

SEMI AUX028-0813
INTERLABORATORY EVALUATION OF NONDESTRUCTIVE METHOD
FOR MEASURING THE EDGE CONTOUR OF SILICON WAFERS

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ASTM COMMITTEE F-1 ON ELECTRONICS
SUBCOMMITTEE F-1.06 ON SILICON MATERIALS AND PROCESS CONTROL

RESEARCH REPORT: F-1: _____

INTERLABORATORY EVALUATION OF NONDESTRUCTIVE METHOD FOR
MEASURING THE EDGE CONTOUR OF SILICON WAFERS

(Method B of ASTM Test Methods F 928)

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INTRODUCTION

Almost all commercially available silicon wafers are supplied with either a rounded or beveled edge contour to avoid chipping of the sharp corners of wafers prepared without edge contouring. When wafers are specified in accordance with SEMI Specifications M1,^{*} the contour shape is routinely tested against a template, as shown in Appendix 1, to determine that it lies within certain limits. This template is suitable for testing both rounded or beveled contours; however, beveled contours are frequently specified according to angle and penetration depth instead of the SEMI template.

Method A of ASTM Test Methods F 928 requires breaking of the wafer in order to view the wafer edge. Method B, which is based on a shadow projection method, uses a well collimated light beam to illuminate the edge of the wafer. This method does not require breaking of the wafer, but it does have some limitations as outlined in Appendix 2, a note prepared by H&L Instruments, a supplier of apparatus for this method.

This experiment was undertaken to determine the reliability of edge contour test instruments to determine the acceptability of edge contoured silicon wafers by the nondestructive method (Method B) of ASTM Test Methods F 928. These test methods have recently been revised to indicate that they can be applied to gallium arsenide and other electronic materials and to glass or aluminum rigid disk substrates. However, the present interlaboratory experiment, being conducted under the auspices of Subcommittee F-1.06, was restricted to edge-contoured silicon wafers. Other tests on other materials may be conducted by other F-1 subcommittees at a later date.

A lot of 25 edge-contoured, 125-mm diameter wafers was tested against the edge contour template and other requirements of SEMI Specifications M1. Some of the wafers in the lot were not expected to meet these requirements while the remainder were expected to do so. A 100× template to the SEMI M1 dimensions for 125-mm diameter wafers was supplied for use in the test, but some laboratories used their own template.

^{*} SEMI Specifications M1, for Polished Monocrystalline Silicon Wafers, Materials Volume, 1992 *SEMI International Standards*, (Semiconductor Materials and Equipment International, Mountain View, CA, 1992).

Ten organizations participated in the test. The test was coordinated by Murray Bullis of Materials & Metrology, acting on behalf of H&L Instruments. Participants were permitted to use one or more instruments in the test. Had data from different instruments at one location been reported, each would have been treated as independent data sets; however, it turned out that in the few cases where measurements were made with several instruments, only one instrument yielded data in a form suitable for inclusion in the analysis of the experiment.

TEST METHOD

A proposed revision of the 1988 edition of Test Methods F 928 was used as the basis of the experiment. This revision was subsequently approved in May 1992 and published in the November 1992 edition of Volume 10.05 of the *Annual Book of ASTM Standards* as F 928-92. This edition of the test methods is included with this report as Appendix 3.

LIST OF PARTICIPANTS

The following organizations reported data for the experiment. In some cases the data were collected by a different individual from the person listed as the contact. The organizations are listed in alphabetical order; the order of listing bears no relation to the code numbers assigned in subsequent sections of this report.

AT&T Bell Laboratories
555 Union Blvd.
Allentown, PA 18103
Contact: Paul Langer
Tel: (215)439-7131

Intel Corporation
3065 Bowers Avenue
Santa Clara, CA 95052-8122
Contact: Nora Yeung
Tel: (408)765-5855

Kawasaki Wafer Technology, Inc.
2400 Walsh Avenue
Santa Clara, CA 95051
Contact: Zeferino Farias
Tel: (408)988-2600

MEMC Electronic Materials
P.O. Box 8, MZ 45
St. Peters, MO 63376
Contact: William M. Hughes
Tel: (314)279-5510

MEMC Electronic Materials
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Spartanburg, SC 29304
Contact: Abe Raghib
Tel: (803)587-3671

OTC Semiconductor Corporation
537 Grandin Road
Mainville, OH 45039
Contact: Robert C. Lee
Tel: (513)583-2699

OTC Semiconductor Corporation
49076 Milmont Drive
Fremont, CA 94538
Contact: David Paul
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SEH America, Inc.
4111 NE 112th Avenue
Vancouver, WA 98682-6776
Contact: John Rudat
Tel: (206)254-3035, 3310#

Siltec Silicon
1351 Tandem Avenue
Salem, OR 97393-0139
Contact: Mary Milbrath
Tel: (503)371-0041, ext. 208

Wacker Siltronic
P. O. Box 83180
Portland, OR 97283-0180
Contact: Mike Smith
Tel: (503)243-2020, ext. 267

TEST PROGRAM INSTRUCTIONS

The instructions to the participating organizations were as follows:

Inspect each wafer in the lot in accordance with Method B of ASTM F 928 three times on three different occasions on the same instrument. If different instruments are available and are used in the experiment, make a separate set of three determinations on each instrument.

Record the name of the company, the make and model of instrument, the template used, and the pass-fail status of each wafer at each inspection on the data report form supplied with the wafers (see Appendix 4). Use the criteria in Paragraphs 5.2 through 5.2.2 and Figures 3 and 4 of SEMI Specifications M1, as outlined in Appendix 1. For wafers which fail, indicate the nature of the failure in accordance with the code in Table 1. In addition, note the quadrant in which the defect occurs. Count the quadrants with respect to the primary flat as shown in Figure 1 adapted from SEMI Specification M20.[†]

Table 1. Failure Codes

Failure Mode	Surface	
	Front	Back
Crossed inside point C	AF	AB
Extended beyond point B	BF	BB
Penetrated above line AD	CF	CB
Protrusion	DF	DB
Sharp Point	EF	EB

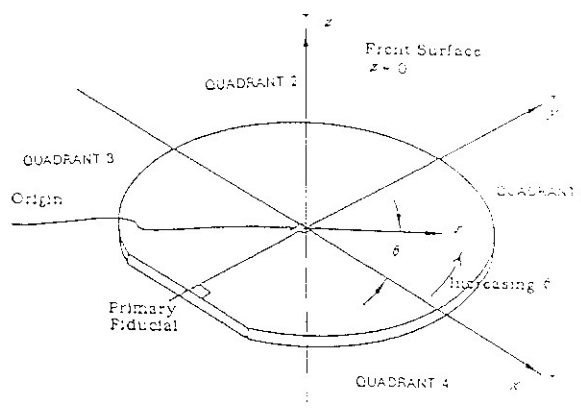


Figure 1. Wafer Coordinate System

When complete, send data to the experiment coordinator as noted on the bottom of the data report form and, after clearance from the experiment coordinator, ship the test specimens by traceable method to the next participant.

DATA REPORT FORMS

Individual data report forms, as returned by the participating organizations are compiled in Appendix 5. In addition, extended reports provided by certain participants are also included in the appendix. As noted on the data report forms, several models of instruments were used in the experiment; however, all had the same type of optical system. However, in some cases, the instruments were not set up specifically for measuring 125 mm wafers which caused some difficulties in alignment of the wafers during the measurements.

DATA ANALYSIS

The first analysis of the results obtained in the experiment was made on the basis of gross pass or fail. The results are summarized in Table 2. In this table, the wafers are listed in order of their total score.

[†] SEMI Specification M20, for Establishing a Wafer Coordinate System, Materials Volume, 1992 SEMI International Standards, (Semiconductor Materials and Equipment International, Mountain View, CA, 1992).

Table 2. Summary of Results
(Including all observations)

Wafer Number	Number of Passes							Total Score
	3 of 3	2 of 3	1 of 3	2 of 2	1 of 2	1 of 1	none	
8	5	2			1	2		22
15	5	1	1		1	2		21
4	5	1	1		1	1	1	20
6	5		1	1		1	2	19
12	5		1	1		1	2	19
14	5			1		2	2	19
5	4		3	1		1	1	18
11	4	1		1		2	2	18
19	4	2				2	2	18
1	4	2				1	3	17
18	5		1			1	3	17
9	3	2		1		1	3	16
10	3	1	1	1		2	2	16
13	3	1		1		1	4	14
3	2	2	2			1	3	13
7	2	1	2	1		1	3	13
21	3		1			2	4	12
20	2		3			1	4	10
2	2	1				1	6	9
16	1	1	3			1	4	9
17	1		1			1	7	5
24	1						9	3
22							10	0
23							10	0
25							10	0

shown in the last column. The total score was constructed as follows:

If all of the three observations on a particular wafer resulted in a pass or fail, the result was entered into the “3 of 3” or “none” column, respectively. If the observations resulted in some passes and some failures, the result was entered into the “2 of 3” or “1 of 3” column, as appropriate. One participant measured the wafers only two times; in this case the result was entered into the “2 of 2,” “1 of 2,” or “none” column, depending on the number of observations which resulted in passes. Two of the participants reported only one valid set of measurements; these results were entered into the “1 of 1” or

"none" column, as appropriate. The total score was calculated as the sum of the product of number of entries in each column times the number of passes represented by that column. Thus the maximum possible score was 25 for wafers which passed in all observations and the minimum score was 0 for wafers which failed in all observations.

In no case did all participants always agree that any of the wafers passed the test. However, in the case of two of the wafers (8 and 15), no participant reported failure for all observations.

All participants agreed that three of the wafers failed the test. However, there was not complete agreement as to the mode of failure even for these three wafers although seven of the ten labs agreed that the failure was due to penetration of the edge profile beyond point B on the wafer. The remainder of the wafers were judged to pass by some and to fail by others; again the same failure mode was not assigned by all participants and in some cases there were differences between multiple observations in a single location.

To understand these differences in observations, it is necessary to consider the observed failure modes. The raw data reported by each participant are given in condensed form in Table 3. In this table, failure modes are indicated by the codes listed in Table 1. Two participants, Laboratories 2 and 4, did not indicate the quadrant of failure, and one participant listed the quadrant only for one of the three runs. For the other data shown, the quadrant of failure is indicated following a "/Q" or as a superscript. "/All" or superscript "All" indicates that the failure mode was observed in all quadrants. A question mark (?) indicates that the failure mode was not listed on the data report form submitted. One laboratory reported observation of "entry-exit marks;" these are coded as "EE." The code "1" is used to indicate a "passed" wafer.

Most of the difficulty centered around whether or not the edge profile extended further into the wafer than 0.508 mm (the specified location of point "B" in the SEMI template). Some participants reported that most of the observed failures occurred on the front surface, some on the back, and some that the failure occurred because the edge contour passed inside point "C." One participant even observed that the profile extended into the region above the line "AB." There appeared to be a systematic aspect to the observations. A given participant frequently tended to report failures of the same type or failure to be observed on the same wafer surface or both. This suggests that instrument alignment is both critical to the success of the measurement and difficult to control. An ancillary alignment procedure is described in paragraph 5.1 of the Test Method for use in difficult cases; this procedure is quite cumbersome and was not employed by any of the participants. The experiment therefore provided no indication of the efficacy of that procedure. However, it would appear to be unrealistic to expect it to be used in most circumstances. Nevertheless it is clear that the procedures employed did not alert operators to improper alignment.

In addition, several participants reported observing numerous protrusions and sharp points. These two types of failures appeared to arise because of the difficulty of distinguishing dirt and other contamination on the profile from the profile itself. In an independent examination of the wafers carried out by the experiment coordinators, which was done with the cover of the instrument removed to facilitate access to the wafer edge during the measurement, every observed protrusion or sharp point could be removed by blowing with dry nitrogen or wiping the edge of the wafer with a tissue. Therefore we concluded that these defects were not correctly identified. When these failures were eliminated, the results are modified as shown in Table 4. Although this somewhat improves the within-laboratory agreement, it does not seem to materially affect the general conclusions drawn above.

In general, participants did not report the laser marked identification on the wafers. However, these were read by two of the participants and by the experiment coordinator during the last half of the experiment. There appeared to be a small amount of mixing of wafer locations in the cassette between each pair of

Table 3. Summary of Raw Data

Wafer #	Laboratory 1			Laboratory 2		Lab 3	Laboratory 4			Laboratory 5		
1	AF/Q2	AF/Q3	AF/Q3	AB	AB	1	BB	1	1	1	1	1
2	DB/Q2	DB/Q2	DB/Q2	AB	AB,AF	1	DF	BB	DF	1	1	1
3	AF/Q2	1	1	BB	BB	1	DF	DF	1	1	1	1
4	1	1	1	1	AB	1	DF,DB	DF	1	1	1	1
5	1	1	1	1	1	1	EF,EE	1	EF,EE	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	EF	1	1	AB/Q4	AB/Q4	AB/Q4
8	1	1	1	AB	1	1	1	EF	1	1	1	1
9	AF/Q2	AF/Q2	AF/Q2	1	1	1	EB,bumps	1	1	1	1	1
10	AF/Q2	AF/Q2	AF/Q2	1	1	1	1	1	1	AB/Q2	AB/Q2	AB/Q2
11	BF/Q2	BF/Q2	BF/Q2	1	1	1	DF	1	1	1	1	1
12	BF/Q4	BF/AII	BF/AII	1	1	1	1	1	1	1	1	1
13	BF/Q2	BF/AII	BF/AII	1	1	1	1	1	1	1	1	1
14	?	BF/AII	BF/AII	1	1	1	1	1	1	1	1	1
15	1	1	1	AF,AB	1	1	1	EF	1	1	1	1
16	1	1	1	EF,AB	EF,AB,AF	1	EF,EE	1	DF	BF/Q4	BF/Q4	BF/Q4
17	BF/Q2	BF/AII	BF/AII	AB	AB,AF,BB	1	BB	BB	EF,EE	1	1	1
18	1	1	1	AB	BB	1	1	EB	EF,EE	1	1	1
19	1	1	1	AB	EF,BB	1	1	DF	1	1	1	1
20	BB/Q2	BF/Q1	BF/AII	EF	EF,AB,BF	1	?	DF	1	1	1	1
21	1	1	1	EF,AB	EF,AB,BB	1	BF	DF	1	AB/Q3	AB/Q3	AB/Q3
22	BF/AII	BF/AII	BF/AII	EB,BB	EB,BB	BB ²³ AB ²³	BB	BB	BB	AB/Q2	AB/Q2	AB/Q2
23	BF/AII	BF/AII	BF/AII	EB,BB	EB,BB	BF ¹⁴ BB ²³ AB ³	BB	BB	BB	AB/Q2-4	AB/Q2-4	AB/Q2-4
24	BF/AII	BF/AII	BF/AII	EB,BB	EB,BB	BF ¹³ BB ²³	BB	BB	BB	AB/Q2-4	AB/Q2-4	AB/Q2-4
25	AF/Q1	AF/Q1	AF/Q1	BB	BB	BB ³	BB	BB	BB	AB/Q2-4	AB/Q2-4	AB/Q2-4

Wafer #	Laboratory 6			Laboratory 7			Laboratory 8			Laboratory 9			Lab 10
1	1	1	1	1	1	1	BF,CB	1	1	1	1	1	BF ¹⁴
2	1	1	DF/Q1	BB/Q4	BB/Q4	BB/Q4	BF ¹ CF ³	BF,CF	BF,CF	1	1	1	BF ^{AB} ,DF ¹
3	1	1	DF/Q1	BB/Q3	BB/Q2	BB/Q4	BF ^{AB} CB ³	1	CB	1	1	1	BF ^{AB} ,DF ¹
4	1	1	1	1	1	1	1	CB	1	1	1	1	BF ^{AB}
5	1	1	1	1	AF/Q4	AF/Q4	BF ^{AB}	BF,CF	1	1	1	1	BF ¹
6	1	1	1	BB/Q4	1	BB/Q4	CB ^{AB}	CB	CB	1	1	1	BF ³⁴
7	1	1	1	BB/Q2	1	AF/Q4	CB ¹⁴	1	CB	DF/Q4	DF/Q4	DF/Q4	BF ²³⁴ ,DF ³
8	1	1	1	1	1	1	1	1	CB,BB	1	1	1	1
9	1	1	1	BB/Q4	1	1	BF ¹²⁴ CB ¹	BF,CB	BF,CB	1	1	1	BF ⁴
10	1	1	1	BB/Q4	1	AF/Q1	BF ¹	1	1	1	1	1	1
11	1	1	1	1	1	1	CB ² BF ⁴ CF ⁴	BF,CF	BF,CF	1	1	1	1
12	1	1	1	1	1	1	BF ¹⁴	1	CB	1	1	1	DF ³⁴
13	1	1	1	BB/Q4	BB/Q4	BB/Q4	BF ¹⁴ CB ²	BF,CB	BF	EB/Q3	1	1	BF ⁴
14	1	1	1	1	1	1	BF ³ CB ¹²	CB	BF,CCB	1	1	1	1
15	1	1	1	1	1	1	BF ^{AB}	1	BF	1	1	1	1
16	1	DF/Q4	DF/Q4	BB/Q4	BB/Q4	AF/Q4	BB ^{AB}	1	BB	DB/Q3	1	1	BF ¹⁴
17	1	EB ² ,DF ¹	DB ² ,DF ⁴	BB/Q4	BB/Q4	BB/Q4	BF ^{AB} CB ³	BF,CB	BF,CB	CF/Q4	CF/Q4	CF/Q4	BF ¹⁴
18	1	1	1	1	1	1	BB ¹⁴ BF ²⁴ CB ¹³⁴ CF ⁴	{BB,BF, CB,CF}		1	1	1	DF ³
19	DE/Q1	1	1	1	1	1	BF ^{AB} CB ¹² CF ⁴	BF,CF	BF,CF	1	1	1	1
20	1	EB/Q4	EB/Q4	1	1	1	BF ² CB ²³	1	BF	EF/Q1	EF/Q2	EF/Q4	DB ^{AB}
21	1	1	1	1	1	1	{BB,BF,CB} ¹²⁴	BB,CB	BF,CB	EF/Q1	EF/Q1	EF/Q1	1
22	BB/Q1	BB/Q2	BB/Q1	BB/Q4	BB/Q4	BB/Q4	BB ^{AB} BF ²⁴ CB ¹⁴	BB,BF,CB	BB,BF,CB	BB/Q3	BB/Q3	BB/Q3	BB ^{AB} ,DB ¹
23	BB/Q1	BB/Q1	BB/Q1	BB/Q4	BB/Q4	BB/Q4	BB ¹²⁴ BF ¹⁴ CB ²³⁴	BB	BB,BF	BB/Q3	BB/Q3	B/Q3	BB ^{AB}
24	1	1	1	BB/Q4	BB/Q4	BB/Q4	BB ^{AB} BF ¹⁴ CB ^{AB}	BB,CB	BB,CB	EB/Q3	EB/Q3	EB/Q3	BB ²³⁴ ,DB ^{AB}
25	BB/Q2	BB/Q2	BB/Q2	BB/Q4	BB/Q4	BB/Q4	BB ^{AB} BF ¹ CB ²³⁴	BB,CB	BB,CB	BB/Q3	BB/Q3	BB/Q3	BF ^{AB}

these observations. However, none of the interchanges appeared to cause a significant effect on the observations because the interchanged wafers seemed to be essentially equivalent. However, there is no certainty that the wafers were not mixed between measurement groupings made before the first

Table 4. Summary of Results
(Excluding Observations of Sharp Points and Protrusions)

Wafer Number	Number of Passes							Total Score
	3 of 3	2 of 3	1 of 3	2 of 2	1 of 2	1 of 1	none	
8	6	1			1	2		23
4	6	1			1	1	1	22
15	6		1		1	2		22
12	5		1	1		2	1	20
18	6					2	2	20
19	6					2	2	20
6	5		1	1		1	2	19
11	5			1		2	2	19
14	5			1		2	2	19
5	4		3	1		1	1	18
1	4	2				1	3	17
9	4	1		1		1	3	17
3	4	1	1			1	3	16
10	3	1	1	1		2	2	16
2	4	1				1	4	15
20	3	1	1		1	2	2	15
7	3		2	1		1	3	14
13	3	1		1		1	4	14
16	3	1	1			1	4	13
21	3	1				2	4	13
17	2		1			1	6	8
24	1						9	3
22							10	0
23							10	0
25							10	0

observation of the laser mark identifications.

SUMMARY

The results of this experiment confirm both the difficulties cited in paragraph 5.1 of the Test Methods regarding alignment in Method B and the possible interference of particles cited in paragraph 5.3 of the Test Methods. In reporting the results of this test, it is also appropriate to strengthen the warning in paragraph 5.1 and to emphasize the necessity of checking the results of Method B against those of Method

A in order to establish correlations for use in commerce. Consequently, the following changes to the 1992 edition of Test Methods F 928 are being proposed as a result of the results found in this test. Material to be removed is ~~struck out~~ and material to be added is redlined.

Change paragraph 4.4 as follows:

4.4 Method A is best suited for referee ~~purposes, while purposes.~~ Method B is appropriate for routine process monitoring such as alignment of wafer edge grinders, routine quality control and incoming/outgoing inspection purposes. In view of the uncertainty of precisely locating the intersection of the contour and the wafer surface when carrying out Method B, use of this method for commercial transactions is not recommended unless the parties to the test establish the degree of correlation which can be obtained.

Change paragraph 5.1 as follows:

5.1 In Method B, the profile of the parallel surfaces of the wafer may not be sharply focused at distances exceeding approximately 0.5 mm (0.20 in.) from the extreme wafer edge toward the wafer center. This uncertainty in the wafer surface location may cause inaccuracy in positioning the wafer with respect to template lines. It may also make it difficult to determine whether the wafer edge profile lies within the permitted zone at point B of the template. These difficulties ~~This difficulty~~ can be overcome by aligning a straight edge surface to the wafer surface by direct contact, observing the shadow extension in the sharply focused region, and extrapolating the straight line edge of the template reference. In applying this technique, exercise care to avoid damaging or contaminating the wafer surface.

Change paragraph 13.1 as follows:

13.1 Although these test methods do not return a test result, an interlaboratory test ~~has been designed~~ was conducted to determine the reliability of the non destructive Method B when applied to ~~typical silicon wafers.~~ When complete, the results of this test will be incorporated into the method. Until the results are established, use of these test methods for commercial transactions is not recommended unless the parties to the test establish the degree of correlation which can be obtained. In this test, a lot of 25, 125-mm diameter, edge profiled, silicon wafers was tested in accordance with Method B against the edge contour template and other requirements of SEMI M1. The wafers were measured by ten different organizations using several types of commercially available edge contour measuring instruments, all of which had similar optical systems. In one case the magnification used was 60× instead of 100× as specified in 6.2.

13.1.1 In no case was a wafer judged to be within the specification requirements by all participants. Only three wafers were judged by all participants to fail, but different participants reported different reasons for failure; the other 22 wafers were judged to pass by some and to fail by others, but again the same failure mode was not always reported. Most of the difficulty centered around determination of whether or not the edge profile extended further into the wafer than 0.508 mm (the specified location of point B in the SEMI template). Some participants reported failure on the front of the wafer, some on the back, and some reported that failure occurred because the contour passed inside point C. These results confirm the difficulties with locating the wafer surface indicated in 5.1. No participant reported use of the straight-edge technique suggested in 5.1, so the efficacy of that procedure was not evaluated in the test.

13.1.2 The results also confirmed the difficulties with interference from particulate contaminants. Several observers reported protrusions or sharp points on the wafer periphery, but these were not generally reported. Examination of the wafers under conditions in which the edge of the wafer could be accessed during the test showed that such apparent protrusions could be removed by

blowing or wiping with lens cleaning tissue.

13.1.3 Detailed results of the test are contained in an ASTM Research Report.

As a final note, it should be emphasized that these results clearly reveal the need to develop a more reliable, more accurate, nondestructive method for evaluating edge contours of wafers.

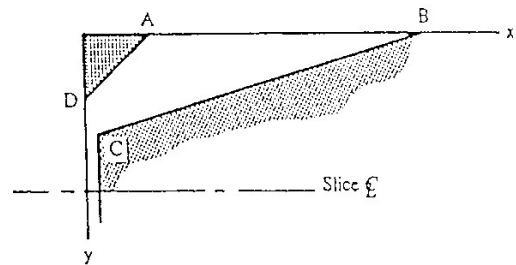


APPENDIX 1. SEMI EDGE CONTOUR REQUIREMENTS FOR 125-mm DIAMETER WAFERS

5.2 If edge contoured wafers are specified on the purchase order, the profile shall conform to the following requirements at all points on the wafer periphery (except interior portions of notches, if present).

5.2.1 When the wafer is aligned with the SEMI Wafer Edge Profile Template (see Figure 3) so that the x-axis of the template is coincident with the wafer surface and the y-axis of the template is tangent with the outermost radial portion of the contour, the wafer edge profile must be contained within the clear region of the template. (See Figure 4 for examples of acceptable and unacceptable contours.)

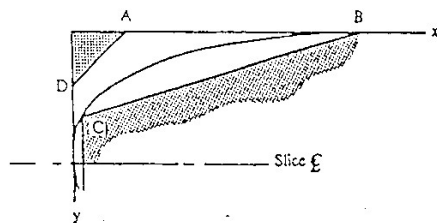
5.2.2 No sharp points or protrusions are permitted anywhere on the wafer edge contour.



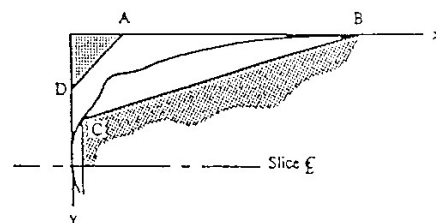
EDGE PROFILE COORDINATES
FOR 125-mm DIAMETER WAFERS

POINT	x, μm	y, μm
A	76	0
B	508	0
C	51	208
D	0	76

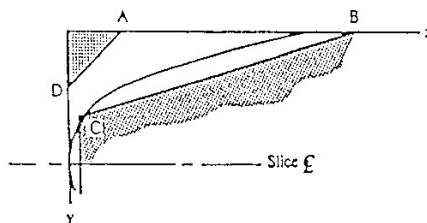
Figure 3
SEMI Wafer Edge Profile Template



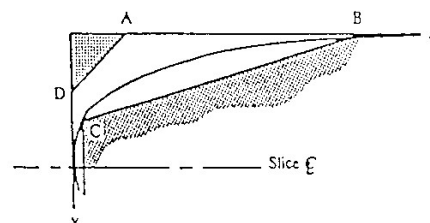
A. Acceptable Contour



B. Unacceptable Contour
Wafer profile includes a protrusion.



C. Unacceptable Contour



D. Unacceptable Contour

Figure 4
Examples of Acceptable & Unacceptable Wafer
Edge Profiles