



Table 1 Impurity and Other Requirements for Various Grades of Hydrogen

<i>Previous SEMI Reference #</i>	<i>C3.19-0200 (Specification)</i>	<i>C3.30-0999 (Specification)</i>
Grade	5.5	5.7
Purity	99.9995%	99.9997% ^{#1}
Impurities	Maximum Acceptable Level (ppm) ^{#2}	
Carbon Dioxide (CO ₂)	0.5	0.2
Carbon Monoxide (CO)	0.5	0.2
Nitrogen (N ₂)	2	2
Oxygen (O ₂)	0.5	0.2
Total Hydrocarbons expressed as Methane (THC)	0.5	0.2
Water (H ₂ O) (v/v)	0.5	0.2
TOTAL SPECIFIED IMPURITIES	4.5	2.8
Particles	#3	#3

^{#1} A purifier is allowed to be used to meet this specification.

^{#2} An analysis of significant figures has not been considered. The number of significant figures is based on analytical accuracy and the precision of the provided procedure.

^{#3} To be determined between supplier and user.

8 Physical Constants

8.1 The physical constants of hydrogen are given in Table 2 (for information only).

Table 2 Physical Constants of Hydrogen (for information only)

	<i>Metric Units</i>	<i>US Units</i>
Molecular weight	2.016	2.016
Boiling point at 1 atm	-252.7°C	-423.0°F
Density of gas at 21.1°C (70°F) and 1 atm	0.0834401 kg/m ³	0.005209 lb/ft ³
Specific gravity of gas at 21.1°C and 1 atm (air = 1)	0.06950	0.06950
Density of liquid at boiling point	68.6 kg/m ³	4.28 lb/ft ³

9 Analytical Procedures for Grade 5.5 Hydrogen

NOTE 1: Introduce the calibration standard as many times as necessary to achieve the desired precision.

NOTE 2: All gases used in the analysis of the sample should contain no more than 10% of the sample value of the component of interest unless otherwise specified.

9.1 *Carbon Monoxide and Carbon Dioxide* — This procedure is for the determination of carbon monoxide and carbon dioxide in hydrogen using a gas chromatograph with a flame ionization detector and methanizer.

9.1.1 *Detection Limit* — 100 ppb (mol/mol).

9.1.2 *Instrument Parameters*

9.1.2.1 *Column*: Porapak T or Q, 3 m (9.8 ft) by 3 mm (1/8 in) ID by 2.2 mm (0.085 in) OD stainless steel; or Chromosorb 102, 2 m (6.6 ft) by 3 mm stainless steel; or equivalent

9.1.2.2 *Carrier Flow*: 30 mL/min helium.

9.1.2.3 *Sample Volume*: 0.5 to 2.0 mL.



9.1.2.4 Temperatures:

Detector	280°C
Column Oven	60°C
Methanizer	350°C

9.1.3 Calibration Standards — 0.5–2.5 ppm (mol/mol) carbon monoxide, 0.5–2.5 ppm (mol/mol) carbon dioxide, balance hydrogen.

9.1.4 Operating Procedure

9.1.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas. The order of elution is carbon monoxide, carbon dioxide.

9.1.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

9.1.4.3 Repeat ¶9.1.4.1.

9.1.4.4 Compare the average peak areas of the calibration standard to that of the hydrogen sample being tested. Calculate the concentrations of carbon monoxide and carbon dioxide, using the formula below.

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \frac{\text{Concentration}}{\text{of Standard}} = \frac{\text{Concentration}}{\text{of Sample}}$$

9.1.4.5 The result may not exceed the specification in Table 1.

9.2 Nitrogen — This procedure is for the determination of nitrogen in hydrogen using a gas chromatograph with a helium ionization detector.

9.2.1 Detection Limit — 500 ppb (mol/mol).

9.2.2 Instrument Parameters

9.2.2.1 Column: 5A molecular sieve 1.9 m (6 ft) by 3.2 mm (1/8 in) OD by 2.2 mm (0.085 in) ID by stainless steel or equivalent.

9.2.2.2 Carrier Flow: 30 mL/min helium.

9.2.2.3 Sample Volume: 3.0 mL.

9.2.2.4 Temperatures:

Detector	125°C
Column Temperature	65°C

9.2.3 Calibration Standard — 0.5–2.5 ppm, (mol/mol) nitrogen in hydrogen.

9.2.4 Operating Procedure

9.2.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas.

9.2.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

9.2.4.3 Repeat ¶9.2.4.1.



9.2.4.4 Compare the average peak area of the calibration standard to that of the hydrogen sample being tested. Calculate the concentration of nitrogen, using the formula below.

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \frac{\text{Concentration}}{\text{of Standard}} = \frac{\text{Concentration}}{\text{of Sample}}$$

9.2.4.5 The result may not exceed the specification in Table 1.

9.3 *Oxygen* — This procedure is for the determination of oxygen in hydrogen using a continuous flow analyzer using an electrochemical method.

9.3.1 *Detection Limit* — 100 ppb (mol/mol)

9.3.2 *Flow Rate* — Set sample flow rates in accordance with the instrument manufacturer's instructions.

9.3.3 *Calibration Standard* — 0.5–2.5 ppm (mol/mol) oxygen in hydrogen or in accordance with the instrument manufacturer's instructions.

9.3.4 *Operating Procedure*

9.3.4.1 Do not change the initial sample flow setting once established.

9.3.4.2 Introduce hydrogen sample and record oxygen reading. The result may not exceed the specification in Table 1.

9.4 *Total Hydrocarbons* — This procedure is for the determination of total hydrocarbons in hydrogen using a continuous flow flame ionization detector equipped total hydrocarbon analyzer.

NOTE 3: The 0–1 range can be used provided that zero and span gas standards in hydrogen with known levels of hydrocarbons between 0 and 1 ppm are used in the calibration of the analyzer.

NOTE 4: As the flow rate and heat capacity of the matrix gas affect the instrument output, the zero gas matrices should be coincided with that of the sample gas.

NOTE 5: The effective response of a flame ionization detector-equipped total hydrocarbon analyzer to different hydrocarbons can vary and must be approximated. However, the response of the common hydrocarbon impurities in hydrogen can be accurately totaled and compared to methane.

9.4.1 *Detection Limit* — 0.1 ppm (mol/mol).

9.4.2 *Flow Requirements*

9.4.2.1 High purity, hydrocarbon-free (less than 0.1 ppm) hydrogen: 35–40 mL/min or 40% hydrogen in either helium or nitrogen matrix at 75–80 mL/min.

9.4.2.2 Dry, hydrocarbon-free (less than 0.1 ppm) air: 350–400 mL/min.

9.4.2.3 Set sample flow rates in accordance with the instrument manufacturer's instructions.

9.4.3 *Calibration Standards*

9.4.3.1 Zero hydrogen with known quantity of hydrocarbons at 0.1 ppm level.

9.4.3.2 The upper level span gas not exceeding five times the concentration of the specification.

9.4.4 *Operating Procedure*

9.4.4.1 Do not change the initial flow settings for hydrogen, air and sample once established.

9.4.4.2 Introduce the zero hydrogen with known quantity of hydrocarbons and using the 0–10 ppm range, set the needle (or output) to read the correct level using the zero adjust knob.

9.4.4.3 Introduce the span gas standard in hydrogen and using the span adjust knob, set the needle (or output reading) to match the level of hydrocarbons in the span gas.

9.4.4.4 Repeat ¶9.4.4.2 and ¶9.4.4.3 until reproducibility of readings is better than 1% full scale.

9.4.4.5 Introduce hydrogen sample into the analyzer and read the quantity of hydrocarbons on the analyzer meter. The result may not exceed the specification in Table 1.



9.5 Water — This procedure is for the determination of trace moisture (water) in hydrogen using a continuous flowing piezoelectric hygrometer.

NOTE 6: The sampling system and hygrometer should be designed to operate under the sample pressure, or the sample pressure should be reduced (by a regulator with a diaphragm of stainless steel or other suitable material) to accommodate the pressure restrictions of the analytical hygrometer.

NOTE 7: Other hygrometers may also be used, e.g. CRDS, FTIR, TDLAS, and vibrating quartz.

9.5.1 Detection Limit — 0.1 ppm (vol/vol) at -90°C (-130°F).

9.5.2 Flow Requirements — Set the sample pressure and flow rate in accordance with the instrument manufacturer's instructions.

9.5.3 Calibration Standards — Construct a calibration curve which contains at least three points covering the range of interest. Verify the standards employed independently by another analytical method.

9.5.4 Operating Procedure

9.5.4.1 Obtain a continuous flow sample of gas from the source using a clean and passivated stainless steel line which has been purged dry after exposure to ambient moisture.

9.5.4.2 After prepurging with a dry gas, allow the sample gas to flow through the sampling system and the piezoelectric moisture hygrometer until a stable reading is obtained.

9.5.4.3 Determine the moisture content of the hydrogen sample by comparing the reading to calibration curve. The result may not exceed the specification in Table 1.

10 Analytical Procedures for Grade 5.7 Hydrogen (See Notes 1 and 2 in §9)

10.1 Carbon Monoxide and Carbon Dioxide — This procedure is for the determination of carbon monoxide and carbon dioxide in hydrogen using a gas chromatograph with a flame ionization detector and methanizer.

10.1.1 *Detection Limit* — 50 ppb (mol/mol).

10.1.2 *Instrument Parameters*

10.1.2.1 *Column*: Porapak T or Z, 3 m (9.8 ft) by 3.2 mm (1/8 in) stainless steel; or Chromosorb 102, 2 m (6.6 ft) by 3.2 mm stainless steel; or equivalent.

10.1.2.2 *Carrier Flow*: 30 mL/min helium.

10.1.2.3 *Sample Volume*: 0.5 to 2.0 mL.

10.1.2.4 *Temperatures*:

Detector	280°C
Column Oven	60°C
Methanizer	350°C

10.1.3 *Calibration Standard* — 1–5 ppm (mol/mol) carbon monoxide, 1–5 ppm (mol/mol) carbon dioxide, balance hydrogen.

10.1.4 *Operating Procedure*

10.1.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas. The order of elution is carbon monoxide, carbon dioxide.

10.1.4.2 Inject the sample to be tested in the same manner as the calibration standard. Record the retention times and peak areas.

10.1.4.3 Repeat ¶10.1.4.1.

10.1.4.4 Compare the average peak areas of the calibration standard to that of the hydrogen sample being tested. Calculate the concentration of each impurity, using the formula below.



$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \frac{\text{Concentration of Standard}}{\text{Concentration of Sample}} = \frac{\text{Concentration of Sample}}{\text{Concentration of Standard}}$$

10.1.4.5 The results may not exceed specifications in Table 1 of this standard.

10.2 *Nitrogen* — This procedure is for the determination of nitrogen in hydrogen using a gas chromatograph with a helium ionization detector (see Figures 1 and 2).

NOTE 8: All carrier lines should be cleaned stainless steel.

NOTE 9: The carrier gas should be 99.9998% purity helium with less than 40 ppb carbon dioxide.

NOTE 10: Use a stainless steel pressure regulator with no pipe threads, PTFE thread sealant or other plastic seal components for the carrier gas.

NOTE 11: Due to the extreme sensitivity of the helium ionization detector, it is imperative that the system be leak tested to 1×10^{-7} atm. cc/sec (helium) or lower with a helium leak detector.

NOTE 12: The hydrogen separator is the palladium tube type where the sample flows through a heated palladium tube through which the hydrogen selectively diffuses separating it from the impurities which are carried to the column by the helium carrier gas.

10.2.1 *Detection Limit* — 12 ppb.

10.2.2 *Instrument Parameters*

10.2.2.1 *Columns:*

Column 1 (Pre-Column):	Molecular sieve 5A, 60/80 Mesh, 2.4 m (8 ft) by 3.2 mm (1/8 in), stainless steel, or equivalent.
Column 2 (Analytical Column):	Molecular sieve 5A, 60-80 Mesh, 2.4 m by 3.2 mm, stainless steel, or equivalent.

10.2.2.2 *Carrier Flow:* 40 mL/min helium.

10.2.2.3 *Sample Volume:* 1.0 mL.

10.2.2.4 *Temperatures:*

Detector	100°C
Column	50°C
Hydrogen Purifier	300°C

10.2.2.5 Determine the breakdown voltage of the detector. Set operating voltage at 10 volts below breakdown.

10.2.3 *Calibration Standard* — 2 ppm (mol/mol) nitrogen, balance hydrogen (99.9999% purity).

10.2.4 *Operating Procedure*

10.2.4.1 Set timing interval on sample select valve to 10 sec.

10.2.4.2 Set timing interval on gas sampling valve to 3 minutes.

10.2.4.3 Set timing interval #3 to 5 minutes.

10.2.4.4 Do not change the initial sample flow setting once established.

10.2.4.5 Obtain a continuous flow of the calibration standard using a clean stainless steel line [0.5 mm (0.02 in.) ID].

10.2.4.6 Inject the calibration standard onto the column with the gas sampling valve. Record the retention times and peak areas.

10.2.4.7 Repeat ¶10.2.4.6 until reproducibility of reading is better than 1% of full scale.



10.2.4.8 Inject the sample to be tested in the same manner as the calibration standard. Record the retention times and peak areas.

10.2.4.9 Compare the average peak area of the hydrogen sample being tested to that of the calibration standard. Calculate the concentration of nitrogen, using the formula below.

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \frac{\text{Concentration}}{\text{of Standard}} = \frac{\text{Concentration}}{\text{of Sample}}$$

10.2.4.10 The result may not exceed the specification in Table 1 of this standard.

10.3 *Oxygen* — This procedure is for the determination of oxygen in hydrogen using a continuous flow analyzer using an electrochemical method.

10.3.1 *Detection Limit* — 50 ppb (mol/mol).

10.3.2 *Instrument Parameters* — Set the sample pressure and flow rates in accordance with the instrument manufacturer's instructions.

10.3.3 *Calibration Standard* — 1–10 ppm (mol/mol) oxygen in hydrogen or in accordance with the instrument manufacturer's instructions.

10.4 *Operating Procedure*

10.4.1 Do not change the initial sample flow setting once established.

10.4.1.1 Introduce hydrogen containing less than 2 ppm oxygen through a deoxygenation catalyst to verify that there is no leakage of air into the system and to demonstrate that the detection limit can be achieved.

10.4.1.2 Introduce the calibration standard. Using the span adjust knob, set the needle (or output reading) to match the level oxygen in the calibration gas.

10.4.1.3 Introduce hydrogen sample and record the oxygen reading. The result may not exceed the specification in Table 1 of this standard.

10.5 *Water* — Use procedure in ¶9.5 for the determination of water.

10.6 *Total Hydrocarbons* — This procedure is for the determination of total hydrocarbons in hydrogen using a continuous flow flame ionization detector equipped total hydrocarbon analyzer.

NOTE 13: The 0–1 ppm range can be used provided that zero and span gas standards in hydrogen with known levels of hydrocarbons between 0–1 ppm are used in the calibration of the analyzer.

10.6.1 *Detection Limit* — 0.1 ppm (mol/mol).

10.6.2 *Flow Requirements*

10.6.2.1 High-purity, hydrocarbon-free (less than 1.0 ppm) hydrogen: 35–40 mL/min or 40% hydrogen in either helium or nitrogen matrix at 75–80 mL/min.

10.6.2.2 Dry, hydrocarbon-free (less than 1.0 ppm) air: 350–400 mL/min.

10.6.2.3 Set sample flow rates in accordance with the instrument manufacturer's instructions.

10.6.3 *Calibration Standards*

10.6.3.1 Zero hydrogen with known quantity of hydrocarbons at 0.1 ppm level.

10.6.3.2 *Span Gas* — Hydrogen with known quantity (1–10 ppm) hydrocarbons.

10.6.4 *Operating Procedure*

10.6.4.1 Do not change the initial flow setting for hydrogen, air and sample once established.

10.6.4.2 Introduce the zero hydrogen with known quantity of hydrocarbons and, using the 0–10 ppm range, set the needle (or output) to read the correct level using the zero adjust knob.

10.6.4.3 Introduce the span gas standard in hydrogen and, using the span adjust knob, set the needle (or output reading) to match the level of hydrocarbons in the span gas.

10.6.4.4 Repeat ¶10.6.4.2 and ¶10.6.4.3 until reproducibility of readings is better than 1% of full scale.

10.6.4.5 Introduce hydrogen sample into the analyzer and read the quantity of hydrocarbons on the analyzer meter. The result may not exceed the specification in Table 1 of this standard.

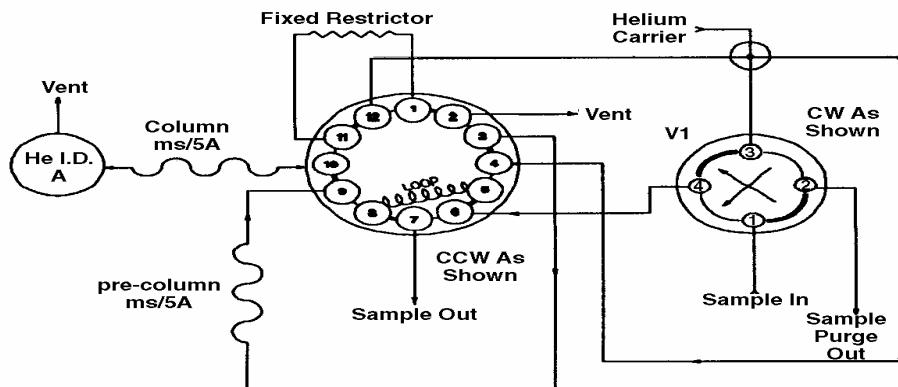


Figure 1
Analysis of Nitrogen

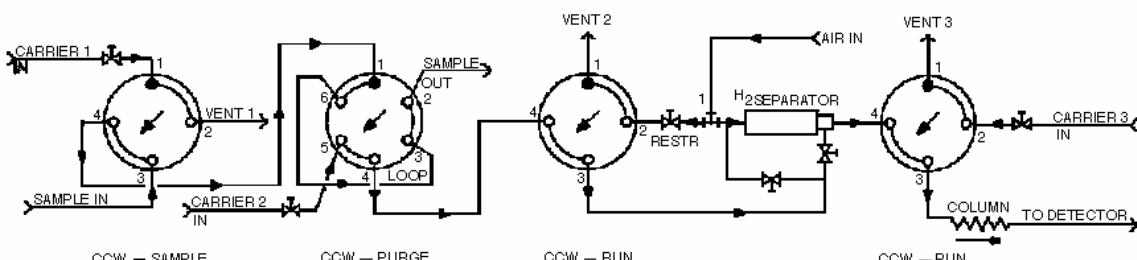


Figure 2
Flow Diagram for Discharge Ionization Detector Gas Chromatograph
with Integral Hydrogen Separator

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SEMI C59-1104

SPECIFICATIONS AND GUIDELINES FOR NITROGEN

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1 Purpose

1.1 The purpose of this document is to provide a series of specifications for different grades of Nitrogen (N_2) that are used in the semiconductor industry.

earth's atmosphere; at cryogenic temperatures it is a colorless liquid. Noncombustible; a cryogenic gas derived from liquid air by fractional distillation.

2 Scope

2.1 This document covers requirements for all grades of nitrogen used in the semiconductor industry.

2.2 If analytical methods are not complete, the requirements are presented as a guideline.

4 Limitations

4.1 None.

5 Referenced Standards

5.1 SEMI Standards

SEMI C1 — Specifications for Reagents

SEMI C3 — Specifications for Gases

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

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

3 Description

3.1 Nitrogen is an odorless, tasteless, noncombustible diatomic gas comprising approximately 78% of the

6 Terminology

6.1 Terminology appropriate to this standard is defined in SEMI C3.

Table 1 Impurity and Other Requirements for Various Grades of Nitrogen

Previous SEMI Reference #	C3.5-93 (Specification)	C3.15-93 (Specification)	C3.48-0200 (Specification)	C3.29-96 (Specification)	C3.28-0200 (Guideline)	C3.49-94 (Specification)
Grade	4.8	5.2	5.4	5.5	5.6	7.0
Purity	99.998%	99.9992%	99.9994%	99.9995% ^{#1}	99.9996%	99.99999%
Impurities						
Carbon Dioxide (CO ₂)	1	1	0.5	0.2	0.5	0.010
Carbon Monoxide (CO)	5	2	2	2	0.5	0.010
Hydrogen (H ₂)	2	2	2	2	1	0.010
Oxygen (O ₂)	3	1	0.5	0.2	0.5	0.010
Water (H ₂ O) (ppmv)	1	1	0.5	0.2	0.5	0.050
Total Hydrocarbons expressed as Methane (THC)	1	1	0.5	0.2	0.5	0.010
TOTAL SPECIFIED IMPURITIES	13	8	6	4.8	3.5	0.100
Particles	#3	#3	#3	#3	#3	Max. 20/ ft^3 > 0.02 μm #4

^{#1} A purifier is allowed to be used to meet this specification.

^{#2} An analysis of significant figures has not been considered. The number of significant figures is based on analytical accuracy and the precision of the provided procedure.

^{#3} To be determined between supplier and user.

^{#4} May be determined after purifier/filter. Sampling point top be agreed between supplier and user.

7 Requirements

7.1 Purity and other requirements for the various grades of nitrogen are given in Table 1.

8 Physical Constants

8.1 The physical constants of nitrogen are given in Table 2 (for information only).

Table 2 Physical Constants of Nitrogen (for information only)

	Metric Units	US Units
Molecular weight	28.013	28.013
Boiling point at 1 atm	-195.8°C	-320.4°F
Density of gas at 21.1°C (70°F) and 1 atm	1.1605 kg/m ³	0.07245 lb/ft ³
Specific gravity of gas at 21.1°C and 1 atm (air = 1)	0.967	0.967
Density of liquid at boiling point	808.8 kg/m ³	50.49 lb/ft ³

9 Analytical Procedures for Grade 4.8 Nitrogen

NOTE 1: Introduce the calibration standard as many times as necessary to achieve the desired precision.

NOTE 2: All gases used in the analysis of the sample should contain no more than 10% of the sample value of the component of interest unless otherwise specified.

9.1 *Carbon Monoxide and Carbon Dioxide* — This procedure is for the determination of carbon monoxide and carbon dioxide in nitrogen using a gas chromatograph with a flame ionization detector and methanizer.

NOTE 3: Carrier gases should contain less than 0.1 ppm carbon monoxide and less than 0.1 ppm hydrogen.

9.1.1 *Detection Limit* — 100 ppb

9.1.2 *Instrument Parameters*

9.1.2.1 *Column*: Porapak T or Q, 3 m (9.8 ft) by 3.2 mm (1/8 in) OD by 2.2 mm (0.085 in) ID stainless steel; or Chromosorb 102, 2 m (6.6 ft) by 3.2 mm (1/8 in) OD by 2.2 mm (0.085 in) ID stainless steel; or equivalent.

9.1.2.2 *Carrier Flow*: 30 mL/min helium.

9.1.2.3 *Sample Volume*: 0.5 to 2.0 mL.

9.1.2.4 *Temperatures*:

Detector	280°C
Column Oven	60°C
Methanizer	350°C

9.1.3 *Calibration Standards* — 1–5 ppm carbon monoxide, 1–5 ppm carbon dioxide, balance nitrogen.

9.1.4 *Operating Procedure*

9.1.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas. Order of elution is carbon monoxide, carbon dioxide.

9.1.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

9.1.4.3 Repeat Section 9.1.4.1.

9.1.4.4 Compare the average peak area of the calibration standard to that of the nitrogen sample being tested. Calculate the concentrations of carbon monoxide and carbon dioxide, using the formula:

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \text{Concentration of Standard} \\ = \text{Concentration of Sample}$$

9.1.4.5 The result may not exceed the specification in Table 1.

9.2 *Hydrogen* — This procedure is for the determination of hydrogen in nitrogen using a gas chromatograph with a helium ionization detector.

9.2.1 *Detection Limit* — 500 ppb.

9.2.2 *Instrument Parameters*

9.2.2.1 *Column* — 5A molecular sieve, 1.9 m (6 ft) by 3.2 mm (1/8 in) OD by 2.2 mm (0.085 in) stainless steel or equivalent.

9.2.2.2 *Carrier Flow* — 30 mL/min helium.

9.2.2.3 *Sample Volume* — 3.0 mL

9.2.2.4 *Temperatures*:

Detector	125°C
Column Temperature	65°C

9.2.3 *Calibration Standard* — 1–5 ppm hydrogen in nitrogen.

9.2.4 *Operating Procedure*

9.2.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention time and peak area.

9.2.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention time and peak area.

9.2.4.3 Repeat Section 9.2.4.1.

9.2.4.4 Compare the average peak area of the calibration standard to that of the nitrogen sample being tested. Calculate the concentration of hydrogen, using the formula:

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \text{Concentration of Standard} \\ = \text{Concentration of Sample}$$

9.2.4.5 The result may not exceed the specification in Table 1.

9.3 Oxygen — This procedure is for the determination of oxygen in nitrogen using a continuous flow analyzer using an electrochemical method.

9.3.1 Detection Limit — 100 ppb.

9.3.2 Flow Rate — Set sample flow rates in accordance with the instrument manufacturer's instructions.

9.3.3 Calibration Standard — 3–15 ppm oxygen in nitrogen or in accordance with the instrument manufacturer's instructions.

9.3.4 Operating Procedure

9.3.4.1 Do not change the sample flow setting once established.

9.3.4.2 Introduce nitrogen sample and record oxygen reading. The result may not exceed the specification in Table 1.

9.4 Total Hydrocarbons — This procedure is for the determination of total hydrocarbons in nitrogen using a continuous flow flame ionization detector equipped total hydrocarbon analyzer.

NOTE 4: The 0–1 range can be used provided that zero and span gas standards in nitrogen with known levels of hydrocarbons between 0–1 ppm are used in the calibration of the analyzer.

NOTE 5: As the flow rate and heat capacity of the matrix gas affect the instrument output, the zero and span gas matrices must coincide with that of the sample gas.

NOTE 6: The effective response of a flame ionization detector-equipped total hydrocarbon analyzer to different hydrocarbons can vary and must be approximated. However, the response of the most common hydrocarbon impurities in nitrogen can be accurately totaled and compared to methane.

9.4.1 Detection Limit — 0.1 ppm.

9.4.2 Flow Requirements

9.4.2.1 High purity, hydrocarbon-free (less than 0.1 ppm) hydrogen: 35–40 mL/min or 40% hydrogen in either helium or nitrogen matrix at 75–80 mL/min.

9.4.2.2 Dry, hydrocarbon-free (less than 0.1 ppm) air: 350–400 mL/min.

9.4.2.3 Set sample flow rates in accordance with the instrument manufacturer's instructions.

9.4.3 Calibration Standards

9.4.3.1 Nitrogen with known quantity of hydrocarbons at 0.5 ppm level.

9.4.3.2 The upper level span gas not exceeding 5 times the concentration of the specification.

9.4.4 Operating Procedure

9.4.4.1 Do not change the flow settings for hydrogen, air and sample once established.

9.4.4.2 Introduce the nitrogen with known quantity of hydrocarbons and, using the 0–10 ppm range, set the needle (or output) to read the correct level using the zero adjust knob.

9.4.4.3 Introduce the span gas standard in nitrogen and, using the span adjust knob, set the needle (or output reading) to match the level of hydrocarbons in the span gas.

9.4.4.4 Introduce nitrogen sample into the analyzer and read the quantity of hydrocarbons on the analyzer meter. The result may not exceed the specification in Table 1.

9.5 Water — This procedure is for the determination of trace moisture (water) in nitrogen using a continuous flowing piezoelectric hygrometer.

NOTE 7: The sampling system and hygrometer must be designed to operate under the sample pressure, or the sample pressure must be reduced (by a regulator with a diaphragm of stainless steel or other suitable material) to accommodate the pressure restrictions of the analytical hygrometer.

9.5.1 Detection Limit — 0.1 ppmv or –90°C (–130°F).

9.5.2 Flow Requirements — Set the sample pressure and flow rate in accordance with the instrument manufacturer's instructions.

9.5.3 Calibration Standards — Construct a calibration curve which contains at least three points covering the range of interest. Verify the standards employed independently by another analytical method.

9.5.4 Operating Procedure

9.5.4.1 Obtain a continuous flow sample of gas from the source using a clean and passivated stainless steel line which has been purged dry after exposure to ambient moisture.

9.5.4.2 After prepurging with a dry gas, allow the sample gas to flow through the sampling system and the

piezoelectric moisture hygrometer until a stable reading is obtained.

9.5.5 Determine the moisture content of the nitrogen sample by comparing the reading to calibration curve. The result may not exceed the specification in Table 1.

10 Analytical Procedures for Grade 5.2 Nitrogen (See Notes 1 and 2 in Section 9)

10.1 *Carbon Monoxide and Carbon Dioxide* — Use the procedure in Section 9.1 for the analysis of carbon monoxide and carbon dioxide.

10.1.1 *Hydrogen* — Use the procedure in Section 9.2 for the analysis of hydrogen.

10.1.2 *Oxygen* — Use the procedure in Section 9.3 for the analysis of oxygen except that the standard should be between 1 and 5 ppm oxygen in nitrogen.

10.1.3 *Total Hydrocarbons* — Use procedure Section 9.4 for the determination of total hydrocarbons except that the calibration standard should be at the 0.1 ppm level.

10.1.4 *Water* — This procedure is for the determination of moisture (water) in nitrogen using a continuous flowing, cooled-surface condensation, dewpoint/ frostpoint hygrometer. (See NOTE 7 in Section 9.)

NOTE 8: The National Institute of Standards and Technology (NIST) provides calibration services for the thermometers used in dewpoint/frostpoint hygrometers.

NOTE 9: This method is not applicable if other constituents in the gas will condense before water vapor, e.g., carbon dioxide and/or oil contamination.

10.1.4.1 *Detection Limit* — 0.6 ppm (vol/vol) or -79°C (-110°F).

10.1.4.2 Flow Requirements

10.1.4.2.1 Set sample flow rate and pressure in accordance with the instrument manufacturer's instructions.

10.1.4.2.2 Gas must flow past the chilled mirror where optic means are provided to detect the deposit (or frost) and to read the thermometer measuring the temperature of the mirror.

10.1.4.3 *Calibration Standard* — A calibration thermometer designed to indicate temperatures in the -79°C (-110°F) range required.

10.1.4.4 Operating Procedure

10.1.4.4.1 Obtain a continuous flow of sample gas from the source using a clean stainless steel (or copper) sampling line which has been purged dry after exposure to ambient moisture.

10.1.4.4.2 After prepurging with a dry gas, allow the sample gas to flow through the sampling system and the dewpoint/frostpoint hygrometer for one hour to 24 hours to allow the entire system to reach equilibrium with regard to moisture content.

10.1.4.4.3 After equilibrium has been reached, cool down the mirror to determine the actual dewpoint/frostpoint of the sample gas. Follow the manufacturer's recommendations to create the temperatures needed.

10.1.4.4.4 Continue to verify the dewpoint/frostpoint for at least 30 minutes after a stable reading has been confirmed.

10.1.4.4.5 Correct the dewpoint reading from the measured pressure to 1 atm of pressure. The result may not exceed the specification in Table 1.

11 Analytical Procedures for Grade 5.4 Nitrogen (See Notes 1 and 2 in Section 9)

11.1 *Carbon Monoxide and Carbon Dioxide* — Use the procedure in Section 9.1 for the analysis of carbon monoxide and carbon dioxide.

11.2 *Hydrogen* — Use the procedure in Section 9.2 for the analysis of hydrogen.

11.3 *Oxygen* — Use the procedure in Section 9.3 for the analysis of oxygen except that the standard should be between 0.5 and 2.5 ppm oxygen in nitrogen.

11.4 *Total Hydrocarbons* — Use procedure Section 9.4 for the determination of total hydrocarbons except that the calibration standard should be at the 0.1 ppm level.

11.5 *Water* — Use procedure in Section 9.5 for the determination of water.

12 Analytical Procedures for Grade 5.5 Nitrogen (See Notes 1 and 2 in Section 9)

12.1 *Carbon Monoxide and Hydrogen* — This procedure is for the determination of carbon monoxide and hydrogen in nitrogen using a gas chromatograph with a reduction gas detector (See Note 3 in Section 9.1).

12.1.1 *Detection Limits* — 2 ppb carbon monoxide, 20 ppb hydrogen.

12.1.2 Instrument Parameters

12.1.2.1 *Column* — 5A molecular sieve, 0.9 m (3 ft) by 3 mm (1/4 in) stainless steel, or equivalent.

12.1.2.2 *Carrier Flow* — 40 mL/min air or nitrogen.

12.1.2.3 *Sample Volume* — 2.0 mL.

12.1.2.4 Temperatures:

Detector	280°C
Column Oven	250°C

12.1.3 Calibration Standard — 1–5 ppm carbon monoxide, 1–5 ppm hydrogen in nitrogen.

12.1.4 Operating Procedure

12.1.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas. Order of elution is hydrogen, then carbon monoxide. Run standard analysis in triplicate for stability determination relative to purging of calibration system components.

12.1.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

12.1.4.3 Repeat Section 12.1.4.1.

12.1.4.4 Compare the average peak areas of the calibration standard to that of the nitrogen sample being tested. Calculate the concentrations of carbon monoxide and hydrogen, using the formula:

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \text{Concentration of Standard} \\ = \text{Concentration of Sample}$$

12.1.4.5 The result may not exceed the specification in Table 1.

12.2 Carbon Dioxide — This procedure is for the determination of carbon dioxide in nitrogen using a continuous flow, non-dispersive infrared analyzer.

12.2.1 Detection Limit — 50 ppb

12.2.2 Set sample flow rate and pressure in accordance with the instrument manufacturer's instructions.

12.2.3 Calibration Standard — Zero nitrogen with a known quantity of carbon dioxide at not more than 0.05 ppm. Span gas nitrogen with a known concentration of 1–10 ppm carbon dioxide.

12.2.4 Operating Procedure

12.2.4.1 Do not change the initial sample flow setting once established.

12.2.4.2 Introduce the zero nitrogen with known quantity of carbon dioxide and set the needle (or output reading) to read the correct level using the zero adjustment knob.

12.2.4.3 Introduce the span gas standard in nitrogen and using the span adjust knob, set the needle (or output reading) to match the levels of carbon dioxide in the span gas.

12.2.4.4 Repeat Section 12.2.4.2 and Section 12.2.4.3 until reproducibility of readings is better than 1% of full scale.

12.2.4.5 Introduce nitrogen sample into the analyzer and read the quantity of carbon dioxide on the analyzer meter. The result may not exceed the specification in Table 1.

12.3 Oxygen — This procedure is for the determination of oxygen in nitrogen using a continuous flow analyzer using an electrochemical method.

12.3.1 Detection Limit — 50 ppb

12.3.2 Set sample pressure and flow rates in accordance with the instrument manufacturer's instructions.

12.3.3 Calibration Standard — 1–10 ppm oxygen in nitrogen or accordance with the instrument manufacturer's instructions.

12.3.4 Operating Procedure

12.3.4.1 Do not change the initial sample flow setting once established.

12.3.4.2 Introduce nitrogen containing less than 2 ppm oxygen through a deoxygenation catalyst to verify that there is no leakage of air into the system and to demonstrate that the detection limit can be achieved.

12.3.4.3 Introduce the calibration standard. Using the span adjust knob, set the needle (or output reading) to match the level of oxygen in the calibration gas.

12.3.4.4 Introduce nitrogen sample and record the oxygen reading. The result may not exceed the specification in Table 1.

12.4 Water — This procedure is for the determination of trace moisture (water) in nitrogen using a continuous flowing piezoelectric hygrometer (See NOTE 7 in Section 9.5).

12.4.1 Detection Limit — 0.1 ppmv or -90°C (-130°F).

12.4.2 Flow Requirements — Set sample pressure and flow rate in accordance with the instrument manufacturer's instructions.

12.4.3 Calibration Standard — Construct a calibration curve which contains at least three points covering the range of interest. The standards employed will be verified independently by another analytical method.

12.4.4 Operating Procedure

12.4.4.1 Obtain a continuous flow of sample gas from the source using a clean and passivated 316 stainless steel line which has been purged dry after exposure to ambient moisture.

12.4.4.2 After prepurging with a dry gas, allow the sample gas to flow through the sampling system and the piezoelectric moisture hygrometer until a stable reading is obtained. The result may not exceed the specification in Table 1.

12.5 *Total Hydrocarbons* — This procedure is for the determination of total hydrocarbons in nitrogen using a continuous flow flame ionization detector-equipped total hydrocarbon analyzer (See Notes 4, 5, and 6 in Section 9.4).

12.5.1 *Detection Limit* — 0.1 ppm

12.5.2 *Flow Requirements*

12.5.3 High-purity, hydrocarbon-free (less than 1.0 ppm) hydrogen: 35–40 mL/min or 40% hydrogen in either helium or nitrogen matrix at 75–80 mL/min.

12.5.4 Dry, hydrocarbon-free (less than 1.0 ppm) air: 350–400 mL/min.

12.5.5 Set sample flow rates in accordance with the instrument manufacturer's instructions.

12.5.6 *Calibration Standards*

12.5.6.1 Zero nitrogen with known quantity of hydrocarbons at 0.1 ppm level.

12.5.6.2 *Span Gas* — Nitrogen with known quantity (1–10 ppm) hydrocarbons.

12.5.7 *Operating Procedure*

12.5.7.1 Do not change the initial flow settings for hydrogen, air and sample once established.

12.5.7.2 Introduce the zero nitrogen with known quantity of hydrocarbons and, using the 0–10 ppm range, set the needle (or output) to read the correct level using the zero adjust knob.

12.5.7.3 Introduce the span gas standard in nitrogen and, using the span adjust knob, set the needle (or output reading) to match the level of hydrocarbons in the span gas.

12.5.7.4 Repeat Section 12.5.7.2 and Section 12.5.7.3 until reproducibility of readings is better than 1% of full scale.

12.5.8 Introduce nitrogen sample into the analyzer and read the quantity of hydrocarbons on the analyzer meter. The result may not exceed the specification in Table 1.

13 Analytical Procedures for Grade 5.6 Nitrogen (See Notes 1 and 2 in Section 9)

13.1 *Carbon Monoxide and Hydrogen* — Use the procedure in Section 12.1 for the determination of carbon monoxide and hydrogen.

13.2 *Carbon Dioxide* — Use procedure Section 12.2 for the determination of carbon dioxide.

13.3 *Oxygen* — Use procedure Section 12.3 for the analysis of oxygen.

13.4 *Water* — Use procedure Section 9.5 for the determination of water.

13.5 *Total Hydrocarbons* — Use procedure Section 9.4 for the determination of hydrocarbons, except that the calibration standard should be at 0.1 ppm hydrocarbons.

14 Analytical Procedures for Grade 6.0 Nitrogen (See Notes 1 and 2 in Section 9)

14.1 *Carbon Monoxide and Hydrogen* — This procedure is for the determination of carbon monoxide and carbon dioxide in nitrogen using a gas chromatograph fitted with a reduction gas detector. (See NOTE 3 in Section 9.1.)

14.1.1 *Detection Limit* — Hydrogen 3 ppb, CO, 0.3 ppb

14.1.2 *Instrument Parameters*

14.1.2.1 *Column 1* — 1/8" OD 77" length Unibead 1S 60–80 mesh, *Column 2* — 1/8" OD 30 3/4" length MS5A

14.1.2.2 *Carrier Flow* — 20 mL/min at 105°C nitrogen.

14.1.2.3 *Sample Volume* — 100 µL

14.1.2.4 *Temperatures:*

Detector	270°C
Column Oven	105°C

14.1.3 *Calibration Standards* — 0.1–0.5 ppm carbon monoxide, 0.1–0.5 ppm hydrogen, balance nitrogen.

14.1.3.1 Construct a calibration curve in the range of interest. Verify the standards employed independently by established traceability to recognized national or international standards.

14.1.4 *Operating Procedure*

14.1.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas. Order of elution is hydrogen, carbon monoxide.

14.1.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

14.1.4.3 Repeat Section 14.1.4.1.

14.1.4.4 Compare the average peak area of the calibration standard to that of the nitrogen sample being

tested. Calculate the concentrations of carbon monoxide and hydrogen using the formula:

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \text{Concentration of Standard} \\ = \text{Concentration of Sample}$$

14.1.4.5 The result may not exceed the specification in Table 1.

14.2 Carbon Dioxide — This procedure is for the determination of carbon dioxide in nitrogen using a gas chromatograph with a flame ionization detector, fitted with a methanizer.

14.2.1 *Detection Limit* — 2 ppb

14.2.2 *Instrument Parameters*

14.2.2.1 *Column* — 1/8" OD 77" Length Hayesep D 100-120 mesh.

14.2.2.2 *Flow Rates*:

Carrier Flow:	30 mL/min nitrogen
Air Flow:	250 mL/min
Hydrogen Flow:	30 mL/min

14.2.2.3 *Sample Volume* — 5 mL

14.2.2.4 *Temperatures*:

Methanizer	315°C
Column Temperature	40°C

14.2.3 *Calibration Standard* — 0.1 ppm carbon dioxide in nitrogen.

14.2.3.1 Construct a calibration curve in the range of interest. Verify the standards employed independently by established traceability to recognized national or international standards.

14.2.4 *Operating Procedure*

14.2.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention time and peak area.

14.2.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention time and peak area.

14.2.4.3 Repeat Section 14.2.4.1.

14.2.4.4 Compare the average peak area of the calibration standard to that of the nitrogen sample being tested. Calculate the concentration of carbon dioxide, using the formula:

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \text{Concentration of Standard} \\ = \text{Concentration of Sample}$$

14.2.4.5 The result may not exceed the specification in Table 1.

14.3 Oxygen — This procedure is for the determination of oxygen in nitrogen using a continuous flow analyzer using an electrochemical method.

14.3.1 *Detection Limit* — 2 ppb

14.3.2 *Flow Rate* — Set sample flow rates in accordance with the instrument manufacturer's instructions.

14.3.3 *Calibration Standards* — 50 ppb oxygen in nitrogen or in accordance with the instrument manufacturer's instructions.

14.3.4 *Operating Procedure*

14.3.4.1 Introduce nitrogen sample and record oxygen reading. The result may not exceed the specification in Table 1.

14.4 Total Hydrocarbons — This procedure is for the determination of total hydrocarbons in nitrogen using a gas chromatograph fitted with a flame ionization detector and a back flush valve.

14.4.1 *Detection Limit* — 2 ppb

14.4.2 *Instrument Parameters*

14.4.2.1 *Column* — 1/8" OD 77" Length Hayesep D 100-120 mesh.

14.4.2.2 *Flow Rates*:

Carrier Flow:	30 mL/min nitrogen
Air Flow:	250 mL/min
Hydrogen Flow:	30 mL/min

14.4.2.3 *Sample Volume* — 5 mL

14.4.2.4 *Temperatures* — Column Temperature 40°C

14.4.3 *Calibration Standard* — 0.1 ppm methane in nitrogen.

14.4.3.1 *Calibration Standards* — Construct a calibration curve in the range of interest. Verify the standards employed independently by established traceability to recognized national or international standards.

14.5 Water — This procedure is for the determination of trace moisture (water) in nitrogen using a continuous flowing phosphorous pentoxide hygrometer. (See Note 7 in Section 9.5.)

14.5.1 *Detection Limit* — 10 ppbv

14.5.2 *Flow Requirements* — Set the sample pressure and flow rate in accordance with the instrument manufacturer's instructions.



14.5.3 *Calibration Standards* — Construct a calibration curve in the range of interest. Verify the standards employed independently by established traceability to recognized national or international standards.

14.5.4 *Operating Procedure*

14.5.4.1 Obtain a continuous flow sample of gas from the source using a clean and passivated stainless steel line which has been purged dry after exposure to ambient moisture.

14.5.4.2 After prepurging with a dry gas, allow the sample gas to flow through the sampling system and the P₂O₅ moisture hygrometer until a stable reading is obtained.

14.5.4.3 Determine the moisture content of the nitrogen sample by comparing the reading to calibration curve. The result may not exceed the specification in Table 1.

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

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SEMI C60-0305

SPECIFICATIONS AND GUIDELINES FOR NITROUS OXIDE (N₂O)

This specification was technically approved by the Global Gases Committee and is the direct responsibility of the North American Gases Committee. Current edition approved by the North American Regional Standards Committee on December 10, 2004. Initially available at www.semi.org January 2005; to be published March 2005.

1 Purpose

1.1 The purpose of this document is to provide a series of specifications for different grades of Nitrous Oxide (N₂O) that are used in the semiconductor industry.

2 Scope

2.1 This document covers requirements for all grades of nitrous oxide used in the semiconductor industry.

2.2 If analytical methods are not complete, the requirements are presented as a guideline.

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

3 Description

3.1 Nitrous oxide is an oxidizing, colorless, liquefied gas with a sweetish odor. It is a simple asphyxiant. Vapor pressure is about 745 psig at 70°F.

4 Limitations

4.1 None.

5 Referenced Standards

5.1 SEMI Standards

SEMI C1 — Specifications for Reagents

SEMI C3 — Specifications for Gases

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

6 Terminology

6.1 Terminology appropriate to this standard is defined in SEMI C3.

7 Requirements

7.1 Purity and other requirements for the various grades of nitrous oxide are given in Table 1.



Table 1 Impurity and Other Requirements for Various Grades of Nitrous Oxide

Previous SEMI Reference #	C3.13-1000 (Specification)	C3.50-1000 (Guideline)
Grade	4.7	5.4
Purity	99.997% ^{#2, #3}	99.9994% ^{#2, #3}
Impurities	Maximum Acceptable Level (ppm) ^{#1}	Maximum Acceptable Level (ppm) ^{#1}
Ammonia (NH ₃)	5	0.1
Carbon Dioxide (CO ₂)	2	0.5
Carbon monoxide (CO)	1	0.1
Hydrocarbons C ₁ -C ₅	1	0.1 (as C ₁)
Nitric Oxide (NO)	1	0.1
Nitrogen (N ₂)	10	3
Nitrogen dioxide (NO ₂)	1	0.1
Oxygen (O ₂)	2	N/A
Oxygen (O ₂) + Argon (Ar)	N/A	0.5
Water (H ₂ O) (v/v)	3	1.0
TOTAL SPECIFIED IMPURITIES	26	5.5

^{#1} An analysis of significant figures has not been considered. The number of significant figures is based on analytical accuracy and the precision of the provided procedure.

^{#2} This specification applies to the gas phase of the cylinder as delivered.

^{#3} It is recommended that the user discontinue use of the cylinder prior to complete consumption of the liquid phase. The contents of cylinders should be determined by weight, not pressure.

8 Physical Constants

8.1 The physical constants of nitrous oxide are given in Table 2 (for information only).

Table 2 Physical Constants of Nitrous Oxide (for information only)

	Metric Units	US Units
Molecular weight	44.01	44.01
Boiling point at 1 atm	-88.5°C	-127.4°F
Density of gas at 70°F (21.1°C) and 1 atm	1.947 g/L	0.1160 lb/ft ³
Specific gravity of gas	1.53	1.53
Critical pressure	71.46 atm	1052 psia
Critical temperature	36.4 °C	97.6°F

9 Analytical Procedures for Grade 4.7 Nitrous Oxide (See Appendix 1)

NOTE 1: Rapid withdrawal of gaseous nitrous oxide from a liquified source (e.g., cylinder) can result in a significant cooling effect which may condense the nitrous oxide in the sampling lines.

9.1 *Ammonia* — This procedure is for the determination of ammonia in nitrous oxide using an apparatus employing a detector tube filled with a color-reactive chemical.

9.1.1 *Detection Limit* — 0.2 ppm (mol/mol).

9.1.2 *Apparatus*

9.1.2.1 *Pressure Regulator* — Outlet Pressure Range 0–30 psig.

9.1.2.2 *Flowmeter* — Range 0–200 mL/min.

9.1.2.3 *Detector Tube* — Range 2–30 ppm.



9.1.2.4 Stop watch.

9.1.2.5 6 mm (1/4 in) flexible tubing.

9.1.3 Operating Procedure

9.1.3.1 Attach a suitable regulator to the cylinder outlet.

9.1.3.2 Connect the flowmeter to the regulator using flexible tubing.

9.1.3.3 Open the cylinder valve and purge the flowmeter with nitrous oxide.

9.1.3.4 After the line is thoroughly purged, stop the flow of nitrous oxide and attach the detector tube to the outlet of the flowmeter.

9.1.3.5 Start the flow of nitrous oxide and set the flow rate to 100 mL/min. The pressure and temperature of the sample must be within the tolerances specified by the manufacturer.

9.1.3.6 Pass 100 mL of nitrous oxide through the detector tube.

9.1.3.7 Determine the concentration of ammonia according to the detector tube manufacturer's instructions. The concentration may not exceed the specification in Table 1 of this standard.

9.2 Carbon Monoxide and Carbon Dioxide — This procedure is for the determination of carbon monoxide and carbon dioxide in nitrous oxide using a gas chromatograph with a flame ionization detector and methanizer with back flush, (see Figure A1-1).

NOTE 2: In order to prevent nitrous oxide interference, a helium backflush to vent is needed for 3–5 times the analysis time (estimated to be 3–5 minutes). Because nitrous oxide is converted into ammonia in the methanizer, stainless steel (ss) is required; copper tubing and fittings are not used. The backflush removes the nitrous oxide from Column No. 1 preparing the column for the next sample. Careful timing is required to identify carbon monoxide and carbon dioxide distinguishing both from the time methane would appear, if present. Carbon monoxide and carbon dioxide are converted to methane in the methanizer; therefore, both will be detected by the FID detector at the specific times determined by the analytical sequence of the standard.

9.2.1 *Detection Limit* — 1 ppm (mol/mol), (50 ppb depending on conditions).

9.2.2 Instrument Parameters

9.2.2.1 *Columns*: Column 1: Porapak QS, 4.6 m (15 ft) by 5 mm (3/16 in) or equivalent. Column 2: Molecular sieve 5A, 1.97 m (6 ft) by 5 mm, 80/100 mesh (reference only) or equivalent.

9.2.2.2 *Carrier Flow*: 30 mL/min helium.

9.2.2.3 *Sample Volume*: 0.5 to 2.0 mL.

9.2.2.4 *Temperatures*:

Detector	35°C
Column Oven	35°C
Methanizer	500°C

9.2.3 *Calibration Standard* — 1–5 ppm (mol/mol) carbon monoxide, 1–5 ppm (mol/mol) carbon dioxide, balance nitrous oxide.

9.2.4 Operating Procedure

9.2.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention times and peak areas. The order of elution is carbon monoxide, methane, carbon dioxide, and nitrous oxide. Back flush 18 minutes.

9.2.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

9.2.4.3 Repeat ¶9.2.4.1.



9.2.4.4 Compare the average peak areas of the calibration standard to that of the nitrous oxide sample being tested. Calculate the concentrations of carbon monoxide and carbon dioxide, using the formula below. The result may not exceed the specification in Table 1 of this Standard.

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \frac{\text{Concentration of Standard}}{\text{Concentration of Sample}} = \frac{\text{Concentration of Sample}}{\text{Concentration of Standard}}$$

9.3 *Hydrocarbons C₁ – C₅* — This procedure is for the determination of hydrocarbons C₁ – C₅ in nitrous oxide using a gas chromatograph with a flame ionization detector.

9.3.1 *Methane Determination*

9.3.1.1 *Detection Limit* — 0.1 ppm (mol/mol).

9.3.1.2 *Instrument Parameters*

9.3.1.2.1 *Column*: 5A molecular sieve, 1.9 m (6 ft) by 6.4 mm (1/4 in) OD by 5.3 mm (0.210 in) ID stainless steel or equivalent.

9.3.1.2.2 *Carrier Flow*: 25 mL/min helium.

9.3.1.2.3 *Sample Volume*: 5.0 mL.

9.3.1.2.4 *Temperatures*:

Detector	150°C
Column Oven	30°C

9.3.2 *Ethane Determination*

9.3.2.1 *Detection Limit* — 0.3 ppm (mole/mole).

9.3.2.2 *Instrument Parameters*

9.3.2.2.1 *Column*: Porapak Q, 1.9 m (6 ft) by 6.4 mm (1/4 in) OD by 5.3 mm (0.210 in) ID stainless steel or equivalent.

9.3.2.2.2 *Carrier Flow*: 50 mL/min helium.

9.3.2.2.3 *Sample Volume*: 1.0 mL.

9.3.2.2.4 *Temperatures*:

Detector	150°C
Column Oven	60°C

9.3.3 *Ethylene, Propane, Acetylene, Propylene, n-butane, and n-pentane Determination*

9.3.3.1 *Detection Limit* — 0.1 ppm (mole/mole).

9.3.3.2 *Instrument Parameters*

9.3.3.2.1 *Column*: Phenylisocyanate/Porasil C, 3 m (10 ft) by 4.8 mm (3/16 in) OD by 3.7 mm (0.147 in) ID stainless steel or equivalent.

9.3.3.2.2 *Carrier Flow*: 25 mL/min helium.

9.3.3.2.3 *Sample Volume*: 1.0 mL.

9.3.3.2.4 *Temperatures*:

Detector	150°C
Column Oven	30°C



9.3.4 *Calibration Standards* — 1–5 ppm (mol/mol) methane in helium, 1–5 ppm (mol/mol) ethane in helium, 1–5 ppm (mol/mol) ethylene, 1–5 ppm (mol/mol) propane, 1–5 ppm (mol/mol) acetylene, 1–5 ppm (mol/mol) propylene, 1–5 ppm (mol/mol) n-butane, and 1–5 ppm (mol/mol) n-pentane, balance in helium.

9.3.5 *Operating Procedure*

9.3.5.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention time and peak area.

9.3.5.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

9.3.5.3 Repeat ¶9.3.5.1.

9.3.5.4 Compare the average peak area of the calibration standard to that of the nitrous oxide sample being tested. Calculate the concentration of hydrocarbons C₁–C₅, using the formula below. The result may not exceed the specification in Table 1 of this Standard.

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \text{Concentration of Standard} = \text{Concentration of Sample}$$

9.4 *Nitric Oxide* — This procedure is for the determination of nitric oxide in nitrous oxide using chemiluminescence. The detector shall have a photomultiplier tube capable of sensing the light emission of the decaying nitrous oxide. The detector shall have variable attenuation, zero and span adjustments, display, and an onboard ozone generator.

NOTE 3: This method does not determine nitrous oxide impurities.

9.4.1 *Detection Limit* — 0.1 ppm (mol/mol).

9.4.2 *Instrument Parameters*

9.4.2.1 *Flow Requirements* — Set the zero gas, span gas, and sample gas in accordance with the instrument manufacturer's instructions.

9.4.3 *Calibration Standards*

9.4.3.1 Zero argon (99.99% minimum) with less than 0.1 ppm nitric oxide.

9.4.3.2 The upper level argon span gas (99.99% minimum) not exceeding 5 times the concentration of the specification.

9.4.3.3 The oxygen supplied to the ozone generator will contain less than 0.1 ppm nitric oxide.

9.4.4 *Operating Procedure*

9.4.4.1 Introduce the zero argon and set the instrument to zero with the zero adjust knob.

9.4.4.2 Introduce the span gas in argon and, using the span adjust knob, set the output reading to match the level of nitric oxide in the span gas.

9.4.4.3 Repeat ¶9.4.4.1 and ¶9.4.4.2 until reproducibility of readings is better than 1% full scale.

9.4.4.4 Introduce the nitrous oxide sample into the analyzer and read the quantity of nitric oxide. The result may not exceed the specification in table 1 of this standard.

9.5 *Nitrogen and Oxygen* — This procedure is for the determination of nitrogen and oxygen in nitrous oxide using a gas chromatograph with a helium ionization detector.

9.5.1 *Detection Limit* — 0.5 ppm (mol/mol).

9.5.2 *Instrument Parameters*

9.5.2.1 *Columns*: Column 1: Porapak Q, 1.9 m (6 ft) by 3.2 mm (1/8 in) OD by 2.2 mm (0.085 in) ID stainless steel, or equivalent. Column 2: Molecular sieve 5A, 2.4 m (8 ft) by 3.2 mm (1/8 in) OD by 2.2 mm (0.085 in) ID stainless steel, or equivalent.



9.5.2.2 *Carrier Flow:* 50 mL/min helium.

9.5.2.3 *Sample Volume:* 1.0 to 3.0 mL.

9.5.2.4 *Temperatures:*

Detector	125°C
Column Temperature	65°C

9.5.3 *Calibration Standards* — 5–20 ppm (mol/mol) nitrogen in helium and 1–5 ppm (mol/mol) oxygen in helium.

9.5.4 *Operating Procedure*

9.5.4.1 Inject the calibration standard into the column using a gas sampling valve. Record the retention time and peak area.

9.5.4.2 Inject the sample to be tested in same manner as the calibration standard. Record the retention times and peak areas.

9.5.4.3 Repeat ¶9.5.4.1.

9.5.4.4 Compare the average peak area of the calibration standard to that of the nitrous oxide sample being tested. Calculate the concentrations of nitrogen and oxygen, using the formula below. The result may not exceed the specification in Table 1 of this standard.

$$\frac{\text{Sample Peak Area}}{\text{Standard Peak Area}} \times \frac{\text{Concentration of Standard}}{\text{Concentration of Sample}} =$$

9.6 *Nitrogen Dioxide* — This procedure is for the determination of nitrogen dioxide in nitrous oxide using an apparatus employing a detector tube filled with a color-reactive chemical.

9.6.1 *Detection Limit* — 0.05 ppm.

9.6.2 *Apparatus*

9.6.2.1 *Pressure Regulator:* Outlet Pressure Range 0–30 psig.

9.6.2.2 *Flowmeter:* Range 0–200 mL/min.

9.6.2.3 *Detector tube:* Range 0.2–6 ppm.

9.6.2.4 *Stop Watch.*

9.6.2.5 6 mm (1/4 in) flexible tubing.

9.6.3 *Operating Procedure*

9.6.3.1 Attach a suitable regulator to the cylinder outlet.

9.6.3.2 Connect the flowmeter to the regulator using flexible tubing.

9.6.3.3 Open the cylinder valve and purge the flowmeter with nitrous oxide.

9.6.3.4 After the line is thoroughly purged, stop the flow of nitrous oxide and attach the detector tube to the outlet of the flowmeter.

9.6.3.5 Start the flow of nitrous oxide and set the flow rate to 100 mL/min. The pressure and temperature of the sample must be within the tolerance specified by the manufacturer.

9.6.3.6 Pass 800 mL of gas through the detector tube.

9.6.3.7 Determine the concentration of nitrogen dioxide according to the detector tube manufacturer's instructions. The concentration may not exceed the specification in Table 1 of this standard.

9.7 *Water* — This procedure is for the determination of trace moisture (water) in nitrous oxide using a piezoelectronic hygrometer.



9.7.1 *Detection Limit* — 1.0 ppm (vol/vol).

9.7.2 *Flow Requirements* — Follow the flow requirements specified in the manufacturer's instrument operation manual.

9.7.3 *Calibration Standards* — Construct a calibration curve which contains at least three points covering the range of interest. The standards employed will be verified independently by another analytical method.

NOTE 4: Other hygrometers may also be used, e.g. CRDS, FTIR, TDLAS, and vibrating quartz.

9.7.4 *Sample System and Proper Operation*

9.7.4.1 The sample system shall be as shown in Figure A1-2.

9.7.4.2 Attach sample system to nitrous oxide cylinder.

9.7.4.3 Partially open valve 2.

9.7.4.4 Open valve 1 and adjust pressure to 50 psig, \pm 5 psig.

9.7.4.5 Adjust valve 2 until a flow of 500 mL/min, \pm 50 mL/min is venting.

9.7.4.6 Tubing, valves and fittings are to be cleaned and passivated 316 stainless steel.

9.7.4.7 Keep tubing lengths to a minimum.

9.7.5 *Operating Procedure*

9.7.5.1 Follow the procedures outlined in the instrument manufacturer's manual.

9.7.5.2 Allow the system to run until a stable reading is obtained for ten minutes.

9.7.5.3 Read the quantity of water on the analyzer meter. The result may not exceed the specification in Table 1 of this standard.

APPENDIX 1 GENERAL ANALYTICAL PRACTICES

NOTICE: The material in this appendix is an official part of SEMI C59 and was approved by full letter ballot procedures on December 10, 2004 by the North American Regional Standards Committee.

A1-1 Introduce the calibration standard as many times as necessary to achieve the desired precision.

A1-2 All the gases used in the analysis of the sample should not contain more than 10% of the specified value at the component of interest, unless otherwise specified.

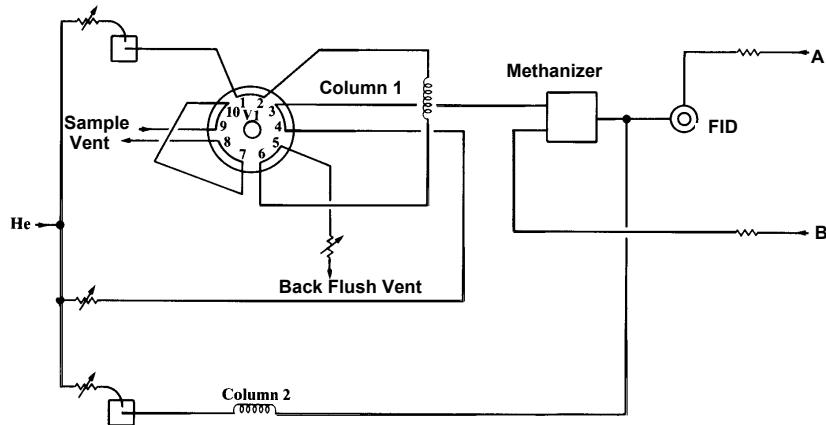


Figure A1-1
Valving Arrangement

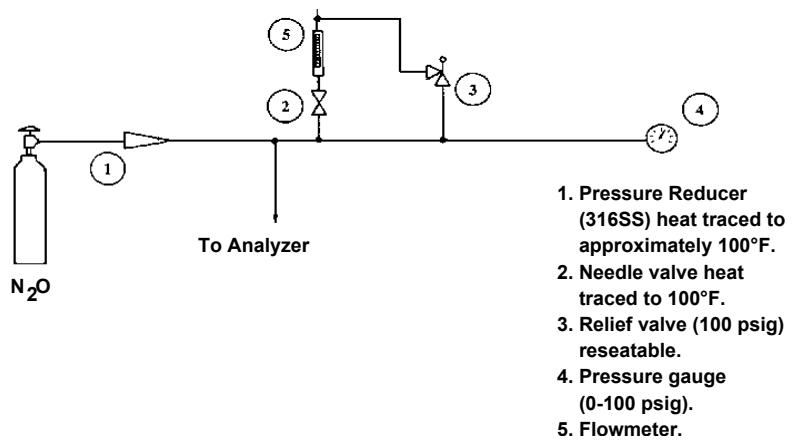


Figure A1-2
Nitrous Oxide Cylinder Sample System

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

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SEMI INTERNATIONAL STANDARDS



MATERIALS

Semiconductor Equipment and Materials International



SEMI M1-0305

SPECIFICATIONS FOR POLISHED MONOCRYSTALLINE SILICON WAFERS

This specification was technically approved by the Global Silicon Wafer Committee and is the direct responsibility of the North American Silicon Wafer Committee. Current edition approved by the North American Regional Standards Committee on November 4, 2005. Initially available at www.semi.org February 2005; to be published March 2005. Originally published in 1978; previously published July 2004.

NOTICE: This standard was completely rewritten in 2005.

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1 Purpose

1.1 Monocrystalline (single crystal) silicon wafers are utilized for essentially all integrated circuits and many other semiconductor devices. To permit common processing equipment to be used in multiple device fabrication lines, it is essential for the wafer dimensions to be standardized.

1.2 In addition, as technology advances to smaller and smaller dimensions for the elements of high density integrated circuits, it has become of interest to standardize additional properties of the wafers.

1.3 This specification provides the essential dimensional and certain other common characteristics of silicon wafers, including polished wafers as well as substrates for epitaxial and certain other kinds of silicon wafers.

2 Scope

2.1 These specifications cover ordering information and certain requirements for high-purity, monocrystalline polished silicon wafers used in semiconductor device and integrated circuit manufacturing or as substrates (or starting wafers) for other kinds of wafers, including epitaxial, annealed, and SOI wafers.

2.2 Dimensional requirements are provided for the following categories of polished wafers:

- Category 1.1 2 in. polished monocrystalline silicon wafers with secondary flat
- Category 1.2 3 in. polished monocrystalline silicon wafers with secondary flat
- Category 1.5 100 mm polished monocrystalline silicon wafers, 525 µm thick, with secondary flat
- Category 1.6 100 mm polished monocrystalline silicon wafers, 625 µm thick, with secondary flat
- Category 1.7 125 mm polished monocrystalline silicon wafers with secondary flat
- Category 1.8.1 150 mm polished monocrystalline silicon wafers with secondary flat and T/3 edge profile template
- Category 1.8.2 150 mm polished monocrystalline silicon wafers with secondary flat and T/4 edge profile template
- Category 1.9.1 200 mm notched polished monocrystalline silicon wafers with T/3 edge profile template
- Category 1.9.2 200 mm notched polished monocrystalline silicon wafers with T/4 edge profile template
- Category 1.10.1 200 mm flatted polished monocrystalline silicon wafers with T/3 edge profile template without secondary flat
- Category 1.10.2 200 mm flatted polished monocrystalline silicon wafers with T/4 edge profile template without secondary flat
- Category 1.11 100 mm flatted polished monocrystalline silicon wafers without secondary flat
- Category 1.12 125 mm flatted polished monocrystalline silicon wafers without secondary flat
- Category 1.13.1 150 mm flatted polished monocrystalline silicon wafers with T/3 edge profile template without secondary flat
- Category 1.13.2 150 mm flatted polished monocrystalline silicon wafers with T/4 edge profile template without secondary flat
- Category 1.15 300 mm notched polished monocrystalline silicon wafers

2.2.1 Values given for thickness, TTV, bow, and warp apply only to wafers prior to application of back surface films, extrinsic gettering treatments, or other thermal treatments.

2.2.2 The dimensional characteristics of Category 1.10.1, 1.10.2, 1.11, 1.12, 1.13.1, and 1.13.2 wafers specified in this document are identical with those specified in JEITA EM-3602, and the dimensional characteristics of Category 1.15 wafers are essentially equivalent with those specified in JEITA EM-3602.



2.3 A complete purchase specification requires that additional physical properties be specified along with test methods suitable for determining their magnitude. This standard provides a comprehensive listing of such properties and associated test methods. This listing provides a systematic basis for constructing the purchase specification for any kind of polished silicon wafer or substrate and is expected to be used for such purposes.

2.4 These specifications apply specifically to prime silicon wafers with at least one chem-mechanically polished surface. Ground, lapped, and unpolished wafers are not covered in this specification but this specification may provide guidance in connection with their procurement.

2.5 In addition, these specifications cover specification requirements for basic 300 mm diameter, double-side polished silicon wafers that are suitable for many advanced integrated circuit applications. If this kind of wafer is desired, physical properties other than those listed in the table of requirements shall not be included in the purchase specification.

2.6 These specifications do not cover the requirements for the following related silicon materials and wafers:

- Polycrystalline silicon (see SEMI M16 or JEITA EM-3601),
- Epitaxial wafers (see SEMI M2 or SEMI M11),
- Epitaxial wafers with buried layer (see SEMI M18),
- Test wafers (see SEMI M8),
- Premium wafers (see SEMI M24),
- Reclaimed wafers (see SEMI M38),
- Annealed wafers (see SEMI M57),
- SOI wafers (see SEMI M34, SEMI M41, SEMI M47, or JEITA EM-3603),
- Dielectrically isolated wafers (see SEMI M22), and
- Solar-grade silicon wafers (see SEMI M6).

They do, however, provide the ordering information for test, premium, and reclaimed wafers, as well as the ordering information for the polished substrates and starting wafers used to prepare epitaxial, annealed, and SOI wafers.

2.7 The complete EDI Code List for items in the Order Form appropriate to silicon wafers, including polished wafers and substrates, can be found in SEMI M18.

2.8 For referee purposes, U.S. customary units shall be used for wafers of 2 in. and 3 in. nominal diameters, and SI (system international, commonly called metric) units for 100 mm and larger diameter wafers.

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

3 Referenced Standards

3.1 SEMI Standards

SEMI M2 — Specification for Silicon Epitaxial Wafers for Discrete Device Applications

SEMI M6 — Specification for Silicon Wafers for Use as Photovoltaic Solar Cells

SEMI M8 — Specification for Polished Monocrystalline Silicon Test Wafers

SEMI M11 — Specifications for Silicon Epitaxial Wafers for Integrated Circuit (IC) Applications

SEMI M12 — Specification for Serial Alphanumeric Marking of the Front Surface of Wafers

SEMI M13 — Specifications for Alphanumeric Marking of Silicon Wafers

SEMI M16 — Specification for Polycrystalline Silicon

SEMI M18 — Format for Silicon Wafer Specification Form for Order Entry



SEMI M20 — Practice for Establishing a Wafer Coordinate System

SEMI M24 — Specification for Polished Monocrystalline Silicon Premium Wafers

SEMI M26 — Guide for the Re-use of 100, 125, 150, and 200 mm Wafer Shipping Boxes Used to Transport Wafers

SEMI M33 — Test Method for the Determination of Residual Surface Contamination on Silicon Wafers by Means of Total Reflection X-Ray Fluorescence Spectroscopy (TXRF)

SEMI M34 — Guide for Specifying SIMOX Wafers

SEMI M35 — Guide for Developing Specifications for Silicon Wafer Surface Features Detected by Automated Inspection

SEMI M38 — Specification for Polished Reclaimed Silicon Wafers

SEMI M40 — Guide for Measurement of Surface Roughness of Planar Surfaces on Silicon Wafer

SEMI M41 — Specification of Silicon-on-Insulator (SOI) for Power Device/ICs

SEMI M43 — Guide for Reporting Wafer Nanotopography

SEMI M44 — Guide to Conversion Factors for Interstitial Oxygen in Silicon

SEMI M45 — Provisional Specification for 300 mm Wafer Shipping System

SEMI M47 — Specification for Silicon-on-Insulator (SOI) Wafers for CMOS LSI Applications

SEMI M53 — Practice for Calibrating Scanning Surface Inspection Systems Using Depositions of Monodisperse Polystyrene Latex Sphere on Unpatterned Semiconductor Wafer Surfaces

SEMI M57 — Guide for Specifying Silicon Annealed Wafers

SEMI M58 — Test Method for Evaluating DMA-Based Particle Deposition Systems and Processes

SEMI M59 — Terminology for Silicon Technology

SEMI MF26 — Test Methods for Determining the Orientation of a Semiconductive Single Crystal

SEMI MF28 — Test Methods for Minority-Carrier Lifetime in Bulk Germanium and Silicon by Measurement of Photoconductive Decay

SEMI MF42 — Test Methods for Conductivity Type of Extrinsic Semiconducting Materials

SEMI MF81 — Test Method for Measuring Radial Resistivity Variation on Silicon Wafers

SEMI MF84 — Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe

SEMI MF391 — Test Methods for Minority Carrier Diffusion Length in Extrinsic Semiconductors by Measurement of Steady-State Surface Photovoltage

SEMI MF523 — Practice for Unaided Visual Inspection of Polished Silicon Wafer Surfaces

SEMI MF525 — Test Method for Measuring Resistivity of Silicon Wafers Using a Spreading Resistance Probe

SEMI MF533 — Test Method for Thickness and Thickness of Variation of Silicon Wafers

SEMI MF534 — Test Method for Bow of Silicon Wafers

SEMI MF657 — Test Method for Measuring Warp and Total Thickness Variation on Silicon Wafers by Noncontact Scanning

SEMI MF671 — Test Method for Measuring Flat Length on Wafers of Silicon and Other Electronic Materials

SEMI MF673 — Test Methods for Measuring Resistivity of Semiconductor Slices or Sheet Resistance of Semiconductor Films with a Noncontact Eddy-Current Gage

SEMI MF847 — Test Methods for Measuring Crystallographic Orientation of Flats on Single Crystal Silicon Wafers by X-Ray Techniques

SEMI MF928 — Test Methods for Edge Contour of Circular Semiconductor Wafers and Rigid Disk Substrates



SEMI MF951 — Test Method for Determination of Radial Interstitial Oxygen Variation in Silicon Wafers

SEMI MF1049 — Practice for Shallow Etch Pit Detection on Silicon Wafers

SEMI MF1152 — Test Method for Dimensions of Notches on Silicon Wafers

SEMI MF1188 — Test Method for Interstitial Atomic Oxygen Content of Silicon by Infrared Absorption with Short Baseline

SEMI MF1239 — Test Method for Oxygen Precipitation Characteristics of Silicon Wafers by Measurement of Interstitial Oxygen Reduction

SEMI MF1366 — Test Method for Measuring Oxygen Concentration in Heavily Doped Silicon Substrates by Secondary Ion Mass Spectrometry

SEMI MF1388 — Test Method for Generation Lifetime and Generation Velocity of Silicon Material by Capacitance-Time Measurements of Metal-Oxide-Silicon (MOS) Capacitors

SEMI MF1390 — Test Method for Measuring Warp on Silicon Wafers by Automated Non-contact Scanning

SEMI MF1391 — Test Method for Substitutional Atomic Carbon Content of Silicon by Infrared Absorption

SEMI MF1451 — Test Method for Measuring Sori on Silicon Wafers by Automated Non-contact Scanning

SEMI MF1528 — Test Method for Measuring Boron Contamination in Heavily Doped *n*-Type Silicon Substrates by Secondary Ion Mass Spectrometry

SEMI MF1530 — Test Method for Measuring Flatness, Thickness, and Total Thickness Variation on Silicon Wafers by Automated Non-contact Scanning

SEMI MF1535 — Test Method for Carrier Recombination Lifetime in Silicon Wafers by Noncontact Measurement of Photoconductivity Decay by Microwave Reflectance

SEMI MF1617 — Test Method for Measuring Surface Sodium, Aluminum, Potassium, and Iron on Silicon and Epi Substrates by Secondary Ion Mass Spectrometry

SEMI MF1619 — Test Method for Measurement of Interstitial Oxygen Content of Silicon Wafers by Infrared Absorption Spectroscopy with *p*-Polarized Radiation Incident at the Brewster Angle

SEMI MF1726 — Practice for Analysis of Crystallographic Perfection of Silicon Wafers

SEMI MF1727 — Practice for Detection of Oxidation Induced Defects in Polished Silicon Wafers

SEMI MF1809 — Guide for Selection and Use for Etching Solutions to Delineate Structural Defects in Silicon

SEMI MF1982 — Test Methods for Analyzing Organic Contaminants on Silicon Wafer Surfaces by Thermal Desorption Gas Chromatography

SEMI MF2074 — Guide for Measuring Diameter of Silicon and Other Semiconductor Wafers

SEMI T1 — Specification for Back Surface Bar Code Marking of Silicon Wafers

SEMI T2 — Specification for Marking of Wafers with a Two-Dimensional Matrix Code Symbol

SEMI T3 — Specification for Wafer Box Labels

SEMI T6 — Procedure and Format for Reporting of Test Results by Electronic Data Interchange (EDI)

SEMI T7 — Specification for Back Surface Marking of Double-Side Polished Wafers with a Two-Dimensional Matrix Code Symbol

3.2 ASTM Standards¹

D 523 — Standard Test Method for Specular Gloss

E 122 — Standard Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process

¹ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, USA. Telephone: 610.832.9585, Fax: 610.832.9555, Website: www.astm.org



3.3 JEITA (formerly JEIDA) Standards²

EM-3401 (43) — TERMINOLOGY OF SILICON WAFER FLATNESS

EM-3501 (18) — Standard Methods for Determining the Orientation of a Semiconductive Silicon Single Crystal

EM-3502 (53) — Test method for recombination lifetime in silicon wafers by measurement of photoconductivity decay by microwave reflectance

EM-3503 (56) — Standard test method for substitutional atomic carbon content of silicon by infrared absorption

EM-3504 (61) — Standard test method for interstitial atomic oxygen content of silicon by infrared absorption

EM-3601 — Standard Specification for Dimensional Properties of Silicon Wafers with Specular Surfaces

EM-3602 (27) — Standard specification for dimensional properties of silicon wafers with specular surfaces

EM-3603 — Standard of SOI wafers and metrology

3.4 JIS Standards³

H 0604 — Measuring of minority-carrier life time in silicon single crystal by photoconductive decay method

H 0607 — Determination of Conductivity Type in Germanium by Thermoelectromotive Method

H 0609 — Test methods of crystalline defects in silicon by preferential etch techniques

H 0611 — Methods of measurement of thickness, thickness variation and bow of silicon wafer

H 0614 — Visual inspection for silicon wafers with specular surfaces

H 0615 — Test method for determination of impurity concentrations in silicon crystal by photoluminescence spectroscopy

Z 8741 — Specular glossiness — Methods of measurement

3.5 DIN Standards⁴

50431 — Measurement of the Electrical Resistivity of Silicon or Germanium Single Crystals by Means of the Four-Point-Probe Direct Current Method with Collinear Four-Probe Array

50432 — Determination of the Conductivity Type of Silicon or Germanium by Means of Rectification Test or Hot-Probe

50433/1 — Determination of the Orientation of Single Crystals by Means of X-Ray Diffraction

50433/2 — Determination of the Orientation of Single Crystals by Means of Optical Reflection Figure

50433/3 — Determination of the Orientation of Single Crystals by Means of Laue Back Scattering

50434 — Determination of Crystal Defects in Monocrystalline Silicon Using Etching Techniques on {111} and {100} Surfaces

50435 — Determination of the Radial Resistivity Variation of Silicon or Germanium Slices by Means of a Four-Point-DC-Probe

50438/1 — Determination of Impurity Content in Silicon by Infrared Absorption: Oxygen

50438/2 — Determination of Impurity Content in Silicon by Infrared Absorption: Carbon

50440/1 — Measurement of Recombination Carrier Lifetime in Silicon Single Crystals by Means of Photoconductive Decay Method; Measurement on Bar-Shaped Test Samples

2 Japan Electronics and Information Technology Industries Association, 3rd floor, Mitsui Sumitomo Kaijo Bldg. Annex, 11, Kanda-Surugadai 3-chome, Chiyoda-ku, Tokyo 101-0062, Japan. Telephone: 81.3.3518.6434; Fax: 81.3.3295.8727; Website: www.jeita.or.jp

3 Japanese Industrial Standards, Available through the Japanese Standards Association, 1-24, Akasaka 4-Chome, Minato-ku, Tokyo 107-8440, Japan. Telephone: 81.3.3583.8005; Fax: 81.3.3586.2014 Website: www.jsa.or.jp

4 Deutsches Institut für Normung e.V., standards are available in both English and German editions from Beuth Verlag GmbH, Burggrafenstrasse 6, 10787 Berlin, Germany, Telephone: 49.30.2601-0, Fax: 49.30.2601.1263, Website: www.beuth.de



50441/1 — Determination of the Geometric Dimensions of Semiconductor Slices: Measurement of Thickness

50441/2 — Determination of the Geometric Dimensions of Semiconductor Slices: Testing of Edge Rounding

50441/3 — Measurement of the Geometric Dimensions of Semiconductor Slices; Determination of Flatness Deviation of Polished Slices by Means of Multiple Beam Interference

50441/4 — Determination of the Geometrical Dimensions of Semiconductor Slices: Diameter and Flat Depth of Slices

50443/1 — Recognition of Defects and Inhomogenities in Semiconductor Single Crystals by X-Ray Topography: Silicon

50445 — Contactless Determination of the Electrical Resistivity of Semiconductor Wafers with the Eddy Current Method

3.6 ANSI Standards⁵

ANSI/ASQC Z1.4 — Sampling Procedures and Tables for Inspection by Attributes

ANSI/EIA 556-B — Outer Shipping Container Standard

3.7 ISO Standard⁶

ISO 14706 — Surface chemical analysis — Determination of surface elemental contamination on silicon wafers by total reflection X-ray fluorescence spectroscopy (TXRF)

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

4 Terminology

4.1 Terms and acronyms associated with silicon wafers and silicon technology are listed and defined in SEMI M59.

5 Ordering Information

5.1 Purchase orders for silicon wafers furnished to this specification shall include the following items. These items are indicated on the Silicon Wafer Specification Format for Order Entry, Parts 1 and 2, shown in Table 1 with a ♦ symbol in the left-most column.

5.1.1 Growth Method.

5.1.2 Crystal Orientation.

5.1.3 Conductivity type.

5.1.4 Dopant.

5.1.5 Wafer surface orientation.

5.1.6 Resistivity.

5.1.7 Diameter.

5.1.8 Fiducial dimensions and orientation.

5.1.9 Edge profile.

5.1.10 Thickness and tolerance.

5.2 In addition, the purchase order must indicate the test method to be used in evaluating each of those items for which alternate test procedures exist.

5.3 The following items must also be included in the purchase order:

⁵ American National Standards Institute, New York Office: 25 West 43rd Street, New York, NY 10036, USA. Telephone: 212.642.4900, Fax: 212.398.0023, Website: www.ansi.org

⁶ International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30 Website: www.iso.ch.



5.3.1 Lot acceptance procedures.

5.3.2 Certification (if required).

5.3.3 Packing and shipping container labeling requirements.

5.4 Finally, many other characteristics may be specified in purchase orders for silicon wafers.

5.4.1 These shall be selected from the other items listed in the Silicon Wafer Specification Format for Order Entry, Parts 1 and 2 (see Table 1).

5.4.1.1 The parameter values provided in the requirements tables in §6 may be used to identify appropriate values in the specification without selecting a value for each line. However, even if these requirements table values are used, the desired test methodology must be selected in accordance with ¶5.2.

5.4.2 It is essential that all choices for the items selected to be specified be made in order not to have unspecified parameters that would lead to surprises between supplier and customer. This is particularly important in the specification of wafer site flatness, for which a variety of parameters must be selected as outlined in Appendix 1.

5.4.3 Of the various items listed, the following (listed in the order in which they appear in Table 1) are most often selected, especially for wafers to be used for advanced integrated circuit manufacture:

- nominal edge exclusion (to define the fixed quality area),
- structural characteristics,
- wafer ID marking,
- total thickness variation (TTV or GBIR),
- warp (and sometimes bow or sori),
- site flatness (SFQR), and
- localized light scatterers (LLS).

6 Requirements

6.1 General Characteristics

6.1.1 The crystal growth method shall be modified Czochralski (Cz), float zone (FZ), or magnetic Czochralski (MCz) as specified on the purchase order. In some cases, the supplier is given the option of selecting Cz or MCz.

6.1.1.1 If the Cz or MCz method is used for crystal growth, it may be permissible to utilize refined (previously melted) polysilicon in the growth charge; when this is the case, the appropriate box should be checked..

6.1.2 The crystal orientation shall be as specified on the purchase order. Usually either (100) or (111) is specified, but (110) is sometimes specified for polished wafers to be used for making SOI wafers. Occasionally, another orientation, such as (311) or (511), is specified.

6.1.3 The conductivity type shall be either *n* or *p*.

6.1.4 The dopant shall be specified to match the conductivity type. In general, boron (B) is used for *p*-type material, while phosphorus (P) is most commonly used for *n*-type material. For some applications, antimony (Sb) or arsenic (As) are used to obtain *n*-type wafers. For high power applications, neutron transmutation doping is often used to obtain high resistivity *n*-type wafers.

6.1.5 The nominal edge exclusion, *EE*, specifies the diameter of the fixed quality area (FQA), which is given by the nominal diameter minus 2·*EE* (see Figure 1). This quantity provides a center-referenced property.



Table 1 Silicon Wafer Specification Format for Order Entry, Parts 1 and 2

Part 1 General Information

ITEM	INFORMATION	Date:
Customer Name		
Purchase Order Number		
Line Number		
Item Number		
General Specification Number		
Revision Level		
Part Number/Revision		

Part 2 Polished Wafer or Substrate

ITEM	SPECIFICATION	MEASUREMENT METHOD
2-1. GENERAL CHARACTERISTICS (Note that ♦ indicates a required item for which a value or choice must be indicated in order to minimally specify a silicon wafer.)		
♦ 2-1.1	Growth Method []Cz; []FZ; []MCz; []Supplier option of Cz or MCz	
2-1.2	Use of Refined Polysilicon []Permitted; []Not permitted	
♦ 2-1.3	Crystal Orientation [](100); [](111); [](110); []Other: (specify) _____	[]SEMI MF26 (X-Ray); [] SEMI MF26 (Optical); []JEITA EM-3501; []DIN 50433/1; []DIN 50433/2; []DIN 50433/3; []Other: (specify) _____
♦ 2-1.4	Conductivity Type []p; []n	[]SEMI MF42; []JIS H 0607; []DIN 50432; []Other: (specify) _____
♦ 2-1.5	Dopant []B; []P; []Sb; []As; []Neutron Transmutation Doped; []Other: (specify) _____	
2-1.6	Nominal Edge Exclusion ^{#1} (See Figure 1)	[]2 mm; []3 mm; []5 mm; []Other: (specify) _____ mm
2-1.7	Co-dopant in Crystal []None; []Nitrogen; []Carbon; []Nitrogen and Carbon; []Argon; []Other: (specify) _____	
♦ 2-1.8	Wafer Surface Orientation (with respect to crystal orientation, see item 2-1.3) []On-orientation: [] $0.00^\circ \pm 1.00^\circ$; [] $0.00^\circ \pm$ _____ []Off-orientation: [] $0.6^\circ \pm 0.4^\circ$ [] $2.50^\circ \pm 0.50^\circ$; [] $4.00^\circ \pm 0.50^\circ$; []_____ $^\circ \pm$ _____ [] $\pm 5^\circ$ max; []Other: \pm [] $^\circ$, max	[]SEMI MF26 (X-Ray); [] SEMI MF26 (Optical); []JEITA EM-3501; []DIN 50433/1; []DIN 50433/2; []DIN 50433/3; []Other: (specify) _____
2-1.9	Orthogonal Misorientation (See Figure 2)	



ITEM		SPECIFICATION	MEASUREMENT METHOD
2-2. ELECTRICAL CHARACTERISTICS (Note that ♦ indicates a required item for which a value or choice must be indicated in order to minimally specify a silicon wafer.)			
♦ 2-2.1	Resistivity Measured at	Nominal [] ± Tolerance [] Ω·cm []Center Point; []Other: (specify) _____	[]SEMI MF84; [] SEMI MF673; []DIN 50431 []DIN50445; []Other: (specify) _____
2-2.2	Radial Resistivity Variation (RRG)	Not greater than []%	SEMI MF81 Figure 1 – []A, []B, []C, []D; []DIN 50435; []Other: (specify) _____
2-2.3	Resistivity Striations	Not greater than []%	[]SEMI MF525; []Other: (specify) _____
2-2.4	Minority Carrier Lifetime	Greater than [] μs	SEMI MF28 []A, []B; SEMI MF391 []A, []B; []SEMI MF1388; []SEMI MF1535; []JEITA EM-3502; []JIS H 0604; []DIN 50440/1; []Other: (specify) _____
2-3. CHEMICAL CHARACTERISTICS			
2-3.1	Oxygen Concentration (Values using the following Calibration Factor, see SEMI M44)	Nominal [] ± Tolerance []; [] $\times 10^{17}$ cm ⁻³ ; []ppma []IOC-88; [] Old ASTM; []New ASTM or Old DIN; [] Original JEITA; []Other: (specify) _____	IR (Interstitial): [] SEMI MF1188; [] SEMI MF1619; [] JEIDA EM-3504; [] DIN 50438-1; []Other: (specify) _____ SIMS (Total): [] SEMI MF1366; []GFA (Total)
2-3.2	Radial Oxygen Variation	Not greater than []%	SEMI MF951 Plan []A1; []A2; []A3; []B; []B1; []C; []D; []Other: (specify) _____
2-3.3	Carbon Concentration (Background, cf 2-1.7)	Not greater than [] []ppma; [] $\times 10^{16}$ cm ⁻³	[] SEMI MF1391; JEITA EM-3503; []DIN 50438/2; []Other: (specify) _____
2-3.4	Boron Concentration in Heavily Doped <i>n</i> -type Silicon	Not greater than [] ppba	[]SEMI MF1528; []Other: (specify) _____
2-4. STRUCTURAL CHARACTERISTICS			
2-4.1	Dislocation Etch Pit Density	[]Not greater than []/cm ²	[]SEMI MF1809; []JIS H 0609; []DIN 50434; []DIN 50443/1; []Other: (specify) _____
2-4.2	Slip	[]None []Other: (specify) _____	[]SEMI MF1809; []JIS H 0609; []DIN 50434; []DIN 50443/1; []Other: (specify) _____
2-4.3	Lineage	[]None []Other: (specify) _____	[]SEMI MF1809; []JIS H 0609; []DIN 50434; []DIN 50443/1; []Other: (specify) _____
2-4.4	Twin Boundary	[]None []Other: (specify) _____	[]SEMI MF1809; []JIS H 0609; []DIN 50434; []DIN 50443/1; []Other: (specify) _____
2-4.5	Swirl	[]Not greater than []% of wafer area	[]SEMI MF1809; []JIS H 0609; []DIN 50434; []DIN 50443/1; []Other: (specify) _____



ITEM		SPECIFICATION	MEASUREMENT METHOD
2-4.6	Shallow Pits	Not greater than []/cm ²	[]SEMI MF1727; []SEMI MF1049; []Other: (specify) _____
2-4.7	Oxidation Induced Stacking Faults (OSF)	Not greater than []/cm ²	Test Cycle: []SEMI MF1727; []JIS H 0609; []Other: (specify) _____ Observation Method: []SEMI MF1726; []JIS H 0609; []DIN 50443/1; []Other: (specify) _____
2-4.8	Oxide Precipitates, BMD	Range: [] to [] Unit: [] cm ⁻² ; [] cm ⁻³	Test Cycle: SEMI MF1239 []A, []B; []Other: (specify) _____
2-4.9	Interstitial Oxygen Reduction ($\Delta[O_i]$)	Range: [] to [] []ppma; [] $\times 10^{17}$ cm ⁻³	Test Cycle: SEMI MF1239 []A, []B; []Other: (specify) _____
2-4.10	Bulk defects by X-ray topography	[]Density: _____ cm ⁻³	[]DIN 50443/1; []Other: (specify) _____

2-5. WAFER PREPARATION CHARACTERISTICS

2-5.1	Wafer ID Marking	[]None; []SEMI M12; []SEMI M13; []SEMI T1; []SEMI T2; []SEMI T7; []SEMI T7 + optional alphanumeric mark (see Figure 3); []Other: (specify) _____	
2-5.2	Front Surface Thin Film(s)	[]None []Description:	
2-5.3	Denuded Zone	[]None []Description:	
2-5.4	Extrinsic Gettering	[]None []Description:	
2-5.5	Backseal	[]None []Description:	
2-5.6	Annealing	[]None []Description:	
2-5.7	Edge Surface Condition	[]Ground; []Etched; []Polished ^{#2}	
2-5.8	Back Surface Condition	[]Supplier Option; []Caustic Etched; []Acid Etched; []Polished ^{#2} (see Item 2-9.8 for required gloss level)	

2-6. DIMENSIONAL CHARACTERISTICS (Note that ♦ indicates a required item for which a value or choice must be indicated in order to minimally specify a silicon wafer.

THE ITEMS LISTED IN THIS SECTION MAY BE []SPECIFIED ACCORDING TO CATEGORY 1. Polished Wafers (see Tables 4 through 9) OR SPECIFIED INDIVIDUALLY. If the items are specified according to a standard Category, the items marked with the symbol ♦ need not be entered individually.

♦♦ 2-6.1	Diameter	[]Nominal [] \pm Tolerance [] mm	[]SEMI MF2074; []DIN 50441/4; []Other: (specify) _____
♦♦ 2-6.2	Fiducial Dimensions	Flat []Length or []Diameter: []Nominal [] \pm Tolerance [] mm []Notch Dimensions (see Figure 5)	[]SEMI MF671 (Flat Length); []DIN 50441/4 (Flat Diameter); []SEMI MF1152 (Notch Dimensions); []Other: (specify) _____



ITEM		SPECIFICATION	MEASUREMENT METHOD
♦	2-6.3	Primary Flat/Notch Orientation [] (crystal axis) [] \pm ____°	[] SEMI MF847 (Flat); [] Other: (specify) _____
♦	2-6.4	Secondary Flat Length [] None; [] Other: ____ \pm ____ mm	[] SEMI MF671; [] Other: (specify) _____
♦	2-6.5	Secondary Flat Location (see Figure 4) [] None; [] Other: (θ) ____ °	
♦	2-6.6	Edge Profile [] (specify) _____	SEMI MF928: Method A [], Method B []; DIN 50441/2: Procedure 1 [], Procedure 2 []; [] Other: (specify) _____
♦	2-6.7	Thickness [] Nominal [] \pm Tolerance [] μm	[] SEMI MF533; [] SEMI MF1530; [] JIS H 0611; [] DIN 50441/1; [] Other: (specify) _____
♦	2-6.8	Total Thickness Variation (TTV) [] [] μm , max.	[] SEMI MF533; [] SEMI MF657; [] SEMI MF1530; [] JIS H 0611; [] DIN 50441/1; [] Other: (specify) _____
♦	2-6.9	Bow [] [] μm , max	[] SEMI MF534; [] JIS H 0611; [] Other: (specify) _____
♦	2-6.10	Warp [] [] μm , max	[] SEMI MF657; [] SEMI MF1390; [] Other: (specify) _____
	2-6.11	Sori [] [] μm , max	[] SEMI MF1451; [] JEITA EM-3401; [] Other: (specify) _____
	2-6.12	Flatness, Global Acronym: ^{#3} [] [] [] Value: [] μm	[] SEMI MF1530; [] DIN 50441/3; [] JEITA EM-3401; [] Other: (specify) _____
	2-6.13	Flatness, Site Acronym: ^{#3} [] [] [] Value: Not greater than [] μm Site Size ____ mm \times ____ mm [] % Usable Area _____ [] Include partial sites; [] Do not include partial sites Offset: x = [] mm, y = [] mm	[] SEMI MF1530; [] Other: (specify) _____
	2-6.14	Nanotopography [] SEMI M43 (specify conditions): _____	

2-7. FRONT SURFACE CHEMISTRY

2-7.1	Surface Metal Contamination		
2-7.1.1	Sodium	[] Not greater than [] $\times 10$ atoms/cm ²	[] ICP/MS; [] AAS; [] SEMI MF1617 (SIMS); [] Other: (specify) _____
2-7.1.2	Aluminum	[] Not greater than [] $\times 10$ atoms/cm ²	[] ICP/MS; [] AAS; [] SEMI MF1617 (SIMS); [] Other: (specify) _____



ITEM		SPECIFICATION	MEASUREMENT METHOD
2-7.1.3	Potassium	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.1.4	Chromium	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.1.5	Iron	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.1.6	Nickel	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.1.7	Copper	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.1.8	Zinc	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.2	Other Surface Metals (List Separately)		
2-7.2.1	_____	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.2.2	_____	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.2.3	_____	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____

ITEM		SPECIFICATION	MEASUREMENT METHOD
2-7.2.4	_____	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.2.5	_____	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.2.6	_____	[]Not greater than [× 10]atoms/cm ²	[]ICP/MS; []AAS; []SEMI MF1617 (SIMS); []SEMI M33 (TXRF);[]ISO 14706 (TXRF); []Other: (specify)_____
2-7.3	Surface Organics	[]Not greater than []ng/cm ²	[]SEMI MF1982; []Other: (specify)_____

2.8. FRONT SURFACE INSPECTION CHARACTERISTICS

FOR ALL WAFER DIAMETERS, THE ITEMS LISTED IN THIS SECTION MAY BE SPECIFIED INDIVIDUALLY. ALTERNATIVELY, FOR WAFERS 150 mm OR LESS IN DIAMETER, WHICH CAN BE INSPECTED VISUALLY, THE ITEMS LISTED MAY BE []Specified according to Table 10. If the items are specified according to Table 10, the items marked with the symbol **✓** need not be entered individually.

✓	2-8.1	Scratches – Macro	[]None; []Other: (specify)_____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____
✓	2-8.2	Scratches – Micro	[]None; []Other: (specify)_____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____
✓	2-8.3	Pits	[]None; []Other: (specify)_____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____
✓	2-8.4	Haze	[]None; []Other: (specify)_____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____
✓	2-8.5	Localized Light Scatterers (LLS)	Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm ² Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm ² Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm ² Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm ² Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm ²	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____
✓	2-8.6	Contamination/Area	[]None; []Other: (specify)_____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____
✓	2-8.7	Edge Chips and Indents	[]None; []Other: (specify)_____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify)_____



ITEM		SPECIFICATION	MEASUREMENT METHOD
☒	2-8.8	Edge Cracks []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.9	Cracks, Crow's Feet []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.10	Craters []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.11	Dimples []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.12	Grooves []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.13	Mounds []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.14	Orange Peel []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
☒	2-8.15	Saw Marks []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []SSIS, ^{#4} []Other: (specify) _____
	2-8.16	Dopant Striation Rings []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []DIN 50443/1; []Other: (specify) _____
	2-8.17	Stains []None; []Other: (specify) _____	[]SEMI MF523; []JIS H 0614; []Other: (specify) _____

2.9. BACK SURFACE INSPECTION CHARACTERISTICS

FOR ALL WAFER DIAMETERS, THE ITEMS LISTED IN THIS SECTION MAY BE SPECIFIED INDIVIDUALLY. ALTERNATIVELY, FOR WAFERS 150 mm OR LESS IN DIAMETER, WHICH CAN BE INSPECTED VISUALLY, THE ITEMS LISTED MAY BE []Specified according to Table 10. If the items are specified according to Table 10, the items marked with the symbol ☒ need not be entered individually.

☒	2-9.1	Edge Chips []None; []Other: (specify) _____	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
	2-9.2	Edge Cracks []None; []Other (specify) _____	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
☒	2-9.3	Cracks, Crow's Feet []None; []Other: (specify) _____	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
☒	2-9.4	Contamination/Area []None; []Other: (specify) _____	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
☒	2-9.5	Saw Marks []None; []Other: (specify) _____	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____



ITEM		SPECIFICATION	MEASUREMENT METHOD
2-9.6	Stains	[]None; [] Other: (specify) _____	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
2-9.7	Roughness	[] _____ nm rms	[] SEMI M40; []Other: (specify) _____
2-9.8	Brightness (Gloss)	[] _____	[]ASTM D 523; []JIS Z 8741; []Other: (specify) _____
2-9.9	Scratches – Macro	[]None; []Cum Length =[]mm	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
2-9.10	Scratches – Micro	[]None; []Cum Length =[]mm	[]SEMI MF 523; []JIS H 0614; []Other: (specify) _____
2-9.11	Localized Light Scatterers	Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm^2 Size: \geq [] μm (LSE) Count: \leq [] [] per wafer; [] per cm^2	[]SEMI MF 523; []JIS H 0614; []SSIS ^{#4} ; []Other: (specify) _____
2-10. OTHER (as required)			

^{#1} The nominal edge exclusion, *EE*, specifies the diameter of the FQA, which is given by the nominal diameter (see Item 2-6.1) minus $2EE$ (see Figure 1). This quantity provides a center referenced property. Although use of edge referenced properties is discouraged, some equipments and procedures are based on edge referenced dimensions. When this occurs, the quality area is not fixed and some part of the fixed quality area may fall outside the evaluated area, which is generally not a desirable situation.

^{#2} If specified as polished, this term is meant to imply a surface condition and not a particular processing technique. If desired, a quantitative measure of surface finish may optionally be indicated by specifying the rms microroughness over a specified spatial frequency (or wavelength) range. Because a standardized test method has not yet been developed for this metric, both values and test procedures, including sampling plan and detrending procedures, shall be agreed upon between supplier and customer.

^{#3} Flatness Acronyms are defined in the Flatness Decision Tree in Appendix 1.

^{#4} In today's technology, it may be possible to inspect for some of these items using automated surface scanning inspection systems (SSIS). Such systems should be calibrated according to SEMI M53 using polystyrene latex spheres deposited in accordance with SEMI M58. Some indication of the defects separable by such instruments is provided in SEMI M35; however, a standard test procedure has yet to be developed. Application of automated inspection with the use of an SSIS must be agreed upon between supplier and customer.

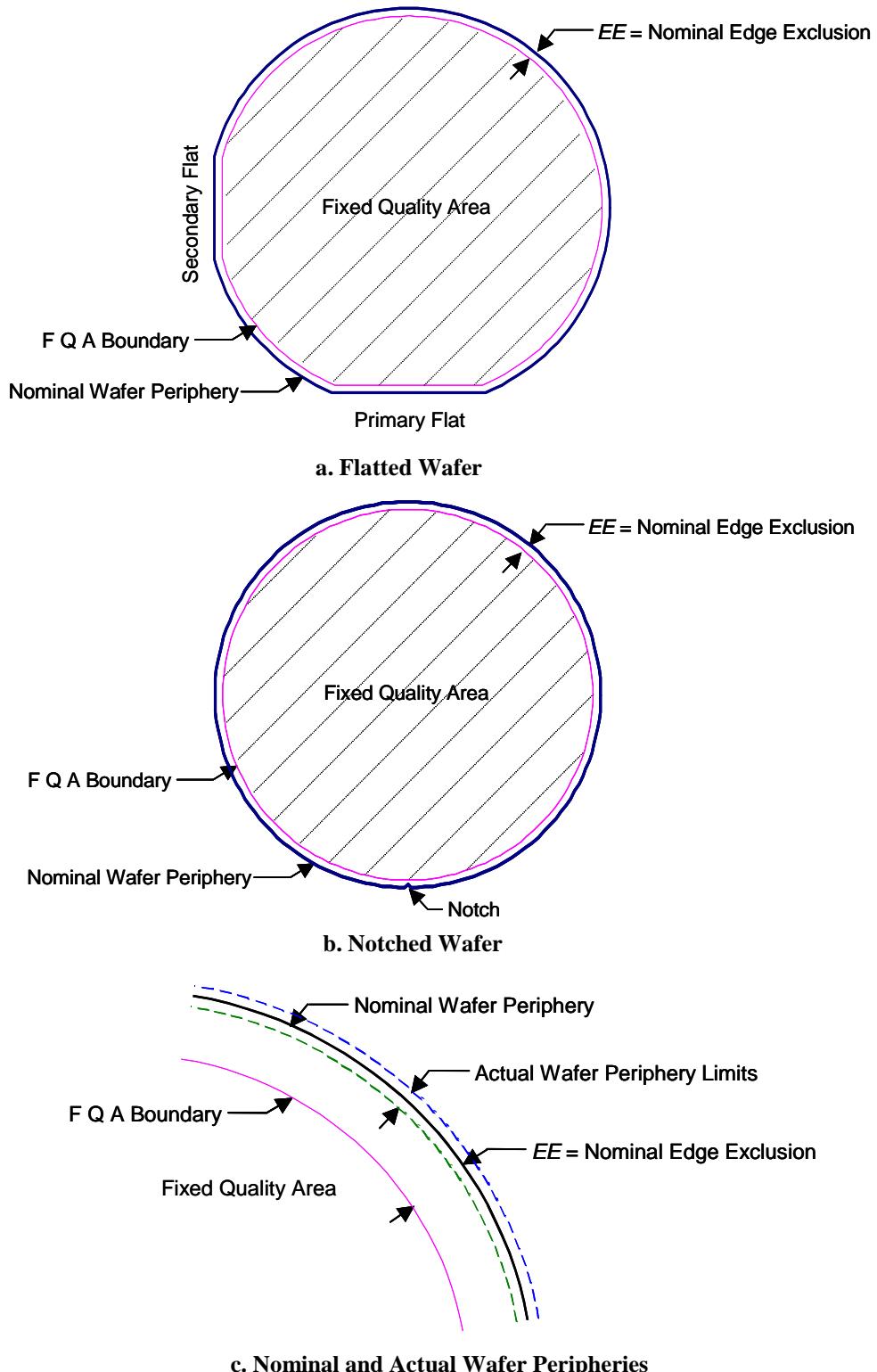


Figure 1
Fixed Quality Area

6.1.5.1 This quantity is usually specified as 2 mm or 3 mm, but some advanced wafer processing technologies are moving in the direction of 1 mm. However, it should be noted that not all processes and metrology can work as close to the wafer edge as implied by the nominal edge exclusion.

6.1.5.2 In addition, it is sometimes necessary to specify additional exclusion zones, such as those for wafer identification marks or wafer holding areas.

6.1.5.3 Although use of edge referenced properties is discouraged, some equipments and procedures are based on edge referenced dimensions. When this occurs, the quality area is not fixed and some part of the fixed quality area may fall outside the evaluated area, which is generally not a desirable situation.

6.1.6 A co-dopant may be required for polished wafers intended to be processed into annealed wafers. Some co-dopants may also be used in connection with control of oxygen precipitation characteristics even when the wafer is not annealed.

6.1.7 *Wafer Surface Orientation* — The wafer shall conform to the surface orientation as specified in the purchase order.

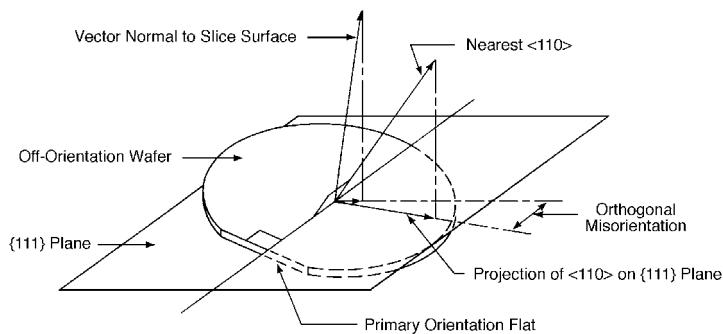
6.1.7.1 For on-orientation wafers, the angular tolerance from the plane perpendicular to the growth axis shall be specified.

6.1.7.2 For off-orientation wafers, both the misorientation angle from the growth axis and its angular tolerance shall be specified.

6.1.7.2.1 A misorientation angle between 0.2° and 1.0° ($0.6^\circ \pm 0.4^\circ$) from a (100) plane is frequently used for some epitaxial substrates.

6.1.7.2.2 A misorientation angle of 2.50° or $4.00^\circ \pm 0.5^\circ$ from a (111) plane is often used for other epitaxial substrates.

6.1.7.3 Orthogonal misorientation is the tilt angle of the normal to a (111) wafer surface toward nearest <110> direction in a plane parallel with the primary flat as indicated in Figure 2.



NOTE: If the off-orientation angle is determined with the seed end up, the polished surface of the finished wafer must be the surface toward the seed end, and vice versa. Polishing of the incorrect wafer surface results in an incorrect wafer tilt, which can cause unwanted pattern shifts and distortions if the wafer is used subsequently for epitaxial layer growth. Because the convention for determining the off-orientation angle is not the same worldwide, it is essential to establish accurately the desired convention.

Figure 2
Orthogonal Misorientation of {111} Wafer

6.1.7.3.1 The contribution of 5° of orthogonal misorientation to the total off-orientation angle is less than 0.5° .

6.1.7.4 For ion implant applications, the following tolerance issues should be considered:

6.1.7.4.1 For general use where channeling is to be avoided, the current wafer orientation specification of $\pm 1.0^\circ$ deviation from the [100] axis (perpendicular to the (100) plane of the wafer) is adequate. This specification is suitable for minimum channeling applications, provided that the appropriate ion implant equipment angle settings are employed.

6.1.7.4.2 Uniform, maximum channeling along the [100] axis perpendicular to the (100) wafer surface is strongly dependent on strict adherence to a 0° tilt angle. To achieve maximum channeling, crystallography requires the orientation to be within $\pm 0.1^\circ$ of a <100> direction. Also, the customer must remove all overlying oxide, nitride, poly, etc., layers from the wafer prior to a channeling implant. The customer must maintain very rigid control of the ion implant equipment angle setting in order to achieve maximum channeling across the wafer.

6.1.7.5 The tolerance of $\pm 0.1^\circ$ is derived from experimental ion implant profile data and ion implant modeling activity for implants into (100) silicon wafers. The ranges for which data was obtained are given in Table 2.

6.2 Electrical Characteristics

6.2.1 The center-point room temperature resistivity of the wafers shall conform to the nominal and tolerance values specified on the purchase order.

6.2.2 The wafers shall conform to any requirements specified on the purchase order for radial resistivity variation, resistivity striations and minority carrier lifetime.

Table 2 Energy Ranges for Ion Implant Modeling

Species	Energy Range (keV)
B	15–80
BF ₂	15–65
As	15–180

6.3 Chemical Characteristics

6.3.1 The wafers shall conform to any requirements specified on the purchase order for oxygen concentration, radial oxygen variation, carbon concentration, and, for heavily doped (low resistivity) *n*-type silicon wafers only, compensating boron concentration.

6.4 Structural Characteristics

6.4.1 The wafers shall conform to any requirements specified on the purchase order for dislocation etch pit density, slip, lineage, twin, swirl, shallow pits, oxidation induced stacking faults (OSF), oxide precipitates or bulk microdefects (BMD), interstitial oxygen reduction upon appropriate heat treatment, and bulk defects by X-ray topography.

6.5 Wafer Preparation Characteristics

6.5.1 *Wafer ID Marking*—Where wafer ID marking is specified on the purchase order, the kind of marking must be indicated.

6.5.1.1 Where alphanumeric marking is specified for wafers of 200 mm diameter and smaller, the code character properties and code field location shall conform either to SEMI M13 or to SEMI M12, as specified on the purchase order.

6.5.1.2 Where back-surface bar code marking is specified for wafers of 200 mm diameter and smaller, the code symbol and its location shall conform to SEMI T1.

6.5.1.3 Where two-dimensional matrix code marking is specified for wafers of 200 mm diameter and smaller, the code symbol and its location shall conform to SEMI T2.

6.5.1.4 All 300 mm diameter wafers (wafer category 1.15, see Table 9) shall be marked with a two-dimensional matrix code symbol on the back surface outside the fixed quality area as soon after slicing as practical in the manner specified in SEMI T7 in order to provide both identification of these wafers and traceability of each wafer back to the ingot from which it was cut. The back surface is identified as the wafer surface with the two-dimensional matrix code symbol.

6.5.1.4.1 Optionally, the user may specify an additional back-surface mark as shown in Figure 3. This mark contains alphanumeric characters with:

- The same message characters as the SEMI T7 mark and appropriate checksum characters as defined by SEMI M12 and
- Character string as specified in SEMI M12.

NOTE 1: It is expected that this optional alphanumeric mark will not be used after users have developed successful experience with SEMI T7 mark usage.

6.5.1.4.2 Single density dot matrix, 5 dots horizontal and 9 dots vertical, shall be used.

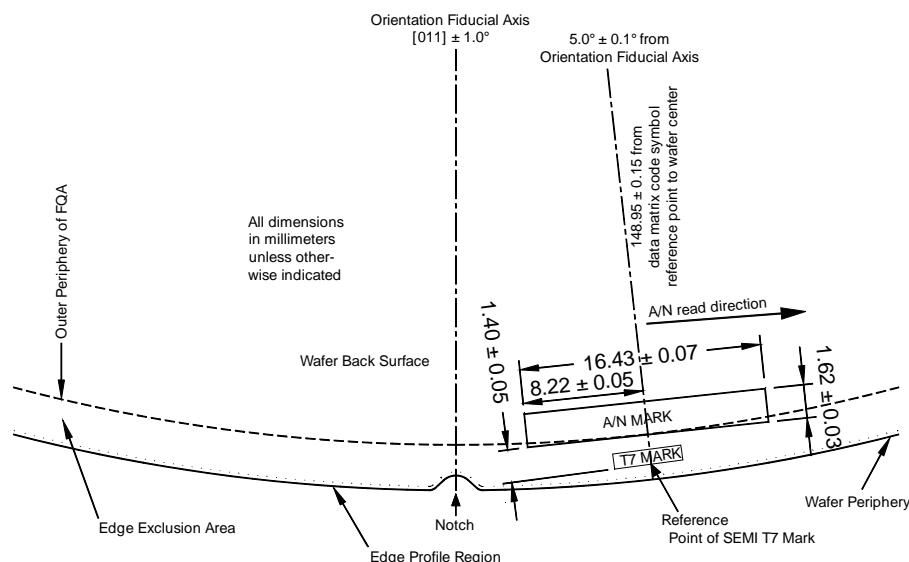
6.5.1.4.3 Dot diameter shall be the same as that used for the two-dimensional matrix code symbol (see 6.5.1.4).

6.5.1.4.4 Character dimensions shall be as defined in Table 1 of SEMI M12 (nominal spacing = 1.42 mm, nominal width = 0.812 mm, nominal height = 1.624 mm).

6.5.1.4.5 Mark location (center of bottommost dot rows) relative to the reference point of the SEMI T7 mark shall be 1.40 ± 0.05 mm toward the wafer center, as shown in Figure 3.

6.5.1.4.6 Mark field height, as defined by the distance between the centers of the topmost and bottommost dot rows of the A/N characters, shall be 1.62 ± 0.03 mm (Note 2).

6.5.1.4.7 Mark field length, as defined by the distance between the centers of the leftmost and rightmost dot columns of the A/N characters, shall be 16.43 ± 0.07 mm.



NOTE: A/N mark field dimensions are defined by the centers of the topmost and bottommost dot rows and the center of the leftmost and rightmost dot columns of the A/N characters. The field dimensions are more tightly controlled than those of a field constructed using SEMI M12. This results from the availability of laser marking capabilities not available when SEMI M12 was developed. In addition, the tolerance on the field dimensions is not cumulative.

Figure 3

Optional A/N Code Field Location on Back Surface of Notched 300 mm Diameter Wafer (Category 1.15)

NOTE 2: The overall length tolerance of the A/N mark is more stringent than that in SEMI M12. Also the height tolerance of the overall mark imposes tighter skew and offset tolerances than are required in SEMI M12.

6.5.1.4.8 The mark-field shall be centered on the radius that passes through the reference point of the SEMI T7 mark as shown in Figure 3.

6.5.1.4.9 Character baseline shall be toward wafer OD and parallel with the row of the SEMI T7 mark that contains that mark's reference point.

6.5.2 *Other* — The wafers shall conform to any requirements specified on the purchase order for any other wafer preparation characteristics including front surface thin films, denuded zone, extrinsic gettering, backseal, annealing, and edge and back surface conditions.

6.6 Dimensional Characteristics

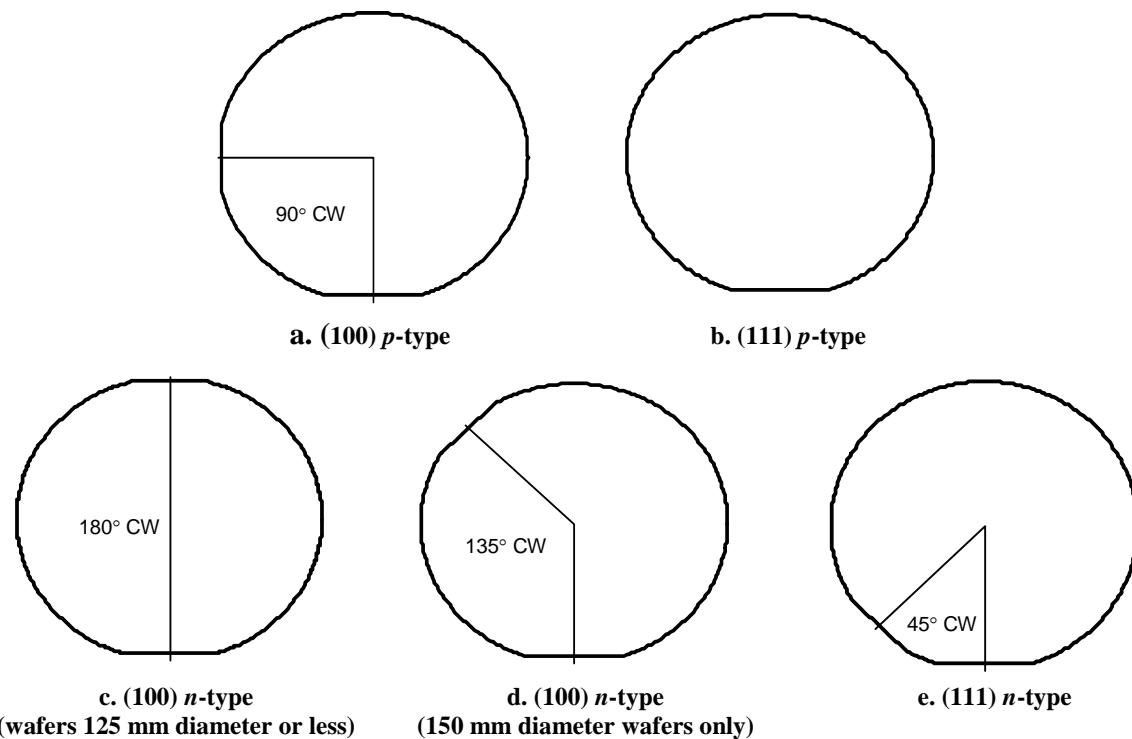
6.6.1 Dimensions and Fiducials — The wafers shall conform to the dimensions, dimensional tolerances, and fiducial (flat or notch) characteristics and locations as specified in the purchase order.

6.6.1.1 Where secondary flats are specified, they shall be located as shown in Figure 4.

6.6.1.2 Where notches are specified, they shall conform to the dimensions in Figure 5.

6.6.2 Edge Profile — The edge profile of edge-profiled wafers shall conform to the following requirements at all points on the wafer periphery (except interior portions of notches, if present).

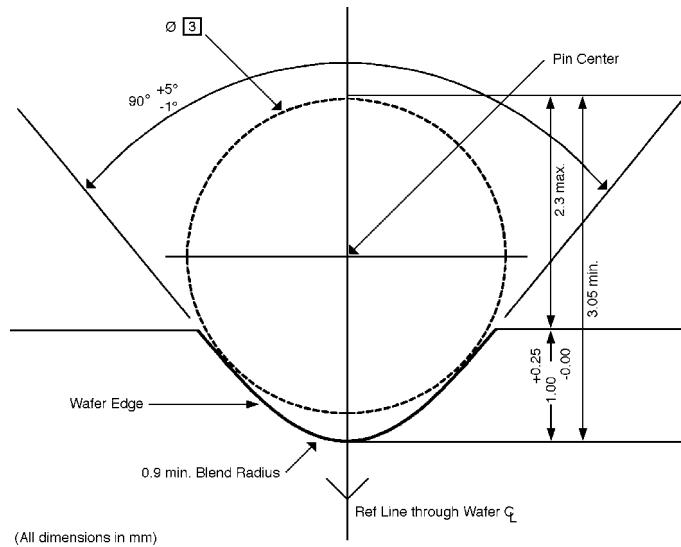
6.6.2.1 The SEMI Wafer Edge Profile Template is shown in Figure 6. There are two sets of dimensions for the template: T/3 and T/4, where T is the nominal thickness of the wafer (see Tables 4 through 9 for values of the nominal thickness for various wafer categories).



NOTE 1: Secondary flat location for 150 mm diameter (100) *n*-type wafers changed from configuration c to configuration d effective January 1, 1990.

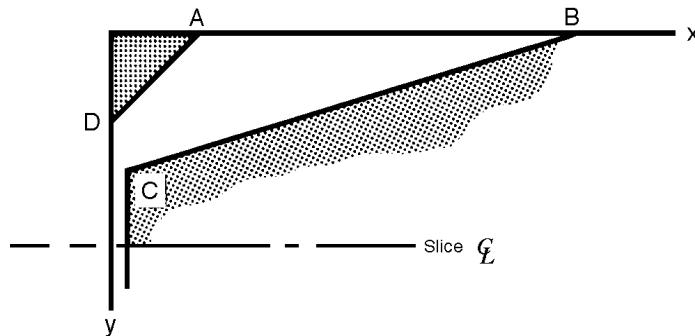
NOTE 2: The angular position of the center point of the secondary flat is given in Tables 4 through 6 both in terms of the clockwise angle from the primary flat, located at the bottom of each figure, to the secondary flat and the angle, θ , from the positive *x*-axis of the wafer coordinate system as defined by SEMI M20 (at 3 o'clock) to the secondary flat.

Figure 4
Secondary Flat Locations



NOTE: The pin shown in the outline on this figure is used to align the notched wafer in a fixture during use. The pin is also used to reference the notched wafer during testing for notch dimensions and dimensional tolerances. The notch dimensions shown in the figure assume a 3 mm diameter for this alignment pin.

Figure 5
Notch Dimensions



NOTE 1: The figure is not to scale

NOTE 2: Only one-half of the template is shown; the wafer surface is aligned with the x-axis, and the outermost radial portion of the edge contour is aligned with the y-axis. The template in this figure is not intended for use in measuring wafer thickness.

NOTE 3: Constant radius profile with blended, tangential front and back surface intercepts is preferred for ease of manufacture and reduced particle and chip generation.

NOTE 4: The x- and y-axes in this template do not correspond with the x- and y-axes in the wafer coordinate system defined in SEMI M20.

Figure 6
SEMI Wafer Edge Profile Template

Table 3 Wafer Edge Profile Template Coordinates (See Figure 6)

T/3 Wafer Edge Profile Template

Point	$x^{\#1}$		$y^{\#1}$	
A	0.0030 in.	76 µm	0.00 in.	0 µm
B	0.0200 in.	508 µm	0.00 in.	0 µm
C	0.0020 in.	50 µm	T/3 ^{#2}	
D	0.00 in.	0 µm	0.0030 in.	76 µm

^{#1} For referee purposes, U.S. Customary units are to be used for 2 and 3 in. diameter wafers SI units are to be used for all other wafers.

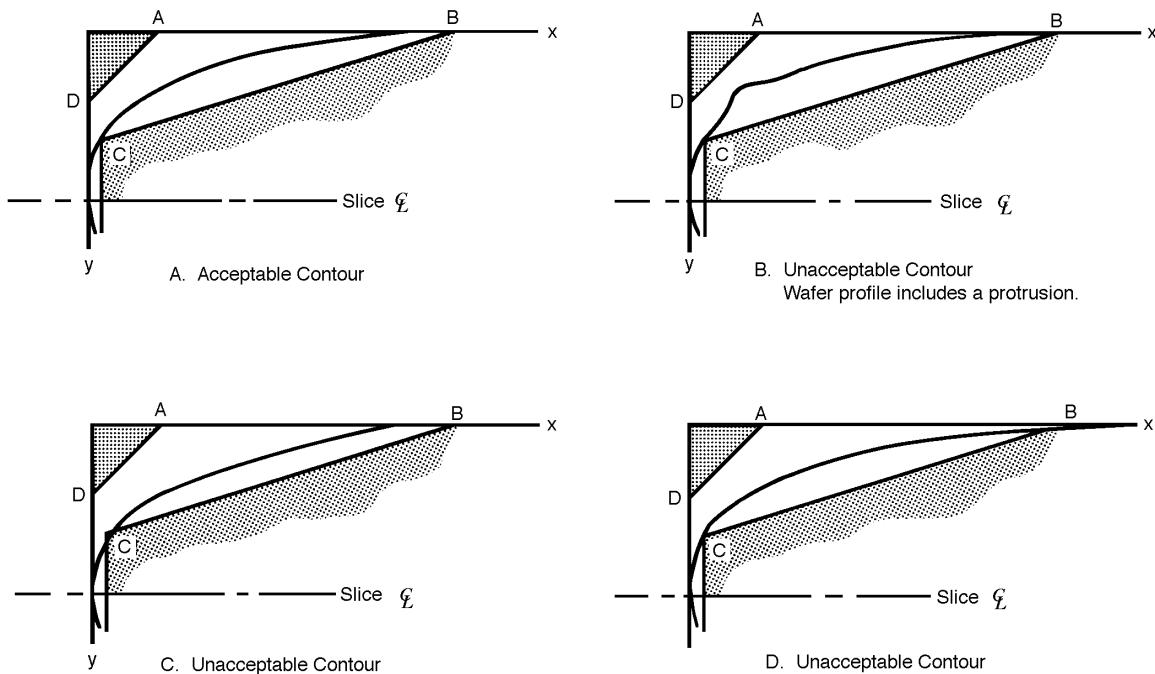
^{#2} For the value of this coordinate, see the specifications for the appropriate wafer category in Tables 4 through 9.

6.6.2.2 The coordinates for the two templates are given in Table 3. Note that this coordinate system differs from that in SEMI M20 in that the origin is at the wafer edge instead of the wafer center and the y-axis is positive in the downward direction toward the wafer median plane instead of being in the plane of the wafer surface. If the nominal edge exclusion, EE , is 1 mm or greater, the edge profile will not extend into the fixed quality area.

6.6.2.3 When the wafer is aligned with the Template so that the x-axis of the template is coincident with the wafer surface and the y-axis of the template is tangent with the outermost radial portion of the profile, the wafer edge profile must be contained within the clear region of the template. (See Figure 7 for examples of acceptable and unacceptable edge profiles.)

6.6.2.4 No sharp points or protrusions are permitted anywhere on the wafer edge profile.

6.6.2.5 Cosmetic attributes of the edge profile are not covered by this specification. They shall be agreed upon between supplier and customer.



**Figure 7
Examples of Acceptable and Unacceptable Wafer Edge Profiles**



Table 4 Dimensional Characteristics of 2 in. and 3 in. Polished Monocrystalline Silicon Wafers^{#1}

<i>Previous SEMI Reference:</i>		<i>SEMI M1.1</i>		<i>SEMI M1.2</i>	
<i>Wafer Category:</i>		<i>1.1</i>		<i>1.2</i>	
<i>Property</i>		<i>2 in. Wafers</i>		<i>3 in. Wafers</i>	
		<i>U.S. Customary^{#2}</i>	<i>Metric (SI)^{#2}</i>	<i>U.S. Customary^{#2}</i>	<i>Metric (SI)^{#2}</i>
2-6.1	Diameter	2.000 ± 0.015 in.	50.80 ± 0.38 mm	3.000 ± 0.025 in.	76.20 ± 0.63 mm
2-6.2	Primary Flat Length	0.625 ± 0.065 in.	15.88 ± 1.65 mm	0.875 ± 0.125 in.	22.22 ± 3.17 mm
2-6.3	Primary Flat Orientation ^{#3}	$\{110\} \pm 1^\circ$			
2-6.4	Secondary Flat Length	0.315 ± 0.065 in.	8.00 ± 1.65 mm	0.440 ± 0.060 in.	11.18 ± 1.52 mm
2-6.5	Secondary Flat Location (See Figure 4) $\{111\}$ p-type $\{100\}$ p-type $\{111\}$ n-type $\{100\}$ n-type	No secondary flat $90^\circ \pm 5^\circ$ clockwise from primary flat ($\theta = 180^\circ \pm 5^\circ$) $45^\circ \pm 5^\circ$ clockwise from primary flat ($\theta = 225^\circ \pm 5^\circ$) $180^\circ \pm 5^\circ$ from primary flat ($\theta = 90^\circ \pm 5^\circ$)			
2-6.6	Edge Profile Coordinate, C_y (T/3 Template, see Table 3)	0.0037 in.	93 μm	0.0050 in.	127 μm
2-6.7	Thickness, Center Point	0.0110 ± 0.0010 in.	279 ± 25 μm	0.0150 ± 0.0010 in.	381 ± 25 μm
2-6.8	Total Thickness Variation, Max.	0.0005 in.	12 μm	0.0010 in.	25 μm
2-6.9	Bow, Max.	0.0015 in.	38 μm	0.0016 in.	40 μm
2-6.10	Warp, Max.	not specified		0.0016 in.	40 μm

^{#1} Note that these specifications were originated in the United States. Care should be taken in applying this configuration to specific applications (see ¶6.6.3).

^{#2} For referee purposes, U.S. Customary units apply. To ensure that product shipped is within specification, any conversion to metric (SI) equivalents should be done following the maximum-minimum convention in which the minimum values are rounded-up and the maximum values are rounded-down to ensure that the equivalent range is always inside the referee range. If the metric (SI) equivalents are used for incoming inspection, minimum values should be rounded-down and maximum values rounded-up to avoid rejection of material that is within the specification when measured by the referee system of units. CAUTION: The significance of the rightmost digit may vary, depending on the quantity being measured and the precision of the test procedure. Refer to the relevant test method for precision data which can be used to construct appropriate guard bands.

^{#3} For (111) wafers, the $(1\bar{1}0)$, $(01\bar{1})$, and $(\bar{1}01)$ planes are the equivalent, allowable (110) planes. For (100) wafers, the allowable equivalent (110) planes are $(01\bar{1})$, (011) , $(0\bar{1}1)$, and $(\bar{0}1\bar{1})$.



Table 5 Dimensional Characteristics of 100 mm and 125 mm Polished Monocrystalline Silicon Wafers with Secondary Flat^{#1}

<i>Previous SEMI Reference:</i>		<i>SEMI M1.5</i>	<i>SEMI M1.6</i>	<i>SEMI M1.7</i>
<i>Wafer Category:</i>		1.5	1.6	1.7
<i>Property</i>		<i>100 mm Wafers (t=525 μm)^{#2}</i>	<i>100 mm Wafers (t=625 μm)^{#2}</i>	<i>125 mm Wafers^{#2}</i>
2-6.1	Diameter	100.00 ± 0.50 mm		125.00 ± 0.50 mm
2-6.2	Primary Flat Length	32.5 ± 2.5 mm		42.5 ± 2.5 mm
2-6.3	Primary Flat Orientation ^{#3}	$\{110\} \pm 1^\circ$		
2-6.4	Secondary Flat Length	18.0 ± 2.0 mm		27.5 ± 2.5 mm
2-6.5	Secondary Flat Location (See Figure 4) $\{111\}$ p-type $\{100\}$ p-type $\{111\}$ n-type $\{100\}$ n-type	No secondary flat $90^\circ \pm 5^\circ$ clockwise from primary flat ($\theta = 180^\circ \pm 5^\circ$) $45^\circ \pm 5^\circ$ clockwise from primary flat ($\theta = 225^\circ \pm 5^\circ$) $180^\circ \pm 5^\circ$ from primary flat ($\theta = 90^\circ \pm 5^\circ$)		
2-6.6	Edge Profile Coordinate, C_y (T/3 Template, see Table 3)	175 μm	208 μm	208 μm
2-6.7	Thickness, Center Point	525 ± 20 μm .	625 ± 20 μm	625 ± 20 μm
2-6.8	Total Thickness Variation, Max.	10 μm		
2-6.9	Bow, Max.	40 μm		
2-6.10	Warp, Max.	40 μm		

^{#1} Note that these specifications were originated in the United States. Care should be taken in applying this configuration to specific applications (see ¶6.6.3).

^{#2} For referee purposes, metric (SI) units apply. To ensure that product shipped is within specification, any conversion to U.S. Customary equivalents should be done following the maximum-minimum convention in which the minimum values are rounded-up and the maximum values are rounded-down to ensure that the equivalent range is always inside the referee range. If U.S. Customary equivalents are used for incoming inspection, minimum values should be rounded-down and maximum values rounded-up to avoid rejection of material that is within the specification when measured by the referee system of units. CAUTION: The significance of the rightmost digit may vary, depending on the quantity being measured and the precision of the test procedure. Refer to the relevant test method for precision data which can be used to construct appropriate guard bands.

^{#3} For (111) wafers, the $(1\bar{1}0)$, $(01\bar{1})$, and $(\bar{1}01)$ planes are the equivalent, allowable (110) planes. For (100) wafers, the allowable equivalent (110) planes are $(01\bar{1})$, (011) , $(0\bar{1}1)$, and $(\bar{0}1\bar{1})$.