Equipment Class Application Guideline

International SEMATECH
Technology Transfer # 97033270B-ENG

Equipment Class Application Guideline

Technology Transfer # **97033270B-ENG**

International SEMATECH

December 5, 1998

Abstract: This revised document is intended to be used when preparing demonstration test plans for semiconductor equipment and processes. It provides detail and direction for applying the I300I *180 nm Equipment Performance Metrics – Revision 1* and I300I *Demonstration Test Method – Revision 1*. The *Equipment Class Application Guideline* defines the I300I equipment classes and will help determine the class in which equipment should be categorized and tested. The guideline provides information about gauges, measurement equipment, process performance, and additional data to be collected during testing. Adaptations for technical differences and specific processes are provided.

Keywords: Test Methods, Equipment Performance, Process Capability, Metrology, Wafer Size Conversion, 300 mm Wafers

Authors: David Carswell, Lorn Christal

Approvals:
David Carswell, Author
Lorn Christal, Author
Randy Goodall, Associate Director of Productivity & Infrastructure
Ashwin Ghatalia, Director of Productivity & Infrastructure
Laurie Modrey, Technical Information Transfer Team Leader

Table of Contents

List of Tables

EXECUTIVE SUMMARY

The International 300 mm Initiative (I300I) has established the I300I *Demonstration Test Method – Revision 1* (DTM) to provide a standardized objective methodology for characterizing the process performance and reliability of semiconductor IC process and metrology equipment at any phase of the development cycle. The I300I *Equipment Class Application Guideline* (ECAG) provides guidance for applying this methodology to tools by categorizing the tools into equipment classes and providing detailed interpretation and technical direction for testing tools within each class.

An equipment class is a grouping of tools that perform generally the same function within the IC fabrication process. Tools within an equipment class share a common process capability and have the same testing approach and requirements. Currently, the I300I program has designated 16 equipment classes, as shown in Table 1. This set of equipment classes was derived from the I300I *180 nm Equipment Performance Metrics*, but it is not intended to be exhaustive. As additional classes are identified and developed, they will be added to revisions of this document.

Table 1 I300I Equipment Classes

Class	Equipment	Class	Equipment
1.1	DUV Litho Stepper/Scanner	4.1	Wet Cleans – Batch
1.2	DUV Litho Track	4.2	Wet Cleans – Single-wafer
2.1	Plasma Etch	5.1	Metrology
2.2	Asher	6.1	Metal Deposition – PVD
3.1	Rapid Thermal Process – Single-wafer	6.2	Metal Deposition – CVD
3.2	Atmospheric Thermal Process	7.1	Dielectric – CVD
3.3	LPCVD Thermal Process	8.1	Chemical Mechanical Planarization
3.4	Ion Implantation	9.0	Automated Material Handling System

The equipment class descriptions provide the criteria for determining the class of a candidate test tool. Once a tool's class has been established, the ECAG gives detailed technical direction and information about performing demonstration tests on tools belonging to that class, the type of gauges and metrology required for the test, functional guidance for mechanical dry cycle (MDC) testing, technical guidance on inputs and outputs of interest for passive data collection (PDC) and sensitivity analysis (SA), information about collecting additional data and metrics, and guidance for working with process- and technology-dependent requirements.

The ECAG enables suppliers to independently perform demonstration testing that complies with the I300I methodology and requirements. It establishes a common direction and common expectations for testing any tool within an equipment class. The ECAG also provides guidance that enables a test team to plan and perform a test based on the I300I *Demonstration Test Method – Revision 1* consistently and effectively.

INTRODUCTION

The I300I *Equipment Class Application Guideline* (ECAG) is a reference guide designed to be used with the I300I *Demonstration Test Method – Revision 1* (DTM) and the I300I *180 nm Equipment Performance Metrics* (EPM) documents. It provides interpretation, guidance, and additional information for implementing the I300I methodology for performing demonstration tests on IC manufacturing equipment.

The ECAG provides test engineers, process engineers, development engineers, and their managers with generic direction for planning and executing demonstration tests. It also provides detailed guidance for testing tools within specific equipment classes. The ECAG does not provide guidance on all elements of the DTM. Instead, it focuses on those areas where test teams may need additional information to apply the DTM appropriately. While the ECAG is designed to support I300I demonstration testing, the guidance and methodology it provides may be applicable to any equipment testing at any phase of the equipment development cycle.

I300I Equipment Classes

Tools within an I300I equipment class share the following basic characteristics:

- They perform a very similar function within the IC fabrication process.
- They have similar process capabilities.
- They require common testing approaches and requirements.

At the same time, tools within an equipment class may employ different technological approaches to perform a process, and they may have very different operating characteristics and configurations.

Currently, 16 equipment classes are defined in this document (see Table 1). These classes do not represent all possible equipment classes, only those that have been defined within the context of the I300I program. As other classes are identified and defined, they will be added to future revisions of this document.

The equipment class descriptions provide the criteria for determining the class to which a candidate test tool belongs. The candidate test tool’s characteristics are evaluated within the context of the class descriptions and the matching class is identified. In many cases, this evaluation can be done by identifying characteristics that the candidate tool lacks.

ABOUT THIS DOCUMENT

The ECAG is divided into 16 main sections—one section for each of the 16 equipment classes. Each of these sections contains parameters and guidelines for performing demonstration tests on tools within that class. The sources of this information include the I300I *180 nm Equipment Performance Metric* (EPM) document, the expertise and judgment of I300I technical staff, and other appropriate technical sources. The listings of test parameters are not exhaustive. Rather, they should be considered to be the minimum set of requirements for performing a test element. At times it may be appropriate for test teams to seek additional direction from other knowledgeable sources when developing test plans.

Each equipment class section contains sub-sections that provide the following information:

- A brief *description of tools* within the particular class, including their process role within the IC manufacturing process, and other key characteristics and capabilities. This description is intended to be broad enough to include a variety of technological approaches and configurations, yet specific enough to facilitate classification of a tool into an equipment category.
- Detailed *interpretations of the requirements* for implementing the elements of DTM testing for tools within the class. This includes the requirements for performing gauge studies, MDC, PDC, and sensitivity analysis (SA) test elements. In addition, each section provides guidance for applying test metrics, collecting additional data, and working with technology- and process-dependent considerations for tools within the particular equipment class.

Below is a brief discussion of material covered in each of the sub-sections of the equipment class descriptions.

IMPLEMENTING THE DEMONSTRATION TEST METHOD (DTM)

This sub-section provides detailed interpretations of the specific element requirements for DTM testing of tools within a particular equipment class.

Gauge Studies

This sub-section provides specific direction on the types of gauges required for demonstration testing. It also provides the corresponding measurements and establishes targets for the tolerance requirements on the gauges where applicable.

The *SEMI Standard M27* methodology must be used when establishing precision/tolerance (P/T) ratios of any gauges that have targets for this value. It is important to note that it may not be necessary to perform a gauge study on a metrology tool that has previously been studied and found to be under statistical process control (SPC).

Ongoing monitoring and control of gauge performance parameters is required to ensure stability following the gauge study. At a minimum, repeatability, reproducibility, and accuracy must be under valid SPC.[1]

Internal control systems, including those calibrated with external references, cannot be considered gauges for measuring the process output parameters for a test. Gauges refer to the traceable metrology equipment used to measure and assess the output results of the tool being tested. At a minimum, the gauges should be traceable to a transfer standard, to an artifact of a product type, or to a reference product.

Mechanical Dry Cycle (MDC)

The intent of the MDC test element is to exercise every mechanical function practical without the complexity of processing. This sub-section establishes expectations and provides guidance on the functional definition of a machine cycle for the equipment class. Where appropriate, alternative or additional goals are established, and special-case considerations are explored.

[1] Douglas Montgomery, *Introduction to Statistical Quality Control* (Second Edition) John Wiley (1991).

The DTM suggests a mean wafers between interrupt (MWBI) goal of 5000 wafer cycles, with an appropriate statistical confidence based upon the maturity and performance level of the equipment and the test scaling applied to the test goals. To calculate the required number of total wafer cycles, the number of allowable failures must be estimated and a corresponding statistical confidence factor test multiplier must be identified and applied to the test goal. The product will be a planning estimate of the total number of cycles required.

There is one common difference between batch process tools and single-wafer process tools in MDC testing. Batch process tools generally have a second metric, which represents the number of batches or machine cycles to complete testing of the requisite number of wafer cycles. Generally, this is a very straightforward calculation accomplished by dividing the total number of wafer cycles required for the test by the batch size and rounding to the higher integer.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The section on PDC and SA identifies the recommended input parameters to monitor and output parameters to measure for tools in the equipment class. No distinction is made between the PDC and SA test elements, since the factors to be investigated during the designed experiments of the SA are generally a subset of the PDC parameters of interest.

During PDC, the inputs are monitored and the process outputs are measured without adjustment or alteration, specifically to establish the stability and repeatability of the process. This stability provides the statistical foundation for the designed experiments that will be used during the SA to investigate the relationship and extent of input interactions as measured in the quality of output results.

APPLYING TEST METRICS

This section summarizes the test metrics and parameters to be measured and reported for a demonstration test for tools within the equipment class. Results should be reported for all test metrics except those specifically removed from the test plan during test scaling and planning.

The test metrics section is generally modeled after the EPM definitions; the same units and guidelines should be considered to apply to the equipment class as a whole. These broad guidelines include equipment process yield = 99.995%, 100% frontside coverage, defect goals for backside contamination, and other broadly stated guidance.

COLLECTING ADDITIONAL METRICS AND DATA

This section provides direction on parameters for which additional data (not stated in the metrics) should be collected during the performance of the test. This additional data may be related to a parameter whose effect or impact on processing is not well understood and has not been quantified or to a case where a robust measurement tool, method, or technique has not been generally accepted. It could also include data of special interest to one member of the test team or to the supplier.

The additional data required for an equipment class must be collected during a test, if possible, to ensure consistent standardized performance of demonstration tests among different tools within the same class. This data is then analyzed statistically by the same methods that are used to analyze the test metric data, and the results are published in the final test report.

WORKING WITH TECHNOLOGY- AND PROCESS-DEPENDENT CONSIDERATIONS

Within an equipment class, certain processes may have specific testing requirements, additional metrics, technological challenges, or other considerations that are particular to them. This section summarizes and provides guidelines for working with these technology- and process-dependent considerations.

EQUIPMENT CLASS 1.1: DUV LITHO STEPPER/SCANNER

Deep ultraviolet (DUV) steppers and scanners are single-wafer processing tools that use a photolithographic process to transfer an image onto a photoresist film-coated wafer. These tools use a coherent 180 nm wavelength illumination source and reduction optics in the image path. Reticle sizes of 6” x 6” or 9” x 9” can be used; the reticles are handled by an automated loading and management system. The I300I program requires that DUV steppers and scanners have high precision systems for positioning and aligning wafers, provisions for the accepting reticle delivery, and integrated environmental control systems. These tools must also have a minimum field size of 26 mm x 32 mm. DUV litho steppers and scanners are often clustered with DUV litho track systems; they are configured to perform the following processes:

- Non-via levels on DUV resist
- Non-via levels on DUV antireflective coating (ARC)
- Via levels on DUV resist
- Via levels on DUV ARC

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when performing demonstration tests on DUV steppers and scanners.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on metrology tools that will used for demonstration testing. Table 2 identifies the measurements and gauges for performing a demonstration test on a DUV litho stepper or scanner. Table 2 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 2 Gauges and Measures for DUV Steppers and Scanners

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥ 0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Surface contamination	TXRF SCA	TBD	atoms/cm^2 Q_{ox} and T_s	10%	SPC
Minority carrier lifetime	Micro photo-conductive decay surface photo voltage	TBD	charge per cm^2	10%	SPC
Critical dimension (CD)	SEM	0.1–0.25	µm	10%	SPC
Overlay	Overlay registration	30-70	nm	10%	SPC

MECHANICAL DRY CYCLE (MDC) TESTS

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of a tool without the complexity of processing. To perform the right type of testing for DUV steppers and scanners, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For a DUV stepper or scanner, a machine cycle comprises two functions: wafer processing and reticle management. Reticle management and alignment system mechanical cycling consists of loading, aligning, and unloading a process reticle. For the MDC test, one reticle management system cycle should be completed for each batch of wafers cycled.

For wafer processing, a cycle consists of the complete pod-to-pod transfer of a wafer, including every intermediate function of the tool. At each intermediate stage, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC test on a DUV litho stepper or scanner, process variables such as photo expose time, precise wafer alignment, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated during testing.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires the monitoring of specific input and output data during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring the inputs and measuring the process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

For DUV steppers and scanners, monitoring the following inputs should be monitored, regardless of process configuration:

- Dose
- Depth of focus
- Reticle alignment

The following two outputs should be monitored regardless of process configuration:

- Overlay registration
- Critical dimension (CD)

MARATHON TESTS

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the phase of maturity of the tool. This document does not provide detailed guidance for planning or performing the marathon test element, since sufficient detail is provided in the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For DUV litho steppers and scanners, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as the results of the demonstration test.

Metric	Units
Critical dimension (CD)	µm
CD control	%
Depth of focus, full field	µm
Total overlay, tool to tool, compatibility with CMP and damascene processes	nm
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following cost performance parameters should be collected, evaluated, and published as the results of the demonstration test.

Metric	Units
Throughput, 6 x 6 reticle	wafers/hour
Throughput, 9 x 9 reticle	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For DUV steppers and scanners, the additional metric and data requirements are summarized in Table 3.

Table 3 Additional Metrics and Data DUV Steppers and Scanners

Parameter	Measurement Method	Gauge	Units
Depth of focus (DOF)	Focus and exposure matrix	SEM	µm
Within field CD uniformity	Critical dimensions measured across the exposed image field	SEM	nm
Overlap DOF parameters	Lens mapping/characterization – analysis of printed images	SEM	nm

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance is required for particular processes or technological challenges that are unique to those classes. For DUV litho steppers and scanners, the complete set of I300I test metrics and recommended goals can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 1.1.2 and 1.1.3. The following additional guidance is provided to deal with the technical challenge of differences in reticle size among these tools.

DIFFERENCES IN RETICLE SIZE

DUV steppers and scanners are designed to support either 6” x 6” or 9” x 9” process reticle formats. It is necessary to investigate and characterize the technical considerations that result from these significant differences in field size and optical path components.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA to characterize differences in reticle size:

- Depth of focus, full field
- Field size
- Dose

The following additional *output* parameters should be measured during the PDC and SA to characterize differences in reticle size:

- Critical dimensions
- Overlay registration
- CD control

EQUIPMENT CLASS 1.2: DUV LITHO TRACK

Deep ultraviolet (DUV) litho track equipment is used for the application, enhancement, or processing of photoresist for use in optical lithography processes. Tools in this class usually have many components or modules, with each module performing a dedicated sub-process. A wafer is processed serially through different modules to complete a process cycle. These tools generally have an integrated, dedicated environmental control system for particulate, air quality, humidity, and temperature control.

A DUV litho track tool must be capable of edge bead removal (EBR) and the application of organic ARC on wafers. This tool is often clustered with a photo exposure tool and typically performs the following processes (either singly or as a composite):

- Resist adhesion enhancement
- Resist coat
- Resist develop
- Pre-expose bake
- Post-expose bake

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when performing demonstration tests on DUV litho track tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for demonstration testing. Table 4 identifies the measurements and gauges required for performing a demonstration test on a DUV litho track tool. Table 4 also provides guidance about the expected range of measurements supported and the P/T ratio requirements for each gauge.

Table 4 Gauges and Measures for DUV Litho Track Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥ 0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Transparent film thickness	Ellipsometer/reflectometer	0.4–1.1K	µm	10%	SPC
Critical Dimension (CD) on Photoresist (post-develop)	SEM	3	%	10%	SPC
Bake temperature uniformity	Thermocouple wafer	90–170	°C	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for a DUV litho track tool, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For a DUV litho track tool, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including every intermediate module of the tool. At each module station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For single-wafer processing tools in this class, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC on a DUV litho track tool, process variables such as process speed, oven temperature, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated during testing.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires that specific input and output data sets be monitored during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

For DUV litho track tools, the following *inputs* should be monitored, regardless of process configuration:

- Oven temperature
- Ambient temperature
- Exhaust flow
- Relative humidity factor
- Ammonia concentration
- Barometric pressure

The following *outputs* should be measured, regardless of process configuration:

- Resist thickness
- Resist uniformity
- CD uniformity

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide detailed guidance for planning or performing the marathon test element, since sufficient detail is provided in the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For DUV litho track tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as the results of the demonstration test.

Metric	Units
Resist Thickness	µm
Coating uniformity total variability (3σ)	%
Develop uniformity total variability (3σ)	%
Bake uniformity total variability (3σ)	%
Edge bead removal (EBR) delta radius	mm
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following cost performance parameters should be collected, evaluated, and published as the results of the demonstration test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements; all results should be published in the final test report. For DUV litho track tools, the additional metric and data requirements are summarized in Table 5.

Table 5 Additional Metrics and Data for DUV Litho Track Tools

Parameter	Measurement Method	Gauge	Units
Track environment	Air sampling/analysis	TBD	TBD
Wafer surface contact angle	Optical inspection	Microscope	Degree

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For DUV litho track tools, the process-dependent detail is provided for each type of dedicated process module. This allows the proper component data to be selected for the configuration to be tested. The complete set of recommended test metrics for this equipment class can be found in the I300I *180 nm Equipment Performance Metrics,* Tool 1.2.1. No specific test metrics have been established for the dedicated process modules.

ADHESION ENHANCEMENT MODULE

This dedicated process module is used to chemically enhance the wafer surface contact angle for greater resist adhesion.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA for this process module:

- Chemical concentration
- Chemical temperature
- Process chamber pressure
- Exhaust flow

The following additional *output* parameter should be measured during the PDC and SA for this process module:

- Resist adhesion

RESIST/ARC COATER MODULE

This module is used to apply a coating of photoresist or ARC to the wafer surface.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA for this process module:

- Module environment temperature
- Wafer temperature
- Resist temperature
- Shot size or resist volume
- Spin speed
- Exhaust flow

The following additional *output* parameters should be measured during the PDC and SA for this process module:

- Film thickness
- Film uniformity

BAKE PLATE MODULE

The bake plate module performs two heated resist-curing processes: a pre-expose bake and a post-expose bake process.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA for this process module:

- Pre-expose bake temperatures
- Post-expose bake temperatures
- Temperature control

The following additional *output* parameters should be measured during the PDC and SA for this process module:

- Film uniformity
- Film thickness

DEVELOP MODULE

This module provides a chemical etch that develops the exposed photo image in photoresist.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA for this process module:

- Chemical concentration
- Chemical temperature
- Chemical to rinse time
- Exhaust flow
- Relative humidity (RH) factor
- Barometric pressure
- Ammonium concentration
- Ambient temperature
- Time between exposure and PEB

The following additional *output* parameters should be measured during the PDC and SA for this process module:

- Critical dimension
- Across wafer critical dimension uniformity

EQUIPMENT CLASS 2.1: PLASMA ETCH

Plasma etch tools are used to anisotropically etch a wafer surface. These tools use high frequency broadcast energy (typically radio frequency [RF]) to excite selected process gases introduced into the process chamber to create the plasma environment. Tools in this class include direct and downstream plasma source configurations. They are often cluster tools that can accommodate modules of other dedicated processes.

A plasma etch tool should have an electrostatic chuck (ESC) and should be capable of auto endpoint and in situ chamber cleaning. The following processes are performed on these tools:

- Poly etch
- Metal etch
- Oxide etch
- Nitride etch

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when performing demonstration testing on plasma etch tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for demonstration testing. Table 6 identifies the measurements and gauges required for performing a demonstration test on a plasma etch tool. Table 6 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 6 Gauges and Measures for Plasma Etch Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥ 0.12 ≥ 0.09	count/cm^2 size in µm	10%	SPC
Patterned wafer defect detection	Optical/SEM image signal processing	≥ 0.12 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TBD	<$1x10^{10}$	atoms/cm^2	10%	SPC
Transparent film thickness	Ellipsometer/reflectometer	50–50K	Å	10%	SPC
Film thickness	Profilometer	0–6K	Å	10%	SPC
Critical dimension	SEM	<0.18	µm	10%	SPC
Defect inspection	Optical /SEM	TBD	nm	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for plasma etch tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For plasma etch tools, a machine cycle is comprised of the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. If a normal process of the tool includes sequential processing in more than one chamber, the MDC should mimic the normal process flow. For single-wafer processing tools in this class, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC on a plasma etch tool, process variables such as RF power, pressure, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise noted, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following additional *input* parameters should be monitored during the PDC and sensitivity analysis, regardless of process:

- RF power
- Process pressure
- Gas flow
- Temperature

The following additional *output* parameters should be measured during the PDC and sensitivity analysis, regardless of process:

- Etch rate
- Etch uniformity
- Profile
- Selectivity
- Plasma damage
- Aspect ratio
- Microloading

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide detailed information or guidance for planning or performing the marathon test element, since sufficient detail is included in the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For plasma etch tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Critical dimension	µm
CD control (3σ)	%
CD bias	µm
Aspect ratio (logic)	ratio
Aspect ratio (DRAM)	ratio
Etch rate	nm/min
Etch uniformity, total variability (3 σ)	%
Selectivity	ratio
Contact profile	degrees
Metallic contamination	TBD
"In film" defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
"On bare Si" defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of ownership	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For plasma etch tools, the additional metric and data requirements are summarized in Table 7.

Table 7 Additional Metrics and Data for Plasma Etch Tools

Parameter	Measurement Method	Gauge	Units
Gate damage	Charge damage on plasma damage monitor	PDM	TBD
Metal corrosion	Visual detection	SEM/Microscope	N/A

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For plasma etch tools, this process-dependent information is provided below.

OXIDE ETCH

The oxide plasma etch process anisotropically etches the thin and thick oxide layer.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

No additional *input* parameters are recommended for the PDC and SA of this process.

The following additional *output* parameters should be measured for this process module during PDC and SA:

- Selectivity to resist
- Selectivity to poly and silicide

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 2.1.1.

POLY ETCH

The poly plasma etch process anisotropically etches the poly layer.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

No additional *input* parameters are recommended for monitoring during the PDC and SA for this process module.

The following additional *output* parameters should be monitored during PDC and SA of this process module:

- Selectivity to resist
- Selectivity to oxide
- Oxide loss

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 2.1.2.

METAL ETCH

The metal plasma etch process anisotropically etches various metal layers.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

No additional *input* parameters recommended for monitoring during the PDC and SA for this process module.

The following additional *output* parameters should be monitored during PDC and SA of this process module:

- Selectivity to resist
- Selectivity to oxide
- Selectivity to TiN
- Oxide loss

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 2.1.3.

EQUIPMENT CLASS 2.2: ASHER

Asher tools use a plasma environment to remove photoresist or organic ARC from the wafer surface. These tools use high frequency broadcast energy (typically microwave or RF) to excite selected process gases introduced into the process chamber to create the plasma environment. Asher tools can be configured for either batch or single-wafer processing.

An asher tool must have auto endpoint, the option of electrostatic chuck, and control of the temperature of the process chamber. Asher tools perform the following processes:

- Resist removal
- Organic ARC removal

Implementing the Demonstration Test Method (DTM)

GAUGE STUDIES

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when performing demonstration tests on asher tools.

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for demonstration testing. Table 8 identifies the measurements and gauges required for performing a demonstration test on an asher tool. Table 8 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 8 Gauges and Measures for Asher Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥ 0.12 ≥ 0.09	count/cm^2 size in µm	10%	SPC
Metallic contamination	TBD	<1x10^{10}	atoms/cm^2	10%	SPC
Transparent film thickness	Ellipsometer/reflectometer	0–30k	Å	10%	SPC
Defect inspection	Microscope/SEM	TBD	nm	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of a tool without the complexity of processing. To perform the right type of testing for asher tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For asher tools configured for single-wafer processing, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

For asher tools configured for batch processing, a machine cycle is comprised of the complete pod-to-pod transfer of a complete batch. Each wafer in the batch is transferred through all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For a batch tool, the number of machine cycles is equal to the total number of wafers cycled divided by the number of wafers per batch. The goal for number of batches or machine cycles to be tested should be based on the mean wafers between interrupts (MWBI) goal and on the level of statistical confidence needed.

When performing an MDC test on an asher tool, process variables such as RF power, gas flow, process pressure, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM § 6.3 through §7.1.2) requires that specific input and output data sets be monitored during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were found to be significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

For asher tools, the following *inputs* should be monitored, regardless of process configuration:

- RF power
- Process pressure
- Gas flow
- Chamber temperature

For asher tools, the following *outputs* should be measured, regardless of process configuration:

- Ash rate
- Ash uniformity
- Selectivity

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For asher tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Ash rate	µm/min.
Ash uniformity total variability (1σ)	%
Selectivity (to all but resist)	ratio
CV shift	to reference
Metallic contamination	atoms/cm^2
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For asher tools, the additional metric and data requirements are summarized in Table 9.

Table 9 Additional Metrics and Data for Asher Tools

Parameter	Measurement Method	Gauge	Units
Plasma damage	Charge damage on plasma damage monitor	PDM	TBD
CV shift	CV plot	Oscilloscope	To reference

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For asher tools, there is no significant process-dependent detail for the processes supported. The complete set of I300I test metrics and recommended goals for these tools can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 2.2.1.

EQUIPMENT CLASS 3.1: RAPID THERMAL PROCESS – SINGLE-WAFER

Single-wafer rapid thermal processors perform a variety of thermal deposition and treatment processes using temperature and selected process gases. The range of operating temperatures is typically between 600°C and 1000°C, with a maximum temperature capability of 1400°C. Single-wafer rapid thermal processors can be configured for low- or near-atmospheric pressure processing.

Single-wafer rapid thermal processors should provide ambient control of O_2/moisture, and they typically perform the following processes:

- Source-drain anneal
- Implant drive-in
- Oxide deposition

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing single-wafer rapid thermal processors.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for demonstration testing. Table 10 identifies the measurements and gauges required for performing a demonstration test on a single-wafer rapid thermal processor. Table 10 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 10 Gauges and Measures for Rapid Thermal Processors – Single-Wafer

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TXRF	<2.00E+10	atm/cm^2	10%	SPC
Film stress	Bow	1E^7–1E^{11}	dynes/cm^2	10%	SPC
Slip	Light decolumnation	0–5	#/mm	10%	SPC
Crystal defect inspection	SEM	—	nm	10%	SPC
Sheet resistance	4-point probe	TBD	Ω/☐	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for single-wafer rapid thermal processors, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For single-wafer rapid thermal processors, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For the single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC on a single-wafer rapid thermal processor, process variables such as temperature, gas flow, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires the monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

For single-wafer rapid thermal processors, the following inputs should be monitored, regardless of process configuration:

- Temperature
- Temperature control
- Gas flow
- Process pressure
- Ramp rate

The following outputs should be measured, regardless of process configuration:

- Uniformity
- Stress
- Crystal defects
- Slip
- Particles

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For single-wafer rapid thermal processors, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Temperature control	°C
Uniformity	%
Metallic contamination	TBD
Ramp rate	°C/sec
Crystal defects	$\#/cm^2$
Slip	count/mm
Stress	$dynes/cm^2$
“In film” defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
“On bare Si” defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
“Backside on Si” defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	Wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members.

Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For single-wafer rapid thermal processors, the additional metric and data requirements are summarized in Table 11.

Table 11 Additional Metrics and Data for Rapid Thermal Processors – Single Wafer

Parameter	Measurement Method	Gauge	Units
Slip free processing @ max. temp	Light decolumnation	Slip	#/mm

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For single-wafer rapid thermal processors, the following additional guidance is provided to deal with the technical challenge of source-drain anneal.

SOURCE-DRAIN ANNEAL

The wafer surface is thermally annealed to remove crystal defects following ion implantation.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

There is one additional input parameter to monitor for the PDC and SA for this process module:

- Ambient/O_2/moisture

There is one additional output parameter to measure for the PDC and SA for this process module:

- Thermal dose

EQUIPMENT CLASS 3.2: ATMOSPHERIC THERMAL PROCESS

Atmospheric thermal processors use temperature, near atmospheric pressure, and selected processes to grow a layer on the wafer surface. The range of operating temperatures is typically between 450°C and 1150°C, with a maximum temperature capability of 1200°C. Tools in this class either process multiple wafers simultaneously in a common environment or they process wafers one at a time. Batch sizes for the multiple wafer processing tools generally range from 50 to 100 wafers. Most of these tools have vertically oriented process chambers, but horizontal configurations are also available.

An atmospheric thermal batch processor is likely to include work in progress (WIP) stocking and some inventory management. These tools perform the following processes:

- Dry oxidation
- Wet oxidation
- Chlorine enhanced oxidation
- Implant drive-in
- Anneal

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when performing demonstration tests on atmospheric thermal processors.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. Table 12 identifies the measurements and gauges required for performing a demonstration test on an atmospheric thermal process batch tool. Table 12 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 12 Gauges and Measures for Atmospheric Thermal Processors

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TXRF	<2.00E+10	atm/cm^2	10%	SPC
Film thickness	Ellipsometer/reflectometer	50–3000	Å	10%	SPC
Film uniformity	Ellipsometer/reflectometer	3%	%	10%	SPC
Slip	Light decolumnation	0 to 5	#/mm	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for atmospheric thermal processors, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For atmospheric thermal batch processors, a machine cycle comprises the complete pod-to-pod transfer of a complete batch of wafers. Each wafer in the batch is transferred through all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For a batch tool, the number of machine cycles is equal to the total number of wafers cycled divided by the number of wafers in a batch. The goal for the number of batches or machine cycles to be tested should be based on the MWBI goal and on the statistical confidence level needed.

For atmospheric thermal single-wafer processors, a machine cycle is comprised of the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For the single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC on an atmospheric thermal process batch tool, process variables such as temperature setpoints, gas flow, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through § 7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for the PDC and sensitivity analysis since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following inputs should be monitored for these tools, regardless of process configuration:

- Temperature
- Temperature control
- Gas flow
- Ramp rate

The following outputs should be measured:

- Film thickness
- Film uniformity
- Growth rate
- Slip
- Particles

MARATHON TEST

The I300I *Demonstration Test Method* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For the atmospheric thermal batch processors, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Film thickness	Å
Film uniformity (total variability, 3 σ)	%
Slip	#, mm
Deposition temperature	°C
Temperature control	°C
"In film" defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
"On bare Si" defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	Wafer
Mean cycles between interrupts (MCBI)	Cycles
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For atmospheric thermal processors, the additional metric and data requirements are summarized in Table 13.

Table 13 Additional Metrics and Data for Atmospheric Thermal Processors

Parameter	Measurement method	Gauge	Units
Ramp rates	In situ thermocouple	Thermocouple	°C/min.
Temperature overshoot	In situ thermocouple	Thermocouple	°C
Temperature delta across the wafer (DT)	In situ wafer temperature measurements	Thermocouple, TC wafer	°C
Metallic contamination	TBD	TBD	TBD
Slip	Optical inspection	Light decolumnation	count size-mm

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance is required for particular processes or technological challenges that are unique to those classes. For atmospheric thermal processors, the complete set of I300I test metrics and recommended goals can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.2.1. The following additional guidance is provided for dry oxidation and wet oxidation process modules.

DRY OXIDATION

This high temperature process uses oxygen to grow both thin and thick oxide layers.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored for the PDC and SA for this process:

- Ambient environment (loading)
- Chamber loading temperature

There are no additional *output* parameters to monitor for the PDC and SA for this process.

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.2.1.

WET OXIDATION

This high temperature oxide process uses steam as the source of oxygen.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

There is one additional *input* parameter to monitor for the PDC and SA for this process:

- Water vapor partial pressure

There are no additional output parameters to measure for the PDC and SA for this process.

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.2.1.

EQUIPMENT CLASS 3.3: LPCVD THERMAL PROCESS

Low pressure chemical vapor deposition (LPCVD) thermal processors use temperature, low pressure, and selected process gases to deposit a film on the wafer surface. These tools usually operate in pressure regimes of 1mTorr to 1000 mTorr and within a temperature range of 450°C and 800°C. Tools in this class either process multiple wafers simultaneously in a common environment or they process wafers one at a time. Batch sizes for multiple-wafer processing tools typically range from 25 to 100 wafers. Most LPCVD thermal processors have vertically oriented process chambers but some have horizontal configurations.

An LPCVD thermal batch processor is likely to include work in progress (WIP) stocking and some inventory management capabilities. LPCVD thermal processors perform the following processes:

- Poly-crystalline silicon deposition
- Doped poly-crystalline silicon deposition
- Amorphous silicon deposition
- Silicon-nitride deposition
- TEOS-based SiO_2 deposition

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing LPCVD thermal processors.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will used for the demonstration test. Table 14 identifies the measurements and gauges required to perform a demonstration test on an LPCVD thermal batch processor. Table 14 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 14 Gauges and Measures for LPCVD Thermal Processors

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Film thickness	Ellipsometer/reflectometer	1000–3000	Å	10%	SPC
Film uniformity	Ellipsometer/reflectometer	3%	%	10%	SPC
Doping concentration	FTIR	0–3	wt%	10%	SPC
Slip	Light decolumnation	0–5	#/ mm	10%	SPC
Film stress	Bow	1E^7–1E^{11}	dynes/cm^2	10%	SPC
Temperature	Thermocouple	200–1200	°C	10%	SPC
Metallic contamination	TXRF	<2.00E+10	atm/cm^2	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing LPCVD thermal processors, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method. There are two machine cycle definitions for this class.

Defining a Cycle

For LPCVD thermal batch processors, a machine cycle comprises the complete pod-to-pod transfer of a complete batch of wafers. Each wafer in the batch is transferred through all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For a batch tool, the number of machine cycles equals the total number of wafers cycled divided by the number of wafers in a batch. The goal for the number of batches or machine cycles to be tested should be based on the mean wafers between interrupts (MWBI) goal and on the statistical confidence level needed.

For the LPCVD thermal single-wafer processors, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For the single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC of a LPCVD thermal batch processor, process variables such as temperature setpoints, pressure setpoints, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following inputs should be monitored for LPCVD thermal processors, regardless of process configuration:

- Temperature
- Temperature control
- Gas flows
- Process pressure
- Wafer spacing
- Wafer preparation

The following *outputs* should be measured for LPCVD thermal processors, regardless of process configuration:

- Film thickness
- Film uniformity
- Film stress
- Slip
- Step coverage
- Particles

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included in the DTM and the methodology for marathon testing is the same for all equipment classes.

Test Metrics

For the LPCVD thermal batch processors, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Film thickness	Å
Film uniformity (total variability 3 σ)	%
Slip	count, length in mm
Stress	dynes/cm^2
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	Wafer
Mean cycles between interrupts (MCBI)	Cycles
Mean time to repair (MTTR)	Hours
Preventative maintenance	Hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For LPCVD thermal processors, the additional metric and data requirements are summarized in Table 15.

Table 15 Additional Metrics and Data for Class 3.3

Parameter	Measurement Method	Gauge	Units
Ramp rates	In situ thermocouple	Thermocouple	°C/min.
Temp delta across the wafer (ΔT)	In situ wafer temperature measurements	Thermocouple, TC wafer	°C
Temp. overshoot	In situ thermocouple	Thermocouple	°C

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technical challenges that are unique to those classes. The following additional guidance is provided for undoped TEOS and doped poly-crystalline silicon process modules.

UNDOPED TEOS

This high temperature process uses evaporated tetraethylorthosilicate (TEOS) as a precursor to the deposition of oxide (SiO_2).

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.3.1.

DOPED POLY-CRYSTALLINE SILICON

This mid-range temperature process is based on the decomposition of silane and the introduction of a doping agent.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

No additional *inputs* are recommended for monitoring during the PDC and SA for this process.

The following *output* parameters should be measured for the PDC and SA for this process:

- Dopant concentration
- Dopant uniformity

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.3.2.

EQUIPMENT CLASS 3.4: ION IMPLANTATION

Ion implanters are used to implant doping agents into the wafer surface by creating ionic species that are delivered by ion beam in a low pressure environment. These tools use high voltage ranges typically KeV to MeV and pressure regimes of $1E^{-6}$ mTorr to $1E^{-11}$ mTorr. Tools in this class typically have single-wafer process configurations.

Ion implanters perform the following processes:

- Medium current arsenic implantation
- High current arsenic implantation
- High energy phosphorous implantation
- Low energy boron implantation

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing ion implanters.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. Table 16 identifies the measurements and gauges required for performing a demonstration test on an ion implanter. Table 16 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 16 Gauges and Measures for Ion Implanters

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect detection (unpatterned)	Laser scattering	≥0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TXRF	<5.00E+10	atm/cm^2	10%	SPC
Doping profile	SIMS	TBD	depth in: nm concentration: atoms/cm^3	10%	SPC
Sheet resistance	4 point probe	TBD	Ω/☐	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for ion implanters, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For ion implanters, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For the single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC of an ion implanter, process variables such as process pressure, beam current, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, the parameters are assumed to be the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for ion implanters, regardless of process configuration:

- Beam energy
- Process pressure
- Arc current
- Filament current
- Beam turning and calibration
- Tilt/twist

The following *outputs* should be measured for ion implanters, regardless of process configuration:

- Sheet resistance
- Uniformity
- Doping profile
- Mass resolution

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide detailed information or guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For the ion implanters, two kinds of test metrics characterize the performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Doping profile	nm & atoms cm^3
Dose uniformity (total variability 3 σ)	%
Dose repeatability (total variability 3 σ)	%
Sheet resistance	Ω/☐
Metallic contamination	TBD
"In film" defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
"On bare Si" defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	wafer
Mean cycles between interrupts (MCBI)	cycles
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For ion implanters, the additional metric and data requirements are summarized in Table 17.

Table 17 Additional Metrics and Data for Ion Implanters

Parameter	Measurement Method	Gauge	Units
Dose purity parameters	Tool history files	Not applicable	TBD
Beam current parameters	Tool history files	Not applicable	kV/ma
Set-up time parameters	Tool history files	Not applicable	min.
Measure high tilt	Measure of maximum implant angle	Not applicable	degrees
Resist and wafer blanket tests	TBD	TBD	TBD

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For ion implanters, the following additional guidance is provided for medium current implantation, high current implantation, and MeV implantation

MEDIUM CURRENT IMPLANTATION

Tools configured for running this process have an energy range of 5 KeV to 250 KeV and a dose range of $1E^{10}$ to $1E^{15}$ ions/cm^2, and they must be capable of a 200 wafer-per-hour mechanical throughput.

Process Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.4.1.

HIGH CURRENT IMPLANTATION

Tools for this process have an energy range of 2 KeV to 180 KeV and a dose range of $1E^{11}$ to $1E^{16}$ ions/cm^2, and they must be capable of a 200 wafer-per-hour mechanical throughput.

Process Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.4.2.

MEV IMPLANTATION

Tools for this process have an energy range of 20 KeV to 1600 KeV and a dose range of $1E^{11}$ to $1E^{15}$ ions/cm^2, and they must be capable of 200 wafer per hour mechanical throughput.

Process Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 3.4.3.

EQUIPMENT CLASS 4.1: WET CLEANS – BATCH

Wet clean batch tools are used for wafer cleaning and surface preparation by applying acid, caustic, or solvent solutions to the wafer surface. These tools process multiple wafers simultaneously in a common environment, with a batch size that ranges from 10 to 100 wafers.

Wet clean batch tools have integrated wafer rinse and isopropyl alcohol (IPA) drying capabilities. These tools are able to control the temperature and concentration of chemical solutions. Wet clean batch tools perform the following processes:

- Diffusion pre-clean
- Nitride etch
- Oxide etch
- Resist strip
- Post-chemical mechanical polish (CMP) clean
- Solvent clean
- Metal strip

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing wet clean batch tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. Table 18 identifies the measurements and gauges required for performing a demonstration test on a wet clean batch tool. Table 18 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 18 Gauges and Measures for Wet Cleans Batch Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥ 0.09 ≥ 0.12 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TXRF/ICPMS	<5.00E+10	atm/cm^2	10%	SPC
Etch rate	Ellipsometer/reflectometer	TBD	Å/min.	10%	SPC
Etch uniformity	Ellipsometer/reflectometer	1–100	%	10%	SPC
Surface roughness	Reflectometer	1–100	%	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for wet clean batch tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For wet clean batch tools, a machine cycle comprises the complete pod-to-pod transfer of a complete batch of wafers. Each wafer in the batch is transferred through all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For a batch tool, the number of machine cycles equals the total number of wafer cycles divided by the number of wafers in a batch. The goal for the number of batches or machine cycles to be tested should be based on the mean wafers between interrupts (MCBI) goal and on the statistical confidence level needed.

The number of cycles required for an MDC is equal to the number of cycles that will be run for the marathon. However, when performing an MDC of a wet clean batch tool, process variables such as temperature setpoints, process chemical concentration, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for wet clean batch tools, regardless of process configuration:

- Chemical concentration
- Temperature
- Chemical to rinse time
- Recirculation flow rate

The following outputs should be monitored for wet clean batch tools, regardless of process configuration:

- Etch rate
- Etch uniformity
- Surface roughness
- Selectivity

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included in the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For wet clean batch tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Etch rate	Å/min.
Etch Uniformity	%
Surface roughness	%
Metallic contamination	TBD
Selectivity	ratio
"In film" defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
"On bare Si" defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$
"On bare Si" defects per-wafer-pass @ 0.12 µm	$\#/cm^2$

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean cycles between interrupts (MCBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified,, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For wet clean batch tools, the additional metric and data requirements are summarized in Table 19.

Table 19 Additional Metrics and Data for Wet Cleans Batch Tools

Parameter	Measurement Method	Gauge	Units
CMP particulate	Unpatterned wafer defect detection after brush clean operation on a CMP wafer	Laser scattering	count and size in µm
Chemical temperature	Thermocouple	Thermocouple	°C

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance is required for particular processes or technological challenges that are unique to those classes. The following additional guidance is provided for diffusion pre-clean and post-CMP oxide processes.

DIFFUSION PRE-CLEAN

The chemical cleaning and surface preparation typically occur before a critical diffusion process.

Process Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 4.1.1.

POST-CMP OXIDE

This is a chemical clean performed after a CMP oxide process step.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

No additional *inputs* are recommended for the PDC and SA of this process.

The following *output* parameter should be monitored for the PDC and SA for this process:

- Remaining oxide film thickness

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 4.1.2.

EQUIPMENT CLASS 4.2: WET CLEANS – SINGLE-WAFER

Single-wafer wet cleans tools are used for wafer cleaning and surface preparation by applying acid, caustic, or solvent solutions to the wafer surface. These tools provide single-wafer processing in standalone or cluster configurations. They have integrated control of both temperature and chemical concentration of chemical solutions as well as integrated wafer rinsing and drying capabilities. They perform the following processes:

- Diffusion pre-clean
- Nitride etch
- Oxide etch
- Resist strip
- Post-CMP clean
- Solvent clean
- Metal strip

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing single-wafer wet cleans tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. Table 20 identifies the measurements and gauges required for performing a demonstration test on a single-wafer wet clean tool. Table 20 also provides guidance about the expected range of measurements to be supported the P/T ratio requirements for each gauge.

Table 20 Gauges and Measures for Wet Cleans – Single Wafer

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Unpatterned wafer defect detection	Laser scattering	≥ 0.09 ≥ 0.12 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TBD	TBD	TBD	10%	SPC
Etch rate	Ellipsometer/reflectometer	TBD	Å/min.	10%	SPC
Etch uniformity	Ellipsometer/reflectometer	4	%	10%	SPC
Film thickness	Ellipsometer/reflectometer	TBD	Å	10%	SPC
Surface roughness	Reflectometer	1–100	%	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for a single-wafer wet cleans tool, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For single-wafer wet cleans tools, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC on the single-wafer wet clean tool, process variables such as temperature, process chemicals, concentrations, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and sensitivity analysis, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the sensitivity analysis is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for single-wafer wet clean tools:

- Chemical concentration
- Temperature
- Chemical to rinse time

The following outputs should be measured for single-wafer wet clean tools:

- Etch rate
- Etch uniformity
- Surface roughness
- Selectivity

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included in the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For single-wafer wet clean tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Etch rate	Å/min
Etch uniformity (total variability 3 σ)	%
Metallic contamination	TBD
“In film” defects per-wafer-pass @ 0.20 µm	#/cm^2
“On bare Si” defects per-wafer-pass @ 0.09 µm	#/cm^2
“Backside on Si” defects per-wafer-pass @ 0. 20 µm	#/cm^2
“On bare Si” defects per-wafer-pass @ 0.12 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	Wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For single-wafer wet clean tools, the additional metric and data requirements are summarized in Table 21.

Table 21 Additional Metrics and Data for Wet Cleans – Single Wafer

Parameter	Measurement Method	Gauge	Units
CMP particulate	Unpatterned wafer defect detection after brush clean operation	Laser scattering	count size µm
Chemical temperature	Thermocouple	Thermocouple	°C

Working with Technology and Process-Dependent Considerations

For certain classes of equipment, additional guidance is required for particular processes or technological challenges that are unique to those classes. The following additional guidance is provided for the post-CMP clean (brush) process.

POST-CMP CLEAN (BRUSH)

A chemical clean using a surface contact mechanism (usually a brush) is performed after CMP.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA for this process:

- Brush spin speed
- Wafer spin speed
- Brush down pressure

The following additional *output* parameter should be monitored during the PDC and SA for this process:

- Remaining oxide film thickness

Process-Specific Performance Parameters

The post-CMP clean process has different requirements within the context of this class because of the nature of the process result. The following table represents the recommended metrics for this application.

Metric	Units
Oxide integrity	TBD
Surface roughness	%
Scratches (µ inch level of detection)	count
"In film" defects per-wafer-pass @ 0.12 µm	$\#/cm^2$
"In film" defects per-wafer-pass @ 0.2 µm	$\#/cm^2$

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 4.2.1.

EQUIPMENT CLASS 5.1: METROLOGY

Metrology tools are used to measure and evaluate the output of other process tools, and they perform a wide range of analytical measurements. These tools are usually single-wafer (or sample) processes that include configurations for automated or manual loading and operation. Tools in this class can be categorized into two sub-classes based on the percentage of the wafer or sample measured. Full scan tools measure 100% of the sample/wafer surface. Low density tools sample a defined number of locations or measurements per sample/wafer. Both destructive and non-destructive measurement tools are included in this class as well. Table 22 provides a representative cross-section of the metrology applications, techniques, and units of measure.

Table 22 Metrology Applications

Application	Metrology Technique	Units
Overlay	Optical verification	nm
Critical dimension	SEM	nm
Defect detection (patterned)	Optical comparison, Laser scattering	count/size - µm
Defect detection (unpatterned)	Laser scattering	count/size - µm
Defect identification review and classification	Optical, SEM (defect review)	defect size/type
Transparent film thickness	Ellipsometer or reflectometer	Å, nm
Opaque film thickness	Acoustic/optical	Å, nm
Film reflectivity	Reflectometer	%
Slip detection	Optical decolumnation	count/mm
Surface roughness	Total integrated light scattering	%
Surface profile	Optical slope, mechanical stylist, or AFM	Å, nm
Doping profile	SIMS	doping depth: nm concentration: atoms/cm^3
Dopant and oxygen concentration	FTIR	weight %
Metal thickness and resistivity	4-point probe	Ω/☐
Film stress	Contact and non-contact (for bow)	dynes/cm^2
Surface contamination	TXRF SCA	atoms/cm^2 Q_{ox} and T_s
Minority carrier lifetime	Micro photo conductive decay Surface photo voltage	charge per cm^2
Optical inspection	Microscope	classification

Table 22 is not meant to be exhaustive. It is intended to provide a representative cross section of the different categories of metrology measurement tools and applications.

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing metrology tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. For the metrology equipment class, this includes metrology tools and standards. Reference and transfer standards that are traceable to a primary standard are accepted as having a de facto completed gauge study and documentation of the source and certification meet the DTM requirements. When a standard does not exist, artifacts of a product type or archive reference samples may be used with adequate data and documentation.

Table 23 provides the common gauges required for performing a demonstration test on a metrology tool. If there is adequate proof of a previous gauge study that satisfies the range requirements of the proposed test and if the gauge has been under valid statistical process control (SPC) since that gauge study, then another gauge study need not be performed. Table 23 provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 23 Gauges and Measures for Metrology Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Unpatterned wafer defect detection	Laser scattering	≥ 0.12 ≥ 0.2	count/cm^2 size in μm	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of a tool without the complexity of processing. To perform the right type of testing for metrology tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For metrology tools, a machine cycle comprises the complete pod-to-pod automated or manual transfer of a wafer/sample, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC on a metrology tool, process variables such as process pressure, vibration, light intensity, temperature, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated during the testing.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for metrology tools, regardless of configuration:

- Sample type
- Sample position
- Calibration
- Measurement recipe

The following *outputs* should be measured for metrology tools, regardless of process configuration:

- Accuracy
- Repeatability
- Reproducibility
- Stability

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For the metrology tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Accuracy	*
Repeatability (total variability 3σ)	*
Reproducibility	*
Precision to Tolerance ratio	ratio
Stability	*
"In film" defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
"On bare Si" defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$

* The unit of measure for these metrics will depend upon the type of metrology tool being tested. The appropriate units should be selected for each test.

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test and published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost Assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts (MWBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the test metrics collected during the MDC, PDC, and marathon test elements, other metrics or data can be collected during the test. Different approaches and techniques can be used to measure the same parameter. The approach, technique, and methods used in the test should be collected as additional data.

The final report should include an analysis of the following items:

- Measurement approach
- Technique
- Test and measurement methods
- Any significant data outputs

Working with Technology- and Process-Dependent Considerations

Below is guidance for testing particular processes or technological challenges associated with metrology tools.

INSPECTION WITH A SCANNING ELECTRON MICROSCOPE

A scanning electron microscope (SEM) is used for inspecting, reviewing, and classifying wafer defects. Tools for this process are capable of 15 kv maximum voltage, 60° sample tilt, and a maximum magnification >150,000 times.

Passive Data Collection (PDC)

The following *inputs* should be monitored during the PDC for this process:

- Operation parameters
- Stage tilt

The following *output* should be measured during the PDC for this process:

- Magnification

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Stage accuracy (including tilt and mechanical rotation)	µm
Resolution @ 1KV	nm

The complete set of I300I test metrics and recommended goals for this process can be found in the 180 nm *Equipment Performance Metrics*, Tool 5.1.1.

DEFECT DETECTION – UNPATTERNED WAFER

This process is used to detect defects on unpatterned wafers through laser scattering. Tools for this process are capable of detecting particles ranging from 0.06 µm to 100.0 µm. They are also capable of stage mapping and pre-alignment laser marking to identify the location of defects.

Passive Data Collection (PDC)

The following *input* should be monitored for the PDC for this process:

- Wafer type/haze level
- Measurement recipe

The following *outputs* should be measured for the PDC for this process:

- Count
- Particle size
- Detection limit
- False count

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Particle sensitivity @ 90% capture rate	µm
Total count reproducibility (3σ)	%
Haze sensitivity	ppm

The complete set of I300I test metrics and recommended goals for this process can be found in the *180 nm Equipment Performance Metrics*, Tool 5.1.2.

DEFECT DETECTION – PATTERNED WAFER

Two types of defect inspection tools for patterned wafers are included for this process: laser scatter and optical comparison. The inputs and outputs listed are identified for applicability to tool type.

Passive Data Collection (PDC)

The following *inputs* should be monitored during the PDC for this process:

- Defect type and size
- Magnification (optical comparison only)
- Lamp intensity (optical comparison only)
- Measurement recipe

The following *outputs* should be measured during the PDC for this process:

- Count
- Particle size
- Detection limit
- False count
- Classification/identification
- Classification rate

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Total count repeatability	%
Total count reproducibility	%
Bias (tool to tool)	%
False count rate	%
Coordinate accuracy	µm
Sensitivity	µm
Accuracy	%
Repeatability	%
Classification/identification	%
Classification rate	Defect/sec

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 5.1.3.

CRITICAL DIMENSION – SCANNING ELECTRON MICROSCOPE (SEM)

A SEM is used to measure critical dimensions of wafer features. Tools for this process can measure from 130 nm to 2000 nm and have integrated pattern recognition capabilities.

Passive Data Collection (PDC)

The following *inputs* should be monitored during the PDC for this process:

- Beam current
- Acceleration voltage
- Process pressure
- Measurement recipe

The following *outputs* should be measured during the PDC for this process:

- Resolution
- Magnification
- CD

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Reproducibility (total variability 3 σ)	nm
Pattern recognition errors	%

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 5.1.4.

OVERLAY REGISTRATION

Optical verification equipment is used to measure overlay error between vertically aligned recursive photolithographic patterns.

Passive Data Collection (PDC)

The following *inputs* should be monitored during the PDC for this process:

- Target design
- Magnification
- Lamp intensity
- Measurement recipe

The following *output* should be measured during the PDC for this process:

- Tool induced shift

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Pattern recognition errors (all layers)	%

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 5.1.5.

TRANSPARENT FILM THICKNESS

This process uses an optical analytical technique to measure transparent films. Tools for this process are capable of measuring refractive index, thickness, extinction coefficient, and stacked films.

When using these tools, the P/T ratio requirement of <10% is related to the base film thickness to be measured:

- For films ≤ 30 Å , use a T of 20% of the mean.
- For films > 30 Å and ≤ 1000 Å, use a T of 10% of the mean.
- For films > 1000 Å and ≤ 100,000 Å use a T of 2% of the mean.

Passive Data Collection (PDC)

The following *inputs* should be monitored during the PDC for this process:

- Wavelength of light
- Estimated film stack
- Measurement recipe

The following *outputs* should be measured during the PDC for this process:

- Thickness
- Refractive index (if required)
- Model fit (if required)

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Pattern recognition failure rate	%
Coordinate accuracy (x, y)	µm
MTBF	hours

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 5.1.6.

OPAQUE FILM THICKNESS

This process uses an optical analytical technique to measure opaque films. Tools for this process are capable of measuring density, thickness, of single layer or stacked films.

When using these tools, the P/T ratio requirement of <10% is related to the base film thickness to be measured:

- For films ≤ 30 Å, use a T of 20% of the mean.
- For films > 30 Å and ≤ 1000 Å, use a T of 10% of the mean.
- For films > 1000 Å and ≤ 100,000 Å, use a T of 2% of the mean.

Passive Data Collection (PDC)

The following *inputs* should be monitored during the PDC for this process:

- Wavelength of light
- Estimated film stack
- Measurement recipe

The following *outputs* should be measured during the PDC for this process:

- Thickness
- Density (if required)
- Model Fit (if required)

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Pattern recognition failure rate	%
Coordinate accuracy (x, y)	µm
MTBF	hours

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 5.1.7.

EQUIPMENT CLASS 6.1: METAL DEPOSITION – PLASMA VAPOR DEPOSITION (PVD)

Metal deposition plasma vapor deposition (PVD) tools use temperature, low pressure, selected process gases, and a plasma environment to deposit a metal film on the wafer surface. These tools usually operate at temperatures of between 25°C and 500°C, with a base vacuum capability of $1x10^{-8}$ Torr. Metal deposition PVD tools are predominantly single-wafer cluster tools.

A metal deposition PVD tool must have an integrated pre-deposition clean capability. These tools perform the following processes:

- Aluminum alloy deposition
- Titanium-nitride deposition
- Tungsten deposition
- Titanium-tungsten deposition
- Titanium deposition
- Copper deposition

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing metal deposition PVD tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. Table 24 identifies the measurements and gauges required for performing a demonstration test on a metal deposition PVD tool. Table 24 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 24 Gauges and Measures for Metal Deposition PVD Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect detection (unpatterned)	Laser scattering	≥ 0.09 ≥ 0.2	$count/cm^2$ size in µm	10%	SPC
Film thickness	4-point probe	0.01–2	µm	10%	SPC
Sheet resistance	4-point probe	$2–200E^{-6}$	Ω/☐	10%	SPC
Film stress	Bow	$1E^{7}–1E^{11}$	$dynes/cm^2$	10%	SPC
Film reflectivity	Reflectometer	0–100	%	10%	SPC
Step-coverage	SEM cross section	0–100	%	10%	SPC
Crystal orientation	XRD	<100>	intensity	N/A	N/A
Film composition	XRF/SIMS/ RBS	—	wt%	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for metal deposition PVD tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For metal deposition PVD tools, a machine cycle comprises the pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. If a normal process of the tool includes sequential processing in more than one chamber, the MDC should mimic the normal process flow. For single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC of a metal deposition PVD tool, process variables such as chamber pressure, temperature, and other process parameters not directly linked to the safe operation of the tool should not be set, monitored, or evaluated during the testing.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for metal deposition PVD tools, regardless of process configuration:

- Temperature
- Temperature control
- Gas flow
- Process pressure
- Plasma power
- Target-substrate spacing

The following outputs should be measured for metal deposition PVD tools, regardless of process configuration:

- Film thickness
- Film uniformity
- Reflectivity
- Etch rate (pre-clean)
- Etch uniformity
- Film composition
- Stress

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is provided in the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For the metal sputter PVD tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as the result of the demonstration test.

Metric	Units
Thickness	Å
Uniformity	%
Bottom hole contact coverage	%
Reflectivity	%
Stress	$dynes/cm^2$
Film composition	wt%
“In film” defects per-wafer-pass @ 0.20 µm	$\#/cm^2$
“On bare Si” defects per-wafer-pass @ 0.09 µm	$\#/cm^2$
“Backside on Si” defects per-wafer-pass @ 0. 20 µm	$\#/cm^2$

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as the results of the demonstration test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, testers may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For metal deposition PVD tools, the additional metric and data requirements are summarized in Table 25.

Table 25 Additional Metrics and Data for Metal Deposition PVD Tools

Parameter	Measurement Method	Gauge	Units
Sidewall coverage	SEM cross-section	SEM	%

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For the metal deposition PVD tools, there are currently no significant process-dependent considerations for demonstration testing. The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 6.1.1

EQUIPMENT CLASS 6.2: METAL DEPOSITION – CHEMICAL VAPOR DEPOSITION (CVD)

Metal deposition CVD tools use temperature, low pressure, and selected gases to deposit metal films on the wafer surface. These tools usually operate at temperatures between 25°C and 500°C, well below atmospheric pressure. Metal deposition CVD tools are usually single-wafer cluster tools.

A metal deposition CVD tool must have an integrated sputter etch capability. These tools perform the following processes:

- Tungsten deposition
- Titanium deposition
- Copper deposition
- Titanium-nitride deposition
- Aluminum alloy deposition

Implementing the Demonstration Test Method (DTM)

Below is detailed guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing metal deposition PVD tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration test. Table 26 identifies the measurements and gauges required for performing a demonstration test on a metal deposition CVD tool. Table 26 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 26 Gauges and Measures for Metal Deposition CVD Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥0.09 ≥0.2	count/cm^2 size in µm	10%	SPC
Film thickness	4-point-probe	15–600	nm	10%	SPC
Sheet resistance	4-point-probe	6–12E^{-6}	Ω/☐	10%	SPC
Stress	Bow	1E^7–1E^{11}	dynes/cm^2	10%	SPC
Surface roughness	Reflectometer	1–100	%	10%	SPC
Contact fill	SEM cross section	0–100	%	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing metal deposition CVD tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For metal deposition CVD tools, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. If a normal process of the tool includes sequential processing in more than one chamber, the MDC should mimic the normal flow of the process through the chambers. For single-wafer processing tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC of a metal deposition tool, process variables such as process pressure, temperature, gas flow, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated during the testing.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, one should assume that the parameters are the same for both the PDC and SA since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for metal deposition CVD tools, regardless of process configuration:

- Temperature
- Gas flow
- Pressure
- Shower head position

The following *outputs* should be measured for metal deposition CVD tools, regardless of process configuration:

- Film thickness
- Film uniformity
- Surface roughness
- Film composition
- Sheet resistance
- Stress

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For metal deposition CVD tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

The process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Film thickness	nm
Film uniformity (total variation 3 σ)	%
Sheet resistance	Ω/☐
Film composition	wt%
Stress	dynes/cm^2
Surface roughness	%
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

The cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For metal deposition CVD tools, the additional metric and data requirements are summarized in Table 27.

Table 27 Additional Metrics and Data for Metal Deposition CVD Tools

Parameter	Measurement Method	Gauge	Units
Very thin film uniformity	Film thickness measurements	4-point probe	μΩ/☐
Carbon, O_2 and Cl in film concentration	Analysis of deposited film	FTIR/ICPSIMS	wt%

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For metal deposition CVD tools, the following additional guidance is provided for tungsten deposition and titanium or titanium nitride deposition processes.

TUNGSTEN DEPOSITION

This is the chemical vapor deposition of tungsten films on a wafer surface.

Process-Specific Performance Parameters

These are process-specific metrics (in addition to the common metrics) to be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Resistivity	μΩ/☐
Contact fill (aspect ratio)	ratio

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 6.2.1.

TITANIUM OR TITANIUM-NITRIDE DEPOSITION

This is the chemical vapor deposition of titanium or titanium nitride, using a process that provides greater than 40% sidewall coverage on a wafer surface.

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Titanium and titanium-nitride bottom coverage	%
Titanium and titanium-nitride contact size	µm
Aspect ratio	ratio
Sheet resistance	Ω/☐
Sidewall coverage	%

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 6.2.2.

EQUIPMENT CLASS 7.1: DIELECTRIC – CHEMICAL VAPOR DEPOSITION (CVD)

Dielectric chemical vapor deposition (CVD) tools use temperature, low pressure, and selected process gases to deposit a thick dielectric film on the wafer surface. These tools may use a plasma environment (typically RF) in the process; they usually operate in pressure regimes from near atmospheric to mTorr and in temperatures of between 200°C and 500°C. Dielectric CVD tools are most often single-wafer cluster tools.

A dielectric CVD tool should have an electrostatic chuck and should be capable of auto endpoint and in situ chamber cleaning. These tools perform the following processes:

– O_3/TEOS deposition
– Phosphorus doped silicon glass
– Low dielectric constant materials
– Undoped silicon glass
– Boron/phosphorus doped silicon glass
– Fluorine doped oxide

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing dielectric CVD tools.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for the demonstration testing. Table 28 identifies the measurements and gauges required for performing a demonstration test on a dielectric CVD tool. Table 28 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 28 Gauges and Measures for Dielectric CVD Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect Detection (unpatterned)	Laser scattering	≥ 0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TBD	TBD	TBD	10%	SPC
Film Thickness	Reflectometer Ellipsometer	5–1000	nm	10%	SPC
Dopant Concentration (B, P)	FTIR	3–7	wt%	10%	SPC
Film Stress	Bow	1E^7–1E^{11}	dynes/cm^2	10%	SPC
Aspect Ratio	SEM	>0.2	µm	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for dielectric CVD tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For dielectric CVD tools, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. If a normal process of the tool includes sequential processing in more than one chamber, the MDC should mimic the normal process flow. For single-wafer processing tools in this class, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC of a dielectric CVD tool, process variables such as process reactor pressure, gas flow, temperature, and other process parameters not directly linked to the safe operation of the tool should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for dielectric CVD tools, regardless of process configuration:

- Process pressure
- Process temperature
- Gas flow
- Exhaust parameters

The following *outputs* should be measured for dielectric CVD tools, regardless of process configuration:

- Film thickness
- Film uniformity
- Film stress
- Dopant concentration and uniformity (boron, phosphorous, fluorine, ...)

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide detailed guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For dielectric CVD tools, two test metrics characterize performance: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metrics	Units
Film thickness	nm
Film thickness uniformity (total variability 3σ)	%
Step coverage	%
Film stress	dynes/cm^2
Gap fill	ratio
Gap spacing	nm
Metallic contamination	TBD
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Common cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For dielectric CVD tools, the additional metric and data requirements are summarized in Table 29.

Table 29 Additional Metrics and Data for Dielectric CVD Tools

Parameter	Measurement Method	Gauge	Units
Metallic contamination	TBD	TBD	TBD
Film shrinkage (after anneal)	Transparent film thickness	Reflectometer Ellipsometer	%
Step coverage	SEM cross section	Vertical SEM	%
Plasma damage	TBD	TBD	TBD

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For dielectric CVD tools, the following additional guidance is provided for atmospheric pressure chemical vapor deposition (APCVD) and sub-atmospheric pressure chemical vapor deposition (SACVD) for pre-metal deposition, high density plasma (HDP) gap-fill, and plasma enhanced chemical vapor deposition (PECVD) processes.

ATMOSPHERIC AND SUB-ATMOSPHERIC PRESSURE CVD FOR PRE-METAL DEPOSITION

APCVD and SAPVD use low temperature and selected process gases to deposit a variety of films including undoped silicon glass (USG), phosphorus doped silicon glass (PSG), and boron/phosphorus silicon glass (BPSG).

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored for the PDC and SA for this process:

- Base pressure (SACVD only)
- Plasma power (SACVD only)

The following additional *output* parameters should be measured for the PDC and SA for this process:

- Dopant uniformity
- Gap-fill

Process Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metrics	Units
B concentration	%
P concentration	$dynes/cm^2$
Defects after reflow	$count/cm^2$

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 7.1.1.

HIGH DENSITY PLASMA GAP-FILL

High density plasma (HDP) chemical vapor deposition uses a plasma environment, low temperature, and selected process gases to deposit a variety of films including USG, PSG, and FSG.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored for the PDC and SA for this process:

- Base pressure
- Plasma power

The following additional *output* parameter should be measured for the PDC and SA for this process:

- Gap fill

Process Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metrics	Units
Oxide film integrity	wt%

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 7.1.2.

PLASMA ENHANCED CHEMICAL VAPOR DEPOSITION (PECVD)

Plasma enhanced chemical vapor deposition (PECVD) uses a plasma environment, low temperature, and selected process gases to deposit a variety of films including tetraethelorthosilicate (TEOS), USG, PSG, and BPSG.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored for the PDC and SA for this process:

- Base pressure
- Plasma power

There are no additional *output* parameters to be measured for the PDC and SA for this process.

Process-Specific Test Metrics

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 7.1.3.

EQUIPMENT CLASS 8.1: CHEMICAL MECHANICAL PLANARIZATION (CMP)

CMP tools provide planarization of the wafer device surfaces by mechanical abrasion in a chemically active slurry. These tools must have the following capabilities: auto pad conditioning, in situ monitoring and control of thickness, and endpoint detection. They must also be capable of clustering with a post-CMP clean tool. CMP tools are typically configured for single-wafer processing; they perform the following processes:

- Oxide planarization
- Tungsten planarization
- Copper planarization

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* in testing this equipment class.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted on the metrology tools that will be used for demonstration testing. Table 30 identifies the measurements and gauges required for performing a demonstration test on a chemical mechanical planarization tool. Table 30 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 30 Gauges and Measures Chemical Mechanical Planarization Tools

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect detection (unpatterned)	Laser scattering	≥ 0.09 ≥ 0.2	count/cm^2 size in µm	10%	SPC
Metallic contamination	TBD	TBD	TBD	10%	SPC
Surface roughness	Total integrated light scattering	1-100	%	10%	SPC
Surface profile	Profilometer	0–1000	Å	10%	SPC
Transparent film thickness	Ellipsometer or reflectometer	100–2000	Å	10%	SPC
Film thickness (metal)	4 point probe	2,000-9,000	Å	10%	SPC
Sheet resistance	4 point probe	2-200E^{-6}	Ω/☐	10%	SPC
Film stress	Bow	1E^7–1E^{11}	dynes/cm^2	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing. To perform the right type of testing for CMP tools, operational considerations that affect the feasibility, extent, and specific sequencing of the tool must be reflected in the test method.

Defining a Cycle

For CMP tools, a machine cycle comprises the complete pod-to-pod transfer of a wafer, including all intermediate process stations. At each process station, as many mechanical functions as possible (without wafer processing) should be activated or cycled. For single-wafer processing CMP tools, the number of machine cycles is the same as the number of wafers cycled.

When performing an MDC of CMP tools, process variables such as platen and head rotational speed, setpoints, flow rate, and other process parameters not directly linked to the safe operation of the tools should not be monitored or evaluated.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and sensitivity analysis test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and sensitivity analysis, since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the sensitivity analysis is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for CMP tools, regardless of process configuration:

- Platen speed
- Head rotation rate
- Temperature
- Slurry flow rate
- Slurry type
- Wafer carrier film
- Pad type and condition

The following *outputs* should be measured for CMP tools, regardless of process configuration:

- Surface roughness
- Film thickness
- Film uniformity
- Edge profile

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide guidance for planning or performing the marathon test element, since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

Applying Test Metrics

For CMP tools, two types of test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

The process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Film removal rate	nm
Uniformity (total variability 3σ)	%
Surface roughness	%
Edge profile	TBD
Planarization rate	Å/min.
Head to head variation	%
"In film" defects per-wafer-pass @ 0.20 µm	#/cm^2
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

The cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as the results of the test.

Metric	Units
Throughput	wafers/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean wafer between interrupts	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members.

Any additional data must be collected during the demonstration testing. It should then be analyzed statistically using the same methods as those used with the standard test elements, and all results should be published in the final test report. For CMP tools, the additional metric and data requirements are summarized in Table 31.

Table 31 Additional Metrics and Data for Chemical Mechanical Planarization Tools

Parameter	Measurement Method	Gauge	Units
Cumulative removal rate	Removal rate (in relation to number of wafers processed)	Ellipsometer/reflectometer	Å/min per # wafers
Selectivity	Surface roughness (profile)	Ellipsometer/reflectometer	%
Dishing/cupping	Surface roughness (profile)	Profilometer	Å
Planarization rate	Surface roughness (profile)	Profilometer	Å/min
Scratches	Lowest level of detectable scratches	AFM	µ”

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance and detail are required for particular processes or technological challenges that are unique to those classes. For CMP tools, the following additional guidance is provided for oxide planarization and tungsten planarization.

OXIDE PLANARIZATION

This is planarization of interconnect dielectric oxides.

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Oxide removal to achieve ≤75 nm step height over 100 nm^2 bond pad	nm
Oxide to nitride selectivity	ratio

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 8.1.1.

TUNGSTEN PLANARIZATION

This is planarization of the tungsten film.

Process-Specific Performance Parameters

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Tungsten to oxide selectivity	ratio

The complete set of I300I test metrics and recommended goals for this process can be found in the I300I *180 nm Equipment Performance Metrics*, Tool 8.1.2.

EQUIPMENT CLASS 9.0: AUTOMATED MATERIAL HANDLING SYSTEMS

Automated material handling systems (AMHS) are integrated systems of individual tools for transporting, handling, storing, and tracking work in progress (WIP) materials. The individual components of AMHS can be broadly grouped into five functional categories, as summarized in Table 32.

Table 32 AMHS Categories

Transport	Storage	Control and Data Systems	Carriers	Integrated System
Interbay Overhead Monorail and Vehicle	Stocker	Interbay MCS	25-wafer FOUP	AMHS
Interbay AGV	Buffer	Intrabay MCS	13-wafer FOUP	—
Intrabay Overhead Monorail and Vehicle (hoist)	Load Port	RMS	Front Opening Shipping Box (FOSB)	—
Intrabay AGV	AGV (with stocker)	—	Reticle Carrying Pod (RCP)	—
Intrabay PGV	Reticle Stocker	—	Single Wafer Carrier (FOUPfor1)	—
Intrabay RGV	Reticle Stocker (for step/scan)	—	—	—
Inter Level Transport	Internal Step/Scan Reticle Buffer	—	—	—
Inter Building Transport	Wafer Sorter/Reader	—	—	—
Reticle Transport		—	—	—

Of the five functional categories of AMHS, only transport and storage categories are candidates for the application of the I300I *Demonstration Test Method – Revision 1*. Valid testing can be performed on an integrated AMHS configuration using the methodology, but it will be valid for that configuration only. The unique nature of each AMHS implementation precludes a standard set of goals and direction for testing. However, a method for projecting and determining system performance from the performance results of the individual tools is provided below (see the section on working with technology- and process-specific considerations [§3.16.4]). Control systems, software, and individual components have testing requirements different from electromechanical machine tools and, therefore, should not be evaluated using the DTM.

Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing tools in the AMHS equipment class.

GAUGE STUDIES

The I300I *Demonstration Test Method – Revision 1* (DTM §6.1) requires that a gauge study be conducted where applicable on the metrology tools that will be used for demonstration testing. Table 33 identifies the measurements and gauges required for performing a demonstration test on an AMHS. Table 33 also provides guidance about the expected range of measurements to be supported and the P/T ratio requirements for each gauge.

Table 33 Gauges and Measures for AMHS

Measurement	Gauge	Range	Unit	P/T Ratio	Stability
Defect detection (unpatterned)	Laser scattering	≥ 0.09	count/cm^2 size in µm	10%	SPC
Metallic contamination	TBD	TBD	TBD	10%	SPC
Vibration	Vibration analyzer, accelerometer	0.2–10K, 100 mV/G or 8 mV/MS^2	Hertz mV/G or mV/MS^2	10%	SPC
AMC (airborne molecular carbon)	SAW device, carbon badge	0–1.5	RF Volts	10%	SPC
Humidity	Humidity sensor	0–100	%	10%	SPC
Particles	Liquid particle counter (LPC)	≥ 0.09	#/ml	10%	SPC
Particles	Sniffer	≥ 0.09	count/cm^2 size in µm	10%	SPC
Electric field	Electrical field meter	10–100,000	Volts	10%	SPC

MECHANICAL DRY CYCLE (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC test be performed to quantify the mechanical performance of the tool without the complexity of processing.

Mechanical dry cycling guidance pertinent to each functional category can be found in the technology- and process-dependent considerations section (§3.16.4). In general, the requirement to exercise every mechanical function within the normal operational flow of a functional tool without the complexity of process should be maintained.

PASSIVE DATA COLLECTION (PDC) AND SENSITIVITY ANALYSIS (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.3 through §7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters will be the same for both the PDC and SA since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following *inputs* should be monitored for AMHS equipment, regardless of process configuration:

- Vibration
- Pod/carrier environment
- Electrostatic charge

The following *outputs* should be measured for AMHS equipment, regardless of process configuration:

- Wafer particulate level (AMC, PWP)
- Wafer vibration damage (stress induced issues such as wafer breakage, cross slotting, etc.)
- Wafer orientation (where applicable)

MARATHON TEST

The I300I *Demonstration Test Method – Revision 1* (DTM §7.2) requires that a marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide detailed guidance for planning or performing the marathon test element since sufficient detail is included within the DTM and the methodology for marathon testing is the same for all equipment classes.

One should note that all types of AMHS equipment are not candidates for marathon testing. Since the AMHS equipment class is primarily comprised of subsystem level designs, an MDC may be more applicable in many cases. For wafer sorters and overhead track designs, a marathon test is definitely applicable.

Applying Test Metrics

For AMHS equipment, two test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

PROCESS PERFORMANCE PARAMETERS

Process performance parameters are the parametric results of wafer processing. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
"On bare Si" defects per-wafer-pass @ 0.09 µm	#/cm^2
"Backside on Si" defects per-wafer-pass @ 0. 20 µm	#/cm^2

COST PERFORMANCE PARAMETERS

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the demonstration test. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Throughput	Wafers-boxes-FOUPs/hour
Tool capital cost assumption	$M
Mean time between failures (MTBFp)	hours
Mean cycles between interrupts (MCBI)	wafer
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	$/wafer pass
Area per tool	m^2
Support area per tool	m^2
Production utilization	%
Cost of Ownership (CoO)	$/wafer pass

Collecting Additional Metrics and Data

In addition to the metrics routinely collected during the MDC, PDC, SA, and marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during the demonstration testing. It should then be analyzed statistically by the same methods as those used with the standard test elements, and all results should be published in the final test report. For AMHS equipment, the additional metric and data requirements are summarized in Table 34.

Table 34 Additional Metrics and Data for AMHS

Parameter	Measurement Method	Gauge	Units
Vibration	Vibration transport system and wafers	Accelerometer	TBD
Airborne particles	Environment sampling	Laser scattering Q3 Sniffer	#/cm^2
Particles	Liquid particle count	LPC	#/ml
Chemical contamination	Pod environment sampling (analysis lab)	TBD	TBD
Alarm conditions	Download of history files	Bit error counter	# of errors
GEM messages	Download of history files	Bit error counter	# of errors
Molecular contamination	Pod environment sampling (analysis lab)	SAW or Carbon Badge	TBD
Interface compatibility with other AMHS components	Inter operability of interfaced systems	Bit error counter	# of errors
Electrostatic charge	Measured voltage at subject object	Electrical field meter	kV
Electromagnetic field	Measured field at and around the subject object	Field meter	Gauss

Working with Technology- and Process-Dependent Considerations

For certain classes of equipment, additional guidance is required for particular processes or technological challenges that are unique to those classes. For AMHS equipment class, the following guidelines are provided for the functional category tool testing requirements.

TRANSPORT

This includes interbay and intrabay transport of wafer carriers in a fab environment.

Mechanical Dry Cycle (MDC)

For transport-functional tools of the AMHS, a complete machine cycle is composed of the port-to-port transfer of a carrier, including all intermediate stations. At each intermediate station, as many mechanical functions as possible should be activated or cycled. The goal for the number of cycles to be tested should be established based on the goal and statistical confidence level selected for number of machine cycles needed in the demonstration test.

During an MDC, transport speeds and other process parameters not directly linked to the safe operation of the equipment should not be monitored or evaluated.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* should be monitored for the PDC and SA for this process:

- Transport speed

The following additional *outputs* should be measured for the PDC and SA for this process:

- Electrostatic field generated charge
- Wafer orientation (where applicable)
- EMI (effect on production equipment)

PROCESS-SPECIFIC PERFORMANCE PARAMETERS

The following process-specific metrics (in addition to the common metrics) should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
TBD	TBD

STORAGE

These are systems for the storage of wafer or reticle carriers in interbay and intrabay buffers and storage.

Mechanical Dry Cycle (MDC)

For carrier/reticle storage functional tools of the AMHS, a complete machine cycle comprises the complete port-to-port transfer of a carrier, including all intermediate stations. At each intermediate station, as many mechanical functions as possible should be activated or cycled. For a storage tool, where a carrier contains multiple wafers, the number of wafer cycles is the product of the number of carriers cycled multiplied by the number of wafers per carrier. The goal for the number of wafer cycles to be tested should be based on the goal and statistical confidence level selected for number of machine cycles needed in the demonstration test.

During a MDC, transport speeds, lift speed, and other process parameters not directly linked to the safe operation of the equipment should not be monitored or evaluated.

Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The following additional *input* parameters should be monitored during the PDC and SA for this process:

- Transfer speed of FOUPs
- Wafer sorting

The following additional *output* parameters should be monitored during the PDC and SA for this process:

- Electrostatic field generated charge
- Wafer orientation (where applicable)
- EMI (effect on production equipment)

PROCESS-SPECIFIC PERFORMANCE PARAMETERS

These are process-specific metrics (in addition to the common metrics) to be collected, evaluated, and published as results of the demonstration test.

Metric	Units
TBD	TBD

INTEGRATED AUTOMATED MATERIAL HANDLING SYSTEM (AMHS)

This is the integration of all components into the AMHS.

TECHNICAL CHALLENGE – TESTING AND MEASUREMENT

Each AMHS implementation is a unique design, precluding a standard set of goals and direction for testing. Valid testing can be performed on an integrated AMHS configuration using the methodology; however, it will be valid for that configuration only. Test goals can be set and AMHS system overall performance summarized by using a simple reliability modeling technique, which has been in use by defense and aerospace for decades and which has gained increasing acceptance in the semiconductor industry over the past five years.

The modeling technique is based upon a fundamental relationship between MTBF and tool failure rate (probability of failure calculated from observed data, λ_q). The failure rate is the reciprocal of the observed MTBF (i.e., 1/MTBF = failure rate). Instantaneous failure rates calculated in this manner are not tied to statistical distributions and can be manipulated algebraically with integrity. A system failure rate is the sum of all of the failure rates of the components of the system. This method can be used with other performance metrics with care to apply it appropriately.

Test goals can be set for an AMHS system test by using performance estimates on the component tools to be included using the model. Actual observed performance is composed of the performance metrics of the component tools in that AMHS configuration. This allows the prediction of performance of other configurations of AMHS using the model to assemble the component tools data of the new configuration. Performance metrics and expected lifetimes and MTBF of AMHS components can be found in the AMHS metrics.

PROCESS-SPECIFIC TEST METRICS

The complete set of I300I test metrics and recommended goals can be found in the *Metrics for 300 mm Automated Material Handling Systems (AMHS) and Production Equipment Interfaces* document.

GLOSSARY

***AGV* -** Automated guided vehicle

AMC - Airborne molecular contaminants

***AMHS* -** Automated material handling system

***APCVD* -** Atmospheric pressure chemical vapor deposition

***ARC* -** Anti-reflective coating. An organic compound applied to the wafer surface to reduce light reflection/refraction and to reduce standing wave formation

***Batch* -** The number of wafers >1 that are processed simultaneously by the production equipment

***BPSG* -** Boron/phosphorus doped silicon glass

***C* -** Symbol for chlorine

***CAM* -** Computer aided manufacturing software for tracking wafer/lot processing status and history

***CD* -** Critical dimensions. Measurements of the photo exposed images

***Chemical to rinse time* -** The amount of time between the end of the active develop process and rinsing of the chemical

***CMP* -** Chemical mechanical planarization

***Cu* -** Symbol for the metal copper

***CVD* -** Chemical vapor deposition

***CV plot* -** A plot of the current vs. voltage measurements

***CV shift* -** Current voltage shift. Change in properties of the measured layer, causing a shift in the ratio of current vs. voltage

Delta T (ΔT) **-** A difference in temperature

Delta T (ΔT) **-** The delta (or difference) between temperature measurements

***DOF* -** Depth of Focus. The focal exposure plane depth of the photo tool

***Dishing/cupping* -** Area-specific indentations in the film layer on the surface of a wafer

***DTM* -** Demonstration Test Method

***DUV* -** Deep ultraviolet

EBR - Edge bead removal. Removal of resist from the edge of a wafer, typically done with a solvent rinse

***ECAG* -** Equipment Class Application Guideline

EMI - Electromagnetic interference

EPM - Equipment Performance Metrics

FOUP - Front opening unified pod wafer carrier

FOSB - Front opening shipping box

FOUPfor1- Front opening unified pod for a single wafer

FSG - Fluorinated silicon glass

Gauge - Metrology equipment that is traceable to standards. This equipment is typically used for measuring the output (or product) of a tool

Gauge Study - A study of a metrology tool to determine its stability

HDP CVD - High density plasma chemical vapor deposition

HF - Hydrofluoric acid

ICPSIMS - Inductive coupled plasma spectroscopy

Input parameter - Equipment parameters that can be adjusted or monitored and that affect operational performance

Interbay - Between fab processing bays

Intrabay - Within a processing bay

IPA - Isopropyl alcohol

LPC - Liquid particle counter

LPCVD - Low pressure chemical vapor deposition. Refers to a process type during which at an elevated temperature and a reduced pressure, films are chemically deposited from the gaseous phase

MCS - Material control system

MDC - Mechanical dry cycle

MWBI - Mean wafers between interrupts

NIST - National Institute of Standards and Technology

Output parameter - The result (typically measured on product) of the equipment process

PDC - Passive data collection

PDM - Plasma damage monitor

PEB - Post-exposure bake

PECVD - Plasma enhanced chemical vapor deposition

PGV - Person guided vehicle

PSG - Phosphorus doped silicon glass

PWP- Particles per wafer pass

P/T ratio **-** The ratio of precision to tolerance of a metrology tool. Reference SEMI M27-96

Ramp rate **-** The rate of temperature change (measured in degrees centigrade) over time (usually measured in minutes)

Ramp rate parameters **-** The ramp-up rate is the rate that the temperature of a system, chamber, or wafer, etc., goes from an ambient, idle, or starting temperature to the final processing temperature over a specified time period. Ramp-down rate is the time it takes a system to go from maximum temperature back down to an idle or ambient state.

RBS **-** Rutherford back scattering

RGV **-** Rail guided vehicle

RMS **-** Reticle management system

SAW **–** Surface acoustical wave

SACVD **-** Sub-atmospheric pressure chemical vapor deposition

SEM **-** Scanning electron microscope or scanning electron microscopy

SIMS **-** Secondary ion mass spectroscopy

Slip **-** Refers to damage detected on a wafer's structure as a result of incurred force(s) during processing

Slip **-** Wafer damage caused by thermal stress, exhibited as a slip of the crystal planes

Slurry **-** An abrasive mixture made up of fine particles suspended in a chemical solution

TBD **-** To be determined at a later date when data and/or detail become available

TC **-** Thermocouple

TC wafer **-** Thermocouple wafer

Temperature delta across the wafer **-** The delta (difference) in temperature at points across the wafer plane (commonly referred to as across wafer ΔT)

Temperature delta across the wafer **-** The difference in temperature between the center and perimeter of the wafer at the same point in time (commonly referred to as across wafer ΔT)

Temperature overshoot **-** The amount, measured in temperature, that a tool exceeds the programmed setpoint before control recovery

Temperature overshoot parameters **-** Refers to the amount of temperature overshoot during process chamber temperature ramp up

TEOS **-** Tetraethelorthosilicate

Ti **-** Symbol for the metal titanium

TiN **-** Symbol for titanium-nitride

TXRF **-** Total x-ray fluorescence

***USG* -** Undoped silicon glass

***VPD* -** Vapor phase deposition

***W* -** Symbol for the metal tungsten

***WIP* -** Work in progress

***WIP* -** Work in progress. This term is used to describe the inventory in an IC manufacturing environment

***XRD* -** X-ray diffraction

***XRF* -** X-ray fluorescence

REFERENCE DOCUMENTS

- *Demonstration Test Method – Revision 1*, I300I, Technology Transfer #97063297B-XFR, September 30, 1997.
- *180 nm Equipment Performance Metrics – Revision 1*, I300I, Technology Transfer #97093360C-ENG, August 31, 1998.
- *Passive Data Collection (PDC) and Analysis*, SEMATECH, Technology Transfer #91090684A-ENG, September 27, 1991.
- *Introduction to Statistical Quality Control* (Second Edition), Douglas Montgomery; John Wiley (1991).
- *Exploratory Data Collection and Analysis,* SEMATECH, Version 0.9, July 1995.
- *Practice for Determining the Precision over Tolerance (P/T) ratio of Test Equipment (SEMI 1996)*, SEMI M27-96.
- *Metrics for 300 mm Automated Material Handling System (AMHS) and Production Equipment Interfaces*, I300I, Technology Transfer #97123416A-TR, December 12, 1997.

SEMATECH Technology Transfer
2706 Montopolis Drive
Austin, TX 78741

http://www.sematech.org
e-mail: info@sematech.org