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IC Inspection Test Masks - Experimental Results*

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Abstract

Integrated circuit inspection test photomasks were scanned with four automated inspection systems to determine if these masks could be used to test and calibrate automated inspection systems. It was found that the dimensions on the background die pattern of such masks must be accurate before an automated system, especially a scanning type, can be used to inspect them. A stepping accuracy better than $\pm 20 \mu\text{in}$ and preferably better than $\pm 10 \mu\text{in}$ is required. When adjustments were made for the stepping error by the operator, an automated system found nearly twice as many defective die as were found during a manual inspection of the same mask.

The fabrication of inspection test masks by the insertion of intentionally defective reticles into an otherwise perfect array suffers from the inability to accurately position the inserts. A better way to achieve randomly positioned defects would be to make them with a laser scribing machine and with chrome patching. Randomly positioned defects are desired if an automated inspection system is to be compared with a manual scan technique. If all that is desired is the calibration of the automated system, then the defects can be positioned in a regular manner but there must be a large number of them in a variety of sizes so that detection statistics can be accumulated.

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INTRODUCTION

This report discusses the results obtained from the use of integrated circuit (IC) inspection test photomasks. The fabrication of these masks is explained in an earlier report.¹ Originally, the masks were to be used to help evaluate various automated inspection technologies. Also, they were to be used to help set the sensitivities or detection levels of an inspection system. This is still their intended purpose. However, in this report, the data presented was taken with the understanding that it would be used to help evaluate the design of the test masks and the method used in their fabrication.

Four companies voluntarily scanned the masks with their automated inspection systems. Two of these systems used the dual beam flying spot scanner technology. One used spatial filtering, and the fourth used a semi-automatic system based on optical comparison.

Two other companies expressed a strong interest in the masks. One was using a microdensitometer type technology and the other was working with the TV-microscope approach. Both of these companies complained of how difficult it was to obtain a mask with information about its defects when they wanted to evaluate a system. They did not actually use the masks because neither had a system up and running during the few months before this report was written.

MANUAL INSPECTION AND MEASUREMENT DATA

All of the masks were manually inspected at LLL. A microscope with an objective magnification of 56X (NA=0.90) and 10X eyepieces was used. The intent of the inspection for defects at LLL was to determine whether the intentional defects on the masks had printed. A total defect scan on one of the masks was made by a participating company. Dimensional measurements of the intentional defects were made at LLL using the image shearing technique. For these image shearing measurements, an objective magnification of 40X (NA=0.85) and a 16X eyepiece were used.

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The first inspection test mask received was designated ITM. As was discussed in UCID-17141, this mask contained scribe marks that could result in a high defect count for the mask because of the way the marks were produced. For this reason, another set of masks designated ITM-A1, ITM-A2, etc., was ordered without scribe marks.

Measurements were made on ITM (chrome) to determine the registration accuracy between adjacent die. The stepping distance between adjacent die must be within $\pm 20 \mu\text{in}$ and preferably within $\pm 10 \mu\text{in}$ or else the automated inspection systems that operate on the comparison principle will have difficulties when they compare adjacent die. These measurements were made using a Leitz* 200-2 Linear Comparator that has a precision of $\pm 10 \mu\text{in}$. This machine uses a photoelectric detector in combination with an optical scale to measure the distance between two lines.

Figures 1 & 2 illustrate the positions on the mask where the measurements were made. Two scans were made for each of the two rows and two columns that were measured. This was so that any tilt in the position of a die could be detected. Also, each scan was performed twice with the machine being returned to the start and rezeroed after each scan. All measurements were made at the center of the first line encountered in order to avoid problems with edge detection. Whenever a die position was measured in both the horizontal and vertical direction, it was possible to get two indications of any tilt on the same die.

Tables I & II list the readings obtained from the die position measurements. The units of the measurements are micro-inches. They indicate the error in location of the line. That is, if all die were in their correct position, (150 mil stepping distance), all of the numbers in Tables I & II would be zero. A negative number means that the die is too close to the first die measured while a positive number means it is too far. Following each scan, the machine was returned to the starting point and rezeroed. The amount by which it had to be rezeroed is also given in Tables I & II.

*"References to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable."

The data in Table I & II is used to determine the stepping error between adjacent die. This is plotted in Figs. 3-10. In these Figures, the stepping error is zero if the adjacent die being considered are 150 mils apart.

Some interesting observations can be made from the data in Figs. 3-10. First, the largest stepping error does not necessarily occur at the position of an insert. Second, there are stepping errors between adjacent die that are greater than 20 μ in. Finally, during the two scans of identical positions on the mask, most of the measurements are reproduced to within 10 μ in. This third observation gives one a lot of confidence in the data. Unfortunately, there is another analysis that causes one to be suspicious of the data.

Notice from Fig. 1 that four of the die on the mask are scanned twice in the horizontal direction and twice in the vertical direction. These die are in the following row and column positions: (3,7), (3,9), (8,7), and (8,9). The angular orientation of these die as determined from the horizontal measurements should agree with their angular orientation as determined from the vertical measurements. This is not the case as can be seen in Figs. 11 and 12. The upper part of these Figures shows the apparent orientation of the die as determined from the horizontal measurements listed in Table I. The lower part shows the apparent orientation as determined from the vertical measurements. Since the orientation as determined by these measurements is not consistent, one must conclude that either the die is distorted or that the measurements are questionable.

Measurements were also made on one row of die on ITM using a laser metered microscope. In this instrument, the line edges are detected by visually positioning a cross-hair. The measurements showed that the stepping error between adjacent die was less than 20 μ in. However, these measurements were made rather hurriedly, on only one row, and they were not repeated.

ITM was scanned manually to determine the total number of defective die. This scan took one hour by an experienced mask inspector. Figure 13 shows the results. As shown, there are a total of 37 defective die even though only 15 were intentionally defective. The only error made in the manual inspection was in the location of defective die (3, 14). This was most likely a recording error.

Another photomask, designated ITM-B1, was fabricated on a laser metered step and repeat camera to see if the stepping accuracy would improve. (ITM had been made on a step and repeat camera that used an optical scale for determining positionings.) Figures 14 and 15 illustrate where the measurements were made on ITM-B1. Notice that the orientation of the images and die inserts are different from those on ITM. This was not done purposely but was the result of the confusing communication link between mask requestors and mask makers. Also, Reticule insert #4 was erroneously placed in position (10,4) instead of position (10,3) because of an instruction error on the part of the mask requestor.

Tables III & IV give the errors in the position of the die on the two rows and columns that were measured. This data is used to plot the stepping errors as shown in Figs. 16-23. Notice that the placement of Reticule #1, the defect free reticle, is more accurate than the placement of the defect free reticle in ITM. However, there is considerable more error in the placement of the insert reticles indicating a problem with the installation of the 10X reticles onto the step and repeat camera.

As with mask ITM, the die orientation of four die on ITM-B1 was determined by row and column measurements. This orientation as determined from these measurements is not consistent as shown in Figures 24 and 25. This implies either a die distortion or an error in the measurements.

ITM-B1 was manually scanned to determine which of the intentional defects did print. Table V indicates which of the smaller intentional defects printed on ITM-B1. All intentional defects 2.8 μm and larger did print.

As discussed in UCID-17141, test mask ITM was not scanned with an automated inspection system because it contained scribe marks that could lead to false indications of defects. Another set of test masks, denoted as ITM-A, were fabricated for use with the automated inspection systems. Eleven chromium masks and 11 iron-oxide masks were made of this ITM-A series.

Before the ITM-A masks were sent to cooperating companies, they were manually inspected to determine which of the intentional defects did print. Table VI indicates which of the smaller intentional defects did print. All intentional defects $2.5\text{ }\mu\text{m}$ and larger did print. One of this series of masks, ITM-A1, was manually inspected to determine all defects both intentional and unintentional. At first an optical magnification of 280X was used for this inspection so that the $1.9\text{ }\mu\text{m}$ defects would be clearly visible. However, it would have taken over four hours to inspect the entire mask with this magnification. An optical magnification of 110X was finally used and the entire inspection took 1-1/2 hours. With the 110X magnification, the $1.9\text{ }\mu\text{m}$ defects were visible if the stage was stopped. They could not be detected while the stage was scanning. Figure 26 shows a defect map for this manual scan. Only 5 unintentionally defective die were found giving a yield of $176/196 = 90\%$.

Figures 27 to 44 show photographs of the intentional defects on one of the intentionally defective die on the ITM-A series of masks. These photos were taken through a microscope with an objective of 56X (NA=0.90) and an ocular of 6.3X. The dimensions of the intentional defects were measured using the image shearing technique. For the particular setup used, the accuracy was determined to be $\pm 0.15\text{ }\mu\text{m}$. Table VII lists

the dimensions of intentional pinholes and spots on one of the defective die for masks ITM-A1 to ITM-A4. The design dimension is also listed so that any under or over etch can be detected.

SCAN WITH AUTOMATED SYSTEM A

Test mask ITM-A1 was scanned with automated system A. This system uses the dual beam flying spot scanner technique. Figure 45 illustrates how this type of system correctly identifies an opaque spot. In part (a) of this figure, an opaque spot is shown in column c. The separate scans of the dual beams are indicated as 1, 2 & 3. Part (b) of the figure indicates the transmission information for the two spots of light during each of the three scans. During scan #2, a difference in transmission is detected and the position of the discrepancy on the mask is recorded. During scan #3, the spot is detected again, and the fact that it was detected twice is recorded. A similar analysis applies for the detection of a pinhole as shown in Figure 46.

Two strips on the edges of the mask are scanned only once. This condition is illustrated in Figs. 47 and 48. Figure 47 shows how a pinhole on the edge of the mask is detected while Figure 48 illustrates the case for an opaque spot. In both cases the defects are detected only once.

The situation for a single detection away from the edges of the mask is more complicated. Here a single detection could be caused by a registration error between adjacent die, a pinhole, or a spot so the defect is labeled as unidentified. Figure 49 illustrates how a pinhole cannot be distinguished from an opaque spot when there is no problem with die registration. Suppose that a single defect indication as shown in Fig. 49a is made. Can one tell whether this is a pinhole or a spot assuming an accurate stepping distance? Figure 49b illustrates how such a single indication could be caused by a pinhole. This would require that the pinhole be missed during scan #2. It could be missed because of its size being very close to the detection threshold. Or, it could be missed if the flying spot does not intersect the defect near its center.

On the other hand, Fig. 49c illustrates how such a single indication could be caused by an opaque spot. This would require that the spot be missed during scan #4 for the same two reasons listed above for why the pinhole was missed. Consequently, when there is a single detection of a defect somewhere away from the edges of the mask, the defect is listed as unidentified.

The results of the scan of mask ITM-A1 with system A are given in Table VIII & IX for the chrome and iron oxide masks. During this scan, the system threshold was set at $2.5 \mu\text{m}$. The mask had to be cleaned because the first attempts to inspect it indicated that there was a lot of surface contamination. Also, the spacing between the two flying spots had to be continually adjusted indicating that there are stepping distance errors on the mask. An array of die, 13 by 13 was inspected instead of the 14 by 14 because of the need to stay away from the edges of the $2\frac{1}{2}$ " by $2\frac{1}{2}$ " glass substrate. The yield given in Tables VIII & IX was calculated on the basis of how many of the 13 by 13 chip areas on the mask did not have any defects. This yield was not calculated on the basis of the statistical formula $1/(1+D_0A)$. Figures 50 and 51 show photos of the CRT readout of defects on the mask. The 15 intentional defective die are clearly visible. Also visible are many unintentional defects. These photographs are used only for record keeping purposes.

SCAN WITH AUTOMATED SYSTEM B

System B utilizes the spatial filtering technique of Axelrod² to inspect masks. Incoherent illumination is added to give the operator a background image of the entire mask. Mask ITM-A1 was inspected with the system. The results were very discouraging. Defects could not be found. The reason given for the failure was that the defects were perfectly round and supposedly the spatial filter had been designed to eliminate round defects in order to avoid the detection of corners on images. However, this explanation does not appear to be correct. In this system, round corners are not identified as defects because the operator can observe that they are reconstructed in the image plane in their correct location. Round defects, on the other hand, should be recognized as defects because they are reconstructed in locations where there should be no features. Any protrusions or intrusions whose edges are in the same direction as the edges of the mask geometry would be filtered out.

SCAN WITH AUTOMATED SYSTEM C

Test mask ITM-A2 was scanned with system C. This system also uses the dual beam flying spot scanner technique. Considerable difficulty was experienced partly because of the stepping errors on ITM-A2 but mostly because of the die orientation errors. There were also problems with airborne particles that had deposited on the mask during its delivery. In order to deal with the die registration errors, the system was adjusted to only detect defects that were 5 μm and larger. Under these conditions it found the intentionally defective die patterns.

SCAN WITH AUTOMATED SYSTEM D

Test mask ITM-A3 was scanned with system D. This system is only partially automated in that it uses an optical comparison technique that requires decisions by an operator. All 15 of the intentionally defective die were found. No unintentional defects were found. Apparently there were no problems caused by the step and repeat errors on the mask. Most likely the threshold sensitivity of the system was set at a level where the step and repeat errors were not a problem. However, in so doing, the smaller unintentional defects were missed.

DISCUSSION

One of the most strikingly obvious conclusions to come out of this work is the absolute necessity for dimensional accuracy on a mask if it is to be inspected with an automated inspection system. This is especially true if the system is a scanning type. The stepping error between adjacent die must be less than $\pm 20 \mu\text{in}$ and preferably less than $\pm 10 \mu\text{in}$. Even more serious than any stepping error between adjacent die is a die orientation error that is caused by a slight oscillation in the stage of the step and repeat camera as it moves along its ways.

The most difficult problem encountered during this project concerned the dimensional accuracy of the masks. It was not uncommon to find stepping

errors of 10 and 20 μin between adjacent die on a mask and errors as high as 55 μin between inserts and adjacent die. There were also die orientation errors. These dimensional errors severely hampered the automated inspection systems in their search for defects. Adding to this problem was the inability to get a conclusive determination of the dimensional errors. Two companies measured the masks. One said the stepping errors were greater than 20 μin and the other said the errors were less than 20 μin .

The spatial filtering technique, at least the approach developed by Axelrod, where horizontal and vertical lines are filtered out, is not as susceptible to dimensional errors. It is quite suitable for detecting lines that are at some angle to the horizontal less than 90° and for detecting defects larger than 5 μm . However, presently mask makers want to search for defects as small as 2 μm .

System A, which uses a dual beam flying spot scanner, found more defects on ITM-A1 than were found with a manual inspection even though the threshold was adjusted so that the smallest detectable defect with System A was 2.5 μm while the manual inspection used a 110X optical magnification that should have been able to detect 2 μm defects. The yield found on ITM-A1 using System A was 56%. However, it is not known how many of the recorded defects were caused by stepping errors in the array. The yield found with a manual scan was 90%. The manual scan took 1-1/2 hours while the automated scan took approximately 15 minutes. One of the main problems with the manual scan was the extreme eye fatigue suffered by the operator. Also, many defects were missed during the manual scan because of the rapid scanning used to try and hold down the inspection time. In order to manually find all the defects down to 2 μm , one should use an optical magnification of at least 280X and scan slowly. This would, however, increase the total inspection time to 3-1/2 hours.

The four companies that volunteered to participate in the evaluation of these masks did so voluntarily. They were quite interested in learning

more about their systems and about the whole area of automated mask inspection. However, due to other urgent assignments, they could not spend as much time inspecting the test masks as they would have liked. In most cases the results reported were incomplete.

Transporting the masks by mail presented another problem. The masks were received with a lot of particulate contamination on their surfaces. Each company had to decide how much time they could spend on cleaning the masks. A comparison of inspection statistics gathered at a cooperating company could not be conveniently compared with inspection statistics at LLL because of the variation in cleaning procedures.

The intentional defects on the test masks discussed in this report were put in the mask by means of die inserts. There is considerable error in the placement of these inserts. The error in the distance between an insert and the adjacent die was as high as 55 μm in some cases. The use of a laser metered step and repeat camera did not decrease this error. Insert placement errors are caused by the inability to accurately position the 10X reticle on the step and repeat camera. A way to eliminate these placement errors would be to use an E-beam mask generator where the inserts are fabricated at the same time as all the other die. Another way to make the test masks would be to use a laser repair system to make pinholes and scratches. Opaque defects could be added by applying photoresist, defining a defect pattern with a mask or a beam of light, and then evaporating more chromium.

Two independent mask vendors were compared for their capability to print small intentional defects. Both companies used positive photoresist throughout all of their process. The company that fabricated the ITM-A series, had some trouble with the 1.9 μm opaque spots but no trouble at all with the 1.9 μm pinholes. The company that produced the ITM-B series, also had some trouble with the 1.9 μm opaque spots but they did not print any of the 1.9 μm pinholes. Differences in exposure times and etch times can explain these two situations.

One must ask if the intentional defects on an inspection test mask must be placed in random locations throughout the mask. If an automated system is to be compared with a manual inspection technique, then it would be wise to place the defects in random positions so that the operator of the manual system cannot anticipate a defect. However, if two automated systems are being compared, or if the sensitivity of one system is being determined, then it is not necessary that the defects be randomly positioned. What is necessary is that the dimensions on the mask be accurate and that the dimensions of the defects be known. A good mask to use would be one with several different sizes and types of defects each one of which is repeated many times so that the threshold of detectivity of the system could be determined on a statistical basis. The defect pattern should be superimposed on a regular IC pattern in order to test the system ability to distinguish valid patterns from defects.

It is expected that by 1980, 90% of all ICs bigger than 150 mils on an edge will be made with projection printing.³ The masks for these projection printers must be near perfect because they are used indefinitely. This means that the masks must undergo a 100% inspection, something that is extremely time consuming and fatiguing for a person to do with a microscope. Automated inspection systems will be used to inspect these masks. Unfortunately, these systems tend to be expensive and will only be found at the larger mask shops. Inspection test masks are needed to help equipment manufacturers evaluate and demonstrate their machines, and to help equipment users calibrate the systems.

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Fig. 1 The stepping distance was measured on row 3, row 8, column 7 and column 9 of ITM (chrome). The Roman Numerals indicate the position of the defective inserts.

Fig. 2 Measurement locations on ITM. The chip spacing is 150 mils in both directions.

Fig. 3 ITM - Stepping error between adjacent 150 mil die.

Row 3 - Upper part of die.

Fig. 4 ITM - Stepping error between adjacent 150 mil die.

Row 3 - Lower part of die.

Fig. 5 ITM - Stepping error between adjacent 150 mil die.

Row 8 - Upper part of die.

Fig. 6 ITM - Stepping error between adjacent 150 mil die.

Row 8 - Lower part of die.

Fig. 7 ITM - Stepping error between adjacent 150 mil die.

Column 7 - Left side of die.

Fig. 8 ITM - Stepping error between adjacent 150 mil die.

Column 7 - Right side of die.

Fig. 9 ITM - Stepping error between adjacent 150 mil die.

Column 9 - Left side of die.

Fig. 10 ITM - Stepping error between adjacent 150 die.

Column 9 - Right side of die.

Fig. 11 Apparent angular orientation of two die as determined from row and column measurements.

No distortion assumed.

Fig. 12 Apparent angular orientation of two die as determined from row and column measurements.

No distortion assumed.

Fig. 13 Manual scan of ITM for defects.

Defective die (3,14) was missed.

Fig. 14 The stepping distance was measured on row 6, row 12, column 7, and column 11 of ITM - B1 (chrome). The Roman Numerals indicate the positions of the defective inserts.

Fig. 15 Measurement locations on ITM-B1. The chip spacing is 150 mils in both directions.

Fig. 16 ITM-B1 Stepping error between adjacent 150 mil die.

Row 6 - Top of die.

Fig. 17 ITM-B1 Stepping error between adjacent 150 mil die.

Row 6 - Bottom of die.

Fig. 18 ITM-B1 Stepping error between adjacent 150 mil die.

Row 12 - Top of die.

Fig. 19 ITM-B1 Stepping error between adjacent 150 mil die.

Row 12 - Bottom of die.

Fig. 20 ITM-B1 Stepping error between adjacent 150 mil die.

Column 7 - Left side of die.

Fig 21 ITM-B1 Stepping error between adjacent 150 mil die.

Column 7 - Right side of die

Fig. 22 ITM-B1 Stepping error between adjacent 150 mil die.

Column 11 - Left side of die.

Fig. 23 ITM-B1 Stepping error between adjacent 150 mil die.

Column 11 - Right side of die.

Fig. 24 ITM-B1 Apparent angular orientation of two die as determined from row and column measurements.

No distortion assumed.

Fig. 25 ITM-B1 Apparent angular orientation of two die as determined from row and column measurements.

No distortion assumed.

Fig. 26 Manual scan of ITM-A1 for defects.

$\pi(14,5)(5,4)$

Fig. 27

Break

Array position (14,5)

Die position (5,4)

Fig. 28

Intrusion

Array position (14,5)

Die position (9,3)

Fig. 29

Bridge

Array position (14,5)

Die position (5,3)

Fig. 30

Opaque extension

Array position (14,5)

Die position (9,7)

II(14,5)(6,4)

Fig 31

Spot - $7.6\mu\text{m}$

Array position (14,5)

Die position (6,4)

II(14,5)(7,9)

Fig. 32

Pinhole - $7.6\mu\text{m}$

Array position (14,5)

Die position (7,9)

II(14,5)(7,4)

Fig. 33

Spot - $6.4\mu\text{m}$

Array position (14,5)

Die position (7,4)

II(14,5)(9,1)

Fig. 34

Pinhole - $6.4\mu\text{m}$

Array position (14,5)

Die position (9,1)

(14,5)(7,1)

Fig. 35

Spot - $5.1\mu\text{m}$

Array position (14,5)

Die position (7,1)

(14,5)(7,6)

Fig. 36

Pinhole - $5.1\mu\text{m}$

Array position (14,5)

Die position (7,6)

$\Pi(14,5)(1,0)$

Fig. 37

Spot - $3.8\mu\text{m}$

Array position (14,5)

Die position (1,0)

$\Pi(14,5)(5,2)$

Fig. 38

Pinhole - $3.8\mu\text{m}$

Array position (14,5)

Die position (5,2)

$\Pi(14,5)(8,5)$

Fig. 39

Spot - $2.8\mu\text{m}$

Array position (14,5)

Die position (8,5)

$\Pi(14,5)(3,9)$

Fig. 40

Pinhole - $2.8\mu\text{m}$

Array position (14,5)

Die position (3,9)

$\Pi(14,5)(2,8)$

Fig. 41

Spot - $2.5\mu\text{m}$

Array position (14,5)

Die position (2,8)

$\Pi(14,5)(4,9)$

Fig. 42

Pinhole - $2.5\mu\text{m}$

Array position (14,5)

Die position (4,9)

Fig. 43

Spot - $1.9\mu\text{m}$

Array position (14,5)

Die position (1,4)

Fig. 44

Pinhole - $1.9\mu\text{m}$

Array position (14,5)

Die position (6,0)

Fig. 45a Opaque spot in column c.

Fig. 45b Double detection of the spot in column c with a dual beam scanner.

Fig. 46a Pinhole in column c.

Fig. 46b Double detection of the pinhole in column c with a dual beam scanner.

Fig. 47a Pinhole at the edge of a mask.

Fig. 47b Single detection of a pinhole at the edge of a mask with a dual beam scanner.

Fig. 48a Opaque spot at the edge of a mask.

Fig. 48b Single detection of an opaque spot at the edge of a mask with a dual beam scanner.

Fig. 49a Single detection of a defect with a dual beam scanner. The location is somewhere in the interior of the mask. This detection is labelled as unidentified.

Fig. 49b The single detection shown in Fig. 36a could be caused by a pinhole in column c if this pinhole is missed during scan #2.

Fig. 49c The single detection shown in Fig. 36a could be caused by an opaque spot in column d if this spot is missed during scan #4.

Fig. 50 CRT readout of defects on a chromium inspection test mask with a dual beam scanner.

Fig. 51 CRT readout of defects on an iron oxide inspection test mask with a dual beam scanner.

TABLE I Die position measurements on ITM (μ in)

Row 3

	Scan	Column Number														Zeroed
		14	13	12	11	10	9	8	7	6	5	4	3	2	1	
Top	#1	0	0	-5	0	-15	-10	-30	-30	-20	-30	-35	-50	-35	-50	0
	#2	0	0	-10	0	-10	-15	-20	-30	-10	-25	-25	-50	-25	-45	0
Bottom	#1	0	-20	-10	-15	-10	-30	-25	-30	-10	-30	-40	-30	-30	-40	0
	#2	0	-20	-15	-15	-20	-25	-30	-30	-10	-30	-40	-35	-35	-45	0

Row 8

	Scan	Column Number														Zeroed
		14	13	12	11	10	9	8	7	6	5	4	3	2	1	
Top	#1	0	-15	-30	-20	-25	-20	-50	-25	-30	-25	-50	-45	-50	-50	5
	#2	0	-10	-30	-25	-30	-20	-50	-20	-30	-20	-50	-50	-50	-55	5
Bottom	#1	0	-30	-20	-50	-15	-40	-45	-40	-20	-45	-30	-60	-30	-20	5
	#2	0	-30	-15	-50	-15	-45	-50	-45	-15	-45	-40	-60	-25	-65	5

TABLE II Die position measurements on ITM (μ in).

Column 7

	Scan	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Zeroed
Right	#1	0	10	10	5	5	5	15	10	20	0	-10	5	-25	-10	5
	#2	0	5	15	0	10	5	20	10	30	0	0	5	-20	-10	5
Left	#1	0	15	10	5	10	20	25	30	10	20	0	10	0	0	5
	#2	0	10	10	0	0	10	15	20	10	10	0	10	0	-5	0

↑
↑
 Reticle II Reticle IV

Column 9

	Scan	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Zeroed
Right	#1	0	0	20	-10	10	15	25	0	10	-5	0	-10	0	-15	5
	#2	0	-5	10	-10	5	10	15	0	5	-5	-5	-15	-5	-15	5
Left	#1	0	15	20	10	10	25	25	20	10	15	0	10	-10	5	0
	#2	0	15	15	10	10	25	25	10	10	10	0	10	-15	0	5

↑
↑
 Reticle IV Reticle III

TABLE III Die position measurements on ITM-B1 (μ in from correct position)

Row 6

	Column Number														Zeroed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Top	0	-10	5	-10	0	-10	10	0	10	0	45	0	10	5	0
Bottom	0	0	0	5	0	10	25	15	10	15	50	10	0	10	0

Reticle II

Reticle III

Row 12

	Column Number														Zeroed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Top	0	-5	5	0	10	10	10	15	15	15	55	10	10	5	0
Bottom	0	10	10	15	10	30	20	35	20	35	70	30	10	30	0

Reticle III

TABLE IV Die position measurements on ITM-B1 (μ in from correct position)

Column 7

	Row Number														Zeroed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Left	0	10	30	10	15	50	20	20	20	15	15	15	20	20	5
Right	0	0	50	5	10	65	10	15	10	10	10	10	10	15	0

Reticle IV

Reticle II

Column 11

	Row Number														Zeroed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Left	0	10	0	20	0	40	10	50	20	30	15	45	20	30	0
Right	0	5	10	10	10	20	25	60	30	10	25	15	25	10	5

Reticle III

Reticle II

Reticle III

TABLE V Verification of Intentional Defects on ITM-B1

% That Did Print

	Chrome	Iron- Oxide
1.9 μ m Spot	37	27%
1.9 μ m Pinhole	0	0
2.5 μ m Spot	100	100
2.5 μ m Pinhole	27%	30%

TABLE VI Verification of Intentional Defects on ITM-A Series

% That Did Print

		1.9 μ m Spot	1.9 μ m Pinhole
ITM-A1	Chrome	60	100
	Iron-Oxide	43	100
ITM-A2	Chrome	10	100
	Iron-Oxide	17	100
ITM-A3	Chrome	7	100
	Iron-Oxide	7	100
ITM-A4	Chrome	0	100
	Iron-Oxide	7	100

TABLE VII Measurement of intentional defects on one die, Reticle II, of four chrome masks.

a) Opaque Spots (μm)

Design Dimension	Measured			
	ITM-A1	ITM-A2	ITM-A3	ITM-A4
7.6	6.8	6.7	6.8	6.8
6.4	5.6	5.4	5.6	5.6
5.1	4.4	4.3	4.3	4.3
3.8	3.3	2.9	3.1	3.2
2.8	2.6	2.4	2.5	2.4
2.5	1.9	1.6	1.3	1.7
1.9	1.0	0.9	0.9	---

b) Pinholes (μm)

Design Dimension	Measured			
	ITM-A1	ITM-A2	ITM-A3	ITM-A4
7.6	7.4	7.5	7.4	7.4
6.4	4.9	4.9	6.2	6.1
5.1	4.8	5.0	6.1	6.0
3.8	3.5	3.6	3.8	3.7
2.8	2.9	3.2	3.0	3.0
2.5	2.4	2.3	2.2	2.3
1.9	1.5	1.3	1.2	1.1

TABLE VIII Scan results with System A on ITM-A1 Chromium Mask.

Array Area	21.99 cm ²
Number of Die	13x13
Double Detection of Holes	130
Double Detection of Spots	154 (0 particles)
Single Detection of Holes	33
Single Detection of Spots	31
Unidentified Defects	<u>194</u>
Total Defects	542
Defect Density	24.64 D/cm ²
Yield	96/169 = 56%

TABLE IX Scan results with System A on ITM-A1 Iron-Oxide Mask

Array Area	21.99 cm ²
Number of Die	13x13
Double Detection of Holes	112
Double Detection of Spots	170 (4 particles)
Single Detection of Holes	26
Single Detection of Spots	22
Unidentified Defects	<u>146</u>
Total Defects	476
Defect Density	21.64 D/cm ²
Yield	98/169 = 57%

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