Figure 1

Counting positions for a 50 mm diameter wafer

NOTICE: These standards do not purport to address safety issues, if any, associated with their use. It is the responsibility of the user of these standards to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. 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 M38-1104
SPECIFICATION FOR POLISHED RECLAIMED SILICON WAFERS

NOTICE: This document was completely rewritten in 2004.

1 Purpose

1.1 Silicon wafers are often subjected to reclaim processes in order to improve manufacturing efficiency in device production. A reclaimed wafer is one that has been re-conditioned for subsequent utilization.

1.2 This specification covers requirements for reclaimed silicon wafers to be used for testing and process monitoring in semiconductor manufacturing.

1.3 In some instances for 300 mm wafers with supplier marked back surfaces, it is necessary to re-inscribe the mark after one or more reclaim cycles. Consequently, this specification also includes an appendix that covers the re-inscription of such wafers.

NOTE 1: Issues related to the re-inscription of such 300 mm wafers are discussed in Related Information 1.

2 Scope

2.1 This specification divides reclaimed wafers into four application categories: Mechanical, Furnace, Particle, and Lithography and provides tables of the specification requirements for each category. Thus, a prospective purchaser of reclaimed silicon wafers needs to know which application matches his or her requirements.

2.2 Only requirements for some attributes are specified in Tables 1 and 2. Other requirements are indicated to be "customer specified" which means that the customer may specify a requirement for that particular attribute, "as-supplied" which means that the attribute has whatever value was supplied in the wafer delivered (or used) for reclaim, and "unspecified" which means that the attribute is not specified and for which the wafer does not need to be tested.

2.3 In addition to the general categories listed in Section 2.1, this specification provides requirements for reclaimed wafers intended for use in advanced device production, including devices in the 180 and 130 nm technology generations in a third table.

2.4 This specification is directed specifically to silicon wafers with one or both polished surfaces. If the wafers have epitaxial deposits, the attributes of the epitaxial layer are not included the specification requirements.

2.5 This specification covers reclaim wafers that are either customer-supplied or third party-sourced. The user should exercise caution when sourcing materials with unknown thermal histories, unknown bulk contamination, or unknown deposits, such as gold (Au) films.

2.6 For applications placing higher demands on silicon wafers such as particle counting, measuring pattern resolution in a photolithography process, or surface ion contamination monitoring, the customer may want to reference SEMI M1, SEMI M8, or SEMI M24.

2.7 For referee purposes, U.S. customary units shall be used for wafers of 2- and 3-inch nominal diameter 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 users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Referenced Standards

3.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M8 — Specification for Polished Monocrystalline Silicon Test Wafers

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

SEMI M24 — Specification for Polished Monocrystalline Silicon Premium Wafers

SEMI M31 — Provisional Mechanical Specification for Front Opening Shipping Box Used to Transport and Ship 300 mm Wafers

SEMI M45 — Provisional Shipping System for 300 mm Wafer Shipping System

SEMI MF1241 — Terminology of Silicon Technology

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

4 Terminology

4.1 Definitions of terms related to silicon wafer technology are given in SEMI M1 and in SEMI MF1241.

4.2 The following definitions apply in the context of this specification:

4.2.1 *furnace wafer* — a silicon wafer suitable for monitoring thermal processes or as an implant monitor, usually used only in a cleanroom environment.

4.2.2 *lithography wafer* — a silicon wafer used specifically for testing lithography equipment wherein surface flatness is the key attribute, usually used only in a cleanroom environment.

4.2.3 *mechanical wafer* — a silicon wafer suitable for equipment or process testing, usually outside of a cleanroom environment.

4.2.4 *particle wafer* — a silicon wafer suitable for monitoring area or process cleanliness, used only in a cleanroom environment.

4.2.5 *reclaimed wafer* — a silicon wafer that has been reconditioned for subsequent utilization.

5 Ordering Information

5.1 Purchase orders for reclaimed silicon wafers furnished to this specification shall minimally include the following items:

5.1.1 Nominal diameter,

5.1.2 Type of application (mechanical, furnace, particle, lithography, 180 nm, or 130 nm),

5.1.3 A statement that the wafers are customer-supplied or third-party sourced,

5.1.4 Resistivity,

5.1.5 Any other requirement specified by the customer (indicated as "customer specified" in the tables),

5.1.6 Any requirements that differ from the tables, and

5.1.7 Methods of testing specified attributes for which either no or multiple test methods exist (see Sections 7.2 and 7.3.

5.2 Customer specified requirements other than resistivity may include:

5.2.1 Nominal edge exclusion for FQA,

5.2.2 Wafer ID marking,

5.2.2.1 For 300 mm wafers, whether the wafers are to be re-inscribed as specified in Appendix 1 or not,

5.2.3 Pits, haze, and/or back surface roughness (particle or lithography wafers),

5.2.4 Localized light scatterers, and

5.2.5 Edge condition (for 200 and 300 mm wafers only),

5.3 In addition the following optional criteria may be included in a purchase order:

5.3.1 Minimum removal requirements (if any),

5.3.2 Lot traceability and lot integrity maintenance requirements,

5.3.3 Lot acceptance criteria,

5.3.4 Certification, and

5.3.5 Packing and Marking.

5.3.5.1 Note that for packing and marking of 300 mm wafers, the requirements of SEMI M31 and SEMI M45 shall be observed.

6 Requirements

6.1 The wafers shall conform to the parameters as specified in the appropriate column of Table 1, Table 2, or Table 3, as augmented and amended by the purchase order.

6.2 The wafers shall be capable of being reconditioned for use.

7 Test Methods

7.1 Values of attributes specified in the tables or purchase order shall be tested in accordance with the test methods indicated for the attribute in SEMI M1 or SEMI M18. Sampling for the test shall be done in accordance with the requirements of SEMI M1.

7.2 If multiple tests are described for any attribute, the purchase order shall indicate which test shall be used, unless the supplier of the reclaimed wafers can make the choice.

7.3 If no standardized test is available for any attribute, the test method to be used shall be agreed upon between purchaser and supplier.

8 Certification

8.1 Upon request of the purchaser in the contract or order, a manufacturer's or supplier's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

8.2 In the interest of controlling inspection costs, the supplier and the purchaser may agree that the material shall be certified as "capable of meeting" certain requirements. In this context, "capable of meeting" shall signify that the supplier is not required to perform the appropriate tests in Section 9. However, if the purchaser performs the test and the material fails to meet the requirement, the material may be subject to rejection.

9 Packing and Marking

9.1 Special packing requirements shall be subject to agreement between the supplier and the purchaser.

Otherwise all wafers shall be handled, inspected, and packed in such a manner as to avoid chipping, scratches, and contamination, and in accordance with the best industry practices, to provide ample protection against damage during shipment.

9.2 The wafers supplied under this specification shall be identified by appropriately labeling the outside of each box or other container and each subdivision thereof in which it may reasonably be expected that the wafers will be stored prior to further processing.

9.3 For 300 mm wafers, the packing and marking requirements of SEMI M31 and SEMI M45 shall be met.

Table 1 Specifications for 150 mm, 200 mm, and 300 mm Silicon Reclaim Wafers

	Item	Mechanical	Furnace	Particle	Lithography
1.0	**General Characteristics**				
1.1	Growth Method	As-supplied			
1.2	Crystal Orientation	As-supplied			
1.3	Conductivity Type	As-supplied			
1.4	Dopant	As-supplied			
1.5	Nominal Edge Exclusion for FQA	Unspecified	Customer specified		
2.0	**Electrical Characteristics**				
2.1	Resistivity	Customer specified			
2.2	Radial Resistivity Variation (RRG)	Unspecified			
2.3	Resistivity Striations	Unspecified			
2.4	Minority Carrier Lifetime	Unspecified			
3.0	**Chemical Characteristics**				
3.1	Oxygen Concentration	Unspecified	As-supplied	Unspecified	
3.2	Radial Oxygen Variation	Unspecified	As-supplied	Unspecified	
3.3	Carbon Concentration	Unspecified	As-supplied	Unspecified	
4.0	**Structural Characteristics**				
4.1	Dislocation Etch Pit Density	Unspecified			None
4.2	Slip	Unspecified	None		
4.3	Lineage	Unspecified	None		
4.4	Twins	Unspecified	None		
4.5	Swirl	Unspecified			
4.6	Shallow Pits	Unspecified			
4.7	OISF	Unspecified			
4.8	Oxide Precipitates	Unspecified			
5.0	**Wafer Preparation Characteristics**				
5.1	Wafer ID Marking	Customer specified			
5.2	Front Surface Thin Films	Unspecified	None	Unspecified	None
5.3	Denuded Zone	Unspecified			
5.4	Extrinsic Gettering	Unspecified	None	Unspecified	None
5.5	Backseal	Unspecified	None	Unspecified	None
5.6	Annealing	Unspecified			

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		Item	Mechanical	Furnace	Particle	Lithography
6.0		**Mechanical Characteristics**				
6.1		Diameter				
		150 mm ±	0.50 mm			
		200 mm ±	0.50 mm			
		300 mm ±	0.50 mm			
6.2		Primary Flat/Notch Dimension	As-supplied			
6.3		Primary Flat/Notch Orientation	As-supplied			
6.4		Secondary Flat Dimension (if Applicable)	As-supplied			
6.5		Secondary Flat Location (if Applicable)	As-supplied			
6.6		Edge Profile	Unspecified			
6.7		Thickness				
		150 mm (SEMI M1.8)	533–675 μm			
		150 mm (SEMI M1.13)	585–725 μm			
		200 mm	600–775 μm			
		300 mm	650–800 μm			
6.8		Thickness Variation (TTV)	Unspecified			
6.9		Surface Orientation	As-supplied			
6.10		Bow	Unspecified			
6.11		Warp (for diameters other than 300 mm)	Unspecified			
		Warp (for 300 mm only)	Unspecified			
6.12		Sori	Unspecified			Customer specified
6.13		Flatness/Global	Unspecified			Customer specified
6.14		Flatness/Site	Unspecified			Customer specified
7.0		**Front Surface Chemistry**				
7.1		Surface Metal Contamination				
		Sodium	Unspecified	Customer specified	Unspecified	
		Aluminum	Unspecified	Customer specified	Unspecified	
		Potassium	Unspecified	Customer specified	Unspecified	
		Chromium	Unspecified	Customer specified	Unspecified	
		Iron	Unspecified	Customer specified	Unspecified	
		Nickel	Unspecified	Customer specified	Unspecified	
		Copper	Unspecified	Customer specified	Unspecified	
		Zinc	Unspecified	Customer specified	Unspecified	
7.2		Surface Organics	Unspecified			
8.0		**Front Surface Visual Characteristics**				
8.1A		Scratches (macro) – total length	Unspecified	None		
8.1B		Scratches (micro) – total length	Unspecified	≤0.10 × Diameter		
8.2		Pits	Unspecified		Customer specified	
8.3		Haze	Unspecified		Customer specified	

	Item	Mechanical	Furnace	Particle	Lithography
8.4	Localized Light Scatterers	Unspecified	$\leq 0.20/cm^2$ @ ≥ 0.20 µm		
8.5	Contamination/area	Unspecified	None		
8.6	Edge Chips	Unspecified	None		
8.7	Edge Cracks	Unspecified	None		
8.8	Cracks, Crow's feet	Unspecified	None		
8.9	Craters	Unspecified	None		
8.10	Dimples	Unspecified	None		
8.11	Grooves	Unspecified	None		
8.12	Mounds	Unspecified	None		
8.13	Orange Peel	Unspecified	None		
8.14	Saw Marks	Unspecified	None		
9.0	**Back Surface Characteristics**				
9.1	Edge Chips	Unspecified	None		
9.6	Roughness	Unspecified	Customer specified		
9.7A	Brightness (gloss) (150 & 200 mm)	Unspecified			
9.7B	Brightness (gloss) (300 mm)	$\geq 80\%$			
9.8	Localized Light Scatterers	Unspecified	Customer specified		
9.9A	Scratches (macro)	Unspecified	$\leq 0.25 \times$ Diameter		
9.9B	Scratches (micro)	Unspecified			
10.0	**Other Characteristics**				
TBD	Edge condition				
	150 mm	Unspecified			
	200 mm and 300 mm	Unspecified	Customer specified		

Table 2 Specifications for 2", 3", 100 mm, and 125 mm Silicon Reclaim Wafers

	Item	Mechanical	Furnace	Particle	Lithography
1.0	**General Characteristics**				
1.1	Growth Method	As-supplied			
1.2	Crystal Orientation	As-supplied			
1.3	Conductivity Type	As-supplied			
1.4	Dopant	As-supplied			
1.5	Nominal Edge Exclusion Distance for FQA	Unspecified	Customer specified		
2.0	**Electrical Characteristics**				
2.1	Resistivity	Customer specified			
2.2	Radial Resistivity Variation (RRG)	Unspecified			
2.3	Resistivity Striations	Unspecified			
2.4	Minority Carrier Lifetime	Unspecified			
3.0	**Chemical Characteristics**				
3.1	Oxygen Concentration	Unspecified	As-supplied	Unspecified	
3.2	Radial Oxygen Variation	Unspecified	As-supplied	Unspecified	
3.3	Carbon Concentration	Unspecified	As-supplied	Unspecified	
4.0	**Structural Characteristics**				
4.1	Dislocation Etch Pit Density		Unspecified		None
4.2	Slip	Unspecified	None		
4.3	Lineage	Unspecified	None		
4.4	Twins	Unspecified	None		

	Item	Mechanical	Furnace	Particle	Lithography
4.5	Swirl	Unspecified			
4.6	Shallow Pits	Unspecified			
4.7	OISF	Unspecified			
4.8	Oxide Precipitates	Unspecified			
5.0	**Wafer Preparation Characteristics**				
5.1	Wafer ID Marking	Customer specified			
5.2	Front Surface Thin Films	Unspecified	None	Unspecified	None
5.3	Denuded Zone	Unspecified			
5.4	Extrinsic Gettering	Unspecified	None	Unspecified	None
5.5	Backseal	Unspecified	None	Unspecified	None
5.6	Annealing	Unspecified			
6.0	**Mechanical Characteristics**				
6.1	Diameter				
	2.00 inch ±	0.020 inch			
	3.00 inch ±	0.025 inch			
	100 mm ±	0.50 mm			
	125 mm ±	0.50 mm			
6.2	Primary Flat/Notch Dimension	As-supplied			
6.3	Primary Flat/Notch Orientation	As-supplied			
6.4	Secondary Flat Dimension (if applicable)	As-supplied			
6.5	Secondary Flat Location (if applicable)	As-supplied			
6.6	Edge Profile	Unspecified			
6.7	Thickness				
	2.00 inch	0.008–0.013 in			
	3.00 inch	0.012–0.018 in			
	100 mm (SEMI M1.5)	432–575 µm			
	100 mm (SEMI M1.6)	533–675 µm			
	125 mm	533–675 µm			
6.8	Thickness Variation (TTV)	Unspecified			
6.9	Surface Orientation	As-supplied			
6.10	Bow	Unspecified			
6.11	Warp	Unspecified			
6.12	Sori	Unspecified			Customer specified
6.13	Flatness/Global	Unspecified			Customer specified
6.14	Flatness/Site	Unspecified			Customer specified
7.0	**Front Surface Chemistry**				
7.1	Surface Metal Contamination				
	Sodium	Unspecified	Customer specified	Unspecified	
	Aluminum	Unspecified	Customer specified	Unspecified	
	Potassium	Unspecified	Customer specified	Unspecified	
	Chromium	Unspecified	Customer specified	Unspecified	

	Item	Mechanical	Furnace	Particle	Lithography
	Iron	Unspecified	Customer specified	Unspecified	
	Nickel	Unspecified	Customer specified	Unspecified	
	Copper	Unspecified	Customer specified	Unspecified	
	Zinc	Unspecified	Customer specified	Unspecified	
7.2	Surface Organics	Unspecified			
8.0	**Front Surface Visual Characteristics**				
8.1	Scratches				
	Number of	Unspecified	2		
	Cumulative length	Unspecified	20 mm		
8.2	Pits	Unspecified		Customer specified	
8.3	Haze	Unspecified		Customer specified	
8.4	Localized Light Scatters	Unspecified	$\leq 0.19/cm^2$ @ $\geq$ customer specified size		
8.5	Contamination/area	Unspecified	None		
8.6	Edge Chips	Unspecified	None		
8.7	Edge Cracks	Unspecified	None		
8.8	Cracks, Crow's feet	Unspecified	None		
8.8	Cracks, Crow's feet				
8.9	Craters	Unspecified	None		
8.10	Dimples	Unspecified	None		
8.11	Grooves	Unspecified	None		
8.12	Mounds	Unspecified	None		
8.13	Orange Peel	Unspecified	None		
8.14	Saw Marks	Unspecified	None		
9.0	**Back Surface Characteristics**				
9.1	Edge Chips	Unspecified	None		
9.6	Roughness	Unspecified	Customer specified		
9.7	Brightness (gloss)	Unspecified			
9.8	Localized Light Scatterers	Unspecified	Customer specified		
9.9	Scratches				
	Number of	Unspecified	Customer specified		
	Cumulative length	Unspecified	Customer specified		

Table 3 Guide for Specification of Polished Reclaim Wafers for 180 nm and 130 nm Technology Generations

	Item	200 mm Wafers for 180 nm	300 mm Wafers for 130 nm
1.0	**General Characteristics**		
1.1	Growth Method	CZ or MCZ	
1.2	Crystal Orientation	{100}	
1.3	Conductivity Type	*p*	
1.4	Dopant	Boron	
1.5	Nominal Edge Exclusion	3 mm (See [#1])	
2.0	**Electrical Characteristics**		
2.1	Resistivity	0.5–50.0 $\Omega{\cdot}cm$	
2.2	Radial Resistivity Variation	Unspecified	

		Item	200 mm Wafers for 180 nm	300 mm Wafers for 130 nm
2.3		Resistivity Striations	Unspecified	
2.4		Minority Carrier Recombination Lifetime	Unspecified	
3.0		**Chemical Characteristics**		
3.1.1		Oxygen Concentration	Unspecified	
3.2		Radial Oxygen Variation	Unspecified	
3.3		Carbon Concentration	Unspecified	
4.0		**Structural Characteristics**		
4.2		Slip	None	
4.3		Lineage	None	
4.4		Twins	None	
4.5		Swirl	Unspecified	
4.6		Shallow pits	Unspecified	
4.7		Oxidation-Induced Stacking Faults (OISF)	Unspecified	
4.8		Oxide Precipitates	Unspecified	
5.0		**Wafer Preparation Characteristics**		
5.1		Wafer ID Marking	Customer specified	
5.2		Front Surface Thin Films	None	
5.3		Denuded Zone	None	
5.4		Extrinsic Gettering	None	
5.5		Backseal	None	
6.0		**Mechanical Characteristics**		
6.1		Diameter	200 ± 0.2 mm	300 ± 0.2 mm
6.2		Primary Fiducial Location	See SEMI M1.9	See SEMI M1.15
6.3		Primary Fiducial Dimension	See SEMI M1.9	See SEMI M1.15
6.7		Thickness	>650 μm (See [#2])	
6.8		Thickness Variation (TTV)	10 μm max.	25 μm max.
6.9		Wafer Surface Orientation	$\{100\} \pm 1°$	
6.11		Warp	Customer specified	
6.12		Sori	Unspecified	
6.14		Flatness/Site	Unspecified	(See [#3])
7.0		**Front Surface Chemistry**		
7.1		Surface Metal Contamination		
		Sodium	$<1 \times 10^{11}/cm^2$	
		Aluminum	$<1 \times 10^{11}/cm^2$	$\leq 1.8 \times 10^{11}/cm^2$
		Chromium	$<1 \times 10^{11}/cm^2$	
		Iron	$<1 \times 10^{11}/cm^2$	
		Nickel	$<1 \times 10^{11}/cm^2$	
		Copper	$<1 \times 10^{11}/cm^2$	
		Zinc	$<1 \times 10^{11}/cm^2$	
		Calcium	$<1 \times 10^{11}/cm^2$	
8.0		**Front Surface Criteria**		
8.1A		Scratches (macro) – total length	None	
8.1B		Scratches (micro) – total length	$<0.10 \times$ Diameter	$<0.50 \times$ Diameter
8.2		Pits	None	
8.3		Haze	None	
8.4		Localized Light Scatterers	$<0.20/cm^2$ @ ≥ 0.20 μm	(See [#4])
8.5		Contamination/Area	None	
8.6		Edge Chips	None	

	Item	200 mm Wafers for 180 nm	300 mm Wafers for 130 nm
8.7	Edge Cracks	None	
8.8	Crack, crows feet	None	
8.9	Craters	None	
8.10	Dimples	None	
8.11	Grooves	None	
8.12	Mounds	None	
8.13	Orange Peel	None	
8.14	Saw Marks	None	
9.0	**Back Surface Criteria**		
9.1	Edge Chips	None	
9.6	Roughness	Unspecified	
9.7	Brightness (Gloss)	Unspecified	
TBD	Localized Light Scatterers	Unspecified	
TBD	Scratches (macro)-total length	<50 mm	<150 mm
TBD	Scratches (micro)-total length	Unspecified	
10.0	**Other Characteristics**		
TBD	Edge Condition	Polished	
TBD	Packaging	See Section 9	See SEMI M31 and SEMI M45.

[#1] For edge exclusion, laser-marked areas are to be given special consideration.

[#2] Minimum thickness may be limited by equipment constraints.

[#3] To be negotiated between customer and supplier.

[#4] The number of Localized Light Scatterers (LLS) per wafer is to be determined by customer/supplier agreement; the LLS size in PSL equivalents is specified as ≥0.16 μm with a goal of decreasing to 0.12 μm. A recommended value is 200 @ ≥0.16 μm (interpreted as particles + COP's) or ≤50 @ ≥0.16 μm (for particles only – which may be distinguished from COP's by metrology with customer/supplier agreement on the tool and methodology.

APPENDIX 1
SPECIFICATION FOR MULTIPLE LASER MARKING (RE-INSCRIPTION) OF 300 mm POLISHED SILICON RECLAIMED WAFERS

NOTICE: The material in this appendix is an official part of SEMI M38 and was approved by full letter ballot procedures on August 16, 2004.

A1-1 Purpose

A1-1.1 Silicon wafers are often subjected to reclaim processes, in order to improve manufacturing efficiency in device production.   This process can remove significant material from the marked surface of a 300 mm wafer. This can lead to reduced dot diameter for marks with "v"-shaped profile, to the point that the mark no longer meets the requirements of SEMI T7. This can compromise the mark's readability.

A1-1.2 This specification is intended to identify locations on the back surface of 300 mm reclaimed silicon wafers for re-inscribing the SEMI T7 and optionally the OCR (according to SEMI M1.15) laser marks in order to maintain traceability after multiple reclaims.

A1-2 Scope

A1-2.1 This specification defines the spatial relationships for back surface marking of reclaimable or reclaimed notched, double-side polished 300 mm wafers of silicon with pre-existing manufacturers' marks which comply with SEMI M1.15.

A1-2.2 Although this specification does not specify the marking equipment or techniques that may be employed when complying with its requirements, it is required that the symbols be a "hard mark" obtained by laser scribing individual dots with diameter as specified in SEMI T7.

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.

A1-3 Referenced Standards

A1-3.1 *SEMI Standards*

SEMI M1.15 — Standard for 300 mm Polished Monocrystalline Silicon Wafers (notched)

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

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

A1-4 Ordering Information

A1-4.1 For 300 mm wafers that are to be re-inscribed the following shall be specified on the purchase order:

A1-4.1.1 Whether the previous inscription is to be obliterated, and the method for such obliteration,

A1-4.1.2 Content of re-inscribed field

- Same as prior mark, or

- New field content

A1-5 Requirements

A1-5.1 *Location of the Laser Inscription*

A1-5.1.1 The original reference point shall be located 148.95 mm ± 0.15 mm from the center of the wafer along a radius at 5.0° ± 0.1° counterclockwise from the axis of the fiducial bisector.

A1-5.1.2 The first re-inscription shall be placed counterclockwise to the original mark at the same distance from the wafer center on a radius 10° counterclockwise from the original mark.

A1-5.1.3 Any subsequent re-inscription shall be placed counterclockwise to the previous mark at the same distance from the wafer center on a radius 10° counterclockwise from the previous mark.
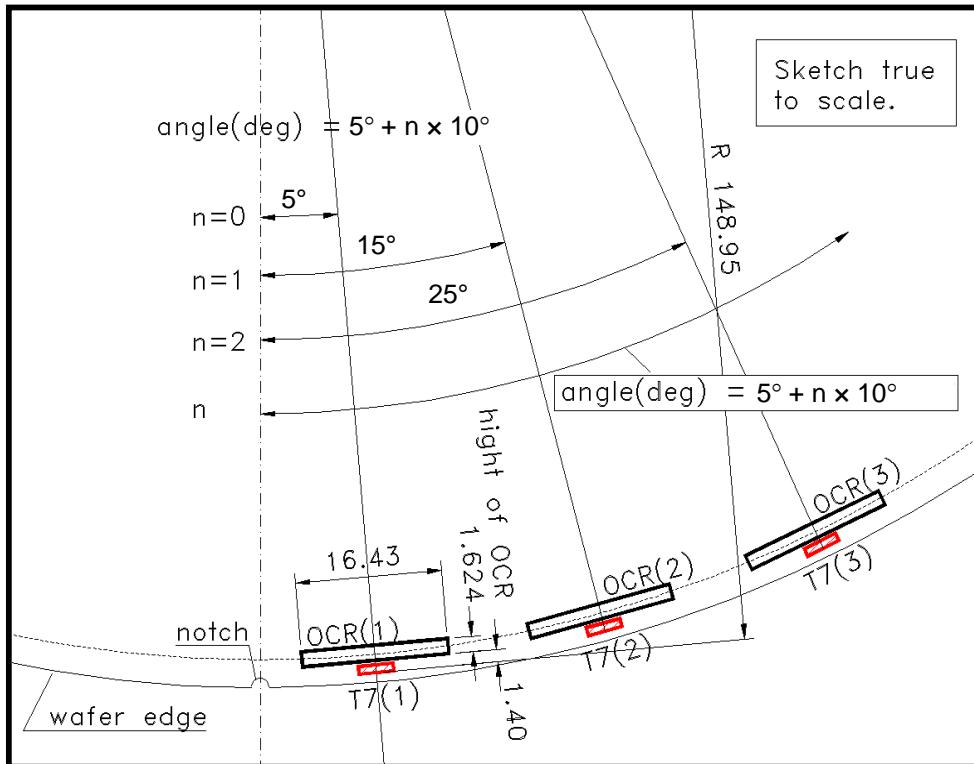
A1-5.1.4 Consequently, the most recent re-inscription is located on a radius an angle θ degrees counterclockwise from the fiducial bisector as follows (see Figure A1-1):

$$\theta = (5.0 + 10.0n) \pm 0.1 \qquad (1)$$

where

n = the total number of re-inscriptions.

A1-5.2 *Maintaining Inscription Utility* — The angle of the new inscription shall be provided to the customer by the supplier so that the tool used to read the inscriptions can be adjusted to read the wafer ID at the new angle. Since it is possible for a tool to be provided the wrong angle to read an inscription, as long as the information remains the same as the prior inscription, errors can be minimized (read attempts at different angles).

Figure A1-1
Locations of Original Inscription and Subsequent Re-inscriptions on Back Surface of Notched 300 mm Diameter Reclaimed Wafer

RELATED INFORMATION 1
BACKGROUND INFORMATION FOR MULTIPLE LASER MARKING (RE-INSCRIPTION) OF 300 mm POLISHED SILICON RECLAIMED WAFERS

NOTICE: This related information is not an official part of SEMI M38. It was developed by the International 300 mm Reclaim Remark Task Force during the development of the specification for multiple-laser marking of 300 mm polished silicon reclaimed wafers. This related information was approved for publication by full letter ballot procedures on August 16, 2004.

R1-1 Multiple Laser Making Issues

R1-1.1 Issues related to multiple laser marking of 300 mm silicon reclaimed wafers were explored at meetings during SEMICON West in San Francisco in July 2002, SEMICON Southwest in Austin in October 2002, SEMICON Japan in Tokyo in December 2002 and a ½ day workshop during SEMICON Europa in Munich in April 2003. Significant input from device makers, wafer reclaimers, and equipment suppliers was received.

R1-1.2 Four major issues emerged.

R1-2 When Is a <u>Remark</u> Field Applied?

R1-2.1 This could be at each reclaim cycle, or when the "first" mark is not readable at the reclaimer.

R1-2.2 Because the latter is a difficult matter, it was decided to make this a decision of the purchaser.

R1-3 Where Should the Remark Field(s) Be Located?

R1-3.1 A device manufacturer suggested that each new remark field be located 10° counter clockwise (CCW) from the previous mark field, and at the same radius.

R1-3.2 A wafer with two of more fields is unambiguously identified as a reclaim wafer and the "*n*" remarked fields it contains indicate the number of reclaim cycles it has experienced, if it is remarked after each use.

R1-4 What Is the Remark Field's Content?

R1-4.1 Two scenarios are possible:

R1-4.1.1 *Different from the Original Mark* — For example, retaining the ID # but changing the supplier code from original to the reclaim supplier's code. This could confuse a device fab's database when two identical ID numbers appear in the database unless it also includes the vendor code. Changing the ID number does not necessarily avoid this problem.

R1-4.1.2 *Same as the Original Mark —* This simplifies the remark coding. However, the is still the possibility of confusing the device manufacturer's database.

R1-4.2 It was decided to make this a decision of the purchaser.

R1-5 How to "Disable" a Previous Mark Field?

R1-5.1 Disabling a mark field requires that a mark field be modified or obliterated sufficiently to ensure the reader reports a "no read."

R1-5.2 It was decided to make both the requirement to obliterate the previous mark and the method of obliteration decisions of the purchaser.

R1-6 Mark Field Obliteration Comments.

R1-6.1 Obliterating an entire field may not be necessary to make it unreadable. For the two mark fields specified in SEMI M1.15, the following may apply:

R1-6.1.1 *Data Matrix Field*

R1-6.1.1.1 Reliable reading of this field requires a quiet zone (no surface disturbance) about four dots wide (400 μm) around the field periphery. Filling the quiet zone with dots insures that the Data Matrix mark cannot be read.

R1-6.1.1.1.1 Surrounding the 8 row × 32 column field with a 4-dot border involves (8 + 32) × 2 × 4 = 320 dots.

R1-6.1.1.1.2 A 3-dot border may work as well, and requires 240 dots.

R1-6.1.1.2 Conversely, overwriting the field involves 8 × 32 = 306 dots.

R1-6.1.1.2.1 A difference of 100 μm (one dot) between the positions of the overwrite field and original field should still produce a "no read."

R1-6.1.1.2.2 Some position difference results from the marker's wafer alignment system. The alignment capability of deployed 300 mm markers is therefore a consideration.

R1-6.2 *Alphanumeric Field*

R1-6.2.1 Obliterating one or more message characters and one or more check sum characters should make the mark unreadable by both camera and human readers.

This requires completely overwriting each of these characters with a filled 5×9 character field (45 dots at "single density"). It was suggested this be done at two ID characters (1 and 6 in the 12-character string) and one check sum character (12).

R1-6.2.2 This overwriting involves 3 fields $\times$ 45 dots = 135 dots.

R1-6.2.3 The alignment comments in Section R1-6.1.1.2.2 also apply to these fields.

R1-7 Use of Remarked Reclaimed Wafers in Device Fabrication

R1-7.1 This may involve two scenarios:

R1-7.1.1 *Incoming Search*

R1-7.1.2 Determine the "good" remark field location $(5 + [10 \times n])$ degrees from the notch bisector for each wafer and store that data in the factory database. Then the manufacturing execution system commands a tool handling that wafer to go to the appropriate field location. This minimizes or eliminates throughput effects.

NOTE 1: This requires variable read location capability (by wafer rotation, for instance) on the tool.

R1-7.2 *Local Tool Search*

R1-7.2.1 When unable to read the original field, the tool scans counterclockwise until it finds a readable field. This cycle can adversely impact tool throughput.

NOTE 2: This requires
- Variable read location capability and
- "Smart" read, i.e., 3 levels, as follows:
  - Good read (this is the "right" field, so keep the data),
  - Bad read (this is an obliterated field, go to "next" location and try again), and
  - No read (no mark is present, search somewhere else).

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 M39-0999
TEST METHOD FOR MEASURING RESISTIVITY AND HALL COEFFICIENT AND DETERMINING HALL MOBILITY IN SEMI-INSULATING GaAs SINGLE CRYSTALS

1 Purpose

1.1 The purpose of this document is to specify a method to measure resistivity and determine Hall mobility of semi-insulating GaAs single crystals by the Van der Pauw method. Especially, this document specifies a simple and practical method for commercial semi-insulating GaAs single crystals.

2 Scope

2.1 This test method covers a procedure for measuring the resistivity and determining Hall mobility of semi-insulating GaAs single crystals by the van der Pauw method. This method requires a singly connected test specimen without any isolated holes, of homogeneous thickness and with a square shape. In this method, contacts must be sufficiently small and located at the corners of the specimen.

2.2 This standard may involve hazardous materials, operation, and equipment. This standard does not purport to address all of the safety problems 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 limitations prior to use.

3 Referenced Standards

3.1 *ASTM Standards*

F 76-73 — Standard Method for Measuring Hall Mobility and Hall Coefficient in Extrinsic Semiconductor Single Crystals

F 76-86 — Standard Test Methods for Measuring Resistivity and Hall Coefficient and Determining Hall Mobility in Single-Crystal Semiconductors

F 43-93 — Standard Test Methods for Resistivity of Semiconductor Materials

NOTE 1: As listed or revised, all documents cited shall be the latest publications of adopted standards.

4 Terminology

NOTE 2: Many of the terms associated with this test method can be found in ASTM Definitions F 76-86.

hall mobility — the ratio of the magnitude of the Hall coefficient to the resistivity; it is readily interpreted only in a system with carriers of one charge type.

resistivity — the ratio of the potential gradient parallel to the current in the material to the current density. For the purpose of this method, the resistivity shall always be determined for the case of zero magnetic flux.

5 Summary of Test Method

5.1 In this method, the thickness of a specimen cut from a semi-insulating GaAs single crystal is measured.

5.2 Ohmic contacts are formed on the specimen.

5.3 The temperature near the specimen is measured.

5.4 Hall-effect measurement is performed and data are taken.

5.5 From the measured data, the resistivity and Hall mobility are calculated and corrected for temperature.

6 Interferences

6.1 Light could cause an error due to photo-conductivity, so the specimen must be placed in a dark environment.

6.2 Temperature fluctuation gives significant error. Specimen itself could be at higher temperature than the environment if one does not take sufficient time after soldering the contacts.

6.3 The current-voltage conditions must be ohmic.

6.4 The damaged layer due to the sawing must be removed by etching the specimen, for example by using mixture of sulfuric acid (H_2SO_4), hydrogen peroxide (H_2O_2) and water ($H_2SO_4:H_2O_2:H_2O = 3:1:1$).

7 Apparatus

7.1 *Measurement of Specimen Thickness* — Dial gauge, micrometer, or electronic thickness gauge

capable of measuring the specimen thickness within ± 1% must be used.

7.2 *Magnet* — A calibrated magnet capable of providing a magnetic flux density uniform within ± 1% over the area in which the test specimen is to be located. Flux densities must be between 3,000−10,000 gauss (0.3T−1.0T).

7.3 *Instrumentation*

7.3.1 *Current Source* — Capable of maintaining current through the specimen constant to ± 1% during the measurement. The current source is accurate to ± 1% on all ranges used in the measurement.

7.3.2 *Electrometer or Voltmeter* — With which voltage measurements can be made to an accuracy of ± 1%. The input resistance of the electrometer (or voltmeter) must be greater than 1E13 Ω. In addition to the Electrometer, the input resistance greater than 1E13 Ω must be kept in the Hall measurement system.

7.4 *Specimen Holder*

7.4.1 *Container* — Used to hold the specimen, to isolate it from surroundings and shield it from light.

7.4.2 *Thermometer* — Located in close proximity to the test specimen and associated instruments for monitoring temperature to an accuracy of ± 0.1°C during the measurement. This may include, for example, a thermocouple.

8 Reagents and Materials

8.1 *Purity of Reagents* — All chemicals for which such specifications exist shall conform to SEMI C1.

8.2 *Purity of Water* — When water is used, it is either distilled water or deionized water having a resistivity greater than 2MΩcm at 25°C as determined by the Non-Referee Test of Test Methods D 1125.

9 Test Specimen Preparation

9.1 Regardless of the specimen preparation process used, high-purity reagents and water are required.

9.2 *Material* — The test specimen is prepared from a sliced wafer of a GaAs single crystal.

9.3 *Specimen Cutting*

9.3.1 Cut wafers which have a thickness ranging from 0.3 to 1.0 mm from a GaAs single crystal.

9.3.2 Clean and etch them, for example by a sulfuric acid/peroxide solution (H_2SO_4:H_2O_2:H_2O = 3:1:1), in order to remove surface damage and to obtain smoother surfaces. Polishing can be used instead of etching.

9.3.3 Cleave or dice the test specimen into a square shape with each side length from 3 mm to 10 mm. The thickness variation over the specimen should be in ± 1%.

9.4 *Contact Formation*

9.4.1 Ohmic contact materials can be In, AuGe/Au or AuGe/Ni.

9.4.2 Place the contacts on four corners of the specimen.

9.4.3 Maintain the contact dimensions as small as possible relative to the peripheral length of the specimen. Recommended dimension of the contact is not greater than 1/10 of the side length of the specimen.

10 Measurement Procedure

10.1 *Thickness Measurement* — Measure the specimen thickness, t[cm] with a precision of ± 1%.

10.2 *Contact Evaluation* — Verify that all combinations of contact pairs in both polarities have linear current-voltage characteristics, without noticeable curvature, about the actual value of current to be used and at the measurement temperature.

10.3 *Specimen Placement* — Place the clean and contacted specimen in its container. If a permanent magnet is used to provide the magnetic flux, keep the magnet and the specimen separate during the measurement of resistivity. If an electromagnet is used, be certain that the residual flux density is small enough not to affect the resistivity measurement.

10.4 *Resistivity Measurement (see Figure 1)* — Measure the temperature, T_1, of the specimen. Set the current magnitude, I, to the desired value in a linear region. Measure the voltages V_1 at I_1 and V_2 at I_2. T_1 shall be 25 ± 5°C and the fluctuation of T_1 shall be maintained to ± 1°C during the resistivity measurement.

10.5 *Hall Mobility Measurement (see Figure 2)*

10.5.1 Position the specimen between the magnet-pole pieces so that the magnetic flux is perpendicular to the two flat faces of the specimen.

10.5.2 Measure the temperature, T_2, of the specimen. Set the current magnitude, I, to the desired value. Measure the voltage V_3 with the magnetic flux and V_4 without the magnetic flux.

10.5.3 T_2 shall be 25 ± 5°C and the fluctuation of T_2 shall be maintained to ± 1°C during Hall mobility measurement.

11 Calculations

11.1 *Resistivity*

$$\rho = (\pi \times t/2\ \ln 2) \times (R_1 + R_2) \times f(R_1/R_2)\ [\Omega \cdot cm]$$

where:

t is the specimen thickness,

R_1 and R_2 are the equivalent resistances

for two opposite sides as follows:

$R_1 = V_1/I_1$

$R_2 = V_2/I_2$

$f(R_1/R_2)$ is the correction factor for specimen shape.

In the case of $R_1/R_2 < 10$,

$$f(R_1/R_2) = 1 - 0.34657A - 0.09236A^2$$

where: $A = [(R_1/R_2 - 1)/(R_1/R_2 + 1)]^2$

11.2 *Hall Mobility*

$$\mu = (t/B) \times R_3/\rho \quad [cm^2 / V \cdot s]$$

where:

B is the magnetic flux density,

$R_3 = |V_3 - V_4| / I$

where:

V_3 is the voltage when the current is I under magnetic flux

V_4 is the voltage when the current is I without magnetic flux.

11.3 *Temperature Conversion*

11.3.1 *Resistivity*

$$\rho_T = \rho_{T1} \cdot \exp[-Ea/k \cdot (1/T_1 - 1/T)]$$

where:

Ea is the activation energy (= 0.75eV)

k is the Boltzman constant (= 8.61E − 5 eV/K)

ρ_T is the resistivity at T(K)

11.3.2 *Hall Mobility*

$$\mu_T = \mu_{T2}(T/T_2)^{-3/2}$$

where: μ_T is the Hall mobility at T(K)

12 Report

12.1 The following information shall be included in the report for referee and research measurement:
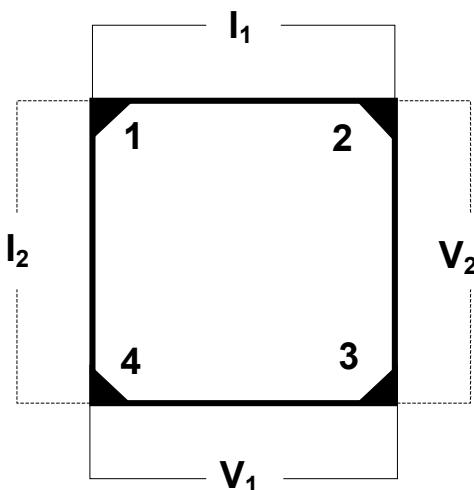
12.1.1 Identification of test specimen,

12.1.2 Test temperature,
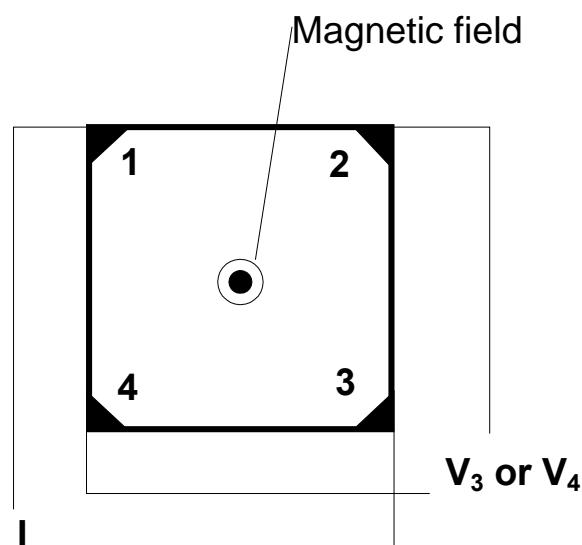
12.1.3 Specimen shape used, orientation, and corresponding dimensions,

12.1.4 Magnitude of magnetic-flux density, and

12.1.5 Calculated resistivity and Hall mobility.

Figure 1
Block Diagram of Resistivity Measurement

Figure 2
Block Diagram of Hall Mobility Measurement

NOTICE: These standards do not purport to address safety issues, if any, associated with their use. It is the responsibility of the user of these standards to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. 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 M40-0200
GUIDE FOR MEASUREMENT OF SURFACE ROUGHNESS OF PLANAR SURFACES ON SILICON WAFER

This guide 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 December 15, 1999. Initially available at www.semi.org February 2000; to be published February 2000.

1 Purpose

1.1 This guide provides procedures for specifying the measurements to be used in characterizing and reporting roughness of the planar surfaces of silicon wafers. It may also be applicable to other types of planar wafer materials.

1.2 This guide provides nomenclature and procedures for roughness determination that employ three key methodologies:

1.2.1 Standardized scan site patterns,

1.2.2 Roughness abbreviations, and

1.2.3 Reference test methodologies with respect to identifying specific roughness measurements.

2 Scope

2.1 This guide incorporates the following methodologies:

2.1.1 Standardized scan patterns for both local and full-area surface characterization,

2.1.2 A set of roughness abbreviations that describe measurement conditions in a short-hand code, and

2.1.3 Reference test methodologies for three generic types of roughness measuring instruments. These general categories may include, but are not limited to:

- Profilometers — AFM and other scanning probe microscopes; optical profilometers; high-resolution mechanical stylus systems,

- Interferometers — interference microscopes, and

- Scatterometers — Total integrating scatterometers (TIS), angle-resolved light scatterometers (ARLS), scanning surface inspection systems (SSIS).

2.2 Procedures to obtain a representative value of roughness for a surface are specified.

2.3 Roughness nomenclature is intended to remove ambiguities with respect to identifying the roughness measurements used and the results achieved.

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

3 Limitations

3.1 This guide does not apply to measurements in the edge region of wafers.

3.2 This guide does not apply to spatial wavelengths $\leq$ 10 nm.

3.3 This guide is not intended to define specific roughness parameters; these can be found in other documents.

3.4 The bandwidth of the measurement tool and the bandwidth used can severely influence the result of roughness measurements.

3.4.1 Differences in either long or short bandwidths used between two instruments can produce significantly different results.

3.4.2 The codes listed in Table 1 of this guide do not identify instrument transfer functions.

3.5 The presence of films may affect light scattering measurements.

4 Discussion

4.1 Roughness of silicon wafer surfaces is becoming frequently specified for bare silicon wafers (cf. the SIA International Technology Roadmap for Semiconductors). These specifications refer to the roughness of both the final polished front and the back surfaces of a wafer. Various techniques are currently used to measure the surface roughness of silicon wafers. These techniques include AFM scanning probes, mechanical and optical profiling, interferometric microscopes, and light (electromagnetic radiation) scattering. Mechanical profiling techniques are widely used in other industries and are well standardized. Profiling techniques are generally limited to line scans and therefore provide information of only a very small part of a surface. Interferometric techniques for roughness measurements are similarly limited, whereas light scattering techniques can scan the entire wafer surface.

4.2 Historically a variety of roughness parameters for profiling techniques have evolved and have been standardized, including rms roughness (R_q) and average roughness (R_a). Profiling instruments measure the surface topography and derive roughness statistics, such as R_q, from a series of height data. Light scattering techniques measure R_q from the angular dependence of scattering; some light scattering systems derive other parameters through interpretation and estimation.

4.3 A roughness value representative of an entire wafer surface, or a large portion of the surface, cannot be based on data obtained at a single point. Yet, specifications often describe a single value for a wafer. Therefore, this guideline suggests and defines standardized patterns of scan sites that can be described and used unambiguously. A model describing the relationship between several types of roughness variation, scan patterns, and reported results is included in the attached Related Information to assist users in specifying and interpreting these variables.

4.4 A common feature of all roughness measurements is their dependence on the bandwidth and transfer function of the tool used. In addition, high or low spatial frequency software filters are common and affect reported results. Widely different numbers can be reported for the same surface by two measurement instruments. This guideline includes suggestions on specifying and reporting the instrument bandwidth and transfer function.

5 Referenced Standards

5.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M20 — Specification for Establishing a Wafer Coordinate System

5.2 *ASME Standard* [1]

ASME B46.1 — Surface Texture (Surface Roughness, Waviness, and Lay)

5.3 *ASTM Standards* [2]

E 1392 — Practice for Angle Resolved Optical Scatter Measurements on Specular or Diffuse Surfaces

F 1048 — Test Method for Measuring the Effective Surface Roughness of Optical Components by Total Integrated Scattering

F 1620 — Practice for Calibrating a Scanning Surface Inspection System Using Monodisperse Polystyrene Latex Spheres Deposited on Polished or Epitaxial Surfaces

F 1811 — Estimating the Power Spectral Density Function and Related Finish Parameters from Surface Profile Data

5.4 *DIN Standards* [3]

DIN 4760 — Form Deviation, Waviness, Surface Roughness; System of Order, Terms and Definitions

DIN 4768 — Determination of Values of Surface Roughness Parameters Ra, Rz, Rmax by Means of Electrical Contact (Stylus) Instruments; Terminology, Measuring Conditions

DIN 4777 — Metrology of Surfaces; Profile Filters for Electrical Contact Stylus Instruments; Phase-Corrected Filters

5.5 *ISO Standards* [4]

ISO 468 — Surface Roughness – Parameters, Their Values and General Rules for Specifying Requirements

ISO 1879 — Instrument for the Measurement of Surface Roughness by the Profile Method - Vocabulary

ISO 1880 — Instruments for the Measurement of Surface Roughness by the Profile Method - Contact (Stylus) Instruments of Progressive Profile Transformation - Profile Recording Instruments

ISO 3274 — Instruments for the Measurement of Surface Roughness by the Profile Method – Contact (Stylus) Instrument of Consecutive Profile Transformation – Contact Profile Meters, System M

ISO 4287/1 — Surface roughness – Terminology – Part 1: surface and its parameters

ISO 4288 — Rules and Procedures for the Measurement of Surface Roughness Using Stylus Instruments

5.6 *JIS Standards* [5]

JIS B 0601 — Surface Roughness - Definitions And Designation

JIS B 0652 — Instruments For The Measurement Of Surface Roughness By The Interferometric Method

JIS B 0659 — Roughness Comparison Specimens

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1 American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY 10017

2 American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohoken, PA 19428-2959

3 Deutches Institut für Normung e.V., Beuth Verlag GmbH, Burggrafenstrasse 4-10, D-10787 Berlin, Germany

4 ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Genève 20, Switzerland

5 Japanese Standards Association, 1-24, Akasaka, 4-Chome, Minato-ku, Tokyo 107 Japan

5.7 *Other Documents*

International Technology Roadmap for Semiconductors[6]

Optical Scattering in the Optics, Semiconductor, and Computer Disk Industries, Second Edition 1995, J C Stover, Editor[7]

NOTE 1: As listed or revised, all documents cited shall be the latest publications of adopted standards.

6 Terminology

6.1 *autocorrelation function* — the Fourier transform of the Power Spectral Density function. It expresses the similarity between a surface profile and the same profile that is slipped, or moved laterally, with respect to itself.

6.2 *autocorrelation length* — the lateral slip required to reduce the Autocorrelation function to a value equal to e-1 times its zero slip value. Sometimes 10% or even 0 value definitions are used instead of e-1.

6.3 *average roughness (R$_a$)* — the average of the surface profile height deviations Z(x) from the mean line taken within the evaluation length (ASME B46.1).

6.4 *bi-directional reflectance distribution function, BRDF* — a description of the distribution of light scattered by a surface, it is the differential radiance normalized by the differential irradiance, and is approximated by the scattered power per unit projected solid angle divided by the incident power (Stover).

6.5 *fixed quality area (FQA)* — the central area of a wafer surface, defined by a nominal edge exclusion, *X*, over which the specified values of a parameter apply (SEMI M1). See also the discussion immediately following this definition in SEMI M1.

6.6 *haze* — non-localized light scattering resulting from surface topography (microroughness) or from dense concentrations of surface or near-surface imperfections (SEMI M1).

DISCUSSION — Haze due to the existence of a collection of imperfections is a mass effect; individual imperfections of the type which result in haze cannot be readily distinguished by the eye or other optical detection systems without magnification. In a particle counter (SSIS), haze results in a background signal and laser light-scattering events together comprise the signal due to light-scattering from a wafer surface. (SEMI M1). It is the total scattered optical flux collected by an optical system normalized by the incident flux.

NOTE 2: Different SSIS instrument types may give significantly different haze values on a given sample.

6.7 *illumination source incidence angle* — the angle of the incoming beam, measured from surface normal.

6.8 *kurtosis (Rku)* — a measure of the sharpness of the histogram of surface profile height deviations *Z(x)* from the mean line within the evaluation length. A complete random surface will have a Gaussian histogram and *Rku* = 3 (ASME B46.1).

6.9 *laser light-scattering event* — a signal pulse that exceeds a preset threshold, generated by the interaction of a laser beam with a discrete scatterer at a wafer surface as sensed by a detector; see also *haze* (SEMI M1). See also the discussion that follows this definition in SEMI M1.

6.10 *lay* – the predominant direction of the surface pattern, ordinarily determined by the production method used (ASME B46.1).

6.11 *microroughness* — surface roughness components with spacing between irregularities (spatial wavelength) less than about 100 μm (SEMI M1).

6.12 *Nyquist Criterion* — the shortest spatial wavelength detected. It is twice the sample spacing.

6.13 *one-dimensional grating equation* — in its most common form, it is an expression that gives the positions of diffracted orders from a one-dimensional sinusoidal grating (Stover).

6.14 *peak to valley (R$_t$)* — the highest to lowest value of the surface profile height deviations *Z(x)* from the mean line taken within the evaluation Length *L* (ASME B46.1).

6.15 *power spectral density (PSD) function* — a surface characterization function that is proportional to the square of the modulus of the Fourier transform of the surface and may be considered as a roughness power per unit of spatial frequency (ASTM F 1811).

6.16 *Rayleigh Criterion (of resolving power)* — a condition for distinguishing a pair of diffraction patterns whereby the maximum of one pattern overlaps with the minimum of the other.

DISCUSSION — When a lens is free from aberrations, the images of point objects appear as diffraction patterns. When the principle maximum of one pattern strikes the first minimum of another, the images are described as being resolved. With respect to circular optics, this criterion applies when the distance between resolvable point objects, viewed from the objective lens of the instrument, is

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6 Semiconductor Industry Association (SIA), 181 Metro Drive, Suite 450, San Jose, CA
7 SPIE, P.O. Box 10, Bellingham, WA 98227-0010

$$\frac{0.61\lambda}{NA}$$

where *NA* is the numerical aperture of the objective lens and λ is the illumination wavelength.[8]

6.17 *rms area microroughness (R_qA)* — the root mean square of the topographic deviations of a surface $Z(x,y)$ from the mean surface taken within the evaluation Area ($=L_xL_y$) (SEMI M1). See also the extended discussion that follows this definition in SEMI M1.

6.18 *rms microroughness (R_q)* — the root mean square of the surface profile height deviations $Z(x)$ from the mean line taken within the evaluation Length *L* (SEMI M1). See also the extended discussion that follows this definition in SEMI M1.

6.19 *rms slope (mq)* — the root-mean-square value of the rate of change of profile departures within the evaluation length (Adapted from ISO 4271/1).

6.20 *roughness* — the more narrowly spaced components of surface texture (SEMI M1). Compare with *waviness*.

6.21 *skewness (Rsk)* — a measure of the asymmetry of the surface topographic deviations of a surface $Z(x,y)$ about the mean line. A perfect random surface will have *Rsk* = 0 (*ASME B46.1*).

6.22 *spatial bandwidth* — the range of wavelengths in which a given instrument operates (Stover).

6.23 *spatial frequency* — spatial frequency ($F_{spatial}$) is the inverse of spatial wavelength ($\lambda_{spatial}$).

6.24 *spatial wavelength* — the spacing between adjacent peaks of a purely sinusoidal profile (*ASME B46.1*).

6.25 *ten point roughness height (R_z)* — the average value of the absolute values of the heights of the five highest profile peaks and the depths of the five lowest profile valleys from the mean line taken within the evaluation length. (Adapted from ISO 4281/1.)

6.26 *transfer function* — the response of an instrument over all measured spatial wavelengths.

DISCUSSION — A perfect instrument would have a 100% response over all spatial wavelengths. Every measuring instrument will have some deviation from a perfect response especially at the low spatial frequency limit (the traversing length) and at the high spatial frequency limit. The power spectrum can be used to examine this limit near the high spatial frequency

8 Optics, Eugene Hecht, et al; 3rd edition (August 1997); Addison-Wesley Publishing Co; ISBN: 0201838877

response. Contact the instrument supplier for this information.

6.27 *traversing length* — the maximum distance sampled in a given direction. The maximum measurable spatial wavelength is always less then the traversing length.

6.28 *wavelength scaling* — a surface is said to wavelength scale if the scatter measurements at one wavelength may be used to predict scatter measurements at another wavelength (Stover).

6.29 *waviness* — the more widely spaced (spatial wavelength) components of surface texture (SEMI M1). Compare with *roughness*.

7 Instruments and Capabilities

7.1 *Profilometers*

7.1.1 The high spatial frequency limit of AFM, mechanical and optical profilers can be approximated by the radius of the mechanical tip or by the diameter and intensity profile of the laser spot, respectively. Their response functions are complicated, and in some cases are a combined effect of the probe and the measured surface. The high spatial frequency limit of such tools has to be set or selected reasonably removed from that limit in order to achieve reasonable, comparable, and repeatable measurements.

7.2 *Interference Microscope*

7.2.1 The high spatial frequency limit of these instruments is defined by the focusing optics or in some cases by the pixel spacing of the detector array. The high spatial frequency limit of such tools has to be set or selected reasonably removed from that limit in order to achieve reasonable, comparable, and repeatable measurements.

7.3 *Scattering Instruments*

7.3.1 A straightforward relation between scattered light intensity and roughness exists only for sufficiently smooth surfaces. The Rayleigh smooth-surface criterion, given below, is frequently used for estimating the smooth-surface limit (Stover).

$$\frac{1}{2}\left(\frac{4\pi a \cos\theta_i}{\lambda}\right)^2 \ll 1 \tag{1}$$

$$m \ll 1 \tag{2}$$

where: *m* = profile slope,

λ = wavelength of incident light,

a = amplitude of sample profile (half of the peak-to-valley height), and

θ_i = incidence angle of light.

7.3.2 Corresponding amplitude examples assuming a limit of 0.1 result in

$a \le 23$ nm for $\lambda = 633$ nm, $\theta_i = 0°$ and

$a \le 51$ nm for $\lambda = 488$ nm, $\theta_i = 70°$

7.3.3 The equivalent rms-roughness values for a sinusoidal profile and for a limit of 0.1 are

$R_q \le 16$ nm for $\lambda = 633$ nm, $\theta_i = 0°$ and

$R_q \le 36$ nm for $\lambda = 488$ nm, $\theta_i = 70°$

7.3.4 Light scattering tools can be applied to rougher surfaces than those surfaces identified in equations 1 and 2, but then other mathematical approaches as compared to PSD curves have to be applied to calculate roughness or slope values. Also, the slope of the PSD curve can be important in certain situations (Stover).

7.3.5 There is a basic high spatial frequency (short spatial wavelength) limit for light scattering tools which cannot be exceeded. This limit is:

a) twice the inverse wavelength, $\dfrac{2}{\lambda}$, of the light used in case of grazing incidence ($\theta_i = 90°$), and

b) one inverse wavelength, $\dfrac{1}{\lambda}$, in the case of normal incidence ($\theta_i = 0°$).

These conditions follow directly from the one-dimensional grating equation

$$f_x = \frac{\sin\theta_s \cos\phi_s - \cos\theta_i}{\lambda}$$

where: θ_s = scattering angle in the incident plane, and

ϕ_s = scattering angle out of the plane-of-incidence.

NOTE 3: f_x becomes -1 when the light is scattered back in the direction of the incoming light in the incident plane ($\phi_s = 180°$).

7.4 *Total Integrating Scatterometers (TIS)*

7.4.1 These instruments most often use an incidence angle close to zero. The low and high frequency limits of the accessible spatial bandwidth are defined by the design of the optical system. An appropriately designed system may be able to access a spatial bandwidth from about 0.8 µm to about 40 µm. These systems may also be designed so that the scattered signal can be broken into low spatial frequency (near specular) and high spatial frequency (large scatter angle) bands.

7.5 *Angle-resolved Light Scatterometers (ARLS)*

7.5.1 The high spatial frequency limit of this technique is defined by incident and scattering angles and the illumination wavelength used.

7.5.2 The low spatial frequency limit is given by

- the above equations (for incidence angle),

- the diameter of the incident illumination spot at the wafer surface,

- the solid collection angle of the optical system, and

- the smallest angular distance allowed by the instrument between specular reflected light and the detector.

7.5.3 The roughness may be measured by using a fixed incidence angle and by recording the intensity of scattered light at various scattering angles in the plane of incidence. The two-dimensional PSD curve of the surface can then be calculated from the angular spectrum of the scattered light (BRDF). R_q as well as mq may be calculated from a one-dimensional or isotropic PSD curve for a given spatial bandwidth as long as the above mentioned limits are accommodated.

7.5.4 Such tools may be able to access a spatial bandwidth range of about one-half the wavelength of the illuminating light up to several hundred µm.

7.6 *Scanning Surface Inspection Systems (SSIS)*

7.6.1 SSIS measurements are integrated scatter measurements similar to those made by TIS systems, in that they gather light over large solid angles; however, there are some significant differences. In general, most SSIS avoid light collection within five to ten degrees of the specular beam, because in this region the scatter tends to be dominated by surface roughness scatter (which becomes background noise) competing with the signal from laser light scattering events. The early (older) scanners generally had one detector measuring light from a very large solid angle collector. Later systems tend to use several smaller collection angles, each with their own detector. Whatever the arrangement, each collection angle can be defined in terms of its spatial frequency band pass region, and each detector will have some background haze component (or threshold) that is caused by surface roughness. Thus, in the absence of laser light scattering events, measured haze may be converted to an rms roughness for the defined spatial frequencies. This conversion assumes that the surface meets the necessary (smooth, clean, front surface reflective) conditions required for roughness calculations, and that

other noise sources, such as background electronic noise and Rayleigh air scatter, are not issues.

8 Roughness Measurements

8.1 *Parameters*

8.1.1 R_q and R_a are generally used for silicon wafer surfaces. Other roughness measurement parameters may also prove useful. This guideline does not suggest which parameters to use, rather it suggests how to incorporate any parameter into a standardized measurement specification.

8.2 *Measurement Sites*

8.2.1 Roughness can vary considerably across a wafer surface. It may also have a preferential direction or anisotropy, often called "lay" (ASME B46.1). Many measurement techniques are limited to a very small measurement area and to one or two scan directions. Therefore specific measurement patterns must be defined to obtain representative and reproducible results. These patterns should correspond to effects observed on wafers in different manufacturing steps. These processing steps can generate features on a wafer surface with rotational symmetries ranging from mirror to infinite. The wafer slicing process may produce low symmetry, while single-wafer polishing can produce high symmetry.

8.2.2 In cases where only a small number of spots is measured, the spot pattern and the scan orientation have to be identified. See Figure 1 for some patterns and orientations; others may be agreed upon between interested parties.

8.3 *Site Patterns*

8.3.1 One-point — This can be useful for rapidly reviewing results of a quantity of wafers. This is often at the wafer centerpoint.

8.3.2 In applications where only a small number of locations are to be measured, the pattern and orientation of the local scans have to be identified. Measurements are performed at locations as outlined in Figure 1. For each local scan, a representative roughness is calculated. The wafer's representative roughness is then a function of the *n* individual representative scan values. The roughness variation can be calculated by the average, the standard deviation, the maximum or the range (Max-Min) of the individual scan values. Other statistical approaches may be employed.

8.3.3 Standard patterns include:

a. 1-point   Wafer center,

b. 5-point   Wafer Center plus four points at 2r/3 from the wafer center, and

c. 9-point   Wafer Center plus four points at 2r/5 and four at 4r/5 from the wafer center.

NOTE 4: These patterns have been shown to be useful with a range of symmetries and values. See Related Information.

8.3.4 Standard measurement orientation patterns include:

a. Type A - linear scans parallel and perpendicular to the fiducial bisector, and

b. Type B - linear scans at 45° relative to the fiducial bisector.

NOTE 5: Type A is generally used for all surfaces. Type B has been reported to be useful for some surface conditions on (111) wafers.

8.4 *Bandwidth*

8.4.1 Two issues affect the bandwidth of the roughness results. The first is the bandwidth of the roughness measuring tool, which is discussed in Section 7. The second bandwidth effect is from the analysis software, which is user selected to emphasize certain spatial frequencies. Both long and short spatial wavelength (or frequency) limits must be defined in μm (or μm^{-1}). When entering this information into a measurement, specification wavelength units shall be used. Profiling instruments should have scan length and bandwidth adjusted according to DIN 4768 and 4777 or ASME B46.1.

8.5 *Precision*

8.5.1 The precision of the roughness measuring instrument (*P*) is important. The relationship between *P* and the tolerance of the parts to be characterized (*T*) is often called the *P/T* Ratio. SEMI M27 describes how to determine and interpret the factors: "A test instrument is usually deemed to be suitable for the purpose if P/T lies below 10%. If *P/T* is greater than 30%, the test instrument is not likely to be suitable for the purpose. Cases for which *P/T* lies between 10% and 30% must be judged on an individual basis, depending on the requirements being placed on the measurement system."

9 Roughness Measurement Specifications

9.1 The process of defining the measurements to be taken involves several distinct steps. The definition sequence below represents one logical sequence; others may be equally useful. See Table 1 for measurement abbreviations.

9.2 First, select the type of instrument to be used, including ALL of the following:

9.2.1 Generic instrument type

9.2.1.1 Interferometer

    a.   Interference microscope

9.2.1.2 Profilometer

    a.   AFM

    b.   Other scanning probe microscopes

    c.   Optical profilometer

    d.   Mechanical stylus

9.2.1.3 Scatterometer

    a.   Total Integrating (TIS)

    b.   Angle-resolved light (ARLS)

    c.   Scanning Surface Inspection System (SSIS)

9.3 Next, select the roughness parameter to by calculated.

9.4 Select the measurement pattern (Figure 1):

    a.   Center point

    b.   5-point

    c.   9-point

    d.   Full-FQA raster scan

    e.   Full-FQA R-theta scan

9.5 Select the pattern orientation (Figure 1)

    a.   Type A

    b.   Type B

9.6 Select the local measuring condition

    a.   Point

    b.   Line

    c.   Area

9.7 Specify the measurement calculations to be reported

    a.   Average (A)

    b.   Range (R)

    c.   Maximum (M)

    d.   Standard Deviation, 1 sigma (S_{n-1})

9.8 Specify the bandwidth and scan length limits within which data is to be gathered.

9.9 Lastly, record the abbreviations describing these selections (see Appendix 1 for examples), separating adjacent abbreviations with a comma and using periods for decimal notation. This creates a seven-field abbreviation. The field sequence described above follows the order of elements in Table 1.

10 Measurement Reporting Sequence

10.1 In general, one value is reported for a wafer. Where more than one pattern is specified the calculated values are reported in the order in which they are listed in Table 1.

Table 1 Roughness Measurement Codes

| Element	Abbreviation Item					
Instrument	A Profilometer	1 AFM	2 SPM	3 OPR	4 MPR	
	B Interferometer	1 IM				
	C Scatterometer	1 TIS	2 ARLS	3 SSIS		
Pattern (See NOTE 1.)	1 Center	5 5-point	9 9-point	R FQA/Raster scan	C FQA/Concentric R-theta scan	S FQA/Spiral R-theta scan
Pattern Orientation	A A	B B				
Local Measurement Condition	P Point	L Line	A Area			
Parameter (See NOTE 1.)	Q Rq	A Ra	Z Rz	T Rt	K Kurtosis	S Skewness
Calculation (See NOTE 1.)	A Average	R Range	M Maximum	D Std. Deviation (1 sigma $_{n-1}$)		
Bandwidth, μm	[__]/[__] (fill in blanks to two significant figures) Long wavelength (μm)/Short wavelength (μm)					
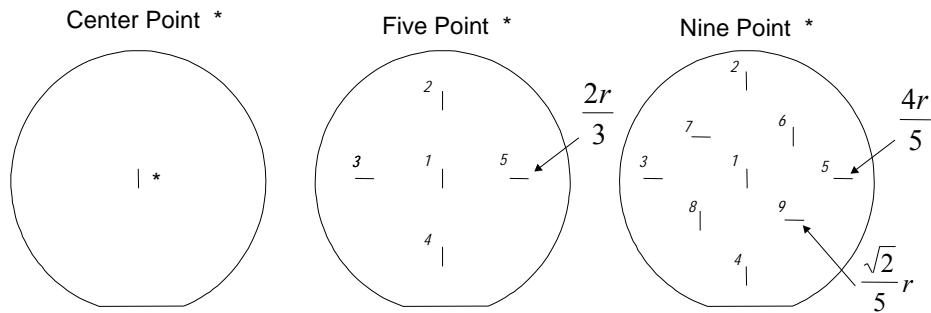
NOTE 1: If more than 1 element is specified, the representative letters are concatenated in the relevant field, in the order specified. See Appendix 1 for examples.

Table 2 Scan Pattern Locations

Location		X, Y Coordinates (per SEMI M20)	Scan Direction (for line and area tools), parallel to:
Center Point		0, 0	Y-axis
5-point Pattern Point # Location			
1	Center Point	0, 0	Y-axis
2	2r/3	0, 2r/3	Y-axis
3	2r/3	-2r/3, 0	X-axis
4	2r/3	0, -2r/3	Y-axis
5	2r/3	2r/3, 0	X-axis
9-point Pattern			
1	Center	0, 0	Y-axis
2	4r/5	0, 4r/5	Y-axis
3	4r/5	-4r/5, 0	X-axis
4	4r/5	0, -4r/5	Y-axis
5	4r/5	4r/5, 0	X-axis
6	$(r\sqrt{2})/5$	$(r\sqrt{2})/5, (r\sqrt{2})/5$	Y-axis
7	$(r\sqrt{2})/5$	$-(r\sqrt{2})/5, (r\sqrt{2})/5$	X-axis
8	$(r\sqrt{2})/5$	$-(r\sqrt{2})/5, -(r\sqrt{2})/5$	Y-axis
9	$(r\sqrt{2})/5$	$(r\sqrt{2})/5, -(r\sqrt{2})/5$	X-axis
Full FQA Scan			
Raster Scan		Full FQA	X-axis
Concentric Circles or Spiral		Full FQA	R – Theta
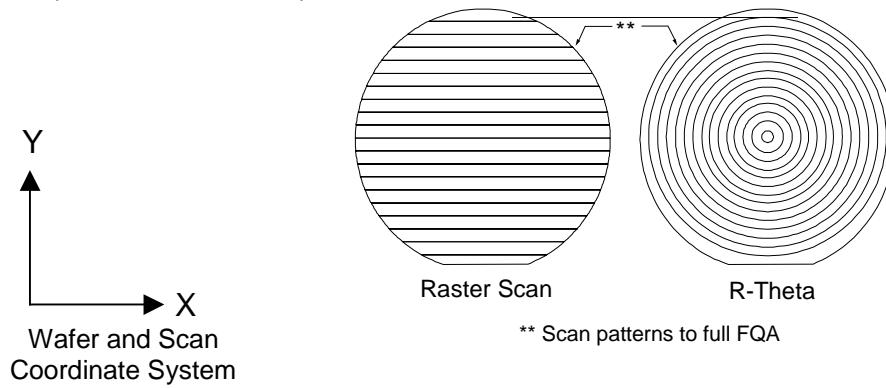
NOTE 1: r = nominal wafer radius

Type A Local Scan Patterns

Center Point *

Five Point *

Nine Point *

$$\frac{2r}{3}$$

$$\frac{4r}{5}$$

$$\frac{\sqrt{2}}{5}r$$
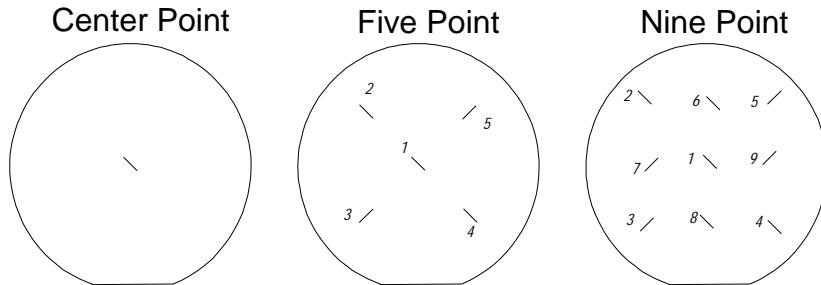
* Line indicates scan direction for all line scans.
Centerpoint of line = location for point measurements

Full FQA Scan Patterns

**

Y

X

Wafer and Scan
Coordinate System

Raster Scan

R-Theta

** Scan patterns to full FQA

Type B Local Scan Patterns

Center Point

Five Point

Nine Point

Full FQA

Raster Scan
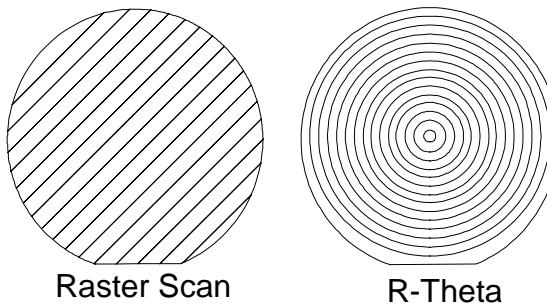
R-Theta

Figure 1
Patterns of Locations on a Silicon Wafer Surface for Measuring
(NOTE: R-Theta scan may be implemented in either a circular or a spiral pattern.)

APPENDIX 1

NOTE: The material in this appendix is an official part of SEMI M40 and was approved by full letter ballot procedures on December 15, 1999 by the North American Regional Standards Committee.

A1-1 Examples of Roughness Measurement Specifications and Related Output

The construction of typical measurement specifications and reported results are shown below. These could be the input to and output from a suitably equipped metrology tool, or directions for manual execution and reporting of the measurement and calculation sequence. The elements and codes are listed only in the first example. The quantitative data below is presented for illustration only, it does not represent actual instrument or sample measurements.

1. Mechanical Profiler

   The Mechanical profiler measurement was specified as MPR,5,L,A,A,A,250/10. This corresponds to measuring a 5-point pattern with a local line-scan and with pattern orientation A, and reporting Ra average value over a bandwidth from 250 to 10 μm.

Elements	Profiler, Mechanical; 5-point; line-scan; orient A; Ra; average; 250/10 μm
Codes	MPR 5 L A A A 250/10
Output Example	MPR,5,L,A,A,A,250/10 = 0.53 nm

2. Angle-Resolved Light Scattering

   The Angle-resolved light scattering instrument measurement was specified as ARLS,9,B,P,Q,A,40/2.0. This corresponds to measuring a 9-point pattern with a single spot and with pattern orientation B, reporting rms (Rq) average value over a bandwidth from 40 to 2 μm.

   Output Example   ARLS,9,B,P,Q,A,40/2.0 = 0.15 nm

3. Interference Microscope

   The Interference microscope measurement was specified as IM,5,A,A,T,D,250/10. This corresponds to measuring a 5-point pattern with a local area and with pattern orientation A, reporting peak-to-valley (Rt) standard deviation over a bandwidth from 250 to 10 μm.

   Output Example   IM,5,A,A,T,D,250/10 = 0.05 nm

4. Total Integrated Scattering

   The Total Integrated Scattering system (TIS) measurement was specified as TIS,S,P,A,Q,D,38/0.50. This corresponds to measuring a full FQA/spiral scan with a local spot and with pattern orientation A, reporting rms (Rq) standard deviation over a bandwidth from 38 to 0.5 μm.

   Output Example   TIS,S,P,A,Q,D,38/0.50 = 0.02 nm

5. Optical Profiler

   The Optical Profiler measurement was specified as OPR,9,L,B,A,AD,80/0.50. This corresponds to measuring a 9 point pattern with a local line-scan and with pattern orientation B, reporting Ra average value and standard deviation over a bandwidth from 80 to 0.5 μm.

   Output Example   OPR,9,L,B,A,AD,80/0.50 = 0.17nm (Ra average), 0.02 nm (Ra, standard deviation)

6. AFM

   The AFM measurement was specified as AFM,5,A,A,Z,A,20/0.04. This corresponds to measuring a 5 point pattern with local area and with pattern orientation A, reporting Rz average value over a bandwidth from 20 to 0.040 μm.

   Output Example   AFM,5,A,A,Z,A,20/0.04 = 0.43 nm

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RELATED INFORMATION 1
EXPERIMENTS AND MODELS RELATING TO ROUGHNESS DISTRIBUTION OF SILICON WAFERS

NOTE: This related information is not an official part of SEMI M40 but was approved for publication by full letter ballot procedures.

R1-1 Executive Summary

R1-1.1 Roughness is measured traditionally only on selected spots on a surface and only a few methods, such as light scattering, are practical for a complete surface scan. Therefore a systematic, standardized approach is required for defining the roughness of the entire surface of a silicon wafer. This can be done by defining one or several patterns of measurement spots which represent the entire surface so that the deviation of the average roughness and its standard deviation from the "true" values are small. The task of finding such patterns and verifying that they represent the entire surface was approached in two steps: 1. by investigating various patterns on various wafer surfaces experimentally, and 2. by simulating the roughness map of surfaces and by applying the selected patterns to them.

R1-1.2 Five different site patterns were used for the experimental investigation of silicon wafer surfaces which were final polished, stock removal polished and acid etched. The patterns consist of one, five, nine, ten and thirteen points (thirteen being the sum of a five and nine point pattern), respectively, and the measurements were performed with 10, 30, 80 and 250 µm filter lengths. Therefore 20 average roughness values and corresponding standard deviations were obtained for every wafer investigated, five for any filter length.

R1-1.3 Haze maps of these surfaces either displayed no variation, variations with an approximately rotational symmetry or a gradient across the surface, respectively. The average roughness of the surfaces measured with the various site patterns varied over four and a half orders of magnitude for the set of wafers used and the filter settings selected. The corresponding standard deviations were found to be <10% of the average roughness with the exception of four 200 mm final polished wafers where standard deviations up to 50-60% occurred. The 5-, 9- and 10-point site patterns were compared with respect to the average roughness and the corresponding standard deviation for every wafer. The variation (standard deviation) of the average roughness and the standard deviations as measured were found to be smaller than or approximately 10% in any case when normalized to the total average roughness of the corresponding wafer (average over all points of all patterns for a wafer).

R1-1.4 Roughness maps were generated for the simulation according to three different models: maps with a roughness pattern with rotational symmetry, with a linear gradient and with mirror symmetry. Two maps with a pixel size of 1 mm^2 were generated for each surface to take into account any anisotropy of the roughness, and center roughness and edge roughness, respectively, were used as free parameters for both maps. These parameters were varied between two level (0.1 and 0.2) for both maps resulting in a 2^5 factorial design of "experiment" where the symmetry was considered as 5th parameter. The 1-, 5- and 9-point site patterns were applied to the various maps and the average roughness and standard deviation of roughness were calculated as well as the true values using all points of a map. Strong effects were observed for the 1-point pattern. As expected one point in the wafer center does in general not represent the average roughness of the entire surface reasonably well. The 5-point measurement provides the correct average ± 6%, the 9-point measurement is ± 2.5%. Similarly, the 5-point standard deviation is correct ± 1.6% and the 9-point one is ± 1%. Second order effects were found to be smaller than the main effects. Therefore it is concluded that the suggested five and nine point measurement patterns provide a good estimate of the roughness of an entire surface and its variations for reasonably homogeneous Si wafer surfaces.

R1-2 Introduction

R1-2.1 Roughness measurement of surfaces is performed with a variety of techniques, the most common ones being mechanical or optical profiling in real space or light scattering in reciprocal space (1,2,3). The numerical result of a roughness measurement process depends significantly on several parameters such as spatial bandwidth of the response function of the tool used including filtering, scan length, probe diameter, scanning speed etc. These parameters are not independent of each other and have been standardized only for mechanical profilers (e.g.4,5). The roughness values reported by different types of tools usually do not agree but they correlate provided their parameters were set up not too differently (6). The standardized roughness metrics such as average roughness R_a or root-mean-square roughness R_q refer mainly to line scans as performed by profiling techniques (e.g. 7). Area scans performed by profiling tools by aligning a series of line scans are usually very slow. Scanning the entire surface of a Si wafer with a profiler therefore

would consume many hours, in the case of AFM (Atomic Force Microscope) many years.

R1-2.2   Techniques based on light scattering are capable of scanning the entire wafer surface quite rapidly, in about 1-2 min.   Their response function, however, has a limited spatial bandwidth ranging approximately from 0.5 to 40 µm.   Standards for light scattering measurements are now emerging (8,9).

R1-2.3   The obvious solution for obtaining a standardized roughness value of an entire surface is a) to define a pattern of sites where one- or two-dimensional scans are performed and b) to report the significant parameters along with the measurement (roughness) result.   The second task can be solved theoretically by collecting the important parameters and by designing an appropriate abbreviation code.   The first task requires experiments to collect data about the variation of roughness across a typical, real wafer surface and numerical simulations to find a set of sites the roughness of which agrees sufficiently well with the roughness of the entire surface.

R1-2.4   This appendix reports the results of corresponding roughness measurements as well as of a numerical simulation using a virtual design-of-experiment (DOX).

R1-3 Roughness Definitions

R1-3.1   A variety of definitions for roughness have been standardized by national and international institutions in the US, Japan and Europe. Corresponding standards are listed in section 5 of the main document and some selected ones again in reference 7. Most widely used are average roughness R_a and root-mean-square roughness R_q. Both refer to the average deviation of a profile from a reference line.

R1-4 Roughness Measurements
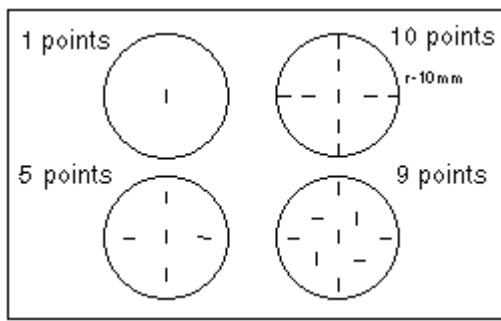
R1-4.1 *Experimental Details*

R1-4.1.1   Four groups of four wafers each were investigated to collect data about the variation of roughness across the wafer surface. The wafers were selected to represent different process steps and polishing techniques:

a)   final polished wafers, 150 mm, #1-4
b)   final polished wafers, 200 mm, #4-8
c)   pre-polished wafers, 200 mm, #9-12
d)   acid-etched wafers, 200 mm, #13-16.

R1-4.1.2 The wafers were characterized for haze with an SSIS (Censor ANS-100) and the roughness measurements were performed with an optical non-contact profiler (Chapman MP-2000+). The roughness data were taken by performing scans of length 3 mm and were evaluated using filters of 19, 30, 80 and 250 µm, respectively.   The scans were performed at a variety of sites according to four different site patterns as displayed in Figure R1-1 where also the directions of the various scans are indicated:

i)   center of wafer, one scan
ii)   five points, center of wafer plus four points at 2/3 of radius
iii) nine points, center of wafer plus four points at 2/5 of radius plus four points at 4/5 of radius
iv)   ten points, two in the center of wafer plus four points at ½ of radius and four points at radius minus 10 mm.
v)   thirteen points, combination of pattern ii and iii.

Figure R1-1
Site Patterns

R1-4.2 *Results*

R1-4.2.1   The average values of each site pattern is reported here together with the corresponding standard deviation. The average might be considered as the characteristic roughness of the entire surface whereas the standard deviation is a measure of roughness inhomogeneity. The results are summarized in Tables R1-1 and R1-3. These averages and standard deviations are called site average or site standard deviation for the respective site patterns for each wafer and each filter length applied.

R1-4.2.2   The variation in average values obtained with the different site patterns employed can be obtained by calculating 1) the average ofthe individual site averages and the standard deviation for each wafer and 2) the average of the individual site standard deviations and the corresponding standard deviation. These averages are called wafer average and wafer standard deviation, respectively.   The corresponding standard deviations are called standard deviation of wafer average and standard deviation of wafer standard deviation. They are reported in Table R1-3 and Table R1-5 and in Figure R1-2 and Figure R1-3.

R1-4.2.3   The site average roughness values found range from 0.09 A for final polished wafers to 350 A for acid etched wafers for a 10 μm filter and from about 5 A to 2200 A, respectively, for a 250 μm filter. In total, a range of about four and a half orders of magnitude is covered. The site standard deviation for the different site patterns is around 10-15% of the average roughness of the wafer indicating a homogeneous roughness of the wafer surfaces. The difference between the site patterns ii, iii, iv and v for the relative site standard deviation is small, typically about 1-2 %. Exceptions are for the 200 mm final polished wafers with standard deviations of about 50-60% for the 10 μm filter.

R1-4.2.4 According to the values in Tables R1-3 & R1-5, the standard deviations of the wafer averages are less than 10 % in any case (Figure RI). The standard deviations of the various site standard deviations (Figure A3) are also smaller than or about 10 % with respect to the wafer average. This indicates that in the present case any site pattern —with the exception of the single site measurement at the wafer center—represents the "true" mean roughness of the entire surface and its standard deviation reasonably well.

Table R1-1 Results of Roughness Measurements, 10 and 30 μm Filters

	Wfr #	Average/Standard Deviation, A 10 μm Filter					Average/Standard Deviation, A 30 μm Filter				
Site pattern		i	ii	iii	iv	v	i	ii	iii	iv	v
Final polished, 150 mm	1	0.08	0.086/ 0.005	0.089/ 0.009	0.090/ 0.007	0.086/ 0.008	0.36	0.390/ 0.020	0.396/ 0.030	0.389/ 0.028	0.396/ 0.025
	2	0.09	0.090/ 0.007	0.094/ 0.010	0.090/ 0.005	0.093/ 0.009	0.43	0.408/ 0.037	0.413/ 0.035	0.410/ 0.028	0.410/ 0.035
	3	0.09	0.090/ 0.000	0.092/ 0.008	0.090/ 0.005	0.092/ 0.007	0.41	0.404/ 0.018	0.401/ 0.030	0.387/ 0.022	0.402/ 0.027
	4	0.09	0.090/ 0.000	0.097/ 0.010	0.090/ 0.004	0.095/ 0.009	0.40	0.402/ 0.015	0.420/ 0.025	0.414/ 0.016	0.415/ 0.024
Final polished, 200 mm	5	0.23	0.14/ 0.05	0.15/ 0.06	0.15/ 0.06	0.14/ 0.06	1.17	0.746/ 0.35	0.827/ 0.33	0.795/ 0.32	0.769/ 0.29
	6	0.26	0.13/ 0.07	0.15/ 0.06	0.15/ 0.06	0.14/ 0.06	1.36	0.746/ 0.35	0.846/ 0.36	0.801/ 0.33	0.768/ 0.32
	7	0.10	0.13/ 0.03	0.12/ 0.04	0.13/ 0.06	0.13/ 0.04	0.53	0.736/ 0.23	0.699/ 0.23	0.752/ 0.32	0.726/ 0.22
	8	0.09	0.12/ 0.02	0.11/ 0.02	0.12/ 0.03	0.12/ 0.02	0.50	0.648/ 0.15	0.626/ 0.14	0.636/ 0.18	0.644/ 0.13
Pre-polished, 200 mm	9	2.64	2.41/ 0.25	2.45/ 0.32	2.39/ 0.39	2.42/ 0.29	7.21	6.398/ 0.77	6.538/ 0.83	6.387/ 0.91	6.432/ 0.78
	10	2.64	2.56/ 0.36	2.69/ 0.19	2.37/ 0.41	2.64/ 0.27	6.84	6.760/ 0.95	7.147/ 0.50	6.419/ 1.00	7.022/ 0.27
	11	2.75	2.77/ 0.07	2.78/ 0.10	2.46/ 0.45	2.78/ 0.09	7.30	7.310 0.19	7.302/ 0.30	6.545/ 1.05	7.305/ 0.27

	12	2.76	2.48/0.32	2.50/0.32	2.43/0.42	2.47/0.31	7.30	6.566/0.91	6.521/0.75	6.146/1.05	6.478/0.77
Acid etched, 200 mm	13	327.2	332.0/6.73	335.0/16.25	352.6/12.37	334.5/13.76	826.2	873.5/43.16	869.5/50.22	906.5/28.56	874.4/46.13
	14	337.9	344.9/18.74	344.7/9.19	353.1/12.11	345.3/13.00	876.8	899.9/60.49	915.5/24.15	930.0/43.19	912.5/39.69
	15	339.5	340.58/13.42	335.2/6.07	363.4/7.22	337.0/9.58	887.7	913.7/68.10	879.1/24.64	966.1/30.75	891.7/47.65
	16	337.6	331.8/8.84	337.6/13.37	348.7/9.26	335.4/12.41	922.8	886.1/37.57	896.0/38.04	921.8/27.16	890.2/37.14

Table R1-2 Results of Roughness Measurements, 80 and 250 µm Filters

|	Wfr. #	Average/Standard Deviation, A 80 µm filter					Average/Standard Deviation, A 250 µm filter				
Site pattern		i	ii	iii	iv	v	i	ii	iii	iv	v
Final polished, 150 mm	1	1.33	1.426/0.075	1.416/0.134	1.434/0.108	1.426/0.115	4.34	4.678/0.484	4.836/0.632	4.786/0.435	4.813/0.578
	2	1.57	1.470/0.112	1.482/0.147	1.444/0.112	1.471/0.133	5.34	4.944/0.312	5.441/0.613	4.592/0.434	5.258/0.591
	3	1.49	1.460/0.025	1.472/0.131	1.357/0.080	1.466/0.108	4.81	4.788/0.403	5.164/0.823	4.353/0.507	5.047/0.735
	4	1.33	1.394/0.089	1.446/0.115	1.461/0.069	1.435/0.106	4.09	4.528/0.619	4.814/0.584	4.934/0.503	4.760/0.585
Final polished, 200 mm	5	3.29	2.582/0.45	2.638/0.71	2.531/0.65	2.566/0.60	7.33	6.676/0.45	6.627/0.99	6.560/0.95	6.592/0.82
	6	3.65	2.560/0.65	2.724/0.79	2.510/0.67	2.590/0.69	7.49	6.804/0.57	6.834/0.93	6.443/0.92	6.772/0.80
	7	2.02	2.682/0.72	2.493/0.56	2.641/0.81	2.602/0.61	5.45	6.914/1.37	6.601/0.81	7.057/1.47	6.810/0.97
	8	1.97	2.400/0.45	2.317/0.40	2.279/0.54	2.375/0.40	5.56	6.268/0.59	6.342/0.69	6.232/1.08	6.374/0.62
Pre-polished, 200 mm	9	11.12	9.94/1.06	10.19/1.09	10.10/1.27	10.02/1.04	15.15	14.25/1.31	14.50/1.18	14.47/	14.36/1.22
	10	10.13	10.54/1.34	11.05/0.78	10.27/1.35	10.92/1.03	14.40	15.44/2.01	15.58/0.77	14.59/1.88	15.62/1.28
	11	11.29	11.35/0.31	11.26/0.45	10.13/1.23	11.29/0.41	15.75	16.56/0.59	16.27/0.81	14.83/1.26	16.42/0.74
	12	10.60	10.11/1.10	9.86/0.95	9.92/1.12	9.90/0.99	14.42	14.33/1.31	14.10/1.14	14.41/1.26	14.17/1.21
Acid etched, 200 mm	13	1257.0	1404/140.8	1391/123.44	1439/88.10	1406/122.83	1789.6	2127/331.59	2118/295.83	2185/270.70	2147/291.78
	14	1421.9	1460/109.9	1514/53.27	1497/95.92	1501/78.94	2154.6	2256/154.21	2366/222.41	2322/216.72	2349/203.72
	15	1374.7	1500/199.2	1396/94.33	1549/95.25	1438/147.56	1970.4	2350/508.52	2071/257.41	2348/198.70	2186/384.36
	16	1478.4	1421/109.9	1450/108.89	1477/104.51	1437/109.71	2006.4	2075/186.85	2219/297.40	2264/252.44	2180/271.75

R1-4.2.5 The five-point site pattern appears to represent the average surface reasonably well for wafers where the roughness does not vary more than by a factor of about two across the entire surface. Patterns with a higher number of sites are recommended for problematic surfaces.

Table R1-3 Average Over Site Patterns ii, iii and iv (wafer average) and Corresponding Relative Standard Deviation for Each Wafer

|	Wfr #	Avg. of Averages, A				Relative Std. Dev. of Averages, %			
Filter		10 μm	30 μm	80 μm	250 μm	10 μm	30 μm	80 μm	250 μm
Final polished, 150 mm	1	0.088	0.392	1.425	4.767	2.34	0.90	0.65	1.69
	2	0.091	0.410	1.465	4.992	2.80	0.66	1.33	8.55
	3	0.091	0.397	1.430	4.768	1.41	2.29	4.43	8.52
	4	0.092	0.412	1.434	4.759	4.17	2.22	2.45	4.38
Final polished, 200 mm	5	0.146	0.789	2.584	6.606	6.09	5.15	2.07	1.24
	6	0.145	0.798	2.598	6.694	7.79	6.25	4.32	3.25
	7	0.128	0.729	2.605	6.857	4.16	3.74	3.81	3.40
	8	0.116	0.637	2.332	6.281	3.35	1.76	2.66	0.89
Pre-polished, 200 mm	9	2.418	6.441	10.08	14.41	1.35	1.31	1.23	0.96
	10	2.541	6.775	10.59	15.21	6.30	5.37	4.18	3.54
	11	2.669	7.052	10.91	15.89	6.89	6.23	6.20	5.83
	12	2.469	6.411	9.96	14.28	1.54	3.60	1.30	1.13
Acid etched, 200 mm	13	339.87	883.15	1411.66	2143.24	3.27	2.30	1.78	1.68
	14	347.57	915.12	1490.70	2314.67	1.37	1.64	1.87	2.40
	15	346.41	919.62	1481.90	2256.45	4.32	4.77	5.29	7.13
	16	339.38	901.30	1449.77	2185.77	2.52	2.04	1.93	4.52

Table R1-4 Average Over the Standard Deviations of the Site Patterns ii, iii and iv (wafer standard deviation) and the Corresponding Relative Standard Deviations for Each Wafer Normalized to the Wafer Average

	Wfr #	Avg. of Std. Deviations, A				Relative Std. Dev. of Std. Devs, %			
Filter		10 μm	30 μm	80 μm	250 μm	10 μm	30 μm	80 μm	250 μm
Final polished, 150 mm	1	0.007	0.026	0.106	0.517	2.2	1.4	2.1	2.2
	2	0.007	0.033	0.123	0.453	2.8	1.2	1.4	3.0
	3	0.004	0.023	0.079	0.578	4.6	1.6	3.7	4.6
	4	0.005	0.019	0.091	0.569	5.5	1.4	1.6	1.3
Final polished, 200 mm	5	0.059	0.302	0.603	0.797	3.8	6.2	5.3	4.6
	6	0.065	0.347	0.703	0.807	4.0	1.8	2.9	3.1
	7	0.042	0.261	0.699	1.219	10.4	7.3	4.9	5.2
	8	0.025	0.156	0.463	0.789	4.7	4.0	3.1	4.1
Pre-polished, 200 mm	9	0.320	0.834	1.14	1.397	3.1	1.1	1.1	1.8
	10	0.321	0.816	1.17	1.553	4.4	4.0	3.2	4.5
	11	0.205	0.516	0.663	0.889	7.9	6.6	4.5	2.2
	12	0.353	0.901	1.06	1.234	2.2	2.3	0.9	0.6
Acid etched, 200 mm	13	11.78	40.65	117.5	299.4	1.4	1.3	1.9	1.4
	14	13.35	42.61	86.4	197.8	1.4	2.0	2.0	1.6
	15	8.90	41.16	129.6	321.5	1.1	2.6	4.1	7.3
	16	10.49	34.25	107.8	245.6	0.7	0.7	0.2	2.5
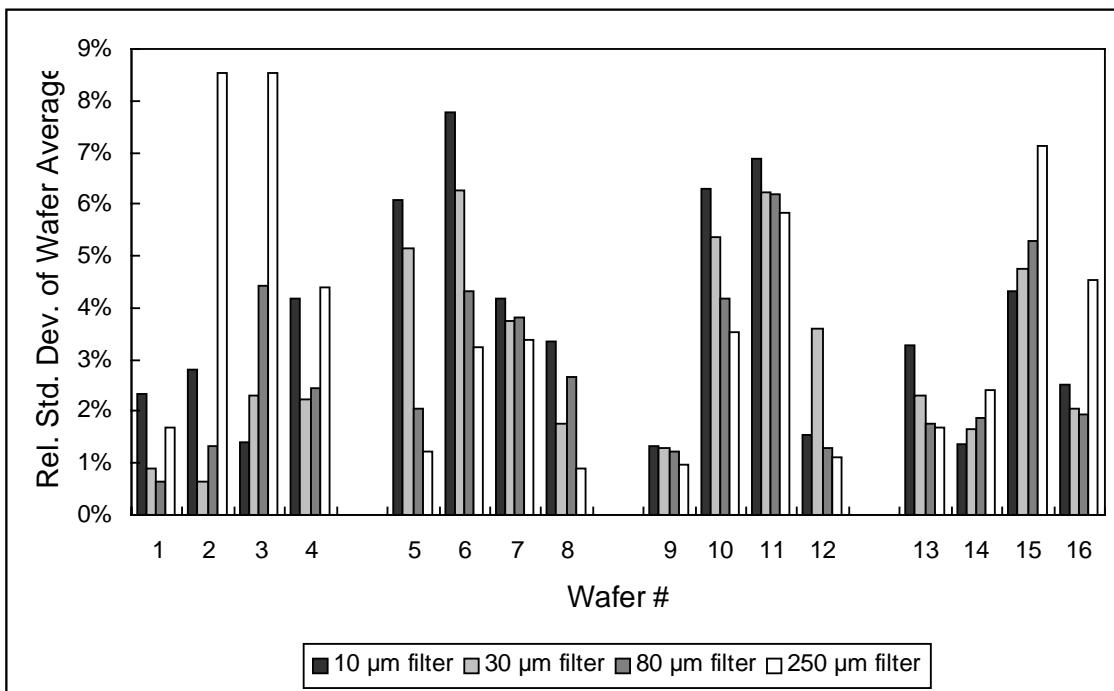
Figure R1-2
The Relative Standard Deviations of the Wafer Averages Normalized to the Wafer Averages for Site Patterns
ii, iii and iv, for All Wafers Investigated and for Filter Lengths of 10, 30, 80 and 250 µm
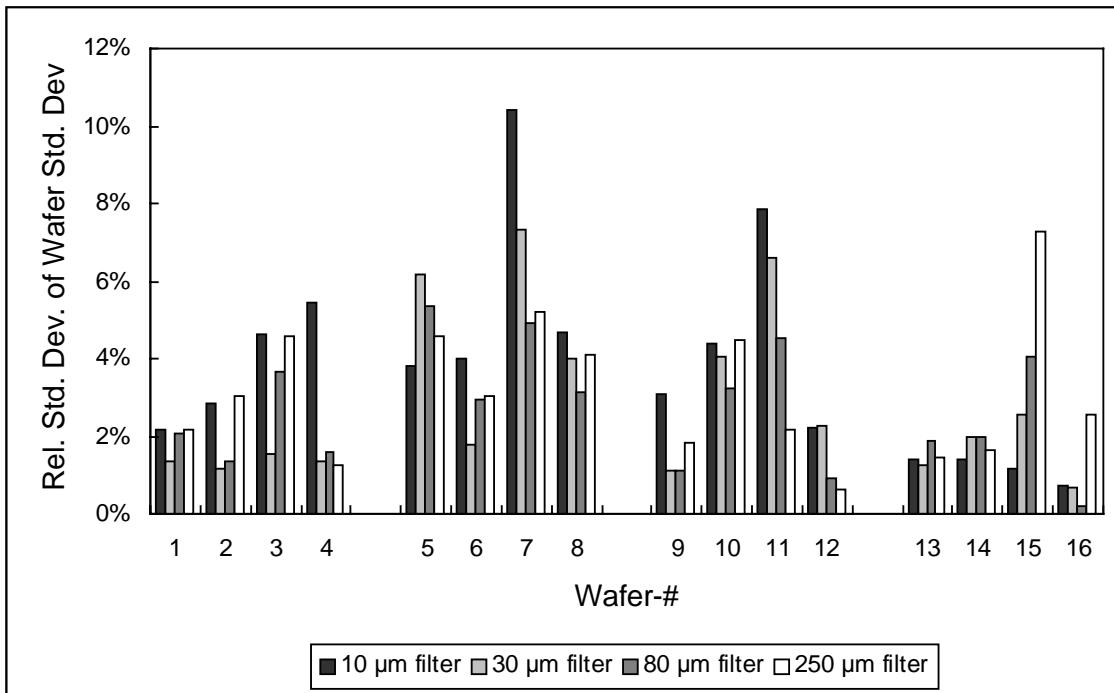
Figure R1-3
The Relative Wafer Standard Deviations of the Wafer Standard Deviations Normalized to the Wafer
Averages for the Site Patterns ii, iii and iv, for All Wafers and for Filter Lengths of 10, 30, 80 and 250 µm

R1-5 Models of Roughness Distribution and their Evaluation with a Virtual Experiment of Factorial Design

R1-5.1 *Goal of the Simulation*

R1-5.1.1   Roughness is measured on the entire wafer surface only in rare cases. Therefore approximations have to be found which represent the roughness of an entire wafer surface with appropriate accuracy. Three discrete site patterns were defined in section 9 of SEMI M40, which are thought to provide such approximations. Performing many measurements using these site patterns is one approach to assess these site patterns with respect to their validity.   Another approach is to simulate roughness variations across a wafer surface and apply the site patterns to them. This allows easy and systematic variations of the surface roughness properties and maps. The assessment of the results again has to be performed in a systematic way. An appropriate tool for doing this is to utilize a factorial design for the variables in the various surface models used.   The goal of finding a site pattern which represents the entire surface is considered to be achieved when the variations of the variables of the different surface models result in a non-significant effect in the evaluation of the factorial design.

R1-5.2 *Simulation of Roughness Maps*

R1-5.2.1 The measurement results that are reported in section 3 provide some insight into the variation of roughness that occurs across actual, typical wafer surfaces.   The variation observed on the different wafers is related to the specific polishing technique (wax mount polishing, wax free polishing) and to the polishing parameters used. Examination of haze maps reveals three basic patterns of variation:

a) a circularly symmetric haze variation
b) a haze variation approximately symmetric with respect to a diameter across the wafer
c) a linear gradient of haze from one wafer edge to the opposite one.

R1-5.2.2 The following relations were used to simulate the variation of roughness according to these three basic models a)-c) with e and c being the roughness values near the edge and at the center of a wafer, respectively:

model a: a parabolic relation
$$z(x,y) = (x^2+y^2)\,(e\text{-}c)/r^2 + c \qquad (equ.\ 1)$$

model b: a semi-cylindrical relation
$$z(x,y) = (r^2-(y \cos a - x \sin a)^2)^{1/2}\,(e\text{-}c)/r + e$$
$$(equ.\ 2)$$

model c: a linear gradient
$$z(x,y) = (y \cos a - x \sin a)\,(e\text{-}c)/r + c \qquad (equ.\ 3)$$

with wafer radius r and angle α corresponding to the angle between the symmetry plane and the x-direction (model b) or the direction of the gradient and the y-direction (model c).

R1-5.2.3   Using equations 1-3, roughness maps of wafer surfaces can be generated with a roughness value assigned to each site. This was performed by using MathCad® software and by assuming 200 mm wafers, the area of each being partitioned into sites of 1 mm^2 size.

R1-5.2.4   Roughness is not necessarily an isotropic property of a surface. Different roughness values are in general obtained when e.g. two scans are performed at the same spot on a wafer surface but in perpendicular directions.   Therefore two maps representing the roughness anisotropy were generated in each case by assuming two sets of the parameters e and c – e1, c1, e2, and c2, per wafer surface.

R1-5.3 *Factorial Design*

R1-5.3.1 A factorial design at two levels was selected in order to compare the various wafer maps generated (10). The parameters ei and ci (i = 1,2) were used as variables and were varied between two levels, 0.1 and 0.2, in arbitrary units. In addition the patterns (models a – c) were also used as a variable and the values –1 and +1 were correspondingly assigned resulting in a 2^5 factorial design. The complete set of parameters used is displayed in Table R1-5.

Table R1-5 Complete Set of Parameters Used in the 2^5 Factorial Design

Variable	e1	c1	e2	C2	Model
High level	0.2	0.2	0.2	0.2	+1 (model b or c)
Low level	0.1	0.1	0.1	0.1	-1 (model a)

Table R1-6 Results of Roughness Simulation for Models a (variable = -1) and b (variable = 1)

Variable Set #	c1	e1	c2	e2	Sym.	avg1	avg5	avg9	avgtrue	stdabw5	stdabw9	stdabwtrue
1	0.1	0.1	0.1	0.1	-1	0.1	0.1	0.1	0.1	0	0	0
2	0.2	0.1	0.1	0.1	-1	0.2	0.143	0.127	0.125	0.038	0.031	0.014
3	0.1	0.2	0.1	0.1	-1	0.1	0.117	0.129	0.125	0.021	0.032	0.014
4	0.2	0.2	0.1	0.1	-1	0.2	0.16	0.156	0.15	0.049	0.05	0
5	0.1	0.1	0.2	0.1	-1	0.1	0.123	0.116	0.125	0.028	0.018	0.014
6	0.2	0.1	0.2	0.1	-1	0.2	0.165	0.143	0.15	0.017	0.02	0.029
7	0.1	0.2	0.2	0.1	-1	0.1	0.14	0.144	0.15	0.021	0.021	0
8	0.2	0.2	0.2	0.1	-1	0.2	0.183	0.171	0.175	0.021	0.032	0.014
9	0.1	0.1	0.1	0.2	-1	0.1	0.117	0.129	0.125	0.021	0.032	0.014
10	0.2	0.1	0.1	0.2	-1	0.2	0.16	0.156	0.15	0.021	0.021	0
11	0.1	0.2	0.1	0.2	-1	0.1	0.135	0.157	0.15	0.017	0.02	0.029
12	0.2	0.2	0.1	0.2	-1	0.2	0.177	0.184	0.175	0.028	0.018	0.014
13	0.1	0.1	0.2	0.2	-1	0.1	0.14	0.144	0.15	0.049	0.05	0
14	0.2	0.1	0.2	0.2	-1	0.2	0.183	0.171	0.175	0.021	0.032	0.014
15	0.1	0.2	0.2	0.2	-1	0.1	0.157	0.173	0.175	0.038	0.031	0.014
16	0.2	0.2	0.2	0.2	-1	0.2	0.2	0.2	0.2	0	0	0
17	0.1	0.1	0.1	0.1	1	0.1	0.1	0.1	0.1	0	0	0
18	0.2	0.1	0.1	0.1	1	0.2	0.158	0.153	0.142	0.047	0.048	0.009
19	0.1	0.2	0.1	0.1	1	0.1	0.102	0.102	0.108	0.003	0.003	0.009
20	0.2	0.2	0.1	0.1	1	0.2	0.16	0.156	0.15	0.049	0.05	0
21	0.1	0.1	0.2	0.1	1	0.1	0.133	0.13	0.142	0.04	0.034	0.009
22	0.2	0.1	0.2	0.1	1	0.2	0.191	0.183	0.185	0.007	0.015	0.017
23	0.1	0.2	0.2	0.1	1	0.1	0.135	0.132	0.15	0.038	0.032	0
24	0.2	0.2	0.2	0.1	1	0.2	0.193	0.185	0.192	0.009	0.016	0.009
25	0.1	0.1	0.1	0.2	1	0.1	0.107	0.114	0.108	0.009	0.016	0.009
26	0.2	0.1	0.1	0.2	1	0.2	0.165	0.168	0.15	0.038	0.032	0
27	0.1	0.2	0.1	0.2	1	0.1	0.109	0.117	0.115	0.007	0.015	0.017
28	0.2	0.2	0.1	0.2	1	0.2	0.167	0.17	0.158	0.04	0.034	0.009
29	0.1	0.1	0.2	0.2	1	0.1	0.14	0.144	0.15	0.049	0.05	0
30	0.2	0.1	0.2	0.2	1	0.2	0.198	0.198	0.192	0.003	0.003	0.009
31	0.1	0.2	0.2	0.2	1	0.1	0.142	0.147	0.158	0.047	0.048	0.009
32	0.2	0.2	0.2	0.2	1	0.2	0.2	0.2	0.2	0	0	0
	Average					0.15	0.15	0.1499	0.15	0.0241	0.0247	0.0066
	Std. Dev.					0.05	0.0335	0.0314	0.0303	0.0198	0.0179	0.0057

Table R1-7 Normalized values of Table R1-6

Variable Set #	ravg1	ravg5	ravg9	rstdabw5	rstdabw9
1	1.0000	1.0000	1.0000	0.0000	0.0000
2	1.6000	1.1440	1.0160	0.1920	0.1360
3	0.8000	0.9360	1.0320	0.0560	0.1440
4	1.3333	1.0667	1.0400	0.3267	0.3333
5	0.8000	0.9840	0.9280	0.1120	0.0320
6	1.3333	1.1000	0.9533	0.0800	0.0600
7	0.6667	0.9333	0.9600	0.1400	0.1400
8	1.1429	1.0457	0.9771	0.0400	0.1029
9	0.8000	0.9360	1.0320	0.0560	0.1440
10	1.3333	1.0667	1.0400	0.1400	0.1400
11	0.6667	0.9000	1.0467	0.0800	0.0600
12	1.1429	1.0114	1.0514	0.0800	0.0229
13	0.6667	0.9333	0.9600	0.3267	0.3333
14	1.1429	1.0457	0.9771	0.0400	0.1029
15	0.5714	0.8971	0.9886	0.1371	0.0971
16	1.0000	1.0000	1.0000	0.0000	0.0000
17	1.0000	1.0000	1.0000	0.0000	0.0000
18	1.4085	1.1127	1.0775	0.2676	0.2746
19	0.9259	0.9444	0.9444	0.0556	0.0556
20	1.3333	1.0667	1.0400	0.3267	0.3333
21	0.7042	0.9366	0.9155	0.2183	0.1761
22	1.0811	1.0324	0.9892	0.0541	0.0108
23	0.6667	0.9000	0.8800	0.2533	0.2133
24	1.0417	1.0052	0.9635	0.0000	0.0365
25	0.9259	0.9907	1.0556	0.0000	0.0648
26	1.3333	1.1000	1.1200	0.2533	0.2133
27	0.8696	0.9478	1.0174	0.0870	0.0174
28	1.2658	1.0570	1.0759	0.1962	0.1582
29	0.6667	0.9333	0.9600	0.3267	0.3333
30	1.0417	1.0313	1.0313	0.0313	0.0313
31	0.6329	0.8987	0.9304	0.2405	0.2468
32	1.0000	1.0000	1.0000	0.0000	0.0000
average	0.9968	0.9987	1.0001	0.1287	0.1254
standard deviation	0.2700	0.0682	0.0521	0.1106	0.1080
maximum	1.6000	1.1440	1.1200	0.3267	0.3333
minimum	0.5714	0.8971	0.8800	0.0000	0.0000

R1-5.3.2 Wafer roughness maps with 1 mm^2 pixel size were generated using all possible 32 combinations of the parameters in Table R1-5. Average roughness and standard deviation were calculated by using all pixels of a map (avgtrue, stdabwtrue) as well as by using the three discrete site patterns displayed in Figure 1 of the main part of this document (avg1, avg5, avg9, stdabw5, stdabw9). Corresponding results for comparing models a and b are displayed in Table R1-6.   These values were normalized for further evaluation, the averages with respect to avgtrue (ravgi=avgi/avgtrue, i=1,5,9), the standard deviations with respect to their difference to the "true" value ((rstdabwi=stdabwi.-stdabwtrue) / stdabwtrue, i=5,9) (Table R1-7). Results for comparing models a and c are similar and are not reported here in detail.

R1-5.3.3 The averages for ravg1,5,9 over the various variable sets differ by less than 1% from unity. The corresponding standard deviations decrease from 27% to 5% going from ravg1 to ravg9, respectively, indicating — as one would expect — that ravg9 is a much more precise value for the roughness of the entire surface as compared to ravg1 or ravg5. The relative standard deviations rstdabw5,9 deviate in the average by about 12% from the true value. The corresponding standard deviations differ not much for rstdabw5 and rstdabw9.

R1-5.3.4 More detailed information is obtained when the results are evaluated according to the factorial design used. The 1st to 5th order effects of varying the variables were calculated by applying using a table of contrast coefficients /10/ to the normalized results of the simulation. The 1st order — or main — effects are the difference of the observations for both levels of one parameter and averages over all other observations. They measure the average effect of a variable over all conditions of the other variables. The 2nd order effects are a measure for the interaction of variables and are obtained by calculating one half of the difference of the average effect of variable 1 with variable 2 at level 1 and variable 1 with variable 2 at level 2. 3rd order and higher effects are not considered in the present work. They are assumed to be negligible and are used to calculate the variance of an effect (=square root of the average of the squares of 3rd to 5th order effects).

R1-5.3.5 The result of this evaluation is displayed in Table R1-8 and Table R1-9 for the main (1st order) and 2nd order effects, respectively.

Table R1-8 Average (over all sets of variables) and Main Effects of the Various Variables on the Observables (The variance as calculated from the 2nd to 5th order effects is displayed in the last column.)
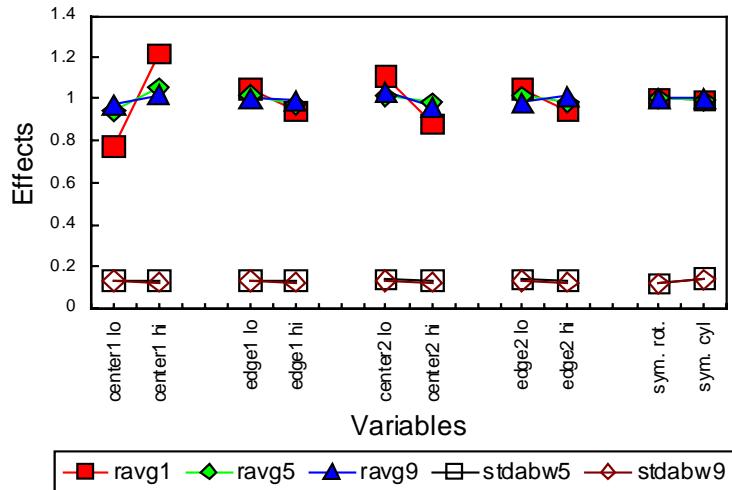
	Average	c1	e1	c2	e2	Sym.	Variance
ravg1	0.9968	0.4482	-0.1111	-0.2237	-0.1111	-0.0064	4.16E-05
ravg5	0.9987	0.1134	-0.0460	-0.0377	-0.0287	-0.0027	3.69E-06
ravg9	1.0001	0.0439	-0.0067	-0.0734	0.0356	-0.0001	4.37E-06
rstdabw5	0.1287	-0.0038	-0.0049	-0.0073	-0.0080	0.0315	3.43E-04
rstdabw9	0.1254	-0.0064	-0.0057	-0.0113	-0.0052	0.0198	4.87E-04

Table R1-9 2nd Order Effects (The variance as calculated from the 2nd to 5th order effects is displayed in the last column.)

	c1/e1	c1/c2	c1/e2	c1/sym	e1/c2	e1/e2	e1/sym	c2/e2	c2/sym	e2/sym	Variance
ravg1	-0.0157	-0.0221	-0.0157	-0.0590	0.0218	0.0160	0.0579	0.0218	-0.0547	0.0579	4.16E-05
ravg5	-0.0015	-0.0079	-0.0040	-0.0067	0.0065	0.0054	0.0064	0.0039	-0.0225	0.0238	3.69E-06
ravg9	-0.0003	0.0023	-0.0057	0.0304	0.0049	-0.0015	-0.0304	-0.0005	-0.0092	0.0119	4.37E-06
rstdabw5	-0.0062	-0.1848	-0.0603	-0.0027	-0.0423	-0.0392	0.0059	0.0335	-0.0005	0.0029	3.43E-04
rstdabw9	0.0080	-0.1471	-0.0722	0.0002	-0.0247	-0.0894	0.0003	0.0518	0.0027	0.0008	4.87E-04

R1-5.3.6 The behavior of the main effects is also illustrated in Figure R1-5, where the variation of ravg1,5,9 and stdabw5,9 are plotted vs. the variables. The clear effect, on ravg1, of varying center1 between 0.1 and 0.2 is easy to understand as ravg1 consists only of one measurement point in the center of the wafer surface. Similar but less pronounced effects are observed for ravg5 and 9. Note that the opposite effect occurs for center 2 as this point is not included in calculating ravg1,5 or 9. Also note that the influence of the variables edge1 or edge2 is much less

pronounced. In any case, the 5-point measurement provides the correct average ± 6%, the 9-point measurement ± 2.5%. In a similar way, the 5-point standard deviation is correct ± 1.6% and the 9-point standard deviation ± 1%.

Figure R1-5
Main Effects of the 2^5 Factorial Design for Models a and b

R1-5.3.7 The significance of numbers given in Table R1-8 and Table R1-9 can be estimated only in relation to the noise or variance of the observables which is also displayed in both tables. The signal-to-noise ratio S/N is obtained by using a logarithmic measure:

$$S/N = 10 \log (\text{effect}^2/\text{variance})$$

R1-5.3.8 The corresponding S/N values for the main and for the second order effects are listed in Table R1-10 and Table R1-11.

R1-5.3.9 A linear signal-to-noise ratio of 3:1 is commonly used to distinguish significant data from insignificant data. This linear ratio corresponds to a S/N of about 10 in the present case of a logarithmic signal-to- noise ration. The S/N ratios > 10 are shaded lightly gray in Table R1-10 and Table R1-11. The variables center1,2 and edge1,2 have a significant effect on the relative averages ravg1,5,9. Mainly the interactions of the model selected with the other variables are significant for the relative averages ravg1,5,9 and the interaction of center1 and center2 for the relative standard deviations rstdabw5,9. The other cases emphasized in Table R1-11 by shading have a S/N ratio only slightly larger than 10.

Table R1-10 S/N Ratios for the Main Effects of Table R1-8

	average	*c1*	*e1*	*c2*	*e2*	*Sym*
ravg1	43.7817	36.8384	24.7251	30.8046	24.7251	-0.0364
ravg5	54.3215	35.4230	27.5959	25.8609	23.4801	2.9416
ravg9	53.5959	26.4387	10.1741	30.9124	24.6260	-26.2612
rstdabw5	16.8383	-13.6750	-11.4959	-8.0646	-7.3246	4.6154
rstdabw9	15.0934	-10.7996	-11.7656	-5.7926	-12.5745	-0.9359

Table R1-11 S/N Ratios for the 2nd Order Effects of Table R1-9

	c1/e1	c1/c2	c1/e2	c1/sym	e1/c2	e1/e2	e1/sym	c2/e2	c2/sym	e2/sym
ravg1	7.7045	10.7110	7.7045	19.2237	10.5897	7.8732	19.0682	10.5897	18.5684	19.0682
ravg5	-2.3106	12.2743	6.3820	10.8291	10.5529	9.0162	10.4414	6.2417	21.3820	21.8517
ravg9	-17.0034	0.7278	8.7438	23.2512	7.3954	-3.1738	23.2558	-11.9623	12.8618	15.1361
Rstdabw5	-9.5587	19.9853	10.2575	-16.7484	7.1802	6.5178	-9.8910	5.1594	-32.1153	-16.1308
Rstdabw9	-8.8505	16.4782	10.2932	-40.5530	0.9730	12.1486	-37.1733	7.4191	-18.3336	-28.6846

R1-5.3.10 The interactions are discussed for two examples, ravg9 and rstdabw5 (Table R1-12). Going from sym lo (model a, parabolic symmetry) to sym hi (model b, cylindrical symmetry) and keeping c1 fixed at the lo level decreases ravg9 from 0.993 to 0.963 whereas it increases from 1.007 to 1.037 when c1 is kept fixed at the lo level. This change in opposite directions indicate an interaction between c1 and sym. c1 and c2 interact in a similar way with respect to rstdabw5.

Table R1-12 2nd Order Effects or Interactions

C1 lo/sym hi	0.963		1.037	c1 hi/sym hi
		ravg9		
C1 lo/sym lo	0.993		1.007	c1 hi/sym lo
c1 lo/c2 hi	0.219		0.031	c1 hi/c2 hi
		stdabw5		
c1 lo/c2 lo	0.132		0.223	c1 hi/c2 lo

R1-5.4 *Summary and Conclusions*

R1-5.4.1 Three different models for surface roughness distribution (roughness maps) were investigated and three different site patterns for measuring the roughness were applied to them. The parameters of the models – roughness in the center and near the edge of the wafer – were used as variables in a factorial design and varied between two levels. Average roughness and the corresponding standard deviations calculated for the site patterns were compared with the "true" values obtained by evaluating all points of the roughness map.

R1-5.4.2 The patterns where the roughness is measured at five or nine points exhibit a standard deviation of 7 and 5 %, respectively, from the true average value for all possible combinations of the variables. The average of the standard deviations of the roughness distribution of the single variable sets differs by about 13% from the true value for the five- as well as nine-point site pattern. A standard deviation of the standard deviations of about 11% is obtained by averaging over the 32 different variables sets.

R1-5.4.3 The evaluation of the factorial design outlines that the variation of the variables c1, c2, e1, and e2 has a significant effect – with respect to "noise" – on the average roughness values but not on the corresponding standard deviations. Varying the surface model does not significantly affect the averages and standard deviations. Some second order effects or interactions are also significant but less pronounced than the main effects. A pronounced interaction of the variables c1 and c2 occurs e.g. for the five point standard deviation rstdabw5. This interaction could be reduced by introducing an additional site for measuring roughness in the center of the wafer with a direction perpendicular to the present one.

R1-5.4.4 The goal of finding a site pattern which results only in non-significant effects is not completely achieved by the five and nine point patterns utilized in the present work. However, they allow to measure the average roughness of wide variety of surface roughness distributions with a one sigma deviation of 5-7 %, or a three sigma deviation of 15-21 %. These values are certainly more than sufficient for present wafer surfaces.

R1-6 Related Documents

ASTM E 1392 — *Practice for Angle Resolved Optical Scattering Measurements on Specular or Diffuse Surfaces*

ASTM F 1048 — T*est Method for Measuring the Effective Surface Roughness of Optical Components by Total Integrated Scattering*

J.M. Bennett, L. Mattson, *Introduction to Surface Roughness and Scattering*, Optical Society of America, Washington, D.C., 1989

G.E.P. Box, W.G. Hunter, J.S. Hunter, *Statistics for Experiments, An Introduction to Design, Data Analysis, and Model Building*, John Wiley, N.Y.

ISO 1879 — *Instruments for the measurement of surface roughness by the profile method -- Vocabulary*

ISO 3274 — *Instruments for the measurement of surface roughness by the profile method – Contact (stylus) instruments of consecutive profile transformation – Contact profile meters, system M*

ISO 4287/1 — *Surface roughness – Terminology – Part 1: Surface and its parameters*

J.A. Ogilvy, *Theory of Wave Scattering from Random Rough Surfaces*, IOP Publishing, Bristol, 1991

J.C. Stover, *Optical Scattering, Measurement and Analysis*, Second Edition, McGraw-Hill, Inc., N.Y. 1995

P. Wagner, H.A. Gerber, in *Particles, Haze and Microroughness on Silicon Wafers*, SEMICON Europe 1995, W. Baylies, P. Wagner, Eds.

SEMI M40-0200 © SEMI 2000

SEMI M41-1101
SPECIFICATION OF SILICON-ON-INSULATOR (SOI) FOR POWER DEVICE/ICs

1 Purpose

1.1 This specification covers requirements for silicon-on-insulator (SOI) for semiconductor power-device/IC manufacture. By defining inspection procedures and acceptance criteria, both users and suppliers may define product characteristics and quality requirements.

2 Scope

2.1 This specification provides requirements of SOI wafers, which are used for power devices/ICs of specific voltage applications. The voltage ranges cover low voltage (40–60V), medium voltage (150–250V) and high voltage (500–600V). The specification covers physical, electrical, and surface parameters pertinent to bonded wafers.

2.2 Included in this document is a list of goals for inspection of these wafers which need to be negotiated between the users and suppliers of bonded wafers.

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

3 Referenced Standards

3.1 *SEMI Standards*

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

SEMI M2 — Specifications for Silicon Epitaxial Wafers

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

SEMI M34 — Guide for Specifying SIMOX Wafers

3.2 *ASTM Standards*[1]

F26 — Standard Test Methods for Determining the Orientation of a Semiconductive Single Crystal

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[1] American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, USA. Telephone: 610.832.9585, Fax: 610.832.9555. Website: www.astm.org

F42 — Standard Test Methods for Conductivity Type of Extrinsic Semiconducting Materials

F43 — Standard Test Methods for Resistivity of Semiconductor Materials

F81 — Standard Test Method for Measuring Radial Resistivity Variation on Silicon Wafers

F84 — Standard Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe

F110 — Standard Test Method for Thickness of Epitaxial or Diffused Layers in Silicon by the Angle Lapping and Staining Technique

F154 — Standard Practices and Nomenclature for Identification of Structures and Contaminants Seen on Specular Silicon Surfaces

F399 — Standard Test Method for Thickness of Heteroepitaxial or Polysilicon Layers

F523 — Standard Practice for Unaided Visual Inspection of Polished Silicon Wafer Surfaces

F533 — Standard Test Method for Thickness and Thickness Variation of Silicon Wafers

F576 — Standard Test Method for Measurement of Insulator Thickness and Refractive Index on Silicon Substrates by Ellipsometry

F613 — Standard Test Method for Measuring Diameter of Semiconductor Wafers

F671 — Standard Test Method for Measuring Flat Length on Wafers of Silicon and Other Electronic Materials

F847 — Standard Test Methods for Measuring Crystallographic Orientation of Flats on Single Crystal Silicon Wafers by X-Ray Techniques

F928 — Standard Test Methods for Edge Contour of Circular Semiconductor Wafers and Rigid Disk Substrates

F1152 — Standard Test Method for Dimensions of Notches on Silicon Wafers

F1153 — Standard Test Method for Characterization of Metal-Oxide-Silicon (MOS) Structures by Capacitance-Voltage Measurements

F1188 — Standard Test Method for Interstitial Atomic Oxygen Content of Silicon by Infrared Absorption

F1241 — Standard Terminology of Silicon Technology

F1390 — Standard Test Method for Measuring Warp on Silicon Wafers by Automated Noncontact Scanning

F1391 — Standard Test Method for Substitutional Atomic Carbon Content of Silicon by Infrared Absorption

F1526 — Standard Test Method for Measuring Surface Metal Contamination on Silicon Wafers by Total Reflection X-Ray Fluorescence Spectroscopy

F1527 — Standard Guide for Application of Silicon Standard Reference Materials and Reference Wafers for Calibration and Control of Instruments for Measuring Resisitivity of Silicon

F1530 — Standard Test Method for Measuring Flatness, Thickness, and Thickness Variation on Silicon Wafers by Automated Noncontact Scanning

F1535 — Standard Test Method for Carrier Recombination Lifetime in Silicon Wafers by Noncontact Measurement of Photoconductivity Decay by Microwave Reflectance

F1617 — Standard Test Method for Measuring Surface Sodium, Aluminum, Potassium, and Iron on Silicon and EPI Substrates by Secondary Ion Mass Spectroscopy

F1619 — Standard Test Method for Measurement of Interstitial Oxygen Content of Silicon Wafers by Infrared Absorption Spectroscopy with p-Polarized Radiation Incident at Brewster Angle

F1620 — Standard Practice for Calibrating a Scanning Surface Inspection System Using Monodisperse Polystyrene Latex Spheres Deposited on Polished or Epitaxial Wafer Surfaces

F1726 — Standard Guide for Analysis of Crystallographic Perfection of Silicon Wafers

F1727 — Detection of Oxidation Induced Defects in Polished Silicon Wafers

3.3 *ANSI Standard*[2]

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

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2 American Society for Quality Control, 611 East Wisconsin Avenue, Milwaukee, WI 53202

3.4 *JEITA Standard*[3]

JEIDA 50 — Standard Specification for SOI Wafers

NOTE 1: Unless otherwise indicated, all documents cited shall be the latest published versions.

4 Terminology

4.1 Many terms relating to silicon technology are defined in ASTM Terminology F1241, "Terminology of Silicon Technology."

4.2 Other terms are defined as follows:

4.2.1 *base silicon wafer* — the silicon wafer below the insulator layer, supporting the top silicon film.

4.2.2 *bonded wafers* — defined as two silicon wafers bonded together with an insulating layer. This insulator layer is typically thermally grown silicon-dioxide.

4.2.3 *bonding interface* — the plane where the bonding between the two wafers takes place.

4.2.4 *buried oxide layer (BOX)* — the insulator layer between the two wafers when the insulator layer is silicon-dioxide.

4.2.5 *non-SOI edge area* — an annulus between the nominal radius of the surface silicon layer and the nominal radius of the base silicon wafer (for bonded SOI wafers). The annulus which implies an area is determined by its width as one dimension. It is the difference in the nominal radius of the surface silicon layer and that of the base silicon wafer.

4.2.6 *thickness of top silicon film —* the distance between the surface of the top silicon film and the top silicon film-buried oxide interface.

4.2.7 *top silicon film* — the silicon layer on top of the insulator film in which the semiconductor active devices are fabricated.

4.2.8 *void* — the absence of a chemical bond at the bonding interface.

5 Ordering Information

5.1 Purchase orders for bonded wafers furnished to this specification shall include the following items:

5.1.1 Substrate Characteristics for the device layer (*diameter, dopant, orientation, resistivity, Oi, etc.*)

5.1.2 Substrate Characteristics for the base wafer (*diameter, thickness, dopant, orientation, resistivity, etc.*)

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3 Japanese Electronic and Information Technology Industries Association, Tokyo Chamber of Commerce and Industry Bldg. 2-2, Marunouchi 3-chome, Chiyoda-ku, Tokyo 100-0005, Japan. Website: www.jeita.or.jp

5.1.3 Buried oxide thickness and thickness tolerances

5.1.4 Top silicon film thickness and thickness tolerances

5.1.5 Warp limits

5.1.6 Top silicon film OSF defect limits

5.1.7 Top silicon film carrier life time limits

5.1.8 Buried oxide defect limits

5.1.9 Edge profile of the top silicon film and non-SOI edge area

5.1.10 Rotation alignment between top silicon film and the base silicon

5.1.11 Position of the bonding interface

5.1.12 Methods of test and measurements (see Sections 8 and 9)

5.1.13 Lot acceptance procedures (see Section 7)

5.1.14 Certification (if required)

5.1.15 Packing and marking (see Section 10)

NOTE 2: Verification test procedures of certification of these items shall be agreed upon between the users and the supplier (see Sections 8 and 9).

6 Requirements

6.1 The complete specifications for Overall Wafer, Top Silicon Film, Buried Oxide (BOX) and Base Silicon Wafer are listed in Tables 1 to 5.

Table 1 Silicon-on-Insulator (SOI) Specifications for Low Voltage (45–60V) Power Device (1)

Parameters (Units)	Value	ASTM Test Method or Measurement Procedure	Acceptance
Wafer(Overall)			
Diameter (mm)	125, 150, 200	F613-93	Note A
Thickness (μm)	(Value of regular silicon wafer) + (SOI thickness) + (Box thickness)	F533-96, F1530-94	Note A
Total Thickness Variation (μm)	Note C	F1530-94	Note C
LTV (μm)	Note C	F1530-94	Note C
Warp (μm)	≤ 100 (Note B, C, F)	F1390-92	Note C, or Certified by Wafer Manufactures
Non-SOI Edge Area (mm)	≤ 3 (Note C)	Optical Metrology	Note C, or Certified by Wafer Manufactures
Edge Profile/Edge Profile Surface Finish	Note C	F928-93	Note C, or Certified by Wafer Manufactures
Top Silicon Film			
Thickness (μm)	2–12	Note D (F399-88)	Note C, E, Must be measured on each wafer
Surface Orientation	Note C	X-ray Diffraction (F26-87a)	Note C, or Certified by Wafer Manufactures
Resistivity (ohm-cm)	Note C	F43-93, F84-93, F1527-94	Note C, or Certified by Wafer Manufactures
Conductivity Type	Note C	F42-93	Note C, or Certified by Wafer Manufactures
Oxygen Concentration (/cm^3)	Note C	F1188-93a, F1619-95	Note C, or Certified by Wafer Manufactures
Carbon Concentration (/cm^3)	Note C	F1391-93	Note C, or Certified by Wafer Manufactures
Surface Cleanliness: Metal Contamination (/cm^2)	Note A, C	AAS, ICP-MS, TXRF (F1526-95), SIMS (F1617-98)	Note A, C
Surface Cleanliness: Particle Density (/wafer)	Note A, C	Light Scattering Tomography (F1620-96) (SEMI M34)	Note A, C

Parameters (Units)	Value	ASTM Test Method or Measurement Procedure	Acceptance
Surface Roughness (nm)	Note A, C	AFM (SEMI M34)	Note A, C
Carrier Lifetime (μsec)	Note C	μ-PCD Method (F1535-94)	Note C
Crystalline Alignment of Top Silicon Film to Base Wafer (°)	Note C	X-ray diffraction (F847-94)	Note C
Surface Feature (Haze, Scratch, etc)	None	F154-94, F523-93, F1726-97	Must be measured on each wafer
OSF Density (/cm^2)	Note C	Optical Metrology (F1727-97)	Note C, or Certified by Wafer Manufactures
Buried Oxide (BOX)			
Thickness (μm)	0.5–2	Ellipsometry (F576-95) or Reflective Spectroscopy (SEMI M34)	Tolerance is ± 5%; Note C, or Certified by Wafer Manufactures
Location of Bonded Interface	Lower Surface (Note C)	TEM	Certified by Wafer Manufactures
Void Density (/cm^2)	None	Scanning Acoustic Tomography, Optical Defect Inspection	Note C
Oxide Defect Density (/cm^2)	Note C	I-V on Capacitor, Cu Decoration (SEMI M34)	Note C
Dielectric Breakdown Voltage (V)	Note C	I-V on Capacitor	Note C
Interface States (/cm^2)	Note C, H	C-V Technique	Note C
Fixed Charge Density (/cm^2)	Note C, H	C-V Technique (F1153-92)	Note C
Bonding Strength (kg/cm^2)	Note C	Tensile Strength	Note C, or Certified by Wafer Manufactures
Base Silicon Wafer			
Crystalline Orientation	Note C	F26-87a	Note C
Resistivity (ohm-cm)	Note C	F43-93, F84-93, F1527-94	Note C
Conductivity Type	Note C	F42-93	Note C
Fiducial Axis Orientation (Flat/Notch)	Note C	F671-90, F1152-93	Note C
To-be-bonded Surface Cleanliness: Metals (/cm^2)	Note C	AAS, ICP-MS, XRF (F1526-95), SIMS (F1617-98)	Note C
Back Surface Finish	Note C	Optical Metrology	Note C

Table 2 Silicon-on-Insulator (SOI) Specifications for Low Voltage (45–60V) Power Device (2)

Parameters (Units)	Value	ASTM Test Method or Measurement Procedure	Acceptance
Wafer(Overall)			
Diameter (mm)	125, 150, 200	F613-93	Note A
Thickness (μm)	Note A	F533-96, F1530-94	Note A
Total Thickness Variation (μm)	Note C	F1530-94	Note C
LTV (μm)	Note C	F1530-94	Note C
Warp (μm)	≤ 50 (Note B, C, F)	F1390-92	Note C, or Certified by Wafer Manufactures
Non-SOI Edge Area (mm)	≤ 3 (Note C)	Optical Metrology	Note C, or Certified by Wafer Manufactures
Edge Profile / Edge Profile Surface Finish	Note C	F928-93	Note C, or Certified by Wafer Manufactures
Top Silicon Film			
Thickness (μm)	0.1–0.5	Note D	Note C, E, Must be measured on each wafer
Surface Orientation	Note C	X-ray Diffraction (F26-87a)	Note C, or Certified by Wafer Manufactures
Resistivity (ohm-cm)	Note C	F43-93, F84-93, F1527-94	Note C, or Certified by Wafer Manufactures
Conductivity Type	Note C	F42-93	Note C, or Certified by Wafer Manufactures
Oxygen Concentration (/cm^3)	Note C	F1188-93a, F1619-95	Note C, or Certified by Wafer Manufactures
Carbon Concentration (/cm^3)	Note C	F1391-93	Note C, or Certified by Wafer Manufactures
Surface Cleanliness: Metal Contamination (/cm^2)	Note A, C	AAS, ICP-MS, TXRF (F1526-95), SIMS (F1617-98)	Note A, C
Surface Cleanliness: Particle Density (/wafer)	Note A, C	Light Scattering Tomography (F1620-96) (SEMI M34)	Note A, C
Surface Roughness (nm)	Note A, C	AFM (SEMI M34)	Note A, C
Carrier Lifetime (μsec)	Note C	μ-PCD Method (F1535-94)	Note C
Crystalline Alignment of Top Silicon Film to Base Wafer (°)	Note C	X-ray Diffraction (F847-94)	Note C
Surface Feature (Haze, Scratch, etc)	None	F154-94, F523-93, F1726-97 (SEMI M34)	Must be measured on each wafer
Buried Oxide (BOX)			
Thickness (μm)	0.4–1.0	Ellipsometry (F576-95) or Reflective Spectroscopy (SEMI M34)	Tolerance is ± 5%; Note C, or Certified by Wafer Manufactures
Location of Bonded Interface	Lower Surface (Note C)	TEM	Certified by Wafer Manufactures
Void Density (/cm^2)	None	Scanning Acoustic Tomography, Optical Defect Inspection	Note C

Parameters (Units)	Value	ASTM Test Method or Measurement Procedure	Acceptance
Oxide Defect Density (/cm^2)	Note C	I-V on Capacitor, Cu Decoration (SEMI M34)	Note C
Dielectric Breakdown Voltage (V)	Note C	I-V on Capacitor	Note C
Interface States (/cm^2)	Note C, H	C-V Technique	Note C
Fixed Charge Density (/cm^2)	Note C, H	C-V Technique (F1153-92)	Note C
Bonding Strength (kg/cm^2)	Note C	Tensile Strength	Note C, or Certified by Wafer Manufactures
Base Silicon Wafer			
Crystalline Orientation	Note C	F26-87a	Note C
Resistivity (ohm-cm)	Note C	F43-93, F84-93, F1527-94	Note C
Conductivity Type	Note C	F42-93	Note C
Fiducial Axis Orientation (Flat/Notch)	Note C	F671-90, F1152-93	Note C
To-be-bonded Surface Cleanliness: Metals (/cm^2)	Note C	AAS, ICP-MS, TXRF (F1526-95), SIMS (F1617-98)	Note C
Back Surface Finish	Note C	Optical Metrology	Note C

Table 3 Silicon-on-Insulator (SOI) Specifications for Low Voltage (45–60V) Power Device with N+ Buried layer

Parameters (Units)	Value	ASTM Test Method or Measurement Procedure	Acceptance
Wafer(Overall)			
Diameter (mm)	125, 150, 200	F613-93	Note A
Thickness (μm)	(Value of regular silicon wafer) + (SOI thickness) + (Box thickness)	F533-96, F1530-94	Note A
Total Thickness Variation (μm)	Note C	F1530-94	Note C
LTV (μm)	Note C	F1530-94	Note C
Warp (μm)	≤ 100 (Note B, C, F)	F1390-92	Note C, or Certified by Wafer Manufactures
Non-SOI Edge Area (mm)	≤ 3 (Note C)	Optical Metrology	Note C, or Certified by Wafer Manufactures
Edge Profile/Edge Profile Surface Finish	Note C	F928-93	Note C, or Certified by Wafer Manufactures
Top Silicon Film			
Thickness (μm)	8–16	Note D (F399-88)	Note C, E, Must be measured on each wafer
Surface Orientation	Note C	X-ray Diffraction (F26-87a)	Note C, or Certified by Wafer Manufactures
Resistivity (ohm-cm)	Note C	F43-93, F84-93, F1527-94	Note C, or Certified by Wafer Manufactures
Conductivity Type	Note C	F42-93	Note C, or Certified by Wafer Manufactures

Parameters (Units)	Value	ASTM Test Method or Measurement Procedure	Acceptance
Oxygen Concentration (/cm^3)	Note C	F1188-93a, F1619-95	Note C, or Certified by Wafer Manufactures
Carbon Concentration (/cm^3)	Note C	F1391-93	Note C, or Certified by Wafer Manufactures
Surface Cleanliness: Metal Contamination (/cm^2)	Note A, C	AAS, ICP-MS, TXRF (F1526-95), SIMS (F1617-98)	Note A, C
Surface Cleanliness: Particle Density (/wafer)	Note A, C	Light Scattering Tomography (F1620-96) (SEMI M34)	Note A, C
Surface Roughness (nm)	Note A, C	AFM (SEMI M34)	Note A, C
Carrier Lifetime (μsec)	Note C	μ-PCD Method (F1535-94)	Note C
Crystalline Alignment of Top Silicon Film to Base Wafer (°)	Note C	X-ray Diffraction (F847-94)	Note C
Surface Feature (Haze, Scratch, etc)	None	F154-94, F523-93, F1726-97	Must be measured on each wafer
OSF Density (/cm^2)	Note C	Optical Metrology (F1727-97)	Note C, or Certified by Wafer Manufactures
Buried Layer	Note C	F110-88	Note C
Buried Oxide (BOX)			
Thickness (μm)	0.5–2	Ellipsometry (F576-95) or Reflective Spectroscopy (SEMI M34)	Tolerance is ± 5%; Note C, or Certified by Wafer Manufactures
Location of Bonded Interface	Note C	TEM	Certified by Wafer Manufactures
Void Density (/cm^2)	None	Scanning Acoustic Tomography, Optical Defect Inspection	Note C
Oxide Defect Density (/cm^2)	Note C	I-V on Capacitor, Cu Decoration (SEMI M34)	Note C
Dielectric Breakdown Voltage (V)	Note C	I-V on Capacitor	Note C
Interface States (/cm^2)	Note C, H	C-V Technique	Note C
Fixed Charge Density (/cm^2)	Note C, H	C-V Technique (F1153-92)	Note C
Bonding Strength (kg/cm^2)	Note C	Tensile Strength	Note C, or Certified by Wafer Manufactures
Base Silicon Wafer			
Surface Orientation	Note C	F26-87a	Note C
Resistivity (ohm-cm)	Note C	F43-93, F84-93, F1527-94	Note C
Conductivity Type	Note C	F42-93	Note C
Fiducial Axis Orientation (Flat/Notch)	Note C	F671-90, F1152-93	Note C
To-be-bonded Surface Cleanliness: Metals (/cm^2)	Note C	AAS, ICP-MS, TXRF (F1526-95), SIMS (F1617-98)	Note C
Back Surface Finish	Note C	Optical Metrology	Note C