GCA 4800 DSN wafer stepper

Matthew J. Comard

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GCA 4800 DSW WAFER STEPPER

BY

MATTHEW J. COMARD

A Thesis Submitted
in
Partial Fulfillment
of the
Requirements for the Degree of

MASTER OF SCIENCE
in
Electrical Engineering

Approved by:

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DEPARTMENT OF ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

ROCHESTER INSTITUTE OF TECHNOLOGY

ROCHESTER, NEW YORK

MARCH, 1988
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Date: 07/19/90
PREFACE

A GCA 4800 DSW wafer stepper, donated by Digital Equipment Corporation, arrived at RIT in late 1986. In late 1987, through the assistance of John Steffan from GCA-Troppel, the machine was brought to operation, making possible an engineering evaluation of its condition and capabilities. This evaluation, however, uncovered problems that could not be dealt with without specific GCA-based expertise. It was therefore necessary to seek the assistance of Timothy Tertinger from Digital Equipment corporation who provided necessary information for the electrical and mechanical optimization of the autofocus system, and for general maintenance procedures. Since that time, work steadily proceeded which culminated in this brief, yet informative dissertation.
RIT'S NEW GCA 4800 DSW WAFER STEPPER

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ABSTRACT

The following work lays the foundation for the further development of high resolution photolithography at RIT using a GCA 4800 DSW wafer stepper. It has been determined experimentally that the machine is presently capable of printing 1.4 micrometer lines and spaces with an exposure latitude of 10% over the entire wafer. The stage precision is within the ± 0.2 micron spec, and the system registration is within the ± 0.35 micron specification. The stage orthogonality has been corrected so that it is within the ± 0.5 arc second specification. Optical distortion is within its spec of ± 0.2 microns, while lens reduction and die rotation were found to be slightly out of their specs of ± 0.2 microns and ± 0.1 microns respectively.

It is intended that this machine be used to produce devices using three micron design rules, and considering these results, that will not be a problem.
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CHAPTER I
INTRODUCTION

The Microelectronic Engineering Department at the Rochester Institute of Technology stresses the study of photolithography as applied to the fabrication of integrated circuits. This was originally done due to the strong program in photographic science available at RIT. By merging this with electrical engineering courses, a strong interdisciplinary program was established, producing students versed in all aspects of integrated circuit development, from design and device physics to photo- and plasma chemistry. One major drawback to the program was the absence of any high resolution exposure tools. The GCA 4800 Wafer stepper has solved that problem.
CHAPTER II
HISTORICAL REVIEW

The direct-step-on-wafer (DSW) projection aligner from GCA was introduced in the late 1970's during the peak in popularity of the 1:1 projection scanner from Perkin-Elmer. Several technical innovations made the GCA successful enough to capture a significant market share (1). The schematic of the illuminator optics in Figure 2.1 shows only one of the four identical branches used to collect radiation. The fiber bundle shown in Figure 2.2 unifies the radiation from each of the four sets of collection optics and delivers it to the condenser optics of Figure 2.3. The 350-W (high-pressure) mercury-arc lamp produces 4mW/sq-cm of g-line radiation in the object area. The elliptically shaped fiber bundle was designed to match the size and shape of the mercury-arc image, as well as to be compatible with the size of the entrance pupil of the micro-objective and its distance from the object plane on the output end (2).

Surprisingly, this illuminator is seven, not four times more intense than conventional sources. This added increase in intensity is due to gains in two areas. First, a conventional heat filter was replaced with a dichroic mirror increasing the g-line intensity 15% (from 80% to 95%). Secondly, the length of the fiber bundle was shortened which increased its g-line intensity while retaining the rotary integration function provided only by fibers (3).
FIGURE 2.1

FIGURE 2.2

FIGURE 2.3
Improved illumination, though important because conventional sources would have resulted in impractically long exposure times for non-scanning processes, was not the major reason for pursuing the new technology. The 10:1 reduction ratio of the GCA wafer stepper was the key to its success. This degree of reduction meant that (4):

1) Stepping each die permits correction for wafer distortion.

2) Vulnerability to dust and related defects is considerably reduced.

3) Resolution capability is extended 30 to 40% beyond 1:1 scanning-exposure aligners using conventional mercury wavelengths.

4) Stepping permits easier exposure of large diameter (6-in) wafers.

5) A chrome reticle may be used in place of a conventional mask, increasing the "starting" resolution.

Here at RIT, we are especially concerned with 2 and 5 above. Number 2 is important for two reasons: first, dust
HISTORICAL REVIEW

will do less damage to the image because any particles will be shrunk by a factor of ten, so they may not even be resolved; second, since the reticle will not be in contact with the wafer as is done presently, the dust will do less damage to the object(reticle). Number 5 is important because it will allow the manufacture of silver halide reticles capable of printing 1.25 micron lines without the use of a direct write e-beam system. In reality, though, RIT is only concerned with 3 micron lines at present.

This work covers the following topics which will allow full use of the wafer stepper:

1) Baseline Correction.
2) Resolution
3) Exposure Latitude
4) Autofocus Precision
5) Stage Precision
6) System Registration
7) Lens Reduction
8) Optical Distortion
9) Die Rotation
10) Stage Orthogonality

Along with these tests will be discussions on image quality, periodic maintenance practices, important system commands for proper setup and execution of jobs, and reticle fabrication procedures.
CHAPTER III
SYSTEM SOFTWARE OVERVIEW

This section will deal with commands of the system control software that enable the user to set up and run jobs on the 4800 DSW. It is by no means a replacement for the DSW Wafer Stepper System Control Manual (5), but is intended as a condensed reference of the most important and frequently used commands.

All of the software commands are set up to prompt the user for the necessary details, and no special computer programing language is needed to use this machine. In the following discussions, an attempt will be made to explain each of the prompts that the user will encounter. The commands to be discussed are the following:

1) MODE
2) SPEC
3) EDIT
4) EXPO
7) EXEC
8) LISTF
THE MODE COMMAND (6)

"MODE" is a global (or machine level) command that allows the user to change certain characteristics to be used by all jobs run on the system. This command should be used either when prompted to by the system in the form "MODE COMMAND MUST BE ISSUED", or when there is a need to change the Baseline Correction or Orthogonality. The system prompts the user with the following questions when the MODE command is issued by the user at the keyboard.

1) METRIC OR ENGLISH UNITS? (*M/E):

2) SCALE CORRECTIONS:
   - X, PPM (-128<P<+128):
   - Y, PPM (-128<P<+128):

3) ORTHOGONALITY, PPM (-128<P<+128):

4) CHUCK SIZE (A,B,2,3,82,100,125):

5) BASELINE CORRECTION (MMS)
   - X:
   - Y:

6) OBJECTIVE SPACING:

7) ROUND TUBE COMPATIBILITY (*Y/N):

8) LIBRARY USER ID & DISK DESIRED? (Y/*N):

9) USE AUTO WAFER HANDLER? (*Y/N):

10) LOADING CORRECTION
    - X:
    - Y:
11) USE AUTOMATIC WAFER ALIGNMENT? (Y/*N):
12) USE PROGRAMMABLE FOCUS CONTROL? (*Y/N):
13) SET FOCUS SETTING IN MODE? (Y/*N):

***** HISTORY FILE PARAMETERS *****
14) LOG IN, LOG OUT, BOOTS, SHUTDOWNS, AND LASER ORIGINATION (Y/*N):
15) WAFER TRANSFER TIMES? (Y/*N):
16) SYSTEM FAULT MESSAGES? (Y/*N):
17) 'EXEC' PARAMETERS? (Y/*N):
18) 'EXPO' AND 'AEXPO' PARAMETERS? (Y/*N):
19) OPERATOR COMMENTS? (Y/*N):
20) 'MODE' PARAMETERS? (Y/*N):
21) SYSTEM LEVEL INTERACTION? (Y/*N):
22) WAFER BATCH NAMES? (Y/*N):

***** END HISTORY FILE PARAMETERS *****
23) WRITE LOCK DX0? (Y/*N):
24) WRITE LOCK DX1? (Y/*N):
25) SAVE MODE DATA ON DISK? (*Y/N):

As the user scrolls through this file, he will notice that some of the questions have values already assigned to them. As with any of these files, a simple carriage return will store the assigned value and move on to the next line if no change is desired. Yes/No questions have an asterisk in front of the default selection. The following is an explanation of the MODE file.
1) METRIC OR ENGLISH UNITS

This question allows the user to choose which system to run all subsequent jobs on. Metric is always chosen, and is the default value.

2) SCALE CORRECTIONS

This question allows the user to specify wafer scale corrections at the machine level in order to match one machine to another. Wafer scaling will be discussed later, but it will not be necessary to consider it here because there is no machine to match it to yet.

3) ORTHOGONALITY

This allows the user to correct for lack of perfect orthogonality (90 degrees) in X and Y stage motion. PPM stands for "parts-per-million", and is a normalized unit of measurement. As a simple example, consider the case of wafer distortion where the diameter changes by 0.001 mm. The nominal diameter is 100 mm, so the distortion in terms of parts-per-million is 0.001/100=0.00001 or 10 PPM. Measurement and correction of orthogonality error will be outlined in detail in the section explaining the STAGE ORTHOGONALITY TEST PROCEDURE.

4) CHUCK SIZE

The chuck size for the RIT stepper is 100 mm.
5) BASELINE CORRECTION
Baseline Correction compensates for error in the relative positioning between the optical column and the alignment microscope. This is explained more thoroughly later in the section explaining The BASELINE CORRECTION TEST PROCEDURE.

6) OBJECTIVE SPACING
The nominal or manufactured value for this stepper is 76.2 millimeters, but this changes constantly due mostly to environment effects. Determination of this value will also be discussed later.

7) ROUND TUBE COMPATIBILITY?
No explanation has been found for this question. Suffice it to say that for this machine, the answer should be "YES".

8) LIBRARY USER ID & DISK DESIRED?
This is only important if each user is to save his own information on his own floppy disk. This will not be necessary.

9) USE AUTO WAFER HANDLER?
The default to this is yes, because this stepper would not accurately pre-align wafers without this AWH system.

10) LOADING CORRECTION
This sets the location that the stage will stop to pick up the wafer after pre-alignment.
11) USE AUTOMATIC WAFER ALIGNMENT?
    There should be no need to use this since it is simple to use manual alignment for small scale production.

12) USE PROGRAMMABLE FOCUS CONTROL?
    Programmable Focus Control, or PFC, maintains a focus setting, as entered at the keyboard, across wafer variations and topography to some degree.

13) SET FOCUS SETTING IN MODE?
    This will be set during job execution only.

14-22) HISTORY FILE PARAMETERS
    History Files store selected information for review by the system supervisor. This may be important for industrial applications, but will not be necessary here.

23) WRITE LOCK DX0?
    This prevents the user from writing to the hard disk. The default to this is "NO" because the hard disk will be used for all storage.

24) WRITE LOCK DX1?
    This prevents the user from writing to the floppy disk. The floppy disk is rarely used, and there is no need to lock it.

25) SAVE MODE DATA ON DISK
    This saves the corrections and additions made on the hard disk.
THE SPEC[ify] COMMAND (7)

This command allows the user to create jobs that will operate the stepper, and expose wafers as desired. As the user scrolls through the file, the following prompts will be encountered.

1) METRIC OR ENGLISH UNITS? (*M/E):

2) COMMENT:

3) TOLERANCE (1,2,*3,4,5,6):

4) SCALE CORRECTIONS
   - X,PPM (-128<P<+128):
   - Y,PPM (-128<P<+128):

5) ORTHOGONALITY,PPM (-128<P<+128):

6) WAFER DIAMETER:
   <<< ARRAY PARAMETERS >>>

7) STEP SIZE IN X:

8) *C-OUNT OR S-PAN:
   
   HOW MANY COLUMNS? (corresponds to an input of C at line 8)
   OR...

   HOW WIDE? (corresponds to an input of S at line 8)

9) STEP SIZE IN Y:

10) *C-OUNT OR S-PAN:
    
    HOW MANY ROWS? (corresponds to an input of C at line 10)
    OR...

    HOW HIGH? (corresponds to an input of S at line 10)
11) TRANSLATE ORIGIN
   IN X:
   IN Y:
12) DISPLAY? (Y/*N):
13) LAYOUT? (Y/*N):
14) ADJUST? (Y/*N):
   <<< ALIGNMENT PARAMETERS >>
15) STANDARD KEYS? (*Y/N):
16) KEY OFFSET
   IN X:
   IN Y:
17) EPI SHIFT
   IN X:
   IN Y:
   <<< PASS >>
18) NAME(<CR> TO EXIT PASS SETUP):
19) COMMENT:
20) EXPOSURE (SEC.):
21) FOCUS SETTING:
22) SHIFT
   IN X:
   IN Y:
23) A-RRAY, P-LUG, OR L-ABEL:
   DROP OUTS:
     R: (corresponds to a response of A at line 23)
PLUGS:

R: (corresponds to a response of P at line 23)

<< END PASS SET-UP >>

24) SAVE PASS? (*Y/N):

<< PASS >>

25) NAME (<CR> TO EXIT PASS SETUP):

26) OUTPUT DEVICE SPECIFICATION:

The following is an explanation of the questions supplied by the system when the SPEC command is issued:

1) METRIC OR ENGLISH UNITS?

A simple carriage return here will select metric units, and the system will respond with:

   METRIC JOB

2) COMMENT:

This is a good place to describe the nature of the job, and to list the names of the associated passes. Passes are the parts of the job that describe the exposure and focus conditions, as well as the specific locations of the exposures (called plugs), or absence of exposures (called dropouts).

3) TOLERANCE (1,2,*3,4,5,6):

Tolerance defines an acceptable range of position and speed values that the stages must fall within before the shutter opens. The tightest tolerance is 1, and the
default is 3.

4) SCALE CORRECTIONS

Scale corrections let the user take into account wafer expansion due to oxidation or other high temperature processes. The user can enter different values for X and Y thereby correcting for anisotropic expansion.

5) ORTHOGONALITY

Orthogonality correction here at the batch level is for mix and match capability. It is used to compensate for skew distortions between exposure tools. The correction for orthogonality here at RIT should be entered only in MODE.

6) WAFER DIAMETER:

This machine uses 100 mm (4 in) wafers.

7) STEP SIZE IN X:

This will be the horizontal distance in millimeters between the centers of the die being stepped across the wafer. This step size should be bigger than the width of the die itself, and should be a factor of the 76.2 mm objective spacing. Take as an example, die size of 5 mm. A step size in X satisfying both of the above conditions would be 5.08 millimeters.

8) *C-OUNT OR S-PAN:

Entering "C" for "COUNT" will cause the system to ask for the number of columns. In the above example, it
will be necessary to specify at least 15 columns, because this will place die directly under the alignment microscope objectives (separated by (5.08)x(15)=76.2mm) for proper alignment of subsequent layers.

Entering "S" for "SPAN" will cause the system to ask how wide of a distance in the X direction should be covered with exposures. An acceptable answer for the above example would upwards of (76.2)+(5.0)=81.2mm.

Entering "A" for "ALL" would cover all the usable width with exposures.

9) STEP SIZE IN Y:
   This is generally the same as the step size in X.

10) *C-OUNT OR S-PAN
   Again, the usual response for this is identical to that for X.

11) TRANSLATE ORIGIN
   This allows the user to offset the array in X and Y in order to maximize the number of whole die images on the wafer. This is a rather extravagant for our purposes, and should be ignored.

12) DISPLAY?
   A response of YES to this question will cause a pictorial display of the array to be shown on the screen, and it looks like this (take for example a 5 X 5 array):
13) LAYOUT?

A response of YES to this will provide the following output corresponding to the previous example.

ARRAY HAS: CENTERED:

5 ROWS . 3
5 COLS  3

In other words, the tabulation gives the number of rows and columns, and the location of the center of the array. Other information is given, but it is not important for our purposes.

14) ADJUST?

This will re-arrange the display, but it is also not important.

15) STANDARD KEYS?

The default answer of YES to this question causes the system to choose its own alignment die. Except where noted in special test procedures covered later, the default will always be used.
OFFSET CONVENTIONS

1. Sign conventions for key offset are shown as X, Y pairs.

FIGURE 3.1
16) KEY OFFSET
This is the distance in X and Y from the die center to the alignment targets in millimeters. Offset conventions are shown in Figure 3.1.

17) EPI SHIFT
When an epitaxial deposition has been performed, a lateral shift will be observed between the substrate and the surface. This shift may be compensated for with this correction. EPI SHIFT conventions are the same as the offset conventions shown in Figure 3.1.

18) NAME(<CR> TO EXIT PASS SET-UP):
At least one pass must be specified. The name should be at most two 6-character strings. The name may be, and it is suggested that it should be, as simple as "1".

19) COMMENT:
This is a good place to put a reminder to yourself as to certain details such as which reticle to use and so forth.

20) EXPOSURE (SEC.):
This will be assigned when the wafers are to be exposed, so it should be skipped here.

21) FOCUS SETTING:
This will also be assigned when the wafers are to be exposed, and should be skipped over at this point.

22) SHIFT
As with the shift discussed previously, this should be skipped.

23) A-RRAY, P-LUG, OR L-ABEL:

"A" for "ARRAY" will cause the system to ask if there are any dropouts in the following format:

DROPOUTS:
R:

At this point, a simple return will tell the machine that an array should cover the entire exposure area with no room for test structures and so forth. This is what will be done for all device runs.

"P" for "PLUG" will cause the system to ask for specific row and column numbers, as well as offsets, for isolated exposures. This is used for some of the test procedures that will be discussed later.

"L" for "LABEL" is for photorepeater applications, and should not be requested.

24) SAVE PASS?

No explanation necessary.

25) NAME(<CR> TO EXIT PASS SET-UP):

This allows the user to create another pass, or to end the job specification by typing return.

26) OUTPUT DEVICE SPECIFICATION:

A carriage return defaults writing the output to the hard disk.
THE EDIT COMMAND (8)

The EDIT command allows the user to modify previously specified jobs. This command tells the computer to call up the appropriate job, and asks the user if it is to be updated. It then allows the user to scroll through the job as when the SPEC Command is used. When a line is encountered that needs to be updated, the appropriate response is entered at that line, followed by a carriage return. For lines that need no update, a simple carriage return will store the existing information. More information can be found by referring to the DSW Wafer Stepper System Control Manual (6).

THE EXPO COMMAND (9)

EXPO is used to expose a wafer with variable exposure values and/or variable focus settings. This is used for running focus and exposure evaluations at the beginning of each new run or test, or to set up a series of variable exposures at optimum focus for evaluation with the development rate monitor. The following is an explanation of what will be encountered at the computer terminal when the EXPO Command is invoked:

: EXPO
SYSTEM SOFTWARE OVERVIEW

1) INPUT FILE SPECIFICATION:
   ******************************************************************
2) { SOME KIND OF COMMENT APPEARS HERE }
   ******************************************************************
3) PASS:
4) STARTING ROW:
5) ENDING ROW:
6) STARTING COLUMN:
7) ENDING COLUMN:
8) OVER A-ARRAY OR *ROW:
9) STARTING EXPOSURE (SEC) = 0.000
10) INCREMENTAL EXPOSURE (SEC) = 0.000
11) FOCUS SETTING: {if the reply to 7 was "A"}
    or
    INITIAL FOCUS SETTING: {if the reply to 7 was "R"
    or <cr>}
    FOCUS INCREMENT:
12) ORIGINATING PFC STEPPER MOTOR...COMPLETE
13) LASER RETUNE IN PROGRESS...COMPLETE
14) ORIGINATING LASER COUNTER...COMPLETE
15) START AWH

From this point on, there is interaction between the computer and the stepper itself, and this will be explained in Chapter IV. This section will deal only
with what the user must interact with at the keyboard to start the job. The following is an explanation of the above EXPO dialogue.

1) INPUT FILE SPECIFICATION
To use the EXPO command, you must use a job stored in memory, or specify your own job. Enter that job name here.

2) COMMENT SECTION
This comment was entered when the job was specified, and no response is necessary.

3) PASS
Enter name of pass associated with the above job.

4) STARTING ROW
Enter the number of the first row to be exposed.

5) ENDING ROW
Enter the number of the last row to be exposed.

6) STARTING COLUMN
Enter the number of the first column to be exposed.

7) ENDING COLUMN
Enter the number of the last column to be exposed.

8) OVER ARRAY OR *R-OW

ARRAY: In array mode, the successive exposures are incremented by a fixed amount over the entire array, but focus remains the same. An example is shown in Figure 3.2.
EXPO COMMAND, ARRAY MODE

<table>
<thead>
<tr>
<th>Rows</th>
<th>Columns</th>
</tr>
</thead>
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<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

- **Focus Fixed at 251**

**FIGURE 3.2**

R3, C4 = Row/column position of starting exposure
.150 = Starting exposure (sec.)
.010 = Incremental exposure (sec.)
--- = Boundary of test array
EXPO COMMAND, ROW MODE

Columns

<table>
<thead>
<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
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</tr>
<tr>
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<td>.150</td>
<td>.160</td>
<td>.170</td>
<td>.180</td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Focus = 251</td>
<td>.150</td>
<td>.160</td>
<td>.170</td>
<td>.180</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>Focus = 254</td>
<td>.150</td>
<td>.160</td>
<td>.170</td>
<td>.180</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>Focus = 257</td>
<td>.150</td>
<td>.160</td>
<td>.170</td>
<td>.180</td>
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</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rows

R3, C4 = Row/column position of starting exposure
.150 = Starting exposure (sec.)
.010 = Incremental exposure (sec.)
--- = Boundary of test array

FIGURE 3.3

23B
R-OW: Row is the default response. In row mode, the exposure time can be varied from column to column, while the focus setting is varied from row to row. An example is shown in Figure 3.3.
9) STARTING EXPOSURE (SEC)

This is the exposure time in seconds that the array should start with.

10) EXPOSURE INCREMENT (SEC)

This is the value that will be added on to each successive exposure in the array.

11) FOCUS SETTING

This is the constant focus setting using ARRAY mode.

INITIAL FOCUS SETTING

This is the starting focus setting used in ROW mode.

FOCUS INCREMENT

This is the value that will be added on to each successive row of the array when using ROW mode. This value may be positive or negative.

12) ORIGINATING PFC STEPPER MOTOR

The PFC or Programmable Focus Control is what keeps the wafer at the proper distance from the optical assembly as specified by the user "programmed" focus setting. This line needs no response from the user. When the origination is complete, the computer will note this and move on to...

13) LASER RETUNE IN PROGRESS

No information could be found to explain what this
means, but at any rate, no reply is necessary from the user. When the retune is complete, the computer notes this and moves on to...

14) ORIGINATING LASER COUNTER

At this point, the stages can be observed moving back to the left rear corner of the machine, as the laser determines the relative position of the origin in terms of "laser counts".

*** NOTE THAT 12-14 WILL ONLY OCCUR FOR THE FIRST RUN AFTER SYSTEM START-UP. ***

15) START AWH

This prompts the user to load the wafers into the machine, and to run the job as will be explained in Chapter IV of this report.

THE EXEC[ute] COMMAND (10)

EXEC, like EXPO is a command that is used to run a previously specified job. Unlike EXPO, EXEC is not used with test wafers, but is used to expose arrays of constant focus and exposure across a wafer for the purposes of device fabrication. The following is an explanation of what will be encountered at the computer terminal when the EXEC command is invoked.

: EXEC
SYSTEM SOFTWARE OVERVIEW

1) INPUT FILE SPECIFICATION

******************************
{ some kind of comment is printed here }
******************************

2) PASS

******************************
{ some kind of comment is printed here }
******************************

3) EXPOSURE (SEC):

4) (*G-O, S-KIP, M-ODIFY EXPOSURE & GO):

5) FOCUS SETTING:

6) ORIGINATING PFC STEPPER MOTOR...COMPLETE

7) LASER RETUNE IN PROGRESS...COMPLETE

8) ORIGINATING LASER COUNTER...COMPLETE

9) START AWH

The following is a discussion of the EXEC dialogue:

1) INPUT FILE SPECIFICATION

In order to invoke EXEC, a job must have been previously specified and stored in memory.

2) PASS

Enter the name of the pass associated with this job.

3) EXPOSURE (SEC)

This is the pre-programmed exposure time in seconds as entered when the job was specified. Since exposure
times can vary radically from day to day and batch to batch, it is best not to specify exposure time until the time of exposure.

4) (*G-O, S-KIP, M-ODIFY EXPOSURE & GO)

The default for this is "G" for "GO", but since the exposure will probably vary, "M" for "MODIFY" will most often be used. This will allow entry of the optimum exposure time as determined by the most recent focus/exposure test.

5) FOCUS SETTING

Enter the focus setting as determined by the most recent focus/exposure test.

6-8) SEE EXPLANATION IN EXPO COMMAND SECTION

9) START AWH

At this point, the user loads the wafers, runs the job. This will be discussed in more detail in the tutorial section.

THE LISTF COMMAND (11)

This command allows the user to view all files in memory.
CHAPTER IV

TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

This section describes a step-by-step approach on how to use the GCA stepper for fabrication of a pmos device with a die size of 5000 by 5000 microns.

I. SYSTEM START-UP

Before the system is turned on, it is very important to make sure the arc lamp is on. This is important because starting of the lamp after the system has been turned on may cause electronic damage to the computer and related systems due to powerful current spikes during ignition. If the lamp is not on, check to see if the lamp may be used by comparing the numbers in the window labeled 4 in Figure 4.1 to the number posted nearby on the front of the machine. If the difference between the two numbers is less than 50, inform your lab instructor, so that the lamp may be replaced. If the difference is greater than 50:

1) Turn on the power to the arc lamp (1 in Figure 4.1). The light next to the switch should turn on.

2) Press the start switch (2 in Figure 4.1), and hold until the start light (3 in Figure 4.1) turns on.

3) Turn on the computer control console (6 in Figure 4.1) by rotating the computer power knob (1 in Figure 4.2) clockwise from the DC OFF position to the DC ON position.

4) Clear the address data window (5 in Figure 4.2) by pressing the CLR button (2 in Figure 4.2).
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

FIGURE 4.1
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

FIGURE 4.2
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

5) Enter the starting address of 171000 by pressing the numerical buttons on the computer control console.

6) Load the address by pressing the LAD button (3 in Figure 4.2).

7) Start the computer by simultaneously pressing CNTRL and START (4 in Figure 4.2).

8) There will be a beep, and on the CRT (7 in Figure 4.1), the following will be displayed:
   
   DRV? (there will be a pause)
   800 WAFER STEPPER SYSTEM V04.03
   DISK SETUP IN PROGRESS... (pause)
   DISK NOT READY (pause) SETUP COMPLETE
   FUNCTION? 0c

9) Press delete twice to remove the "0c", press return, and then the following will be displayed:
   
   ENTER TIME & DATE (HH:MM:SS DD/MM/YY):

10) Enter the time and date in the format shown, and press return. The system prompt (:) will then be displayed.

11) Log in at the system prompt:
   
   : LOG IN $!!$DX0 (the last character is zero)

At this point, you may do any number of operations as explained in the COMMANDS section of this report. For exposing the first level (diffusion) of the pmos process, the first thing to do is perform a focus/exposure test on one of the two oxide control wafers that each run should
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

have. Two are suggested in case the results of the first focus/exposure test warrant the running of a second.

II. DETERMINATION OF OPTIMUM FOCUS AND EXPOSURE

This test will pinpoint the optimum focus and exposure settings for your particular oxide and photoresist combination.

1) Open the front doors to the stepper environmental chamber, and access the reticle platen by first rotating the "SPINDLE LOCK" knob on the right side of the machine's central column counterclockwise, and then moving the illuminator system to the left.

2) Place the (clean) ETMS-1 Test Reticle on the platen, chrome side down, and center it manually.

3) Turn on the platen vacuum. The control for this can be found on a panel which at this time is located below the illuminator head.

4) Bring the illuminator head back over the platen/reticle combination, and rotate the spindle lock clockwise.

5) Place the clean, resist coated control wafer directly in front of the input wafer cassette on the air track.

6) Return to the computer keyboard, and at the system prompt, type "EXPO FOCEX SET". This will enable the running of a job named FOCEX SET. This job allows the user to set up an array in which each of 9 columns has a different exposure time, and each of 9 rows has a different focus setting. A
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

summary of important details follows (USER RESPONSES ARE BOLD AND UNDERLINED):

PASS: 1
STARTING ROW: 1
ENDING ROW: 9
STARTING COLUMN: 1
ENDING COLUMN: 9
OVER A-RRAY OR *R-OY: <CR>
STARTING EXPOSURE (SEC): 0.3 (this is a helpful suggestion, but things change with time and with process conditions)
EXPOSURE INCREMENT (SEC): 0.05
INITIAL FOCUS SETTING: 225 (again, just a suggestion)
FOCUS INCREMENT: 5

At this time, the system will undergo routines discussed in the COMMANDS section, and finally end with "START AWH".

Discussion of Button Box Controls: (12)

Figure 4.3 shows a diagram of the Automatic Wafer Handler (AWH) "button box". The following list explains the each control:

1) LAMP ON/OFF PUSHBUTTON

Turns the alignment illumination lamp on and off.
FIGURE 4.3
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

2) LAMP INTENSITY CONTROL KNOB
This knob controls the intensity of the alignment illumination.

3) FOCUS CONTROL KNOB
This is used to bring the wafer into best focus when using either the microscope or the television monitor.

4) THETA JOYSTICK
This is used to rotate the wafer about its theta axis for minor angular adjustments.

5) X/Y JOYSTICK
This is used to move the wafer forward/backward and left/right for X and Y alignment position adjustments.

6) EXP (EXPOSE) BUTTON
This is used after the wafer has been aligned and scaled to expose the wafer.

7) HLT (HALT) BUTTON
This will stop operation after the current pass has finished exposing.

8) WS (WAFER SCALE) BUTTON
This button is used after the X/Y and THETA targets have been aligned as best as possible. Press WS, and move the left cross in the X direction only until is aligned. Pressing EXP will now calculate the required scaling in PPM and expose the wafer.
9) RTY (RETRY) BUTTON
This is to be used when prealignment is poor, and alignment is made impossible.

10) MAN (MANUAL) ALIGN BUTTON
This button is used in conjunction with the START/CONTINUE button to activate manual mode when the automatic wafer aligner is turned on (the AWA is usually left off).

11) RES (RESET) BUTTON
The RESET command stops the AWH immediately, turns off vacuum, initializes the program count, and awaits a START command.

12) REJ (REJECT) BUTTON
The REJECT button allows the user to remove a wafer from the chuck using the AWH. The wafer is returned to the prealign station, and vacuum is turned off to allow removal of the wafer.

13) ELV (RAISE) BUTTON
Pressing this will raise the input and output carriers.

14) S/C (START/CONTINUE) BUTTON
When pressed at the start of a run, START/CONTINUE initiates AWH operation. This includes indexing the carriers, transferring a wafer to the prealign station, prealigning the wafer, and notifying the control program that a wafer is ready for transfer to the wafer chuck. When this button is pressed after the HALT button, or after an AWH Time Out, the
A WH resumes operation and completes its cycle.

15) 1ST L (FIRST LAYER START) BUTTON
When this is pressed in conjunction with the START/CONTINUE button, exposure takes place without alignment.

16) LOW WA​FER VAC Warning Light
This warns the user that chuck vacuum is low.

17) Press the S/C button on the button box (Figure 4.3) to the left of the keyboard. This is the START/CONTINUE button. This action will enable the Automatic Wafer Handler, and load the wafer onto the prealigner where the machine will find and position the wafer's major flat. After the flat has been found, the transfer arm picks up the wafer, and places it on the chuck. The stages move the wafer under the optical column where a focus check is made, and then bring the wafer under the objectives of the alignment microscope for alignment. Actually, no alignment is needed, and this step could have been by-passed by simultaneously pressing the S/C and 1ST L buttons on the button box (Figure 4.3). It is best not to use this procedure (which notifies the computer that this is a first level exposure), because it will not give the user a chance to check to see if the pre-alignment was done properly. When the wafer stops under the alignment microscope, the user should check to see if the major flat
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

of the wafer is parallel to the flat on the chuck. If they are obviously not parallel, pressing the RTY button on the button box (Figure 4.3) will tell the computer to RE-TRY the pre-alignment process again.

18) Press the EXP button on the button box (Figure 4.3) to start the exposure process. The stages move the wafer to the 0,0 position located at the far left "corner" of the wafer with the flat towards the rear of the machine.

19) When the array has been exposed, and the stages returned to the loading position, press the RES button on the button box (Figure 4.3), and carefully remove the wafer from the chuck with your tweezers (preferably designed for 4 inch wafers).

At this point, the wafer should be developed carefully, and observed under a good microscope. The Nanoline microscope is a good choice.

20) With the major flat to the rear of the microscope, and using the 40X objective, search the wafer and find a die that has 1.4 micron lines and spaces resolved.

21) Using the 10X objective, proceed to focus star on that die, and travel up and down that column until the star with the tightest ring pattern is found. If several focus stars appear identical, choose the center one.

22) Now, with the 40X objective, travel back and forth
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

along that row, and determine which die has the best 1.4 micron linepairs.

23) Record the row and column numbers of the best die, and return to the stepper.

24) The CRT screen of the stepper is now asking for the row number of the best die. Enter what you found and press return.

25) Now enter the column number of the best die and press return.

26) The computer will return with the optimum focus and exposure settings to be used for this level.

III. EXPOSURE OF THE FIRST LEVEL

1) Specification of diffusion level job. The following is a step-by-step procedure for creating a new job to expose a PMOS5000 diffusion level. At the keyboard:

:SPEC P5000 DIFF (user inputs are bold and underlined)

METRIC OR ENGLISH UNITS? (*M/E): <CR>

METRIC JOB

COMMENT: DIFFUSION LEVEL EXPOSURE FOR PMOS5000

TOLERANCE (1,2,*3,4,5,6): <CR>

SCALE CORRECTIONS

X,PPM (-128<P<+128): <CR>

Y,PPM (-128<P<+128): <CR>
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

ORTHOGONALITY, PPM (-128<P<+128): <CR>

WAFFER DIAMETER: 100

<< ARRAY PARAMETERS >>

STEP SIZE IN X: 5.08

Discussion is necessary at this point, because the reader may be wondering where this step size came from. Alignment marks are required to be 76.2mm apart, and this is done by arranging the step size in X and the number of columns so that this condition exists. With a step size in X of 5.08mm over 16 columns, the separation of any two matching points on the outermost die will be 76.2mm.

*C-OUNT OR S-PAN: <CR>

HOW MANY COLUMNS: 16

STEP SIZE IN Y: 5.08

HOW MANY ROWS: 16

TRANSLATE ORIGIN

IN X: <CR>

IN Y: <CR>

DISPLAY: <CR>

LAYOUT: <CR>

ADJUST: <CR>

<< ALIGNMENT PARAMETERS >>

STANDARD KEYS? (*Y/N): <CR>

KEY OFFSET
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

IN X:  <CR>
IN Y:  <CR>

EPI SHIFT
IN X:  <CR>
IN Y:  <CR>
<< PASS >>

NAME (<CR> TO EXIT PASS SETUP): 1

COMMENT: MAKE SURE CORRECT RETICLE IS IN. NO ALIGNMENT NECESSARY.

EXPOSURE (SEC): <CR>
FOCUS SETTING: <CR>

SHIFT
IN X:  <CR>
IN Y:  <CR>

A-ARRAY, P-LUG, OR L-ABEL: A

DROPOUTS:
R: <CR>
<< END PASS SETUP >>

SAVE PASS? (*Y/N): <CR>
<< PASS >>

NAME (<CR> TO EXIT PASS SETUP): <CR>
OUTPUT DEVICE SPECIFICATION: <CR>

The next line will appear if this file is in memory already.

FILE ALREADY EXISTS. REPLACE WITH NEW FILE? (*Y/N): <CR>
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

2) EXECution of the diffusion level job. The following is a step-by-step procedure for exposing wafers according to the job P5000 DIFF. At the keyboard:

:EXEC P5000 DIFF (user inputs are bold and underlined)

*****************************************************************************
DIFFUSION LEVEL EXPOSURE FOR PMOS5000
*****************************************************************************

PASS: 1

*****************************************************************************
MAKE SURE CORRECT RETICLE IS IN. NO ALIGNMENT NECESSARY
*****************************************************************************

EXPOSURE (SEC):
(*G-O, S-KIP, M-ODIFY & GO): (input optimum exposure from the focus/exposure test)

FOCUS SETTING: (input optimum focus from focus/exposure test)

START AWH

3) At the button box, press S/C to load the first wafer onto the prealigner.

4) Once the wafer is on the chuck, check to make sure that the major flat of the wafer is very nearly parallel to the flat of the wafer chuck. If not, press RTY on the button box.
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

until the wafer is prealigned properly.

5) When satisfied with prealignment, press EXP on the button box to expose the wafer.

6) Expose all device wafers in the lot, and move on to subsequent processing steps.

IV. EXPOSURE OF THE SECOND LEVEL

Again with this level, it is important to run a new focus exposure test on the control wafers because the new substrate has changed the processing conditions. So do that now before we go on to specify the second level job.

1) SPECification of the oxide level job. At the keyboard:

:SPEC P5000 OXIDE (user inputs are bold and underlined)

METRIC OR ENGLISH UNITS? (*M/E): <CR>

METRIC JOB

COMMENT: OXIDE LEVEL EXPOSURE FOR PMOS5000

TOLERANCE (1,2,*3,4,5,6): <CR>

SCALE CORRECTIONS

  X,PPM (-128<P<+128): <CR>
  Y,PPM (-128<P<+128): <CR>

ORTHOGONALITY,PPM (-128<P<+128): <CR>

WAFER DIAMETER: 100

<< ARRAY PARAMETERS >>
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

STEP SIZE IN X: 5.08
*C-OUNT OR S-PAN: <CR>

  HOW MANY COLUMNS: 16

STEP SIZE IN Y: 5.08

  HOW MANY ROWS: 16

TRANSLATE ORIGIN

  IN X: <CR>

  IN Y: <CR>

DISPLAY: <CR>

LAYOUT: <CR>

ADJUST: <CR>

<< ALIGNMENT PARAMETERS >>

STANDARD KEYS? (*Y/N): <CR>

KEY OFFSET

  IN X: 2.35

  IN Y: 0.0

EPI SHIFT

  IN X: <CR>

  IN Y: <CR>

<< PASS >>

NAME (<CR> TO EXIT PASS SETUP): 1

COMMENT: MAKE SURE CORRECT RETICLE IS IN.

EXPOSURE (SEC): <CR>

FOCUS SETTING: <CR>

SHIFT
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

IN X:  
IN Y:  

ARRAY, P-LUG, OR L-ABEL: A

DROPOUTS:

R:  

<< END PASS SETUP >>

SAVE PASS? (*Y/N):  

<< PASS >>

NAME (<CR> TO EXIT PASS SETUP):  

OUTPUT DEVICE SPECIFICATION:  

The next line will appear if this file is in memory already.

FILE ALREADY EXISTS. REPLACE WITH NEW FILE? (*Y/N):  

2) EXECution of the oxide level job. The following is a step-by-step procedure for exposing wafers according to the job P5000 DIFF. At the keyboard:

:EXEC P5000 OXIDE (user inputs are bold and underlined)

**********************************
OXIDE LEVEL EXPOSURE FOR PMOS5000
**********************************

PASS: 1

**********************************

MAKE SURE CORRECT RETICLE IS IN.
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

**********************************
EXPOSURE (SEC):
(*G-O, S-KIP, M-ODIFY & GO): (input optimum exposure from the focus/exposure test)

FOCUS SETTING: (input optimum focus from focus/exposure test)

START AWH

3) At the button box, press S/C to load the first wafer onto the prealigner.

4) Once the wafer is on the chuck, check to make sure that the major flat of the wafer is very nearly parallel to the flat of the wafer chuck. If not, press RTY on the button box until the wafer is prealigned properly.

5) At this point, the left and right alignment targets should be visible on the alignment microscope camera monitor (8 in Figure 4.1).

6) Adjust focus and lamp intensity knobs on the button box as well as the contrast and brightness knobs on the monitor to get the best image.

7) Use the X-Y joystick (4 in Figure 4.3) to get the right wafer alignment key positioned in the center of the left system alignment target shown on the monitor.

8) Use the THETA joystick (5 in Figure 4.3) to center the
TUTORIAL FOR EXPOSING TWO LAYERS OF A PMOS DEVICE

left wafer alignment key vertically with respect to the left system alignment target.

9) Repeat 7 & 8 until proper alignment has been achieved. It is not necessary for the left wafer alignment key to be exactly in the center of the system alignment target because it is for THETA adjustment only.

10) Press Ws (WAFER SCALE), and use the X-Y joystick to move the wafer in the X direction only until the left targets are aligned.

11) Once alignment has been completed, press EXP on the button box to expose the second level pattern.

*** SEE FIGURE 4.4 FOR A PICTORIAL EXPLANATION OF THE ALIGNMENT PROCESS ****************************

12) Repeat the alignment process on the rest of the device wafers, and continue on with subsequent processing.

The final two levels are left to the user. The only thing that really changes on these is the location of the alignment keys. This will change the KEY OFFSETS:

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTACT CUT LEVEL</td>
<td>2.35mm</td>
<td>-0.3mm</td>
</tr>
<tr>
<td>METAL LEVEL</td>
<td>2.35mm</td>
<td>-0.6mm</td>
</tr>
</tbody>
</table>
After prealignment, Automatic Wafer Handler places wafer on chuck and stages move to align position.

With X, Y alignment joystick, user aligns right key in X and Y.

With Ø joystick, user aligns left key in Y only.

User presses WAFER SCALE and, using X, Y joystick, brings left cross into alignment in X only. Right cross typically moves out of alignment in X.

**FIGURE 4.4**
CHAPTER V

IMAGE QUALITY

The GCA stepper is capable of producing by far the best images at RIT. Although it is true that contact printing has the potential for better resolution (13), the use of the photorepeater to print 1:1 contact masks imposes severe limitations. The stepper and the photorepeater both use reticles produced by the pattern generator, but the stepper's superior resolution, and direct step on wafer (DSW) capability overwhelm the contact printers' advantages.

By removing the limiting factor (photorepeater), two micron geometries have been produced using silver halide stepper reticles. Silver halide plates have a much greater g-line optical density than do chrome plates (D=4.9 for silver halide, and D=2.99 for chrome), and therefore will not be a limiting factor in image quality.

THE AERIAL IMAGE

The aerial image is the light intensity distribution that emerges from the optical system and converges onto the substrate of the silicon wafer (14). The image is a fairly complex function of the mask pattern, the numerical aperture, the exposure wavelength, and the degree of coherence of the illumination. Although it is straightforward to calculate the aerial image for both
incoherent and coherent systems (15), this author could not find any correspondingly practical methods for calculating the aerial image from a partially coherent system. Fortunately, the Perkin-Elmer development rate monitor (DRM) can calculate and display the aerial image for different linewidths exposed with partially coherent illumination using a program called Prosim.

With the use of Prosim, the modulation of the aerial image may be determined. The ratio of the modulation at the image plane (aerial image modulation), to the modulation at the object plane, is called the MTF or modulation transfer function (16).

\[
\text{MTF} = \frac{[\text{Imax-Imin}]/[\text{Imax+Imin}]}{[\text{Imax-Imin}]/[\text{Imax+Imin}]} \quad \text{image plane}
\]
\[
\frac{[\text{Imax-Imin}]/[\text{Imax+Imin}]}{[\text{Imax-Imin}]/[\text{Imax+Imin}]} \quad \text{object plane}
\]

EQUATION 5-1

The modulation at the object plane is always assumed to be 1.0 because any properly made photomask or reticle will have 100% transmittance in the clear areas, and very nearly 0.0% transmittance in the line, or dark, areas. Therefore, MTF is usually determined as the modulation of the aerial image at the image plane as shown in Figure 5.1. Figure 5.2 shows modulation as a function of line pair frequency. The GCA has a coherency factor (sigma) of 0.7 (17).

MTF is not an appropriate term for partially coherent systems, though, because the functional relationship between the object and image spectral components is non-linear,
Schematic representation of image transfer efficiency for a 1:1 projection printer.

**FIGURE 5.1**

Modulation of an image as a function of the spatial frequency, \( \nu \), for three coherency factors, \( \sigma = 0, 0.7, \) and \( \infty \).

**FIGURE 5.2**
whereas with an incoherent system the relationship is linear (18).

The concept of MTF is still useful in the characterization of partially coherent projection systems when the exposure tool is used near its resolving limit (1.25 microns), where only the fundamental frequency, or Fourier component, of the mask pattern reaches the wafer. With mask features of greater than two microns, many spatial frequency components reach the wafer, and MTF becomes meaningless with regard to partially coherent illumination (19). However, since three micron geometries are almost perfectly resolved with the GCA stepper, MTF is not needed to predict the image quality for device wafers.

Using Prosim, the MTF for 1.0 and 1.4 micron linewidths was determined to be 0.93 and 0.94 respectively. These values are the modulation values of the aerial images of 1.0 and 1.4 micron lines. The aerial image of a 1.4 micron line is shown in Figure 5.3.
FIGURE 5.4

Resist Profile

Initial Thickness 1.020
Resist Breakthrough at 193.543 Seconds

Distance Along Wafer (um)

0 1 1.5 2 2.5 3

0 .5 1 1.5 2

Resist Height (um)

Prosim

V 1.2

Exposure 140.00

ST.run7

Time

160.000
180.000
200.000
220.000
240.000
260.000
280.000
300.000
320.000
340.000
360.000
380.000
400.000

10:55
17-Mar-88
THE PHOTORESIST IMAGE

Figure 5.4 shows the Prosim resist profile of a 1.4 micron line at various development times ranging from 160 to 400 seconds. The exposure dose was 140 mj/(sq cm). Standing wave effects are present here as shown by the rippled sidewall profile. They can also be observed in Figure 5.5 which shows the thickness of the developing resist as a function of time in the developer. The periodically fluctuating development rate is caused by a periodically fluctuating intensity pattern as a function of depth into the resist (20) (see Figure 5.6).

Standing waves occur as a result of coherent interference from reflecting substrates, creating a periodic intensity distribution (21) with maxima separated by \( \lambda/4n \). This means that standing wave peaks should be separated by \( (0.436/(4)(1.65)=0.066 \) microns (660.6 angstroms) in positive photoresist. This is supported by Figure 5.4 which shows four standing wave patterns in just over a quarter micron of resist. Theoretically these intensity peaks should be separated by \( (.066)\times(4)=.264 \) microns.
ST.run3
Thickness vs Time
Zone 2 Initial Thickness is .985 um

Zone Positions

Roch. Inst. of Tech.
Microelectronic Eng.
Perkin-Elmer DRM 5900

15-Mar-88
16:43
Ei Tc
100.0 161.2
Standing Wave Effects: The Problems and the Solutions.

Standing wave effects have been a problem in microlithography since the first day monochromatic light was used for the exposure of resist. If an intensity minimum occurs at the resist-substrate interface, the developer may not be able to remove that thin, underexposed layer at the bottom of a narrow space, and "scumming" may result. Naturally, solutions to this problem were investigated, and the two most practical approaches will be discussed here.

The thicknesses of the resist and oxide layers dramatically affects the degree of the standing wave effects in the resist. As light travels through the resist and meets the resist-oxide interface, little reflection takes place due to the similarity in index of refraction:

\[
\text{index of refraction of resist} = n_r = 1.65
\]

\[
\text{index of refraction of oxide} = n_o = 1.5
\]

\[
\text{index of refraction of silicon} = n_s = 5.4
\]

EQUATION 5-2

However, at the oxide-silicon interface, much more reflection takes place due to the large difference in index of refraction between oxide and silicon. This reflectivity can be found using the expression (22):

\[
R = \frac{(n_s-n_o)^2}{(n_s+n_o)^2}
\]

EQUATION 5-3

Which turns out to be 0.319 or 32% reflectance at the
silicon-oxide interface ignoring absorbance effects. Therefore, the incoming waveform strikes the silicon surface, and 68% of its energy is absorbed and converted to heat while 32% undergoes a pi phase shift and changes direction by 180 degrees (23). This reflected wave now interferes with the incoming waveform, and creates standing wave patterns in both the oxide and the resist. By adjusting the oxide and photoresist thicknesses, the reflectivity of the system can be controlled (24). The lower the reflectivity, the less the standing wave effect, and the less the chance of scumming and "haloing" (edge blurring due to reflection into the masked regions of the resist).

It has been determined (25) that the minimum reflectivity will occur when the total optical thickness:

\[(\text{no}) \times (\text{oxide thickness}) + (\text{ns}) \times (\text{resist thickness})\]

**EQUATION 5–4**

is an odd number of quarter wavelengths of the exposing light. An even number of quarter wavelengths will produce maximum reflectivity, and maximum haloing. Figure 5.7 shows data taken in 1970 when this effect was first studied in photoresist. Notice the absence of haloing, the reduction in reflectance, and the increase in exposure time whenever the total optical thickness is an odd number of quarter wavelengths.

Another, and much simpler, way of handling standing wave
Plot of exposing light intensity as a function of depth in a photoresist on a reflecting substrate.

**FIGURE 5.6**

<table>
<thead>
<tr>
<th>Oxide Thickness $d_2$ (Å)</th>
<th>$n_2$</th>
<th>AZ-1350 Thickness $d_1$ (Å)</th>
<th>$n_1$</th>
<th>$\frac{1}{\lambda}$</th>
<th>Reflectance %</th>
<th>Halo</th>
<th>Exp Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1210</td>
<td>0.441-2/4</td>
<td>3200</td>
<td>1.19-5/4</td>
<td>7</td>
<td>No</td>
<td>65</td>
<td>7</td>
</tr>
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<td></td>
<td>4000</td>
<td>1.49-6/4</td>
<td>8</td>
<td>Yes</td>
<td>44</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4800</td>
<td>1.79-7/4</td>
<td>8</td>
<td>No</td>
<td>49</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5800</td>
<td>2.16-9/4</td>
<td>10</td>
<td>Yes</td>
<td>32</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>2160</td>
<td>0.735-9/4</td>
<td>3200</td>
<td>1.19-5/4</td>
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<td>Yes</td>
<td>48</td>
<td>5</td>
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<td>4000</td>
<td>1.49-6/4</td>
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<td>8</td>
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<tr>
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<td>48</td>
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<tr>
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<td>No</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>5800</td>
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<td>17</td>
<td>No</td>
<td>17</td>
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<td></td>
</tr>
</tbody>
</table>

*Compared to Si reference

Variations of halting with oxide and photoresist thickness.

**FIGURE 5.7**
IMAGE QUALITY

effects is to use a post exposure bake. This method was discovered accidentally in the early 1970's when post exposure bake was being investigated for increasing adhesion and eliminating pinholes (26). At the time no explanation for the effect was given, but in 1975, E.J. Walker of IBM suggested that diffusion of inhibitor from regions of low exposure to regions of high exposure during the post exposure bake was the responsible mechanism (27). When this is done, development is more uniform due to the even distribution of inhibitor. Figure 5.8 shows the DRM results when a post exposure bake was performed on a hotplate at 100 degrees for 60 seconds.
ST.run6
Thickness vs Time
Zone 1 Initial Thickness is .881 um

Zone Positions

Roch. Inst. of Tech.
Microelectronic Eng.
Perkin-Elmer DRM 5900
Compared to Figure 5.5, Figure 5.8 shows uniform development rate due to a "curing" of the standing wave effects.

By combining the post exposure bake with proper oxide and photoresist combinations, the deleterious effects of standing waves can be kept to a minimum.

**Experimental Determination of MTF**

As mentioned earlier, the MTF can be calculated for partially coherent systems as the modulation of the aerial image. This is a theoretical value, and does not give specific information on the performance of any particular machine. A method has been suggested (28) for the determination of MTF from observable process conditions. The idea is to determine $I_{min}$ and $I_{max}$ in terms of the sensitivity ($E_o$), and the exposure time necessary to bring about certain process conditions.

$$I_{min} = E_o / \text{(exp time to clear a masked line)}$$

**EQUATION 5-5**

$$I_{max} = E_o / \text{(exp time to start to clear a space)}$$

**EQUATION 5-6**

$E_o$ is the energy needed to make the resist soluble to the developer within the development time specified (29), and is
found as follows:

\[ E_0 = (I_0) \times (\text{exp time to clear a large area}) \]

**EQUATION 5-7**

Where \( I_0 \) is the measured illuminator intensity in mW/(sq cm). Because of diffraction effects, the intensity in the clear regions will be less than \( I_0 \), while the intensity in the masked or shadow regions is greater than zero (30). This diffraction effect is the reason that the aerial image of Figure 5.1 is not a square wave.

An exposure of \( E_0 \) is necessary for the removal resist, regardless of the intensity, because positive photoresist, with a quantum efficiency of 1.0, does not suffer from reciprocity law failure (31). Therefore, the exposure necessary to just start to clear the resist in a clear region is the same as the exposure necessary to completely remove a line in a masked region. The only thing that changes is the intensity and the exposure time. The exposure time will be known, and the intensity can be calculated as shown in Equations 5-5 & 5-6.

To do this experiment, run an exposure series using the EXPO command which will range exposures from near zero to well over 500 mj/(sq cm). Determine \( E_0 \) by multiplying the measured illuminator intensity by the exposure time needed to clear a large area (not affected by diffraction). Then determine the exposure time necessary to just clear the
center of the space of a 1.4 micron linepair, and calculate Imax using Equation 5-6. Next, determine the exposure time necessary to completely expose a 1.4 micron line until it is developed away, and calculate Imin using Equation 5-5. Calculate modulation using Equation 5-1.
CHAPTER VI
EXPLANATION OF TEST PROCEDURES

The following tests may require the use of the GCA Technical Note on the Universal Vernier Test Reticle to be found in Appendix E. It provides useful information of reticle layout and on how to read the interlocking verniers.

BASELINE CORRECTION (32)

Baseline correction is a necessary test on the GCA due to the indirect alignment process. "Indirect" here indicates that the alignment camera does not aim through the reticle, but through a separate alignment microscope. This alignment microscope's position with respect to the reticle must be known and corrected for through the system software in order for any accurate alignments to take place.

This system is designed so that the reticle and the alignment microscope (through baseline correction) are both aligned to the optical system, and therefore to each other. The alternative is to have through-the-reticle, popularly called through-the-lens, alignment. In this case the alignment illumination would need to be g-line like the exposure illumination in order to avoid problems with chromatic aberration. Chromatic aberration is the result of different wavelengths converging at different focal planes, and causing a blurred image.
Through-the-lens alignment is used in many modern day steppers, but when GCA designed this system, it was probably avoided due to complexity and for fear of unintentionally exposing areas of resist.

The following procedure is used to correct for any error in the baseline setting. As with all of the following tests, a determination of optimum focus and exposure should be performed, as detailed in the tutorial section, before starting.

1) Check for necessary materials:
   (a) ETMS-1 reticle
   (b) Universal Vernier Test Target #4800-005
   (c) "GCA standard wafers"

****** GCA STANDARD WAFERS ARE BARE SILICON WITH 5250 ******
************ ANGSTROMS OF OXIDE ************
   (d) reticle apertures

2) Log in to the computer, and enter "MODE" (user's response is underlined and bold).

   METRIC OR ENGLISH UNITS? (M/E): M
   CHUCK SIZE (A,B,2,3,82,100,125): 100
   BASE LINE CORRECTION (MMS)

       X: _____ (for the first wafer, hit return)

       Y: _____

   OBJECTIVE SPACING: 76.2
SAVE MODE DATA ON DISK? (*Y/N): Y

3) Load and align the appropriate universal vernier test reticle.

4) Load a clean, resist coated wafer.

5) Place the X=55MM, Y=90MM aperture on the reticle.

6) At the keyboard, type "EXEC 4BLB;1" (see Appendix A) in order to run the Baseline Correction test.

7) Develop the resist for 1/2 the normal development time.

8) Reload the same wafer into the cassette.

9) Place the X=55MM, Y=55MM aperture on the reticle.

9) At the keyboard, type "EXEC 4BLB;2".

11) Align and expose the wafer.

12) Develop the resist for the normal development time.

13) Locate and read the interlocking X and Y Precision/Registration verniers at location R in Figure 6.1. Record both readings.

14) Locate and read the Y-axis Precision/Registration vernier at location L in Figure 6.1. Record the reading.

15) Find the new Baseline Correction values by taking the current values, and subtracting the readings (in mm) taken from location R:

   New X value(mm) = Old X value - X vernier(microns)/1000

   New Y value(mm) = Old Y value - Y vernier(microns)/1000
BASELINE CORRECTION ARRAY (IMAGE SURFACE UP)

FIGURE 6.1
16) Enter the new Baseline Correction values into MODE.

17) Determine the alignment microscope theta error as follows:

\[
\text{Theta error} = (Y \text{ reading from L}) - (Y \text{ reading from R}).
\]

18) If Theta error is more than \( \pm 0.2 \) microns, hardware adjustment is necessary. Contact Scott Blondell.

19) After corrections have been made, repeat steps 4 through 15 in order to verify the settings.

GCA provides no specs for the X and Y Baseline Correction values, so it is assumed that the readings should be as accurate as possible. A good safe value would be \( \pm 0.35 \) microns as measured at location R.

RESOLUTION

In classical optics, the Rayleigh Criterion states that two lines of equal irradiance are just resolvable when the combined irradiance of both fringes at the center, or saddle point, of the resultant broad fringe is \( \frac{8}{(\pi^2)} \) times the maximum irradiance.

In photolithography, the criterion is much simpler to evaluate. Given a certain equal line/space pair, that linewidth is said to be resolved if equal lines and spaces
EXPLANATION OF TEST PROCEDURES

can be observed after development of the exposed image.

The RIT stepper uses a Ziess 10-78-82 10x lens with the following characteristics.

* FOCAL LENGTH = 49.1 mm
* MINIMUM LINEWIDTH = 1.25 microns
* IMAGE FIELD = 14.5 mm
* EXPOSURE WAVELENGTH = 436 nm
* DISTANCE FROM PLATEN (RETICLE) TO ENTRANCE PUPIL OF THE REDUCTION LENS SYSTEM = 486 mm
* NUMERICAL APERTURE = 0.28
* REDUCTION RATIO = 1:10
* DISTANCE FROM THE ILLUMINATOR CONDENSER LENS TO THE PLATEN (RETICLE) = 25 mm

EXPOSURE LATITUDE

Exposure latitude describes the range in energy that a material is photoactive. More specifically, it is the difference between the logarithmic value of the energy needed to clear the resist completely, and the logarithmic value of the highest energy used without exposing the resist at all.

The following test describes a method for determining whether or not the system maintains a specified resolution over a ten percent change in exposure, what the minimum
EXPLANATION OF TEST PROCEDURES

resolvable linewidth is, and how well the autofocus system maintains focus across the wafer (33).

1) Check for proper materials:
   a) ETMS-1 reticle
   b) "GCA Standard Wafers"

2) Log into the computer, place the ETMS-1 reticle on the platen, enter "EXPO FOCUSRES.SET", and determine the optimal focus and exposure.

3) Calculate 93%, 103%, and 2% of the optimum exposure time.

4) Enter "EDIT RES;1", and enter 93% of the optimum as the start time for RES pass 1, and 2% as the exposure increment.

5) Enter "EDIT RES;2", and enter 103% of the optimum as the start time for RES pass 2, and 2% as the exposure increment.

6) Enter "EXPO RES;1,2" (see Appendix A), and expose an array that looks like Figure 6.2.

7) Develop the wafer.

8) Verify that 1.4 micron lines and spaces are maintained across a 10% change in exposure.

9) Using the optimum exposure and focus setting, Use SPEC to set up a job that will fill the entire wafer. Use a stepping
FIGURE 6.2

FIGURE 6.3

PRECEB
EXPLANATION OF TEST PROCEDURES

distance of 11mm.

10) Use EXEC, and expose that array onto a new wafer.

11) Develop the wafer.

12) Verify that the specified resolution is maintained across the entire wafer.

STAGE PRECISION

Stage precision is a measure of how well the X and Y stages repeat their previous maneuvers. The acceptable tolerance is only ± 0.2 microns.

SYSTEM REGISTRATION

System registration is a measure of how well a second level pattern can be aligned to the first level. This involves more error than the precision test because the wafer and reticle are both removed from the machine and re-aligned. The acceptable tolerance for this test is only ± 0.35 microns.

The following procedure is used to measure both precision and registration of the stepper system (34).

1) Check for proper materials:

   a) ETMS-1 reticle
EXPLANATION OF TEST PROCEDURES

b) GCA Universal Vernier Test Reticle #4800-005

c) "GCA Standard Wafers"

d) reticle apertures

2) Log into the computer, and enter "MODE" (User's response is underlined and in bold. Also, programs lines in the computer not shown here, should be responded to with a carriage return.)

   METRIC OR ENGLISH UNITS? (M/E): M

   CHUCK SIZE (A,B,2,3,82,100,125): 100

   OBJECTIVE SPACING: 76.2

   SAVE MODE DATA ON DISK? (*Y/N): Y

3) Using the ETMS-1 reticle, run a focus/exposure matrix using the EXPO command to determine the optimal focus and exposure settings.

4) Load and align the Universal Vernier Test Reticle.

5) Place the X=55mm/Y=90mm aperture on the reticle.

6) Load a clean resist coated wafer.

7) Enter "EXEC PREC4B;1,2,3". (Answer "YES" to change reticles between passes.)

8) After pass 1 has been run, place the X=55mm/Y=55mm aperture on the reticle.

9) Expose passes 2 and 3.

10) Develop resist for the normal time.

11) Remove, reload, and align the Universal Vernier Test
Reticle.

12) Reload the same wafer into the input cassette.

13) Enter "EXEC PREC4B;4", load align, and expose the wafer.

14) Locate and read the Precision/Registration Verniers at the locations labeled P1-P14 in Figure 6.3.

15) Locate and read the Precision/Registration Verniers at locations labeled R1-R10 in Figure 6.3.

**REDUCTION**

In any optical system, the ratio between the transverse dimension of the final image and the corresponding dimension of the original object is called the lateral magnification. The inverse of lateral magnification is called lateral reduction, or reduction for short. The theoretical lens reduction of this machine is 10X, but may acceptably vary by as much as ± 0.000025X.

Trapezoid is the measure of the change in reduction error from extreme ends of the die. The spec for trapezoid is ± 0.35 microns.
OPTICAL DISTORTION

Distortion is best explained by referring to Figure 6.4. Diagram (a) shows an undistorted image of an object consisting of a rectangular mesh pattern. Diagram (b) shows the image of the same mesh suffering from "barrel" distortion, while diagram (c) shows the image of the mesh suffering from "pincushion" distortion (35).

Although thin lenses are practically free from distortion, they cannot, however, be free from all other aberrations at the same time. Lenses with stops placed in front or behind them invariably produce distortion, while a stop placed between two symmetrical lenses will correct distortion and astigmatism (36).

This is illustrated in Figure 6.5. Diagram (a) shows a stop placed in front of a lens. Rays from points at or near the axis, like M, are refracted through the center part of the lens, while off-axis points like Q2 are refracted predominantly through the upper portion of the lens only. This decreases the ratio of the image to object distance as measured along the chief ray, and produces "barrel" distortion. With the stop in back of the lens, the reverse happens, the refraction being predominantly in the lower
(a) A pinhole camera shows no distortion. Images of a rectangular object screen shown with (b) no distortion, (c) barrel distortion, and (d) pincushion distortion.

(a) A stop in front of a lens giving rise to barrel distortion. (b) A stop behind a lens giving rise to pincushion distortion. (c) A symmetrical doublet with a stop between is relatively free of distortion.
part of the lens, increasing the ratio of image to object
distances measured along the chief ray as shown in diagram
(b). This produces "pincushion" distortion.

As shown in diagram (c), if a stop in placed midway
between two identical lenses, a system is created which,
due to symmetry, is free from distortion for unit
magnification. With other magnifications, however,
correction must be made for spherical aberration with
respect to the entrance and exit pupils. Pupils S' and S''
coincide with the principal planes of the combination, and
correct spherical aberration for the entrance and exit
pupils, but not the object and image planes. Although these
types of lenses, called "orthoscopic doublets" or rapid
rectilinear lenses, are considered high quality photographic
systems, they suffer form astigmatism and aberration.

Although the stepper lens is corrected for distortion, it
is necessary to determine how well it has been corrected in
order to judge whether it is acceptable. The GCA
specification is plus (for barrel distortion) or minus (for
pincushion distortion) 0.2 microns.
**EXPLANATION OF TEST PROCEDURES**

**DIE ROTATION**

Die rotation is a measure of the theta skew in the image of the reticle. The specification for this error is plus or minus 0.1 microns. There are six major sources of this problem (37).

1) Non-parallelism between reticle alignment marks and stage motions.

2) A mis-aligned reticle.

3) Asymmetrical keystoning of the system.

4) Twisting of the optical column from exposure to exposure.

5) Stage Yaw.

Sources 1-3 produce constant rotation errors, so that all die will have the same readings. Sources 4 and 5 may vary from die to die, producing different readings on each. Unfortunately, only mis-alignments of the reticles can be improved for all practical purposes.

The following procedure is used to determine the amount
EXPLANATION OF TEST PROCEDURES

of reduction error, distortion (pincushion or barrel), and
die rotation (38).

1) Check for necessary materials:
   a) ETMS-1 reticle
   b) GCA Universal Vernier Test Reticle #4800-005
   c) "GCA Standard Wafers"

2) Load the ETMS-1 reticle, and perform a focus/exposure
test to determine the optimum focus and exposure settings.

3) Load and align the 4800-005 reticle.

4) Load a clean, resist coated wafer.

5) Using the command "EXEC VET8;1" (see Appendix A), expose
the wafer.

6) Develop the resist.

7) Locate and read the Reduction verniers labeled M1-M4 in
Figure 6.6.
   a) Compute the means of F, B, L, and R.
   b) Compute MX and MY:
      
      MX = |(MEAN F)+(MEAN B)|/2 in microns
      MY = |(MEAN L)+(MEAN R)|/2 in microns
   c) Compute front/back and left/right trapezoid:
      FRONT/BACK = (MEAN F)-(MEAN B) in microns
      LEFT/RIGHT = (MEAN L)-(MEAN R) in microns

8) Locate and read the Distortion (D) verniers shown at
locations DX1-DX4 and DY1-DY4 shown in Figure 6.6.
   a) Compute the means of DX and DY.
   b) Compute X and Y distortion:
FIGURE 6.6

FIGURE 6.7

FIGURE 1. Reduction, Distortion, Rotation Array (Image Surface Up)

Key: M1-M4: Reduction Verniers
     DX1-DX4: X-Axis Distortion Verniers
     DY1-DY4: Y-Axis Distortion Verniers
     R1-R8: Rotation Verniers
EXPLANATION OF TEST PROCEDURES

\[
X\text{-DISTORTION} = \frac{(MX-(\text{MEAN DX}))}{2} \text{ in microns}
\]
\[
Y\text{-DISTORTION} = \frac{(MY-(\text{MEAN DY}))}{2} \text{ in microns}
\]

9) Locate and read the Rotation (THETA) verniers at locations R1 through R8 in Figure 6.6.
   a) Compute the average value of THETA.
   b) Compute total excursion:
      \[
      \text{EXCURSION} = (\text{HIGHEST THETA}) - (\text{LOWEST THETA}) \text{ microns}
      \]

STAGE ORTHOGONALITY

Stage orthogonality is a measure of the actual angle between the X and Y stages. This error can be corrected for in the software, and the tolerance is ± 0.5 arc seconds.

The following procedure is used to measure the error in the orthogonality of the stage motions, and to correct this error through software revision (39).

1) Check for necessary materials:
   a) ETMS-1 reticle
   b) GCA Universal Test Reticle #4800-005
   c) "GCA Standard Wafers"
   d) reticle apertures

2) Load the ETMS-1 reticle and run a focus/exposure test to
EXPLANATION OF TEST PROCEDURES

determine the optimum focus and exposure settings.
3) Verify Baseline setting.
4) Load and align the 4800-005 reticle.
5) Place the X=90MM/Y=55MM aperture on the reticle.
6) Load a clean resist coated wafer.
7) Use the command "EXEC ORTH4B;1" (see Appendix A) to load and expose the wafer.
8) Develop the resist for 1/2 the normal development time.
9) Place the X=55MM/Y=55MM aperture on the reticle.
10) Use the command "EXEC ORTH4B;2" (see Appendix) to load the same wafer onto the chuck.
11) Turn off chuck vacuum (clamp off chuck vacuum line), and rotate the wafer 90 degrees counterclockwise, and manually perform a course alignment.
12) Unclamp the chuck vacuum line, and use the X-Y and THETA joysticks to perform a fine alignment.
13) Expose the wafer.
14) Develop the resist for the normal development time.
15) Read the Y-oriented verniers in the locations A1-A4 shown in Figure 6.7. Y-verniers run perpendicular to the flat.
16) Compute the and record the stage orthogonality according to the following formula:

\[ \text{ANGLE} = \frac{(A3+A4)-(A1+A2)}{1.27} \text{ in arc seconds} \]
17) Compute the orthogonality correction according to the
following formula:

\[ \text{CORRECTION} = (\text{ANGLE}) \times (-5) \text{ in PPM} \]

18) Enter correction in MODE. **NOTE**: This correction value should be added to the existing orthogonality value. It should not be used to replace the existing value.
CHAPTER VII
RESULTS OF TEST PROCEDURES

The following is a table of results from the GCA Acceptance Test Procedures. The actual data sheets may be found in Appendix B.

**TABLE 7-1**

<table>
<thead>
<tr>
<th>TEST NAME</th>
<th>GCA SPECIFICATION</th>
<th>TEST RESULT</th>
<th>IN SPEC?</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESOLUTION (MICRONS)</td>
<td>1.25</td>
<td>1.4</td>
<td>NO</td>
<td>1/27/88</td>
</tr>
<tr>
<td>STAGE PRECISION (MICRONS)</td>
<td>± 0.2</td>
<td>-0.05≤X&lt;+0.05</td>
<td>YES</td>
<td>2/7/88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.00≤Y&lt;+0.05</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>SYSTEM REGISTRATION (MICRONS)</td>
<td>± 0.35</td>
<td>-0.30≤X&lt;-0.15</td>
<td>YES</td>
<td>2/7/88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.05≤Y&lt;+0.05</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>STAGE ORTHOGONALITY (ARC SECONDS)</td>
<td>±0.5</td>
<td>-0.4</td>
<td>YES</td>
<td>2/10/88</td>
</tr>
<tr>
<td>DIE ROTATION (MICRONS)</td>
<td>≤ ± 0.1</td>
<td>0.263</td>
<td>NO</td>
<td>2/9/88</td>
</tr>
<tr>
<td>OPTICAL DISTORTION (MICRONS)</td>
<td>± 0.2</td>
<td>X=-0.0531</td>
<td>YES</td>
<td>2/9/88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y=-0.0594</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>LENS REDUCTION (MICRONS)</td>
<td>± 0.2</td>
<td>MX=0.2688</td>
<td>NO</td>
<td>2/9/88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MY=0.2315</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>TRAPEZOID (MICRONS)</td>
<td>0.35</td>
<td>F-B=-0.0875</td>
<td>YES</td>
<td>2/9/88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L-R=-0.0125</td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER VII

DISCUSSION

The GCA 4800 DSW wafer stepper has been shown to be an effective lithographic tool for the fabrication of fine line geometries. Although three out of eight system tests did not meet GCA specifications, this should not effect the ability to print excellent three micron geometries. The fact that resolution is out of spec is more a matter of judgement than of hard fact. It is presently possible to produce 1.25 micron lines, but overexposure is required to clear the 1.25 micron spaces. This overexposure causes larger geometries to be degraded. It was determined by visual inspection that it is possible to clearly resolve both 1.4 and 3.0 micron linepairs accurately. The problem with die rotation is small, and may be due to something as small as a misaligned reticle. Again, this is not a problem, and may be a source for future work. The reduction error is small and is only important for mixing and matching with other machines.
CHAPTER IX
CONCLUSIONS

The GCA DSW 4800 wafer stepper has been shown to be a very effective tool for producing fine-line geometries, and it is available now for device fabrication as well as for photolithographic research. It will prove to be an excellent educational tool due to its ease of operation and versatility, as well as its capability for quick turn-around time from design to exposure.

The stepper has been shown to have an alignment tolerance of better than $\pm 0.35$ microns, and this will result in almost perfect alignment using three micron design rules.

The Tutorial section shows the beginner all the steps necessary to start a nmos device with 5mm chip size. It explains how to specify jobs for the exposure of the first and second levels, and also how to align the second level to the first.

The stepper has also been used in conjunction with the development rate monitor for the characterization of resist and developer processes. This has resulted in the demonstration of the effectiveness of post exposure bakes for eliminating standing wave problems. From the experimental data collected by the development rate monitor, 1.4 micron lines were modelled showing steep sidewalls and only 5% resist loss in the unexposed regions.
Also, DRM information supports the fact that high contrast images are produced by reducing the exposure dose, and increasing the development time as much as possible and practical (40).

The theoretical MTF has been determined using Prosim, and an experimental method for the determination of MTF has been suggested. There is significant discrepancy between the theoretical and experimental values (25% error), so this is also an area for future work.

Appendix C details reticle manufacture and alignment procedures for five inch silver halide glass plates. It has been shown that silver halide emulsions offer a practical alternative to chrome, with a much simpler fabrication process.

Appendix D briefly discusses the periodic procedures necessary to keep the stepper running in peak condition.

A final area for future work is in Wafer Scaling. This is a procedure which allows for the compensation of wafer diameter expansion due to high temperature oxidation. This work has mentioned it in theory, but due to time and processing constraints, it was never worked on experimentally. Information for this is provided in Appendix E.

Finally, after over a year in the waiting, RIT's new GCA 4800 DSW Wafer Stepper is operational. It has been
CONCLUSIONS

characterized for reticle fabrication details, system performance, and image quality. It should prove to be instrumental in bringing RIT's capabilities into the VLSI era.
ACKNOWLEDGEMENTS

This project was made possible by the equipment and financial contributions of Digital Equipment Corporation. Scott Blondell is appreciated for his role in the start-up and optimization of the stepper. Mozafar Maghsoudnia offered his expertise with the DRM, and a whole new field of study was introduced towards the completion of this report. Finally, I'd like to thank Dr. Lynn Fuller who bailed me out in times of need.
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(3) Ibid., 69.

(4) Elliot, Integrated Circuit Fabrication Technology, 199.

(5) DSW Wafer Stepper System Control Manual, GCA Technical Publications Library, Document Part No. 036035, Rev. 5A.

(6) Ibid., 4-2.

(7) Ibid., 5-2.

(8) Ibid., 5-25.

(9) Ibid., 6-23.

(10) Ibid., 6-14.

(11) Ibid., 3-4.

(12) Ibid., 6-3.


(15) Ibid.

(16) Thompsen, Willson, & Bowden, 36-37.


(19) Ibid.


(21) Thomp sen, Willson, & Bowden, 44.


(24) Ilten, Patel, "Standing Wave Effects in Photoresist Exposure."


(31) Elliot, "Integrated Circuit Fabrication Technology", 177.

(32) DSW Wafer Stepper Acceptance Test Procedures, GCA Technical Publications Library, Document Part No. 004202C.

(33) Ibid.

(34) Ibid.


(36) Ibid., 173-174.

(37) DSW Wafer Stepper Technical Note, "The Universal Vernier
Test Target" GCA Technical Publications Library.

(38) DSW Wafer Stepper Acceptance Test Procedures.

(39) Ibid.

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DSW Wafer Stepper Acceptance Test Procedures. GCA Technical Publications Library, Document Part No. 004202C.

DSW Wafer Stepper System Control Manual. GCA Technical Publications Library, Document Part No. 036035, Rev. 5A.

DSW Wafer Stepper Technical Note, "The Universal Vernier Test Target". GCA Technical Publication Library.


APPENDIX A

PROGRAMS FOR GCA ACCEPTANCE TEST PROCEDURES
PROGRAM FOR DETERMINING BASELINE CORRECTION (JOB NAME = 4BLB)

This program exposes two alignment keys on the first pass. On the second pass, those keys are aligned to, and exposed with a shift to offset the verniers properly for an interlocking pattern. The offset represents the error in alignment of the alignment microscope and the optical column, and must be corrected for in the software.

:SPEC 4BLB

METRIC OR ENGLISH UNITS? (*M/E):

METRIC JOB

COMMENT: BASELINE CORRECTION FOR 4 INCH WAFERS WITH 3 INCH OBJECTIVE SPACING.

TOLERANCE(1,2,*3,4,5,6): 3
WAFER DIAMETER 100
<< ARRAY PARAMETERS >>
STEP SIZE IN X: 6.35
*C-OUNT OR S-PAN:
HOW MANY COLUMNS? 15
STEP SIZE IN Y: 6.35
*C-OUNT OR S-PAN:
HOW MANY ROWS? 15
<< ALIGNMENT PARAMETERS >>
STANDARD KEYS (*Y/N): N
RIGHT ALIGNMENT DIE CENTER
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 11
C: 14

KEY OFFSET:
IN X: -1.8
IN Y: -3.605

<< PASS >>

NAME (<CR> TO EXIT PASS SET-UP): 1

COMMENT: SET APERTURES X=55MM Y=90MM

EXPOSURE (SEC): ______

FOCUS SETTING: ______

A-ARRAY OR P-LUG: P

PLUGS:

R: 11

Y-OFFSET:

C: 2

X-OFFSET:

R: 11

Y-OFFSET:

C: 14

X-OFFSET:

R:

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): 2
APPENDIX A: TEST PROCEDURE PROGRAMS

COMMENT: SET APERTURES X=55MM Y=55MM

EXPOSURE (SEC): ________

FOCUS SETTING: ________

SHIFT

IN X: -.5

IN Y: .5

ARRAY OR P-LUG: P

PLUGS:

R: 11

Y-OFFSET:

C: 2

X-OFFSET:

R: 11

Y-OFFSET:

C: 14

X-OFFSET:

R:

<< END PASS SET UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): <CR>
APPENDIX A: TEST PROCEDURE PROGRAMS

RESOLUTION/EXPOSURE LATITUDE PROGRAM (JOB NAME = RES)

The following program exposes a 2-row by 3-column array of exposures at optimal focus, and 93%, 95%, 97%, 103%, 105%, and 107% of optimal exposure.

:SPEC RES

METRIC JOB

COMMENT: SETUP FOR EXPOSURE LATITUDE TOLERANCE

TOLERANCE (1,2,*3,4,5,6): 1

WAFFER DIAMETER: 100

<< ARRAY PARAMETERS >>

STEP SIZE IN X: 21.00

*C-OUNT OR S-PAN:

HOW MANY ROWS? 1

<< PASS >>

NAME: 1

COMMENT: FIRST ROW ARRAY

EXPOSURE (SEC.): __________

FOCUS SETTING: __________

SHIFT

IN X:

IN Y: -10.5

A-RRAY, P-LUG OR L-ABEL: A

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):
APPENDIX A: TEST PROCEDURE PROGRAMS

<< PASS >>

NAME: 2

COMMENT: SECOND ROW ARRAY

EXPOSURE (SEC): __________

FOCUS SETTING: __________

SHIFT

IN X: 

IN Y: 10.5

ARRAY, P-LUG OR LABEL: A

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP):

OUTPUT DEVICE SPECIFICATIONS:
APPENDIX A: TEST PROCEDURE PROGRAMS

PROGRAM FOR MEASURING STAGE PRECISION AND SYSTEM REGISTRATION

(JOB NAME = PREC4B)

This program exposes a large and varied pattern over the surface of the wafer, and then repeats those motions on 14 of the locations to gauge stage precision. The wafer is then removed and processed, and re-aligned along with the reticle. The remaining 10 locations are re-exposed to gauge the level to level alignment accuracy, or registration.

:SPEC PREC4B

METRIC OR ENGLISH UNITS? (*M/E):

METRIC JOB

COMMENT: PRECISION/REGISTRATION TEST FOR 4 INCH WAFERS, 3 INCH OBJECTIVE SPACING.

TOLERANCE(1,2,*3,4,5,6): 3

WAFER DIAMETER 100

<< ARRAY PARAMETERS >>

STEP SIZE IN X: 6.35

*COUNT OR S-PAN:

HOW MANY COLUMNS? 15

STEP SIZE IN Y: 6.35

*COUNT OR S-PAN:

HOW MANY ROWS? 15

<< ALIGNMENT PARAMETERS >>

STANDARD KEYS? (*Y/N): N

RIGHT ALIGNMENT DIE CENTER
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 11
C: 14

KEY OFFSET:

IN X: -1.8
IN Y: -3.605

LEFT ALIGNMENT CENTER

R: 11
C: 2

LEFT KEY OFFSET

IN X: -1.8
IN Y: -3.605

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): 1

COMMENT: SET APERTURES X=55MM Y=90MM

EXPOSURE (SEC): ______

FOCUS SETTING: ______

SHIFT

IN X:

IN Y:

ARRAY OR P-LUG: P

PLUGS:

R: 11

Y-OFFSET:

C: 2

X-OFFSET:
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 11
   Y-OFFSET:
C: 14
   X-OFFSET:
R:

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): 2

COMMENT: SET APERTURES X=55MM Y=55MM

EXPOSURE (SEC): _______

FOCUS SETTING: _______

SHIFT
   IN X:
   IN Y:

ARRAY OR P-LUG: P

PLUGS:
   R: 2
      Y-OFFSET:
   C: 7
      X-OFFSET:
   R: 2
      Y-OFFSET:
   C: 9
      X-OFFSET:
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 4
Y-OFFSET:
C: 7
X-OFFSET:
R: 4
Y-OFFSET:
C: 9
X-OFFSET:
R: 6
Y-OFFSET:
C: 4
X-OFFSET:
R: 6
Y-OFFSET:
C: 12
X-OFFSET:
R: 8
Y-OFFSET:
C: 2
X-OFFSET:
R: 8
Y-OFFSET:
C: 4
X-OFFSET:
R: 8
APPENDIX A: TEST PROCEDURE PROGRAMS

Y-OFFSET:
C: 7
X-OFFSET:
R: 8
Y-OFFSET:
C: 9
X-OFFSET:
R: 8
Y-OFFSET:
C: 12
X-OFFSET:
R: 8
Y-OFFSET:
C: 14
X-OFFSET:
R: 10
Y-OFFSET:
C: 7
X-OFFSET:
R: 10
Y-OFFSET:
C: 9
X-OFFSET:
R: 13
Y-OFFSET:
APPENDIX A: TEST PROCEDURE PROGRAMS

C: 7
   X-OFFSET:
R: 13
   Y-OFFSET:
C: 9
   X-OFFSET:
R: 15
   Y-OFFSET:
C: 7
   X-OFFSET:
R: 15
   Y-OFFSET:
C: 9
   X-OFFSET:
R: 11
   Y-OFFSET:
C: 5
   X-OFFSET:
R: 11
   Y-OFFSET:
C: 11
   X-OFFSET:
R: 6
   Y-OFFSET:
C: 7
APPENDIX A: TEST PROCEDURE PROGRAMS

X-OFFSET:
R: 6
Y-OFFSET:
C: 9
X-OFFSET:
R:

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):
<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): 3

COMMENT: PRECISION PASS

EXPOSURE (SEC.):

FOCUS SETTING:

SHIFT

IN X: -.5

IN Y: .5

ARRAY OR P-LUG: P

PLUGS:

R: 2

Y-OFFSET
C: 2

X-OFFSET
R: 4

Y-OFFSET
C: 2
APPENDIX A: TEST PROCEDURE PROGRAMS

X-OFFSET
R: 6
Y-OFFSET
C: 4
X-OFFSET
R: 6
Y-OFFSET
C: 12
X-OFFSET
R: 10
Y-OFFSET
C: 7
X-OFFSET
R: 10
Y-OFFSET
C: 9
X-OFFSET
R: 11
Y-OFFSET
C: 2
X-OFFSET
R: 11
Y-OFFSET
C: 14
X-OFFSET
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 13
   Y-OFFSET
C: 9
   X-OFFSET

R: 15
   Y-OFFSET
C: 9
   X-OFFSET

R: 11
   Y-OFFSET
C: 5
   X-OFFSET

R: 11
   Y-OFFSET
C: 11
   X-OFFSET

R: 6
   Y-OFFSET
C: 7
   X-OFFSET

R: 6
   Y-OFFSET
C: 9
   X-OFFSET

R:
APPENDIX A: TEST PROCEDURE PROGRAMS

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): 4

COMMENT: REGISTRATION PASS

EXPOSURE (SEC): __________

FOCUS SETTING: __________

SHIFT

IN X: -.5

IN Y: .5

ARRAY OR PLUG: P

PLUGS:

R: 2

Y-OFFSET:

C: 7

X-OFFSET

R: 4

Y-OFFSET:

C: 7

X-OFFSET

R: 8

Y-OFFSET:

C: 2

X-OFFSET

R: 8

111
APPENDIX A: TEST PROCEDURE PROGRAMS

Y-OFFSET:

C: 4
X-OFFSET
R: 8
Y-OFFSET:

C: 7
X-OFFSET 
R: 8
Y-OFFSET:

C: 9
X-OFFSET .
R: 8
Y-OFFSET:

C: 12
X-OFFSET
R: 8
Y-OFFSET:

C: 14
X-OFFSET
R: 13
Y-OFFSET:

C: 7
X-OFFSET
R: 15
Y-OFFSET:
APPENDIX A: TEST PROCEDURE PROGRAMS

C: 7

X-OFFSET

R:

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP):
APPENDIX A: TEST PROCEDURE PROGRAMS

PROGRAM FOR DETERMINATION OF REDUCTION ERROR, DISTORTION, AND ROTATION (JOB NAME = VET8)

This program exposes an array of die stepped on 8mm centers so that the verniers at the boundaries of the die will be interlocked. In this way, parameters dependent upon the shape, size, and orientation of the die may be measured.

:SPEC VET8

METRIC OR ENGLISH UNITS? (*M/E):

METRIC JOB

COMMENT: REDUCTION/DISTORTION/ROTATION FOR LENS #10-78-82

TOLERANCE (1,2,*3,4,5,6): 1

WAFER DIAMETER: 100

<< ARRAY PARAMETERS >>

STEP SIZE IN X: 8

*C-OUNT OR SPAN:

HOW MANY COLUMNS? 6

STEP SIZE IN Y: 8

*C-OUNT OR S-PAN:

HOW MANY ROWS? 6

<< ALIGNMENT PARAMETERS >>

STANDARD KEYS? (*Y/N):

KEY OFFSET

IN X: -1.8

IN Y: -3.605

<< PASS >>
APPENDIX A: TEST PROCEDURE PROGRAMS

NAME(<CR> TO EXIT PASS SET-UP): 1

COMMENT: USE RETICLE #4800-005

EXPOSURE (SEC): __________

FOCUS SETTING: __________

SHIFT
  IN X:
  IN Y:

ARRAY OR P-LUG: A

DROPOUTS:
  R: 1
  C: 1
  R: 1
  C: 6
  R: 6
  C: 1
  R: 6
  C: 5-6
  R:

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP):

115
APPENDIX A: TEST PROCEDURE PROGRAMS

PROGRAM FOR COMPUTING CORRECTION FOR STAGE ORTHOGONALITY ERROR
(JOB NAME = ORTH4B)

The following program exposes a line of die in parallel to the X-axis during the first pass. On the second pass, the wafer rotated so that these exposures are now parallel to the Y-axis, and an overlay exposure is run to interlock the Precision/Registration verniers.

:SPEC ORTH4B

METRIC OR ENGLISH UNITS? (*M/E):

METRIC JOB

COMMENT: ORTHOGONALITY TEST FOR 4 INCH WAFERS WITH 3 INCH OBJECTIVE SPACING.

TOLERANCE (1,2,*3,4,5,6): 1

ORTHOGONALITY,PPM(-128<P<+128):_________

WAFER DIAMETER: 100

<< ARRAY PARAMETERS >>

STEP SIZE IN X: 6.35

*COUNT OR S-PAN:

HOW MANY COLUMNS: 15

STEP SIZE IN Y: 6.35

*COUNT OR S-PAN:

HOW MANY ROWS: 15

<< ALIGNMENT PARAMETERS >>

STANDARD KEYS? (*Y/N): N

RIGHT ALIGNMENT DIE CENTER
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 10
C: 14

KEY OFFSET:
   IN X: -1.8
   IN Y: -3.605

LEFT ALIGNMENT DIE CENTER
   R: 10
   C: 2

KEY OFFSET:
   IN X: -1.8
   IN Y: -3.605

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP): 1

COMMENT: SET APERTURES X=90MM Y=55MM

EXPOSURE (SEC):__________

FOCUS SETTING:__________

SHIFT:
   IN X:
   IN Y:

A-ARRAY OR P-LUG: P

PLUGS:
   R: 2
   Y-OFFSET:
   C: 6
   X-OFFSET:
APPENDIX A: TEST PROCEDURE PROGRAMS

R: 14
    Y-OFFSET:
C: 6
    X-OFFSET:
R: 8
    Y-OFFSET:
C: 2
    X-OFFSET:
R: 8
    Y-OFFSET:
C: 4
    X-OFFSET:
R: 8
    Y-OFFSET:
C: 7
    X-OFFSET:
R: 8
    Y-OFFSET:
C: 9
    X-OFFSET:
R: 8
    Y-OFFSET:
C: 12
    X-OFFSET:
R: 8
APPENDIX A: TEST PROCEDURE PROGRAMS

Y-OFFSET:
C: 14

X-OFFSET:
R:

<< PASS >>
NAME(<CR> TO EXIT PASS SET-UP): 2
COMMENT: SET APERTURES X=55MM Y=55MM

EXPOSURE (SEC):

FOCUS SETTING:

SHIFT:

IN X: 

IN Y:

ARRAY OR PLUGS: P

PLUGS:

R: 2
Y-OFFSET:
C: 8

X-OFFSET:
R: 4
Y-OFFSET:
C: 8
X-OFFSET:
R: 7
Y-OFFSET:
C: 8

119
APPENDIX A: TEST PROCEDURE PROGRAMS

X-OFFSET:
R: 9

Y-OFFSET:
C: 8

X-OFFSET:
R: 12

Y-OFFSET:
C: 8

X-OFFSET:
R: 14

Y-OFFSET:
C: 8

X-OFFSET:
R:

<< END PASS SET-UP >>

SAVE PASS? (*Y/N):

<< PASS >>

NAME(<CR> TO EXIT PASS SET-UP):
APPENDIX B

GCA ACCEPTANCE TEST PROCEDURES ORIGINAL DATA SHEETS
Customer: Dr. Fuller

Instrument No: 

Wafer No: 

Date: 2/3/86

<table>
<thead>
<tr>
<th>DIE</th>
<th>Vernier Reading (µm)</th>
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<tbody>
<tr>
<td></td>
<td>X-Axis</td>
</tr>
<tr>
<td>R</td>
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</tr>
<tr>
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New Baseline Correction

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<tr>
<th>X-axis</th>
<th>Y-axis</th>
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<tbody>
<tr>
<td>0.0566</td>
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Current Value From MODE

<table>
<thead>
<tr>
<th>Vernier Reading From Die R + 1000</th>
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</thead>
<tbody>
<tr>
<td>0.00015</td>
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<tr>
<td>0.00016</td>
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</tbody>
</table>

Vernier Reading From Die L

\[
\text{Vernier Error} = (\text{Y-axis Vernier From Die R}) - (\text{Y-axis Vernier From Die L}) = 0.45 - 0.35 = 0.10
\]

(Alignment Microscope Error = Y-Axis Vernier From Die L - Y-Axis Vernier From Die R)

Comments: THETA ERROR SPEC IS ± 0.2 µm

Test Performed By: MJC

Date: 2/3/86
Customer: Dr. Fuller

Instrument No: 

Wafer No: 

Date: January 27, 1988

T: __________ T: __________ Time: 2 PM

Selected Die: Row: 5 Column: 7

Optimum Exposure Time: 0.150 sec. 

93% of optimum exposure: 604.5 msec. 

103% of optimum exposure: 649.5 msec. 

2% of optimum exposure: 13 msec. 

Optimum Focus Setting: 242 -1 in. 

Resolution: 0.0000013 m

Die | Smallest Size Lines Clearly Resolved
---|----------------------------------
1 | 1.4 μm
2 | 1.2 μm
3 | 1.4 μm
4 | 1.4 μm
5 | 1.4 μm

Does this meet specification? 

Yes No

Comments: The specified resolution is maintained over a 10% change in exposure.

Excellent resolution (~1.4 μm) was maintained across a 4" wafer with 4 exposures. (And this wafer was wafered like a potato chip.)

Test Performed By: 

Date: 1/27/88

Approved By: 

Date: 
<table>
<thead>
<tr>
<th>DIE</th>
<th>VERNIER READING (μm)</th>
<th>X-AXIS</th>
<th>Y-AXIS</th>
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<tr>
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<tr>
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<tr>
<td>P14</td>
<td>0</td>
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<td>0.05</td>
</tr>
</tbody>
</table>

Comments:

- PRECISION SPEC IS ± 0.20 μm 2 SYSTEM
- REGISTRATION SPEC IS ± 0.35 μm 3 GOOD

Test Performed by: Matthew J. Connard  Date: 2/7/88
Approved by:  Date:
DSW Wafer Stepper®
Data Sheet

Customer: ________________________________

Instrument No: __________________________

Wafer No: 2

Date: 2/7/88

T: __________ T_AIR __________ Time 10:05

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<td>X-AXIS</td>
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</table>

Comments: Both precision & registration in spec - System Good

Test Performed by: Matthew J. Comard Date: 2/7/88

Approved by: ________________________________ Date: ________________________________
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Comments: **ALL WITHIN SPECS**

Test Performed by: **David C. Comard**

Approved by:  

Date: 2/4/88
**DSW Wafer Stepper®**

**Data Sheet**

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<thead>
<tr>
<th>Customer:</th>
<th>Instrument No:</th>
<th>Wafer No: 4</th>
<th>Date: 2/7/88</th>
<th>Test Performed by: Matthew O'Connor</th>
<th>Date: 2/24/88</th>
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**Time:** 1:30

**DIE** | **VERNIER READING (µm)** | **X-AXIS** | **Y-AXIS** |
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**Comments:** All within specs

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<tr>
<th>DIE</th>
<th><strong>VERNIER READING (µm)</strong></th>
<th><strong>X-AXIS</strong></th>
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Test performed by: Matthew O'Connor
**DSW Wafer Stepper Data Sheet**

Customer ____________________________

Instrument No: ________________________

Wafer No: ____________________________

Date: 2/19/88

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<tr>
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<td>M3</td>
<td>0.20</td>
</tr>
<tr>
<td>M4</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Average: $\bar{F} = 0.205 \mu m \quad \bar{B} = 0.325 \mu m \quad \bar{L} = 0.225 \mu m \quad \bar{R} = 0.2395 \mu m$

$\bar{M}_X = (\bar{F} + \bar{B}) / 2 = 0.268 \mu m$

$\bar{M}_Y = (\bar{L} + \bar{R}) / 2 = 0.2313 \mu m$

Trapezoid: $\bar{F} - \bar{B} = -0.0895 \mu m$

$\bar{L} - \bar{R} = -0.0125 \mu m$

Comments: MAGNIFICATION SPEC IS 0.267  MY IS OUT OF SPEC

TRAPEZOID SPEC IS 0.350  SYSTEM WELL WITHIN SPEC 0.350

Test Performed By: ____________________ Date: ____________________

Approved By: ________________________ Date: ____________________
DSW Wafer Stepper®

Data Sheet

Customer

Instrument No:

Wafer No:

Date: 2/9/88

T, T_AIR, Time

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<tr>
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<th>VERNIER READING (µm)</th>
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<tr>
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<tr>
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<td>0.35</td>
</tr>
<tr>
<td>DY3</td>
<td>0.35</td>
</tr>
<tr>
<td>DY4</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Average: $\overline{DX} = 0.3750 \mu m$  $\overline{DY} = 0.3500 \mu m$

X-DISTORTION $= (MX - \overline{DX}) + 2 = -0.0531 \mu m$

Y-DISTORTION $= (MY - \overline{DY}) + 2 = -0.0594 \mu m$

Comments: SPEC IS $\leq 0.2 \mu m$ SYSTEM GOOD

Test Performed By: ___________________________  Date: ___________________________

Approved By: ___________________________  Date: ___________________________
<table>
<thead>
<tr>
<th>DIE</th>
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<tr>
<td>R8</td>
<td>0.25</td>
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</tbody>
</table>

**Average:** $\theta = 0.2625\,\mu m$

**Excursion:** $\Delta \theta = (\text{Max. Reading}) - (\text{Min. Reading}) = 0.05\,\mu m$

**Comments:** DIE ROTATION SPEC IS $+0.1\,\mu m$

---

Test Performed By: [Signature]  Date: 2/4/88

Approved By:  Date:
Customer: ________________________________

Instrument No: ____________________________

Wafer No: ________________________________

Date: 2/10/88

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<tr>
<td>A3</td>
<td>0.40</td>
</tr>
<tr>
<td>A4</td>
<td>0.45</td>
</tr>
</tbody>
</table>

For ORTH3:

$$\text{ANGLE} = \frac{(A3 + A4)}{2} - \frac{(A1 + A2)}{2}$$

$$\text{arc seconds} = 0.508$$

For ORTH4A and ORTH4B:

$$\text{ANGLE} = \frac{(A3 + A4)}{2} - \frac{(A1 + A2)}{2}$$

$$\text{arc seconds} = -0.0394 \text{ arc sec}$$

For ORTH5:

$$\text{ANGLE} = \frac{(A3 + A4)}{2} - \frac{(A1 + A2)}{2}$$

$$\text{arc seconds} = 0.889$$

CORRECTION = (ANGLE) x (-5) PPM

Comments: THIS IS GOOD BECAUSE SPEC IS ±0.5 arc sec

Test Performed by: Matthew Conrad

Date: 2/10/88

Approved by: ________________________________

Date: ________________________________
APPENDIX C

RETICLE FABRICATION PROCEDURES
This section describes how to fabricate 10X reticles for the GCA stepper. It is a very simple procedure that will save time that used to be spent on mask making.

**DESIGN**

ICE is now set up with GCA alignment keys for all the pmos standard processes (pmos1900, pmos3000, pmos5000). Figure AC-1 shows the ICE template for all pmos processes, both contact printer and stepper based.

**RETICLE FABRICATION**

The reticle processes are backwards with respect to the processes used to make 1:1 contact printer masks. For instance, all the levels except metal require reversal processing of the stepper reticles, whereas only metal undergoes reversal processing in standard contact printer reticles. Furthermore, with the standard contact printer processes, a border was placed around each of the first three levels, but with the stepper process, only metal gets the boarder.

The following development procedure was used for reversal processing of the first three stepper levels.

1) 8 minutes in 2:1 (H2O:HRP) HRP developer.
2) 1 minute rinse in cool running water.
3) 5 minutes in bleach.
4) 1 minute rinse in cool running water.
5) 5 minutes in clearing agent.
6) 1 minute rinse in water.
7) Blow dry. 
8) Expose for 45 seconds. 
9) 3.25 minutes in 2:1 developer. 
10) 30 seconds in stop bath. 
11) 1 minute in fixer. 
12) 2 minute rinse in water. 

RETICLE ALIGNMENT

Difficulty was encountered when reticles were first run on the pattern generator because the stepper requires the centers of the fiducial marks to be 103mm apart. The pattern generator, however, is only capable of printing the fiducial mark centers 4 inches apart, or only 101.6mm apart. Figure AC-2 shows the standard reticle fiducial marks that GCA requests. Figure AC-3 shows what proper alignment of the reticle and platen fiducial marks looks like.

The only way to create effective reticle fiducial marks on the pattern generator was to make them as shown in Figure AC-4. Figure AC-5 shows what the proper alignment of reticle and platen fiducial marks should look like. The left reticle fiducial mark can be thought of as half a cross.
APPENDIX D

PERIODIC PROCEDURES
1) Change lamp every 500 hours.
   * If lamp is turned off and then on again before the 500 hours have elapsed, subtract 50 hours from the life of the lamp.

2) Oil keys and ways twice a week with fine machine oil.

3) Run Baseline Correction at least once a week.

4) Measure intensity at the object plane (platen), multiply by 100, and record in Figure AD-1.

5) Run Focus/Exposure test each time a new substrate is used, or if the system has been idle for over 4 hours since the last test.
<table>
<thead>
<tr>
<th>DATE</th>
<th>IL440 PROBE#</th>
<th>READING IRRAD. VALUE (mW/cm²)</th>
<th>EXPOSURE DOSE (mJ/cm²)</th>
<th>TIME (sec)</th>
<th>PROJECT</th>
<th>MASKING LEVEL</th>
<th>RESIST TYPE</th>
<th>COMMENTS</th>
</tr>
</thead>
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</tbody>
</table>
APPENDIX E

IMPORTANT TECHNICAL REFERENCE PAPERS

1) UNIVERSAL VERNIER TEST RETICLE INSTRUCTIONS

2) WAFER SCALING INFORMATION
1.0 INTRODUCTION

The Universal Vernier Test Targets (See Chart below), are hard surface reticles used to perform various phototests on DSW Wafer Stepper® systems. Every copy is a master generated directly on the GCA Pattern Generator in the photoresist mode using 5 in. x 5 in. x .090 in. ultra grade, chrome plates.

1.1 The Universal Vernier Test Target, in its present configuration, is capable of performing the following tests:

1.1.1 System Precision
1.1.2 System Registration
1.1.3 X, Y Mirror Orthogonality
1.1.4 Image Rotation
1.1.5 Optical System Reduction Ratio
1.1.6 Optical System Distortion
1.1.7 Trapezoid

1.2 The precision test may be performed at any stepping distance greater than 4 mm.

1.3 The reduction, distortion, and rotation tests for GCA lens family use the Universal Vernier Test Target and stepping distances as follows:

<table>
<thead>
<tr>
<th>Lens #</th>
<th>Reticle #</th>
<th>Step Size for Measuring Reduction, Distortion and Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zeiss</td>
<td>10-78-45</td>
<td>8mm</td>
</tr>
<tr>
<td></td>
<td>10-77-82</td>
<td></td>
</tr>
<tr>
<td>Tropel</td>
<td>2923</td>
<td>16mm</td>
</tr>
<tr>
<td>Zeiss</td>
<td>10-78-47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-78-05</td>
<td></td>
</tr>
<tr>
<td>Full Field</td>
<td>4800-003</td>
<td></td>
</tr>
<tr>
<td>Tropel</td>
<td>52232</td>
<td></td>
</tr>
<tr>
<td>Tropel</td>
<td>52035</td>
<td></td>
</tr>
<tr>
<td>Zeiss</td>
<td>10-78-37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-78-46</td>
<td>11mm</td>
</tr>
</tbody>
</table>

2.0 THE VERNIER PATTERN

2.1 The vernier pattern consists of two halves—male and female which, when interlocked, permit very small "interlocking errors" to be accurately determined without measurement in the classic sense.

2.2 The vernier halves are shown in Figure 1. Note that each half consists of two arrays of parallel structures: coarse and fine. The difference in periodicity of the male and female coarse arrays is 1.0μm (at 1X) while the difference in periodicity of the male and female fine arrays is 0.1μm (at 1X). All arrays consist of ten structures on each side of center. Thus, when the two halves are interlocked, the coarse vernier can measure errors from -10μm to +10μm with a 1.0μm least count. The fine vernier measures errors from -1.0μm to +1.0μm with a 0.1μm least count. Please note that the coarse and fine verniers are not cyclic. That is, one can read an error of say 4μm, but not 4.1μm, 4.2μm, 4.3μm, etc.

2.3 Figure 2 shows the male and female halves interlocked with no error. Note that the "inside" edges of the structures on the female fine vernier are stepped, thus causing a series of three ever-widening gaps upon interlocking. This configuration was chosen to aid the user in reading the vernier.

2.4 Figure 3 shows the male and female halves interlocked with various errors.

3.0 DESCRIPTION OF TEST TARGET

3.1 Figure 4 shows the Number 4800-005 Universal Vernier Test Target. In addition to the pattern of vernier halves described below, the target includes the following features.

3.1.1 Nomenclature

3.1.1.1 The Name, Reticle Number, and Serial Number are within the field size of the DSW Wafer Stepper® and will appear on the wafer.

3.1.1.2 The nomenclature at the bottom of the target is outside the field of the DSW Wafer Stepper® and will not print.

3.1.2 Reticle Alignment Marks

3.1.2.1 Alignment marks for all available aligner options are on all Universal Vernier Test Target reticles.
Technical Note

3.1.2.2 This permits the reticle to be aligned in the normal orientation and at 90°, 180°, and 270° on all instruments.

3.1.3 Wafer Alignment Keys

3.1.3.1 Four sets of wafer alignment keys are located to permit wafer alignment for various wafer sizes, periodicities and reticle orientations.

3.1.3.2 Figure 5 shows the detail of a typical wafer alignment key. Note that each key is uniquely identified as to periodicity and microscope separation (wafer size).

3.1.4 Resolution Targets

3.1.4.1 Several resolution targets are located on the target to aid in determining the proper focus and exposure time.

3.2 The Vernier Patterns

3.2.1 The Reduction Verniers

3.2.1.1 The vernier halves in the corners of each field are used to measure the lens reduction. (See Figure 4).

3.2.1.2 These verniers are labeled F, B, L, R indicating the front, back, left side, and right side of the platen opening.

3.2.1.3 Since the vernier halves are separated by the stepping periods, any reduction ratio error will show up as an interlock error on the vernier.

3.2.1.4 Example: Assume reduction ratio is that with a Zeiss 10-77-82 or 9.9996:1

\[ D = \text{Distance between vernier halves on image plane} \]
\[ = 60.049.9996 \text{ mm} \]
\[ = 8.0003 \text{ mm} \]

\[ E = \text{Reduction error in 8.0 mm} \]
\[ = D - \text{Stepping Distance} \]
\[ = 8.0003 \text{ mm - 8.0 mm} \]
\[ = +0.0003 \text{ mm} \]
\[ = +0.3 \mu\text{m reading.} \]

Thus, the vernier pattern will show a +0.3 \mu m reading.

3.2.1.5 Figures 6 and 7 show the interlocked verniers as they appear on the wafer at 8.0 and 5.5 mm respectively. Note that the four reduction verniers are located in a cluster and are easily found using the frame lines as a glide path. Note: "+" reading indicates the image is too big, i.e., the reduction ratio is <10:1.

3.2.1.6 Trapezoid is determined by subtracting the average B from the average F, and the average R from the average L.

3.2.2 The Distortion Verniers

3.2.2.1 The vernier halves on the X and Y axis at the edges of each field are used to measure lens distortion. (See Figure 4)

3.2.2.2 These verniers are labeled D.

3.2.2.3 In use, the distortion is determined by subtracting the distortion vernier (D) reading from the average of a number of reduction vernier (F, B, L, R) readings. The residual is a measure of the actual displacement of two points. This number is divided by 2 to determine the displacement of a single point from its theoretical grid position. Note: A "+" reading indicates pin-cushion distortion. A "-" reading indicates barrel distortion.

3.2.3 The Rotation Verniers

3.2.3.1 The vernier halves labeled Θ are used to measure image rotation. (See Figure 4)

3.2.3.2 Image rotation can result from a variety of sources:

A. Non-parallelism between reticle alignment marks and stage motions.

B. A mis-aligned reticle.

C. Asymmetrical keystoning of the system.

D. Twisting of the optical column from exposure to exposure.

E. Stage yaw.

3.2.3.3 Contributions from sources A, B, and C will tend to create a constant error. That is, all the Θ verniers on a wafer will show the same reading.

3.2.3.4 Contributions from sources D and E will create a variable error. That is the Θ verniers on a wafer will differ from image to image.

3.2.3.5 In order to accommodate all of the
above sources of error in a rotation specification, two tolerances must be set: one for the average of a number of vernier readings and one for the range.

3.2.4 The Precision and Registration Verniers

3.2.4.1 The vernier halves located near the center of the die are used to measure both the system precision and the system registration. (See Figure 4)

3.2.4.2 In practice, the vernier halves are interlocked as follows:

Step 1 - Expose an array.
Step 2 - Enter a - 0.5 mm X and a + 0.5 mm Y pass shift and expose a second array at the same stepping distance.

3.2.4.3 The resultant image is shown in Figure 8.

3.2.4.4 Note that the interlocked verniers are surrounded by a box.

3.2.4.5 The system precision test is executed by performing Step 2 immediately after Step 1.

3.2.4.6 The system registration test is executed by performing Step 1, developing the resist image, re-aligning the wafer, removing and re-aligning the reticle, and finally performing Step 2.

3.2.5 The Orthogonality Verniers

3.2.5.1 The X, Y mirror orthogonality test uses the same vernier halves as the precision test. (See Figure 4)

3.2.5.2 The vernier halves are interlocked as follows:

Step 1 - Expose an array.
Step 2 - Develop the resist image.
Step 3 - Rotate the wafer 90° and reload.
(X becomes Y, Y becomes X)
Step 4 - Align.
Step 5 - Expose a second array at the same stepping distance.

3.2.5.3 The resultant image is shown in Figure 9.

3.2.5.4 The interlocked verniers measure twice the difference between 90° and the angle between the X and Y axis mirrors.

4.0 TEST PROCEDURES

Detailed procedures for the above described tests are available from IC Systems Group. The Universal Vernier Test Target reticle is available from IC Systems Group as part of a set of several DSW Wafer Stepper© test reticles.

HOW TO ORDER: Call the GCA/IC Systems Group Customer Support Center nearest you. Our salespeople will answer your questions and assist you.

GCA/IC Systems Group is dedicated to the continued improvement in product performance and reliability of its systems. It reserves the right to modify specifications and details of design without notice.

GCA CORPORATION
IC Systems Group
209 Burlington Road
Bedford, Massachusetts 01730
Telephone 617-275-5400
Telex 95-1257
FIGURE 1A. FEMALE VERNIER HALF

FIGURE 1B. MALE VERNIER HALF
FIGURE 3B. INTERLOCKED VERNIER PATTERN INDICATING +0.8 μm

FIGURE 3C. INTERLOCKED VERNIER PATTERN INDICATING -2 μm
FIGURE 4. THE UNIVERSAL VERNIER TEST TARGET

KEY:
1. REDUCTION VERNIERS (TYPICAL)
2. PRECISION/REGISTRATION VERNIERS
3. ROTATION VERNIERS (TYPICAL)
4. RETICLE ALIGNMENT MARKS (TYPICAL)
5. DISTORTION VERNIERS (TYPICAL)
6. WAFER ALIGNMENT KEYS (TYPICAL)
7. RESOLUTION TARGET (TYPICAL)
FIGURE 5. WAFER ALIGNMENT KEY DETAIL (TYPICAL)

KEY: 1. WAFER ALIGNMENT KEY  
      (LINE WEIGHT = 2.0\text{m})

2. STEPPING DISTANCE IN MILLIMETERS

3. OBJECTIVE SEPARATION IN INCHES  
   (LONG BAR = 1", SHORT BAR = \frac{1}{2}"")
FIGURE 6. SIMULATION OF VERNIER TARGETS AS THEY APPEAR ON THE WAFER WHEN STEPPED ON 8.0mm CENTERS
FIGURE 8. SIMULATION OF INTERLOCKED PRECISION/REGISTRATION VERNIERS
1.0 INTRODUCTION

Integrated circuit geometries have become smaller, requiring better registration of masking levels. During the past few years semiconductor manufacturers have found wafer diameter size changes slightly in processing 5 to 15 PPM (Parts Per Million) being typical, and diameter changes for extreme cases being 40 PPM. This change is most pronounced for oxide layers. This phenomenon can generally be treated in a linear fashion. One way to achieve the registration accuracy required today is to make an adjustment of pitch, or die stepping distance to compensate for variations in wafer size caused by processing. For instance, if a 100mm wafer is heated in processing in such a fashion as to cause inelastic thermal expansion, the final size of the wafer, after cooling might be 100.001mm. The diameter change (.001mm) divided by the nominal size (100mm) yields .00001 or 10 PPM. With linear, isotropic expansion, any two locations on the wafer will be separated by an additional 10 PPM. A convenient location for determining
changes in wafer size is the alignment dice. The DSW Wafer Stepper® utilizes a measurement taken at the alignment dice to calculate a PPM size change to adjust stepping for each die. This is accomplished through the function called WAFER SCALE.

The WAFER SCALE Feature is initiated during alignment, and adds only 5 to 10 seconds during manual alignment, or one or two seconds during automatic alignment (AWA). Experimental data indicates that the short period of time taken to use WAFER SCALE will give results well within alignment tolerances required for current and next generation devices. The ability to accurately accommodate changes in wafer size between masking levels is one of the key advantages of the DSW Wafer Stepper® over conventional 1:1 projection or contact printers.

2.0 DESCRIPTION OF WAFER SCALE

The DSW Wafer Stepper allows the user to accurately overlay a photolithographic layer to a previous layer that had changed size since originally being stepped. In addition, proper use of various scaling features will allow a layer to be scaled in both X and Y, to more closely overlay to another photolithographic exposure tool (GCA DSW or other manufacturer). This is accomplished by the use of multiple scale factors.

Scale factors may be assigned at the Machine Level (in MODE) and at the Batch or Job Level (in SPEC). Additionally, the final scale corrections will be performed at the Wafer Level
during EXEC (as part of the alignment cycle i.e., WAFER SCALE).

2.01 Machine Corrections

The purpose of MODE scale factors is to match one machine to another. The X and Y scale factors in MODE compensate for slight misalignments between the laser metering beams and the X and Y axes of mechanical stage-motion.

An orthogonality compensation is also necessary for any small interaction between Y stage motion and X laser metering (and conversely). The orthogonality correction is a PPM correction and is available in MODE. Unlike the scale factors, which are a change in X scale per unit moved in X (or similarly in Y), the orthogonality correction is a change in Y per unit movement in X. An orthogonality correction will change the angle between the X and Y axis (presumably to make them 90 degrees). Some examples of orthogonality corrections are given later in this text.

The MODE scale factors are particularly relevant to first level jobs in which no Wafer Scale operations are performed. Scale factors in MODE allows the first level to be accurately positioned so that subsequent levels can utilize other DSW scale factors to compensate for X and Y scale factors other than those attributed to machine level scale factors. The first level on a wafer can be "blind stepped", using only the scaling in MODE and/or JOB. The accuracy of initial die placement (first layer)
depends totally on \( x \) and \( y \) offset and orthogonality PPM's assigned by the System Supervisor in MODE, and the JOB, when Wafer Scale is disabled.

2.02 Batch Corrections

The purpose of JOB or SPEC scale factors is to compensate for distortions of wafer geometry resulting from wafer batch processing. Provision can be made for anisotropic materials in that different scale factors for \( x \) and \( y \) may be entered via the Job SPEC.

Compensation for skew may be included in SPEC as Orthogonality. Once machines have been standardized using MODE, JOB/SPEC orthogonality provides an opportunity for non-SXS users to compensate for skew distortions between exposure tools.

Job scale factors can be used to accommodate wafers exposed on an uncompensated machine, either another DSW or a 1:1 projection or contact printer. In this application it is necessary for the user to know the relative difference in scale factors between the uncompensated machine and the DSW for which JOB scale factors are being SPEC'ed.
2.03 Wafer Corrections

The DSW Wafer Scale feature allows user measurement and correction of wafer to wafer induced scale changes. This is accomplished during normal wafer alignment by comparing the actual wafer alignment key separation to the known alignment microscope objective spacing. The result of this comparison will be true indication of the X scale factor (given in Parts Per Million(PPM)). This calculated X scale factor value will be used to compensate die position for expansion or contraction and replace the specified X scale factor for the next wafer in the batch. Subsequent Wafer Scale operations will continue to update the operational value of SPEC (JOB) scale factors. In multi-wafer batches, it may be necessary to Wafer Scale only the first wafer of the batch, to minimize the time spent aligning subsequent wafers in the batch. A new execution of the job causes the operational X-scale factor to return to the X-SPEC (JOB) scale factor, rather than the updated value resulting from the last Wafer Scale operation.

3.0 ANISOTROPIC OVERLAY CONSIDERATIONS

Changes in wafer size typically occur linearly in both X and Y. However, there may be small differences in X and Y scale, or the previous masking layer may have been exposed by photolithographic equipment having different scale factors for the X and Y axes. The relationship between X and Y scale
Factors can be anticipated via experience, or experimentally determined. Different scale correction for the X and Y axis can be entered into the JOB specification. For example, the JOB may be SPEC'ed with XPPM = 3 and YPPM = 7. The X wafer scale correction determined during alignment is applied to the Y axis according to the difference between the X and Y scale corrections in the job spec. For this example the X Wafer Scale would be increased by 4PPM and then applied to the Y axis. The MODE and JOB X scale factors are stored in the control computer, and will be summed to be equal to a constant K, for each job. The difference between the measured X Wafer Scale measured during alignment) and K is known as the ALIGN X scale correction factor and is used to step the wafer when wafer scale is enabled. The ALIGN X and ALIGN Y factors are calculated as follows:

\[
\text{WAFER SCALE} - (\text{MODE X} + \text{SPEC X}) = \text{ALIGN X} \quad [1]
\]

\[
\text{MODE Y} + \text{SPEC Y} + \text{ALIGN X} = \text{ALIGN Y} \quad [2]
\]

Rearrangement of equation [1] with MODE X = MODE Y = 0 yields:

\[
\text{ALIGN X} = \text{WAFER SCALE} - \text{SPEC X} \quad [3]
\]

Substituting into equation [2]

\[
\text{ALIGN Y} = \text{SPEC Y} + \text{ALIGN X} \quad [4]
\]
ALIGN Y = SPEC Y + WAFERSCALE - SPEC X

This means that ALIGN Y value will differ from ALIGN X by the amount (SPEC Y - SPEC X). Measured X axis Wafer Scale is applied isotropically on X and Y axis when SPEC X is equal to SPEC Y and anisotropically when SPEC X is not equal to SPEC Y but never proportionally.

4.0 EXAMPLE

The DSW Wafer Stepper accommodates several alignment microscope objective separations, but for ease of discussion the 63.5mm (2.5 inch) separation will be considered.

It is not necessary to fabricate the wafer alignment microscope objective spacing to the exact dimension required, because the actual separation can be determined and used to correct instrument functions requiring accurate objective spacing. When utilizing Standard Alignment keys the control computer can calculate the difference between the designed separation of the wafer alignment keys (63.500mm) and the nominal microscope objective separation and compensates for any differences observed.

The actual objective spacing is typically determined by exposing a baseline wafer and comparing the X vernier readings for the left and right alignment dice. The actual value is calculated by the following:
\[(X_{\text{LEFT}} - X_{\text{RIGHT}}) = \Delta X\]

Actual microscope objective spacing = Nominal - \(\Delta X\)

For example, suppose that a measurement of the microscope objective separation indicates a separation of 63.490mm, instead of the normal 63.500. Properly spaced (63.50mm) wafer alignment keys would appear to be further apart than they actually are, when viewed on the video monitor. To compensate, GCA® personnel or trained user can enter the actual separation (in this case 63.490mm) into the software using the MODE command. A complete procedure for determining objective spacing is illustrated by Product Support Procedure 22, titled: "Measurement of the DSW Objective Spacing".

Typically, an X offset of the left hand alignment key will be apparent after the right hand alignment key has been aligned in X, Y, and theta. Some of this offset will be caused by the change in wafer size, and some by an objective spacing offset. The operator will press the WAFER SCALE button on the AWH button box, or this function is performed automatically if the AWA is used. The stage will then move to compensate for any specified objective spacing offset. In this example, the stage will then move ten microns to the right. In the AWA mode, the stages are moved by the AWA, and do not automatically move prior to alignment.
After the operator has pressed the WAFER SCALE button, or the AWA generates a WAFER SCALE signal, the stage is moved by the control computer or AWA to compensate for objective spacing. Any remaining offset is entirely due to change in the wafer size.

It should be noted that it is possible to have equal and opposite offsets of objective spacing and wafer expansion, causing an apparent perfect alignment. Such a situation would tempt the operator to omit WAFER SCALE step in manual alignment and proceed directly to the EXPOSE step. Care must be taken to assure that the WAFER SCALE button is always pressed during manual alignment, if wafer-to-wafer corrections are needed.

Typically, issuing the WAFER SCALE signal, either manually or automatically, will reveal an offset in the left hand portion of the video display on the first wafer in a set. The operator, (or AWA), will translate the stage until the left hand alignment key is aligned in X and issue the EXPOSE signal. The right hand cross typically appears to move out of X alignment. The amount of X translation required to achieve the alignment is then compared to the specified alignment and actual objective spacing key separation to compute a Part Per Million (PPM) compensation (i.e. Wafer Scale). This correction is introduced accurately into the center location of each die, rather than simply averaging the misalignment, as is typically done in most 1:1 projection systems. For example, if the wafer has expanded to a point where the separation between the wafer alignment keys is 63.50064mm (.64 microns more than nominal), the system will
compute a 10 PPM correction. Assuming SPEC X = SPEC Y, the 10 PPM correction will be applied linearly in both X and Y for each die step. For example, if the die separation is 5mm in both X and Y then each die step will increase by .05 micron in X and Y. The resulting step size will be 5.00005mm in X and Y. The die containing the right hand alignment key will be used as the origin in WAFER SCALE compensation. In the example, the die adjacent to the origin will be stepped 5.00005mm from the origin, the next at 10.0001mm and so on.

Once the WAFER SCALE factor has been determined for the first wafer of a batch to be exposed, the PPM correction remains intact in the program for the next wafer. The operator or AWA will then issue the WAFER SCALE signal and the stage will move enough to compensate for both objective spacing and the previous WAFER SCALE factors (in the manual mode). If the process induced expansion of the second wafer is the same as that of the first, (which is usually the case) the left hand wafer alignment key will be aligned after the WAFER SCALE signal has been issued (in the manual mode). If the alignment achieved after issuing the WAFER SCALE signal is not perfect, the operator (or AWA) must move the stage in the X direction until alignment has been achieved. The operator (or AWA) will then issue the EXPOSE signal, and a new PPM compensation factor will be calculated and stored in memory. This factor will remain in memory whether or not WAFER SCALE is utilized on subsequent wafers, until the job is ended.
The above procedure will be repeated for each wafer, with the DSW Wafer Stepper "remembering" the WAFER SCALE PPM compensation of the previous wafer. The scale factors stored in the job specification will be updated each time a Wafer Scale is performed.

During exposure the scale factors obtained from alignment (Wafer Scale) are added to the machine specific scale factors stored in MODE. For example, if X and Y are equal and both SPEC (the job tape) and MODE contain 5 PPM scale factors and the correction determined from the last alignment is 2 PPM, the working job specification will be updated to 2 PPM correction (modified job parameter). Thus the total correction for this exposure run will be 2 PPM from alignment and 5 PPM from MODE which equals a 7 PPM correction.

**Implementation Variations**

There are four conditions that must be considered when talking about wafer scale.

A. Manual alignment, standard alignment keys

B. Manual alignment, nonstandard alignment keys

C. Automatic alignment, nonstandard alignment keys

D. Automatic alignment, standard alignment keys
Conditions A and B are performed in the same manner, both in calculating the final wafer scale, and in presentations of the PPM corrections on the computer video terminal (CVT). The cases of Automatic Alignment differs slightly in CVT presentation from the other conditions. The reasons are as follows:

During manual alignment, the initiation of the Wafer Scale command will result in a rapid stage motion to a position that approximates final X-alignment of the left-hand alignment key. The amount of this rapid stage motion is derived from the operational X-scale correction and the actual alignment key separation. This automatic stage motion is intended to minimize the amount of stage motion required to perform the X-alignment of the left hand alignment key subsequent to initiation of the Wafer Scale function. Prior to initiating the Wafer Scale function the X and Y scale corrections displayed on the CVT will be equal to the SPEC scale corrections input for the job being executed. The numbers displayed when the EXPOSE command is issued will be equal to the actual Wafer Scale PPM correction (as measured on the wafer) in X, and Y.

While aligning in the Automatic Mode, sudden stage motions can cause the AWA to lose track of the wafer alignment key, and have to re-initiate the search for the alignment key. This searching generally takes more time than simply making the alignment, starting from the initial position. Consequently, the software inhibits the rapid stage motion, when using AWA.
In order to inhibit the rapid stage motion, a value is inserted into the operational SPEC X scale factor by the control computer that will result in the amount of rapid stage motion calculated being zero. Thus the number displayed on the CVT, at the time of Wafer Scale initiation, will not be equal to the JOB spec'd scale factors. After successful X-alignment on the left, the CVT displayed Scale Factors will be, as in the other cases, the Wafer Scale value for X and Y. Thus, the end result for AWA and manual alignment will be the same.

Wafer Scale operation with standard and non-standard alignment keys is very similar except for the "place" the control computer "looks" to "find" key locations with standard alignment die. Stage position to fix alignment die under objectives is fixed by die size, objective spacing and wafer size. Non-standard die can theoretically exist anywhere on the wafer. When AWA exists with non-standard alignment die, separation of left die from the right must position left die within the field of view of AWA search area. This corresponds to a left die located within plus or minus 0.5 inches from the center of the location defined by objective spacing of the instrument. If the left die cannot be within this limit, AWA should not be used.

5.0 WAFFER SCALE AND 5X-10X MATCHING
The use of Wafer Scale in manufacturing lines utilizing a mixture of 5X and 10X imaging systems can provide enhanced overlay, but requires care in selecting offsets when overlay tolerances are extremely rigid.

Actual PPM corrections derived with Wafer Scale enabled are utilized in altering the step size for each exposure. With block printing, on a 5X systems, a slight mis-match can occur between the block-printed exposures and a single die 10X exposure. This is best illustrated by example. (Note: All dimensions given in the example assume no machine or reticle error.)

Figure 1 shows an overlay comparison between block printing (solid lines) and single die exposure (dashed lines) for a device 10mm square (at the wafer) and a Wafer Scale developed PPM correction of 20 PPM on both the 5X and 10X systems. The blockprinted (5X) exposure used here is a 2X2 array (only one row drawn). Each single-die (10X) exposure has a 20 PPM (0.2 um) step alteration. The 5X exposure also has the 20 PPM correction per array exposure, but the intra-exposure spacing is not scaled. A point in the center of the second die on the blockprinted wafer will be 15.0000mm from an arbitrary reference ("0 REF" on the drawing).

Since each 10X exposed die is individually exposed, the second exposure will be 10.0002mm (0.2 um delta) from the first, resulting in the mid-point of the second die being displaced from the corresponding block-exposure point by 0.2 um. This
displacement error could have been decreased by altering the stepping distance by 10 PPM when the 5X reticle was created.

The above example is a worst-case situation. However, it was included to indicate that some care must be exercised in order to avoid situations such as the above example. If the process, and related wafer size change, can be characterized and predicted, the block printed reticle can be changed to include the anticipated scale correction.

Scaling backwards is also possible by knowing what happens to the wafer at each process step. If you know what happens by the time you get ready to overlay a 5X exposure over an array of 10X, you can adjust the 10X to fit the 5X die.

Block printing becomes more confusing when one block array is being overlaid to another, such as a 3X2 array and a 2X2 array. Each case must be reviewed separately, and appropriate action (if required) must be taken.
Figure 1: Comparison of block-printed (5X) and single-die exposure (10X) overlay dimensions.

- Dimensions or block printing are shown as solid lines.
- Single-die exposure dimensions are shown as dashed lines.

NOTE: 0.2um difference in location of corresponding point between black printed and single die exposures.
The Wafer Scale command is issued either manually, via the operator controls (button box) or by the AWA. AWA and the button box are electrically in parallel, as shown on the Wafer Scale Signal Flow Diagram (Figure 2). The signal (momentary low) enters the 9284 (AWH) chassis at pin K of connector J28, and is utilized on the AW2 and AW3 boards. The information is transmitted to the control computer interface at octal address 167672, bit number 4.
WAFFER SCALE

FUNCTIONAL TEST RESULTS

Tables I-IV show results of the four sets of experiments on Wafer Scale implementation variations: manual alignment, standard and non-standard keys; and automatic alignment, standard and non-standard keys. To be in the manual alignment mode, the switch or the panel of the AWA must be in the MANUAL position, and the MODE question regarding AWA must be answered "NO". The tables listed here show MODE, SPEC PPM corrections, as well as the SCALE FACTORS displayed on the computer video terminal (CVT) after final alignment of the left hand alignment key. The PPM corrections measured on the wafer through vernier readings are also given. Since the wafers used in these experiments were developed resist, with little chance of any thermal expansion or contraction, MODE offsets in both X and Y were used to simulate a typical, real world process situation. In addition, the first layer (alignment marks and first half of the vernier) was exposed with all PPM corrections = 0. The data presented here was rounded off, to compensate for slight alignment or reading errors. Version 4.03 of the DSW MOP was used.
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* MODE values changed for purposes of the Wafer Scale experiment; the nominal values are zero or experimentally determined values to match/compensate the DSW instrument.
### TABLE III: AUTOMATIC ALIGNMENT, STANDARD KEYS

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TABLE IV: AUTOMATIC ALIGNMENT, NON-STANDARD KEYS

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ORTHOGONALITY AND WAFER SCALE

The orthogonality correction in MODE is used to change the relative angle between the X and Y axis. The orthogonality corrections are generally not altered once established for a given instrument. There may be some cases in which a masking level was exposed using an exposure tool with a different orthogonality than the exposure tool being utilized for subsequent exposures. This would necessitate alteration of the orthogonality corrections for the DSW used for the second layer exposure.

The orthogonality of stage motions on the DSW is maintained to a tolerance of +/- 1.0 arc seconds or less. This specification is difficult to obtain mechanically, so an orthogonality correction in the control computer is used. The correction is a plus or minus PPM (parts per million) correction and corresponds to a change in Y axis per X axis distance traversed. The correction is the same for both English and metric units with 1 PPM approximately equal to 0.2 arc seconds.

Orthogonality is affected by the effects of Wafer Scale corrections. When correct stage position is developed by the control computer the Wafer Scale PPM correction is included in the calculation.
The experiment to demonstrate the effects of Wafer Scale on orthogonality are very similar to the four variants of Wafer Scale illustrated by the data in Table I through IV. Once again MODE and SPEC offsets are used on the last layer to simulate the effects of wafer size changes related to real-world processing.

Reduction of data on this experiment uses procedures other than those defined by orthogonality test procedures (TP4800-016). This procedure uses the universal test target reticle and relies on the super position of alignment mark exposures with a 90 degree wafer rotation between exposures. The experiment defined here should not be considered as a replacement for existing orthogonality tests.

Figure 3 illustrates general die layout for this experiment. Xn, Yn represent X and Y vernier readings on the test wafer. Vernier pairs X1,Y1; X4,Y4 are separated sufficiently to allow computation of an orthogonality offset (i.e., (Y1 - Y4)/d2). Expressed in PPM this number represents the end result of machine characteristic orthogonality, MODE and/or, SPEC orthogonality input and Wafer Scale. The experiment simply determines two of the orthogonality components via other tests or calculations.
\[ \theta \text{ (PPM)} = \frac{Y_4 - Y_1}{d_2} \]

\[ \theta = \tan^{-1} \left[ \frac{\text{change in } X}{\text{change in } Y} \right] \]

for \( \theta \leq 1^\circ \)

\[ \theta = K \tan \theta \]

\[ \theta = K \left[ \frac{\text{change in } X}{\text{change in } Y} \right] \]

FIGURE 3
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**TABLE V: ORTHOGONALITY TABLE**
Table V illustrates the combined and separate effects of Wafer Scale and both MODE and SPEC orthogonality. Vernier 1 defines machine characteristic orthogonality with only MODE orthogonality input. The 4PPM MODE orthogonality causes a -3PPM shift in orthogonality verniers. Vernier 2 inputs +10PPM into MODE and SPECX with 4PPM in MODE orthogonality. By equation [7] Y wafer vernier is zero with canceling MODEY and SPECX offsets. Orthogonality remains at -3. Vernier 3 increases MODE orthogonality by +10 to +14. This causes orthogonality X vernier to increase to -13. The Y wafer vernier is -10 in response to the +10 MODEX input. X orthogonality increases necely to -13PPM.

Vernier 4 reverses the sign of MODEX input causing the Y wafer vernier to go to +10PPM, with MODE orthogonality input held at 14. While the -10PPM Y wafer vernier wasn't observable at vernier 3 the +10PPM Y wafer vernier on vernier 4 increases X orthogonality to -15PPM.

Vernier 5 sets MODE Y at +10PPM. This would seem to rotate X orthogonality about the same amount as vernier 4. Statistical nature of the process produces an X orthogonality vernier to be -18PPM.

Vernier 6 causes approximately a 20.4PPM change in observed orthogonality from vernier 5 with a 20PPM change in MODE orthogonality.
Vernier 7 utilizes offsetting XMODE and XPEC offsets while adding +14PPM to the effective orthogonality variable of vernier 6. The 14PPM orthogonality input causes +8.7PPM X orthogonality vernier change from vernier 6.

Vernier 8 compares favorably with vernier 5 with the Y wafer vernier going from +10PPM on vernier 5 to -10PPM on vernier 8.

Vernier 9 causes a 19PPM X orthogonality vernier change for a 20PPM change in MODE orthogonality.

CONCLUSION

We hope this document removes some of the mystery from the Wafer Scale function. The Wafer Scale function is intricate to explain and completely understand. The function will allow the experienced user to obtain maximum functionality from the DSW and be just that much more compatible with the next generation integrated circuit geometries.