TEST STRUCTURES FOR THE VISUAL CHARACTERIZATION OF OPTICAL LITHOGRAPHY

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Abstract

Special parameter-isolating visual test patterns have been designed, calibrated and documented for stepper characterization. The patterns include traditional and exploratory targets for monitoring exposure, focus, astigmatism, coma, flare and printability of defects. The test pattern shapes and sizes were selected through simulation of pattern sensitivities to various optical system parameters. The two-dimensional aerial image simulator SPLAT and resist profile simulation with SAMPLE were used for this purpose. The patterns were designed and laid out as a graduate class project at U.C. Berkeley during the fall semester. The patterns were then scaled for use with the AWIS deep-UV optical stepper with 0.5 resolution during the Spring 1988 semester by George Misium.

February 8, 1988.

DUV Lithograhy Test Mask

Designer:

George Misium

Based on the VisuaLith test mask designed by
William Haller and Davor Sutija (ERL 1987).

Electronics Research Laboratory
Department of Electrical Engineering and Computer Science
University of California, Berkeley

ABSTRACT

The mask described in this report contains a set of test structures for the visual characterization of optical lithography processes in a deep UV stepper. Structures for characterizing process variations and stepper performance have been designed; that is, patterns for determining resolution, lens aberrations, flare, dose levels, critical defects and SEM inspection. Varying various process parameters such as surface treatment, soft bake and post exposure bake will produce a set of wafers that can be directly compared for the development of deep-UV lithographic processes.

Contents

CHIP FLOOR PLAN

The collection of test structures is divided into several different subsets as listed below.

BasicSet: Contains the following: elbows, 1D and 2D focus targets, Aberration targets. Located at 13 locations to identify field dependent characteristics.

Dose: Targets with varying levels of DC transmission. Located only at the center of the field due to the high flash count in producing these targets.

Flare: Targets designed to be sensitive to large feature proximity effects. Three locations: center, edge, and corner.

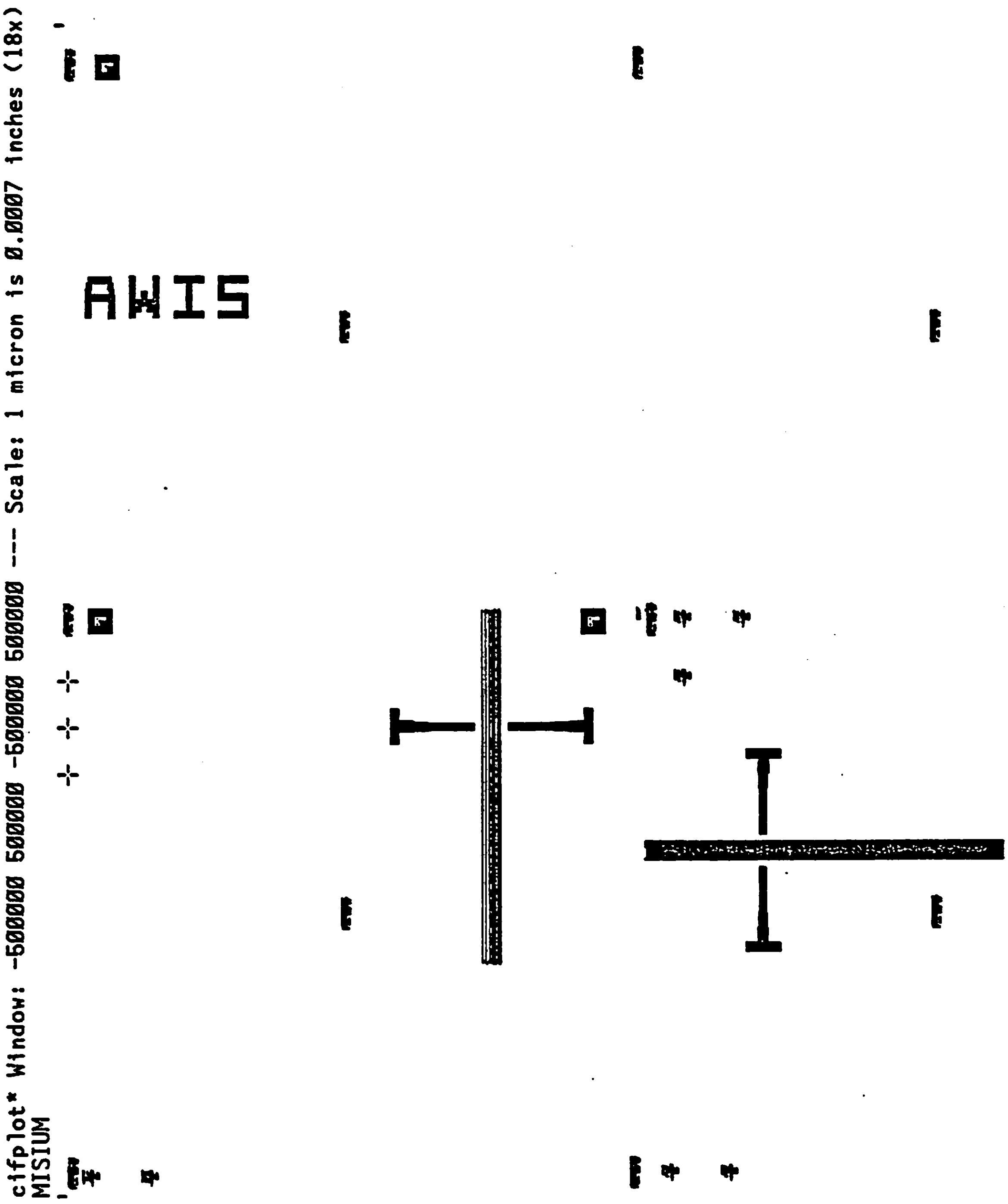
DefectSet: Features with programmed defects next to or within them. Three locations, center, edge, and corner.

ClearSet: The same features as in DefectSet without the defects, for comparison. Four locations: two in the center next to the DefectSet and one next to each of the other DefectSet.

SEMlines: Long lines of varying width and period for SEM use. Two locations by the center of the chip.

The test structures listed above are located on a 1 cm square test chip as shown on the following page. One copy of each test pattern (excluding SEMlines) is located in the center portion of the chip, with additional copies located on the chip as shown in fig. 1. Finally, an empty area has been left for the measurement of film thicknesses.

Fig. 1 : Overall floor plan of the test mask.



SUMMARY TABLE OF PATTERNS

The test patterns used are tabulated below.

File Name	Structure	Purpose	Coordinates
elbows	Elbows of various sizes in both polarities	resolution	A
focus1D	lines of various sizes in both polarities	resolution	A
focus2D	boxes of various sizes in both polarities	2D resolution	A
coma	lens aberration sensitive targets	lens aberrations	A
flare	flare sensitive target	flare measurement	B
DefectSet	lines and elbows with programmed defects	measure defect sensitivity	C
ClearSet	same features as DefectSet without defects	control for DefectSet	C
dose	arrays of boxes	monitor dose	D
SEMlines	long lines of various dimensions	SEM cross sections	F

Key to coordinates (all dimensions in mm):

A - 13 locations: center, 4 corners, center of 4 edges, center of 4 quadrants.

B - 3 locations: center, edge ($x = 4.8$, $y = 0$), corner ($x = 4.8$, $y = 4.8$).

C - 3 locations: center, edge ($x = 0$, $y = -4.8$), corner ($x = 4.8$, $y = -4.8$).

D - 1 location: center.

F - 2 locations: horizontal and vertical lines by the center of the chip.

PROCESSING

(A) Mask Making

The VisuaLith mask is intended to be fabricated as a chrome mask (without reversal) due to the fine nature of some of the features, as such it requires about 20,000 flashes.

(B) Wafer Preparation

It is useful to examine the effects of varying various processing parameters on different substrate reflectivities. Towards this end several different substrates should be prepared, including but not limited to

1. Si: Plain, clean silicon with only native oxide.
2. Al: Aluminum deposited on Si to provide a high reflectivity substrate.
3. Very Hard Baked Photoresist: Silicon wafer coated with Kodak 820 photoresist and placed on a hot plate at 120 C which is then ramped up to 300 C over a period of 15 minutes or more. This produces a low reflectivity substrate.
4. Thin Film Stack: A matched substrate can be produced by using thin films such as nitride, this reduces reflectivity as seen in the photoresist to a minimum and eliminates standing waves in the resist.

Substrates shoud be cleaned using standard procedures. It is recommended that an HMDS treatment should be used just prior to coating with photoresist.

(C) Photoresists

The standard Kodak 820 resist can be used initially. The use of a thin resist to investigate aerial imaging on a matched or low reflectivity substrate is a possible option. For a full characterization of the lithography process a great number of resist processing parameters can be varied. It is suggested that splits only for a post exposure bake initially be made.

(D) Exposure

Expose using the VisuaLith test mask using the standard focus dose exposure matrix, centered on the current best operating point used in the microlab.

(E) Developement

Develope using MTI and standard resist developing program.

The result of the above steps will be a set of wafers of varying reflectivity patterned with the mask here described.

DISCUSSION

VisuaLith Test Structures

BasicSet

The set of structures contained in BasicSet is intended to provide a means of comparing resolution and image quality within a single die site as well as from die site to die site. Towards this end the patterns are duplicated in thirteen locations on the mask. Targets are included that are sensitive to resolution as well as lens aberrations.

Components of BasicSet:

Elbows:A set of elbows composed of equal lines and spaces are included for a basic resolution target. They range in size from 0.35 lambda/NA to 1.55 lambda/NA (0.25 to 1.1 um), exist in both polarities, and have isolated lines included in the form of extensions of the center lines.

Checks: Three sets of checkerboard patterns with squares of .4, .5 and .6 um.

1 D Focus: These are isolated lines in clear and dark fields, ranging from 0.35 lambda/NA to 0.7 lambda/NA (0.25 to 0.50 um). They are sensitive to focus and should be marginally printable.

2 D Focus: These are isolated boxes in clear and dark fields, ranging from 0.42 lambda/NA to 0.85 lambda/NA (0.3 to 0.6 um). They should be even more sensitive than the 1 D Focus target for determining best focus.

Coma: It has been shown that small defect-like features that are in close proximity to larger features can be sensitive to lens aberrations, in particular coma. To explore the usefulness of this phenomenon two structures using different sized 'defects' arranged in a radial and symmetric manner around a larger structure are included.

Flare

This structure is intended to identify the presence of flare in the optical system by using small features whose imaging would be sensitive to low DC levels of light intensity. This background intensity can be dependent on large features and field location, therefore the flare test target is included in three locations. This background level is generally not included directly in simulation programs such as SAMPLE; the flare target is hoped to provide some feed back on the importance of the effect.

Dose

In principle it is possible to mimic a neutral filter of arbitrary transmission by using sub-imagable features to scatter a portion of the light being transmitted through the mask. If we assume that features of less than 0.5 lambda/NA will not be imaged, then arrays of appropriately sized boxes with periods in each direction of this size or less can be used to produce areas on the wafer that will recieve only a fraction of the normal clear field dose. A structure of this kind is included so that the effective dose as recieved by the resist (which varies with substrate reflectivity as well as exposure time) can be monitored.

SEM Lines

A set of long lines for making cross sectional SEM photograhs of resist profiles, including equal lines and spaces, and isolated lines and spaces.

FUNCTIONAL DESCRIPTION

DUV Lithography Test Mask

Elbows

File Name:

elbows

Purpose:

Evaluate resolution of lithographic process.

Description:

The elbows used here range from 0.25 um to 1.1 um, corresponding to approximately 0.3 lambda/NA to 1.5 lambda/NA. They are realized in both polarities and have short extensions to compare isolated lines with line space patterns [fig. 2].

Testing:

Expose wafer using a focus-dose matrix. Visually inspect elbows to find best combination of equal lines and spaces and resolution of smallest features. This gives a best operating point of focus and dose.

1 D Focus Target

File Name:

focus1D

Purpose:

Determine best focus setting of stepper.

Description:

This pattern consists of 6 sets of dark lines in a clear field and 6 sets of clear lines in a dark field ranging from 0.25 um to 0.5 um corrsponding to 0.3 lambda/NA to 0.7 lambda/NA. They are marginally resolvable and hence sensitive to defocus [fig. 2].

Testing:

Expose wafer using focus-dose matrix. Visually inspect die sites; the best site will exhibit the smallest lines resolved. The die site with the best resolved targets should be the best focus setting.

Within the best site, compare the targets at 13 locations in the field; determine if there is variation in focus across the field. Evidence of nonuniform focus may indicate presence of lens aberrations or other stepper problem.

2 D Focus Target

File Name:

focus2D

Purpose:

Determine best focus setting of stepper.

Description:

This pattern consists of 7 sets of dark boxes (contacts) in a clear field and 7 sets of clear boxes in a dark field ranging from 0.8 um to 1.3 um corresponding to 0.5 lambda/NA to 1.0 lambda/NA. They are marginally resolvable and hence sensitive to defocus [fig. 2].

Testing:

Expose wafer using focus-dose matrix. Examine die sites, the best site will exhibit the smallest lines resolved. The die site with the best target will be the best focus setting.

Within the best site, compare the targets at 13 locations in the field; determine if there is variation in focus across the field. Evidence of nonuniform focus may indicate presence of lens aberrations or other stepper problem.

Coma

File Name:

coma

Purpose:

Detect lens aberrations.

Description:

This pattern consists of a large symmetric feature surround by small defect like features in close proximity. Simulations have shown that imaging of defects near larger features can be dependent on lens aberrations, these results further investigation and hence the inclusion of these targets. They are realized for two different sizes of defects, 0.5 um and 0.3 um [fig. 2].

Testing:

This target would be best utilized on a thin resist, where resist processing impact can be minimized. Examine each target for nonsymmetric characteristics that might be characteristic coma. Compare targets in the thirteen different locations of a single die site. It would probably be easiest to do this by photographing the targets. Anisotropic resist processing biases may also cause nonsymmetric resist structures.

Flare

File Name:

flare

Purpose:

Detect long range proximity effects of large features.

Description:

A set of small, marginally printable boxes are located in the center and edge of light and dark fields. The features are 'encased' in a small light field area to eliminate the influence of near-proximity effects.

Testing:

The use of a thin resist would be preferable. Compare the smallest feature printed in the different locations within the target to detect if there is a variation in the DC background light level. Check different locations within the die site to determine if there is a dependence on field location.

Features With Defects

File Name:

DefectSet

Purpose:

Determine critical defect sizes and locations.

Description:

DefectSet contains five categories of features with 'defects' to determine the critical locations and sizes of mask defects. Line widths are 0.65 um, corresponding to 0.9 lambda/NA. All designs are realized in both polarites. The patterns are located in files as follows:

defects1: Isolated lines with adjacent boxes of the same polarity sized 0.15, 0.25, and 0.3 um seperated from the lines by distances of 0.1, 0.15 and 0.25 um [fig. 4].

defects2: 5 um square boxes with 0.25 um boxes located at distances of 0.1, 0.15, 0.2, and 0.25 um in the following configurations: diagonally from a corner in the same polarity as the large box, collinear with an edge in the same polarity as the large box, and on the interior diagonal in the opposite polarity as the box [fig. 4].

defects3: Equal lines and spaces with boxes sized 0.15, 0.25, 0.3, and 0.4 um located in the center and edge of a line [fig. 4].

defects4: Nested elbows with 0.25 um boxes of the same polarity as the lines, located on both the diagonal and collinear to an interior edge of the outer most elbow at distances of 0.1, 0.15. 0.2, and 0.25 um. Boxes are also included between elbows [fig. 5].

defects5: Isolated elbows with 0.25 um boxes removed from the lines, various locations.

Testing:

There is a second set of targets called clear1, clear2 etc. up to clear5 which make up ClearSet; they correspond to defects1 to defects5 and are the same except they do not have the program defects. There are two copies of ClearSet in the center of the die, translated in the x and y direction from the copy of DefectSet there, for the other two instances of DefectSet there is one copy of ClearSet translated in the x direction. With the combinations given it should be possible to determine critical mask defect locations and sizes by comparing to the features of DefectSet to those of ClearSet.

Dose

File Name:

dose

Purpose:

Monitor exposure dose.

Description:

A series of neutral density filters are designed to allow monitoring of resist exposure [fig. 6]. They are produced by using arrays of small boxes below the resolution limit of the stepper; the simple model used assumes that the fraction of incident light transmitted through these arrays is the same as the fraction of area that is clear. Only discrete values of this fraction are possible due to the limits on the box size that the mask generator can produce. The arrays are approximately 5 um on a side and are constructed from the accompanying table.

The 50.0 percent transmission case is slightly different; it is composed of a checkerboard composed of 0.15 um boxes. Even assuming that the model of transmission is valid it should be expected that the bias of the mask generator will produce a departure from the above calculated values.

Testing:

The dose targets can be measured in two different ways. The first is to consider which target has cleared; for higher doses, targets with lower transmission will clear. When it has been determined which target clears for the proper dose on a given substrate, the same target would be expected to clear for a substrate of a different reflectivity. This can be explained by noting that the dose targets are measuring the energy delivered to the resist, not the incident exposure time. Thus if the correct dose causes the 65 percent target to clear on a Si, we should expect the correct dose on Al to just clear the same target. By viewing the targets on different substrates

Box Dimension (um)		Array Spacing (um)		Percent Transmission	
x	y	x	y	Dark Field	Light Field
0.1	0.1	0.4	0.25	10.0	90.0
0.15	0.1	0.4	0.25	15.0	85.0
0.2	0.1	0.4	0.25	20.0	80.0
0.15	0.15	0.3	0.3	25.0	75.0
0.15	0.15	0.3	0.25	30.0	70.0
0.2	0.15	0.35	0.25	34.3	65.7
0.2	0.15	0.3	0.25	40.0	60.0
0.2	0.2	0.3	0.3	44.4	55.6

of differing reflectivity it should be possible to verify if this is the case. The second way to measure these targets is to consider the color of the thin film that results from a target not clearing; thus a particular site may be blue for the correct dose. This is more subjective and hence less reliable, but may be useful for process monitoring.

When the correct transmission range for the dose targets has been determined, this design should be revised to include only critical values; otherwise the flash count is very high.

SEM Lines

File Names:

SEMlines

Purpose:

Resist profiles for SEM inspection.

Description:

These are a set of lines of varying width 3 mm long to provide resist profiles for SEM inspection. They are grouped in sets consisting of one isolated line, one isolated space and 5 periods of line=space for the following linewidths: 0.35, 0.4, 0.45, 0.5, 0.6, 0.8 and 1.1 um.

Testing:

The SEM lines are included so that resist profiles of interest can be examined in cross section.

Job: stdin
Date: Sun Feb 7 17:27:18 1988

cifplot* Window: -50000 50000 -50000 50000 --- Scale: 1 micron is 0.036185 inches (894x)

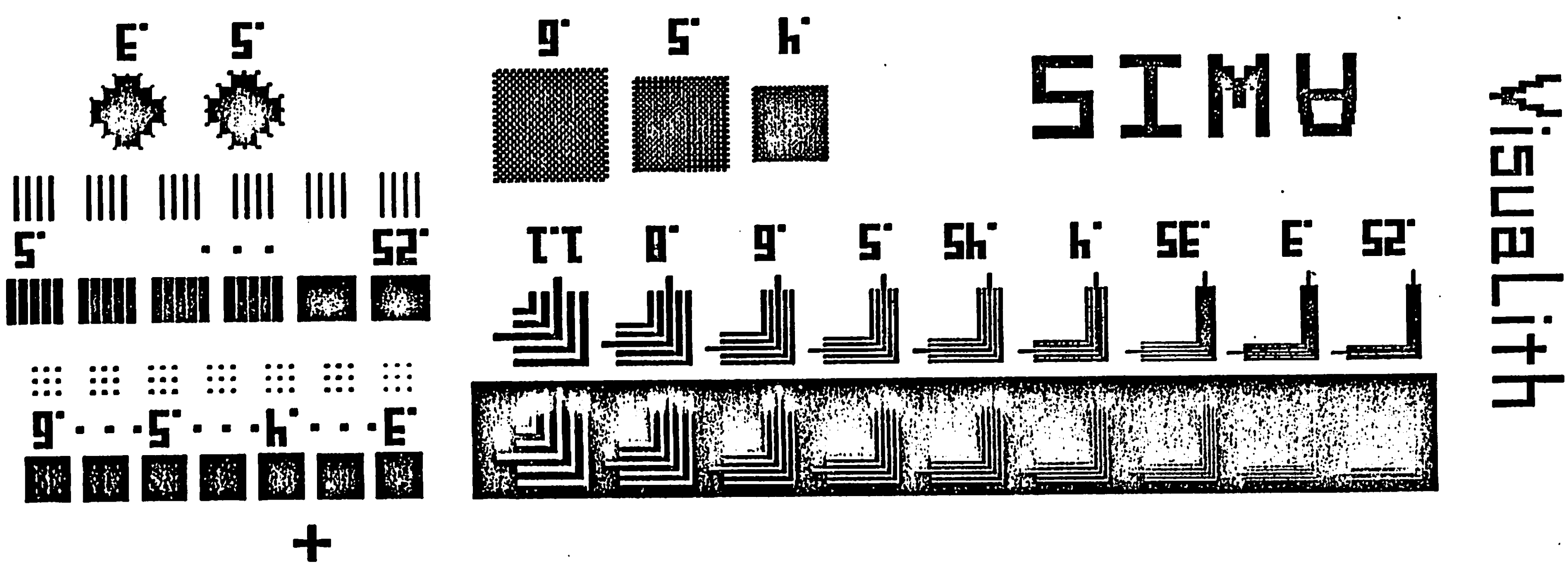


Figure 3 : flare.

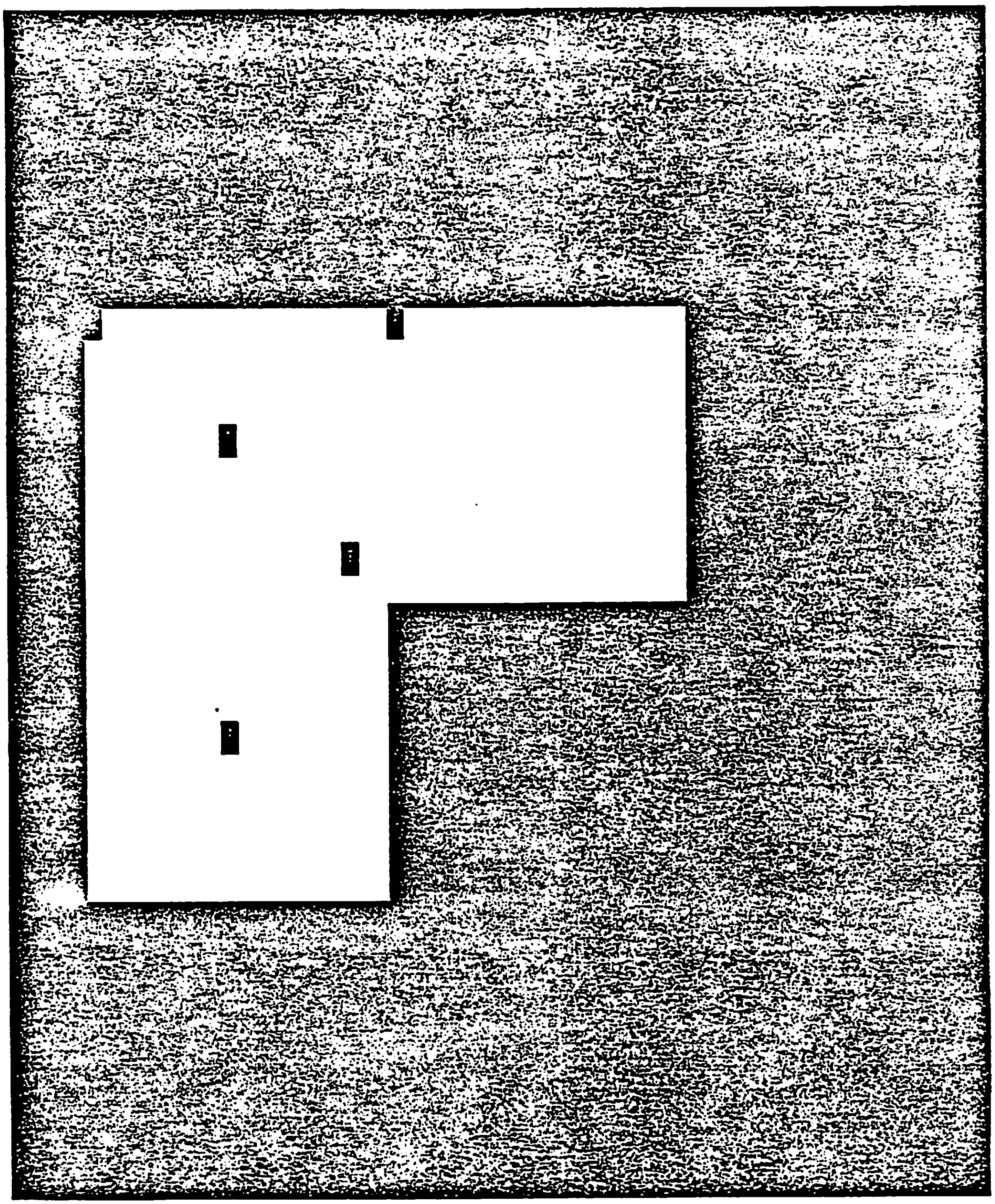


Figure 4 : defects1, defects2 and defects3.

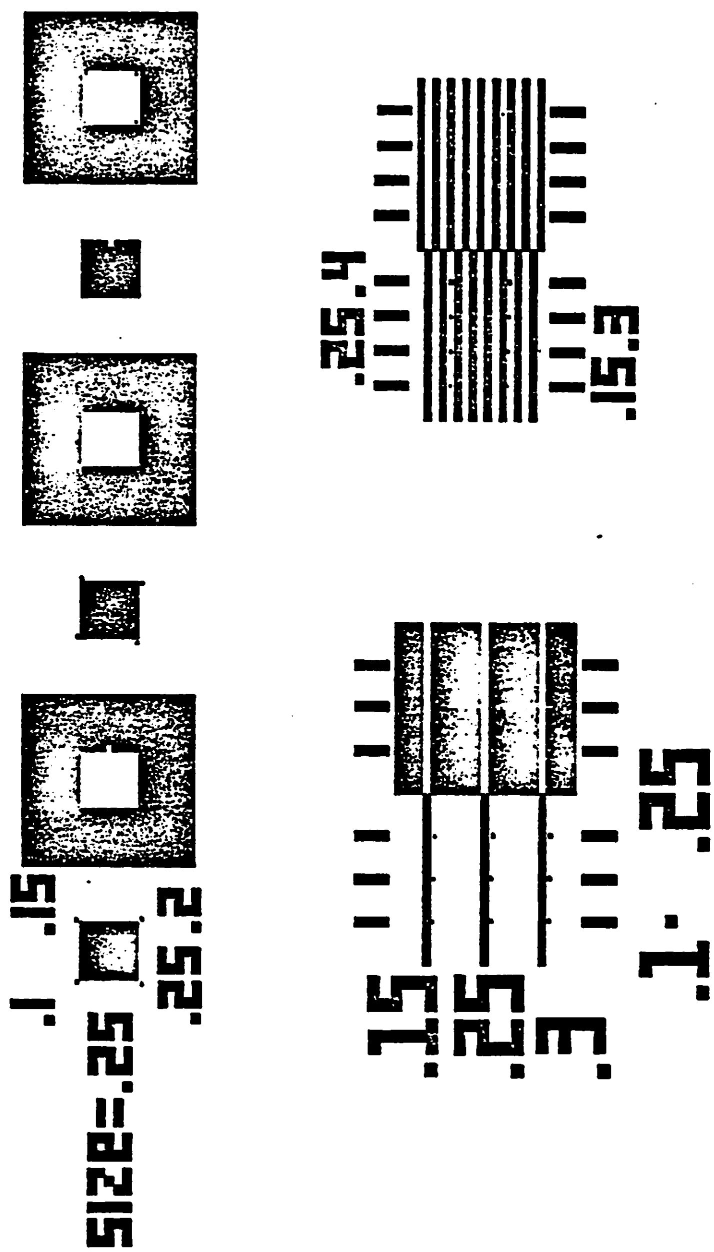


Figure 5 : defects4 and defects5.

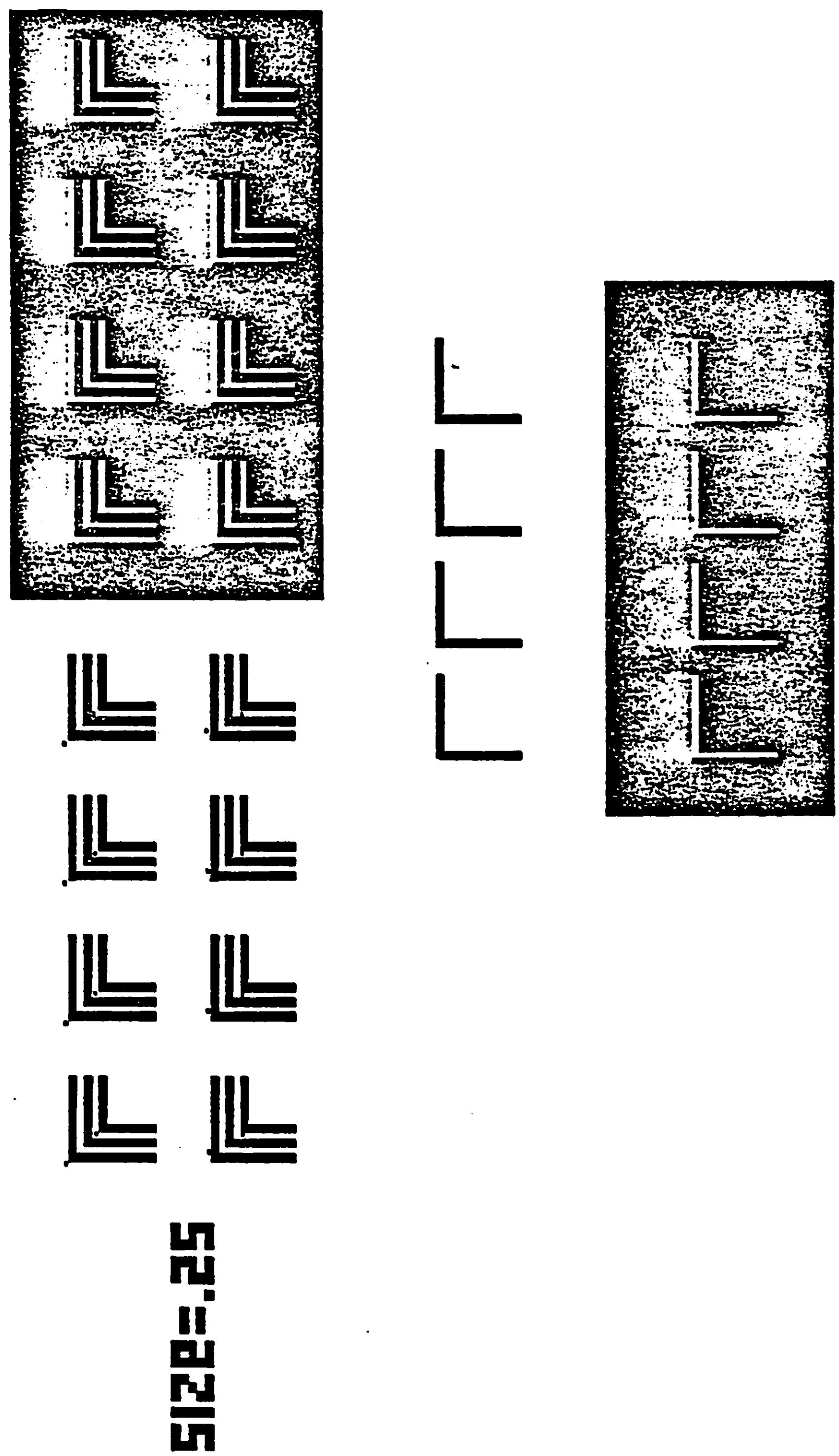
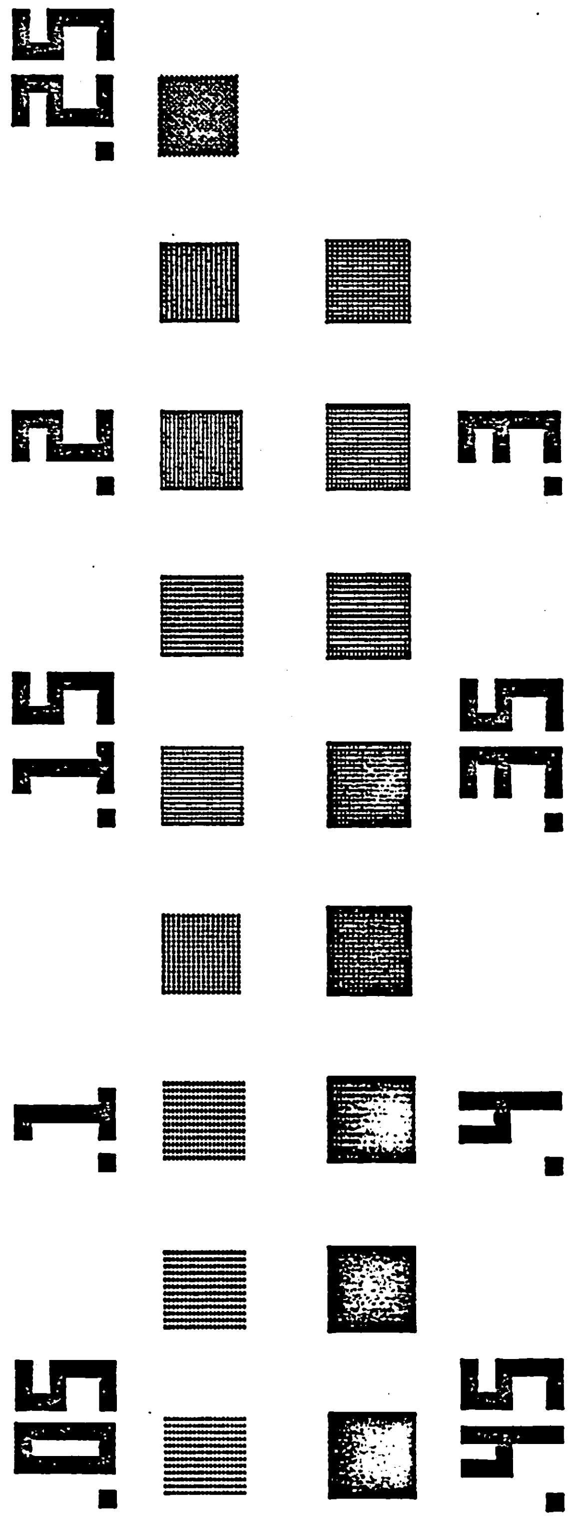


Figure 6 : dose.



Cell Hierarchy

- VisuaLith
  - BasicSet
    - elbowsR
      - elbows*
    - focus1D*
    - focus2D*
    - coma*
    - check*
    - logo
  - DefectSet
    - defects1*
    - defects2*
    - defects3*
    - defects4*
    - defects5*
      - size
  - ClearSet
    - clear1*
    - clear2*
    - clear3*
    - clear4*
    - clear5*
  - flare
  - label
  - dose*
  - SEMlines*
  - alignment
  - corner

* These cells contain one or more instances of the following:

0	1	2	3	4	5
6	7	8	9	period	