
| **5** | **135.8** | | | | |
| | | $ZAS_{max}$ = | | $SAS_{max}$ = | |
| **1** | **308** | | 0 | | 0 |
| **2** | **308** | | | | |
| **3** | **308** | | | | |
| **4** | **308** | | | | |
| **5** | **308** | | | | |
| | | $ZAS_{max}$ = | | $SAS_{max}$ = | |

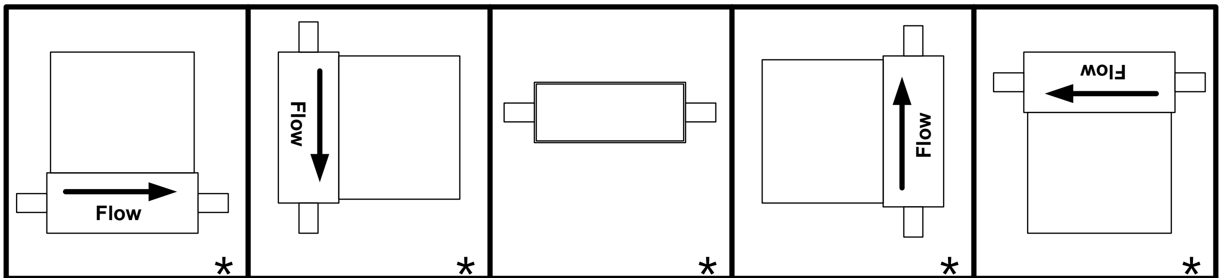
**Table 2 Sample Attitude Test Data**

MFC Mfg/Model/Serial # Acme/ XYZ-100/0001
Name Plate Gas/Range Nitrogen 100 sccm
Test Gas Nitrogen
Temp 20.2 °C Date 3/9/98
Factory Calibration Gas Nitrogen

| *Attitude* | *Pressure (kPa)* | *Indicated Flow by DUT with Zero Actual Flow (% F.S.)* | *Zero Attitude Sensitivity Compared to Attitude 1 (% F.S.)* | *Actual Flow by Flow Standard at 100% DUT Setpoint (% F.S.)* | *Span Attitude Sensitivity Compared to Attitude 1 (% F.S.)* |
|---|---|---|---|---|---|
| **1** | **135.8** | 0 | ***0*** | 100 | ***0*** |
| **2** | **135.8** | 0.1 | ***-0.1*** | 100.2 | ***0.2*** |
| **3** | **135.8** | 0 | ***0*** | 100 | ***0*** |
| **4** | **135.8** | -0.1 | ***0.1*** | 99.8 | ***-0.2*** |
| **5** | **135.8** | 0 | ***0*** | 100 | ***0*** |
| | | $ZAS_{max}$ = | ***0.2*** | $SAS_{max}$ = | ***0.4*** |
| **1** | **308** | 0 | ***0*** | 100 | ***0*** |
| **2** | **308** | 0.15 | ***-0.15*** | 100.2 | ***0.2*** |
| **3** | **308** | 0 | ***0*** | 100 | ***0*** |
| **4** | **308** | -0.15 | ***0.15*** | 99.8 | ***-0.2*** |
| **5** | **308** | 0 | ***0*** | 100 | ***0*** |
| | | $ZAS_{max}$ = | ***0.3*** | $SAS_{max}$ = | ***0.4*** |

NOTE 1: The values in ***bold italics*** are calculated values.

## 16 Illustrations




| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| HBD | VIU | HED | VID | HUD |
| | VFD | | VFU | |

* For this test method the DUT must be mounted ±1$^{O}$ in all axes

HBD = Horizontal Base Down
VIU = Vertical Inlet Up
VFD = Veritical Flow Down
HED = Horizontal Either side Down
VID = Vertical Inlet Down
VFU = Vertical Flow Up
HUD = Horizontal Upside Down

**Figure 1**
**MFC Mounting Attitudes**

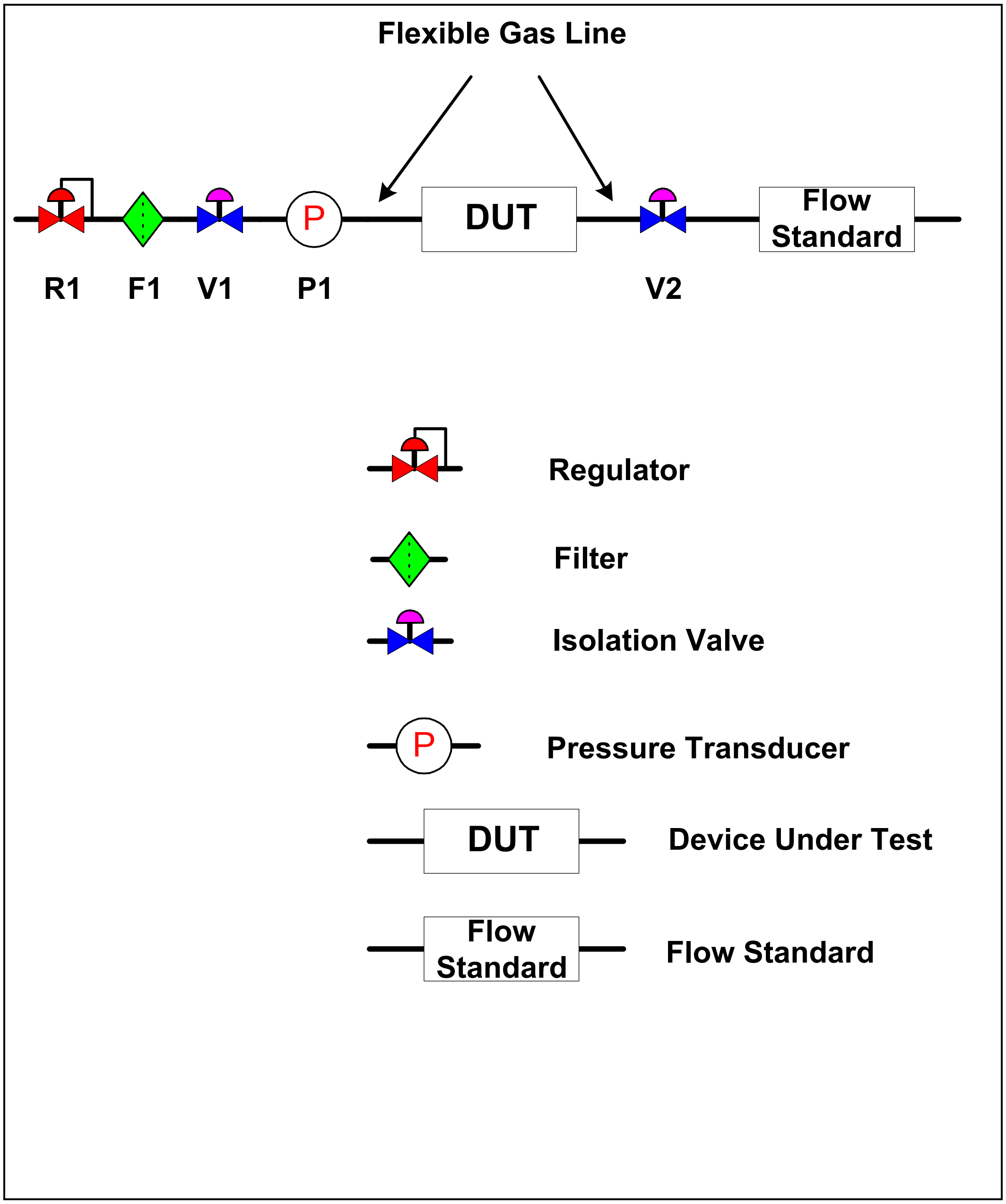



**Figure 2**
**Test Setup**

## 17 Related Documents

17.1 *ANSI Standards*[1]

ANSI C39.5 — Safety Requirements for Electrical and Electronic Measuring and Controlling Instrumentation

ANSI C42.100 — Dictionary of Electrical and Electronics Terms

17.2 *ISA Standard*[2]

ISA S51.1 — Process Instrumentation Terminology

17.3 *ISO Standard*[3]

ISO 10012-1 — Quality Assurance Requirements for Measuring Equipment

**NOTICE:** SEMI makes no warranties or representations as to the suitability of the standards set forth herein for any particular application. The determination of the suitability of the standard is solely the responsibility of the user. Users are cautioned to refer to manufacturer's instructions, product labels, product data sheets, and other relevant literature, respecting any materials or equipment mentioned herein. These standards are subject to change without notice.

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2 The Instrumentation, Systems, and Automation Society, 67 Alexander Drive, PO Box 12277, Research Triangle Park, NC 27709, Telephone: 919-549-8411, Fax: 919-549-8288, http://www.isa.org
3 International Organization for Standardization (ISO), 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland, Telephone +41 22 749 01 11; Fax +41 22 733 34 30, http://www.iso.org/

# SEMI E83-1000
# SPECIFICATION FOR 300 mm PGV MECHANICAL DOCKING FLANGE

This Provisional Specification was technically approved by the Global Physical Interfaces & Carriers Committee and is the direct responsibility of the North American Physical Interfaces & Carriers Committee. Current edition approved by the North American Regional Standards Committee on July 14, 2000. Initially available at www.semi.org August 2000; to be published October 2000. Originally published June 1999.

## 1 Purpose

1.1 This specification is intended to promote consistent interface features between Person Guided Vehicles and SEMI E15.1 equipment.

## 2 Scope

2.1 This specification defines a mechanical standard for the stationary (equipment) side of the docking flange used by 300 mm Person Guided Vehicles (PGVs). This flange is to be mounted to the floor within the volume defined by SEMI E64 at SEMI E15.1 and SEMI E64 compliant equipment.

2.2 This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

## 3 Limitations

3.1 This standard does not define the PGV (active) side of the docking interface or carrier transfer. The PGV and the PGV side of the docking interface designs should comprehend the physical limitations of equipment to which they are being applied.

## 4 Referenced Standards

4.1 *SEMI Standards*

SEMI E15 — Specification for Tool Load Port

SEMI E15.1 — Provisional Specification for 300 mm Tool Load Port

SEMI E64 — Provisional Specification for 300mm Cart to SEMI E15.1 Docking Interface Port

## 5 Terminology

5.1 *Acronyms and Abbreviations*

5.1.1 *PGV* — Person Guided Vehicle (cart)

5.2 *Definitions*

5.2.1 *carrier* — Any cassette, box, pod, or boat that contains wafers (per SEMI E15).

5.2.2 *cart* — A floor based carrier transfer vehicle (per SEMI E64).

5.2.3 *docking* — The act of locating a floor-based carrier transport vehicle for carrier transfer to/from equipment (per SEMI E64).

5.2.4 *facial datum plane* — A vertical plane that bisects the wafers and that is parallel to the front side of the carrier (where wafers are removed or inserted). On tool load ports, it is also parallel to the load face plane specified in SEMI E15 on the side of the tool where the carrier is loaded and unloaded (per SEMI E57).

5.2.5 *load face plane* — The furthest physical vertical boundary plane from carrier centroid on the side(s) of the equipment where loading of the tool is intended (per SEMI E15).

5.2.6 *load port* — The interface location on a tool where carriers are placed to allow the tool to process wafers (per SEMI E15).

5.2.7 *transfer* — To either load or unload (per SEMI E15).

## 6 Requirements

6.1 The dimensions that define the universal docking flange are listed in Table 1 and shown on Figure 1.

6.1.1 The minimum length of the docking flange is defined by $2 \times w11$. This minimum length is intended to fit under the shadow of the smallest possible width SEMI E15.1 compatible load port. The PGV and PGV docking must provide full functionality given a minimum length docking flange. No maximum length has been specified.

6.1.2 One vertical pin (labeled VP in Figure 2) is intended to be used for horizontal registration of the PGV to the docking flange. This pin is also intended as a feature for an active mechanism on the PGV to lock on to.

6.2 There are three surfaces on the flange and a vertical pin that can be used as the initial docking contacts point(s) with the PGV. These have been identified as surfaces A, B and C and pin VP as shown in Figure 2. These features are the primary load bearing features during the act of docking, no other features or surfaces shall be used as initial docking contact points.

**Table 1 Dimensional Requirements**

| *Symbol* | *Value, mm (in.)* | *Tolerance (mm)* | *Type* |
|---|---|---|---|
| a11 | 0 deg. | +/- 0.25 deg. | angle |
| ∅d11 | 15.0 (.591) | +/- 0.2 | diameter |
| d12 | 33.0 (1.299) | +/- 0.2 | distance |
| d13 | 39.0 (1.535) | +/- 0.2 | distance |
| d14 | 62.0 (2.441) | +/- 0.2 | distance |
| d15 | 80.0 (3.150) | +/- 0.2 | distance |
| d16 | 237.5 (9.350) | +/- 2.5 | distance |
| d17 | 68.0 (2.677) | minimum | distance |
| h11 | 24.0 (.945) | +/- 0.2 | distance |
| h12 | 39.0 (1.535) | +/- 0.2 | distance |
| h13 | 40.0 (1.575) | +/-0.2 | distance |
| h14 | 83.0 (3.268) | +/-0.2 | distance |
| h15 | 20.0 (.787) | maximum | distance |
| r11 | 2.0 (.079) | +/-0.2 | radius |
| r13 | 4.0 (.157) | +/-0.2 | radius |
| r14 | 5.0 (.197) | +/-0.2 | radius |
| w11 | 200 (7.874) | minimum | distance |

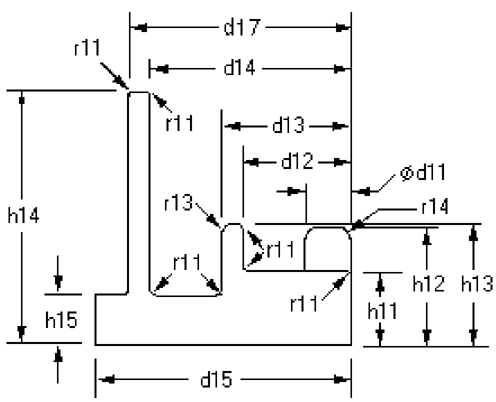


**Figure 1**
**Side Elevation View I**

6.3 The flange must be installed such that the vertical pin (VP) is capable of being aligned with the load port bilateral datum plane (as defined in SEMI E15.1) and surface A is a distance of *d*16 from the load port facial datum plane (as defined in SEMI E15.1). The angle of incidence between surface A and the facial datum plane should be capable of adjustment to *a*11 listed in Table 1.

6.3.1 The docking flange is to be physically isolated from the equipment and should be mounted such that the equipment and equipment load port are protected from the impact incurred during docking.

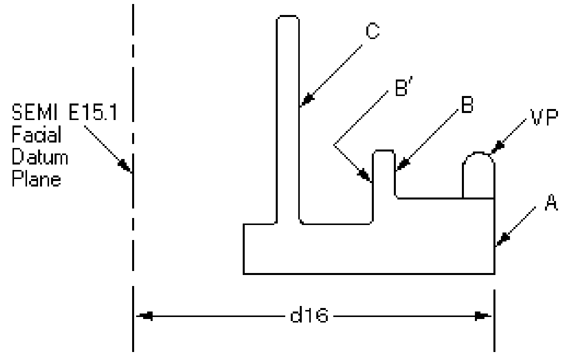


**Figure 2**
**Side Elevation View II**

6.4 When the flange is removed, no mounting hardware shall remain protruding from the floor.

6.5 Surfaces A, B, B' and C shown on Figure 2 must exist per tolerances listed in Table 1.

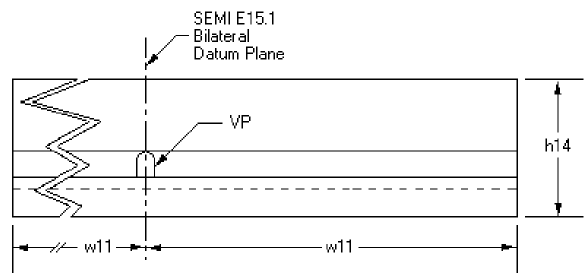


**Figure 3**
**Front Elevation View**

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