ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

Introduction to ASML PAS 5500 Wafer Alignment and Exposure

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DEFINITIONS

ASML (today) – ASM Lithography (1988) – ASM International and Royal Phillips (1984)

PAS – Phillips Automatic Stepper as in ASML PAS 5500/200

Reticle – quartz plate with single layer of chip layout (or array) at 5X actual size (also called photomask)

PM – primary marks (same design for mask and wafer alignment)

SPM – scribe line primary marks

NA- numerical aperture

σ - sigma or coherency

DOF – depth of focus

REMA –Reticle Masking System

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OUTLINE

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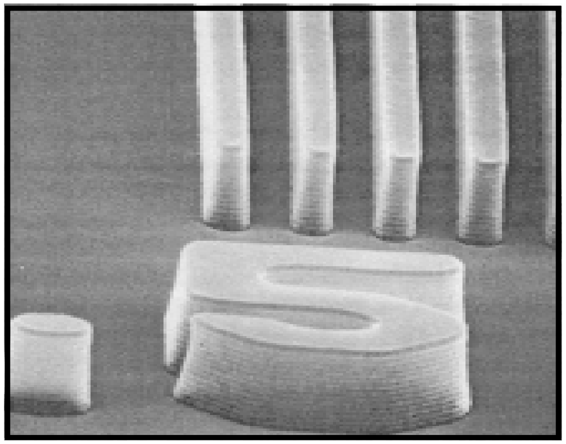
INTRODUCTION

Overlay (alignment) is as important as resolution in lithography. Modern CMOS integrated circuits have ~ 30 layers to be aligned. The RIT SUB-CMOS processes use up to 15 layers. Alignment marks are placed on the wafer at the beginning of the process during the first level lithography or in a special zero level lithography. The wafers then undergo many processing steps such as CMP, oxide growth, metal deposition and LOCOS like processes. These processes change the appearance of the alignment marks. Marks that start out as trenches can change to mesas, marks with topology can become flat after CMP, marks can change color and can become buried or even invisible. Thus a strategy for alignment must be devised as part of the process design and chip layout. The strategy may include zero level wafer alignment marks, zero and first level combined wafer alignment marks, clear out exposures over wafer alignment marks for some levels, and/or use of street alignment marks.

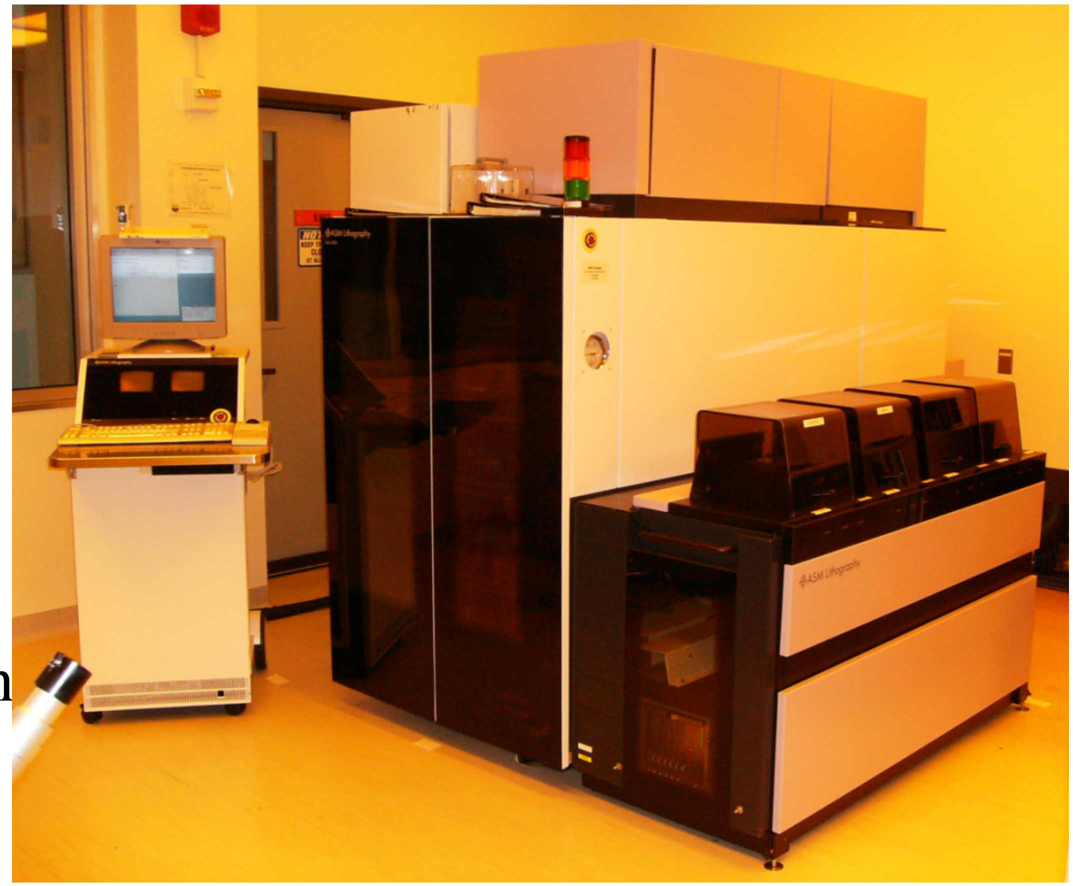
INTRODUCTION (cont.)

The ASML PAS 5500 uses wafer alignment marks that are diffraction gratings. There are marks for both the x and y directions. These marks are illuminated with a HeNe laser at a single wavelength near 632.8nm. The reflected wave exhibits a diffraction pattern of bright and dark lines that are focused on a sensor. The stage is moved slightly to learn the best position to match the sensor and that stage position is used to calculate the stage position to place the die under the center of the optical column. The wafer is moved to the lens center (or shifted by a fixed amount from center) and the die is exposed. The stage position for the remaining die are calculated and those die are also exposed. The wafer marks are lines and spaces etched into the starting wafer. To give maximum contrast in the diffracted pattern the etch depth $\lambda/4n$ results in a optical path difference of π, λ is the wavelength of the laser light and n is the index of refraction of the material above the marks (usually photoresist or oxide). The etch depth calculation gives a value of approximately 632.8/4/1.45 = 110 nm (1100Å)

RIT's - ASML PAS 5500/200



NA = 0.48 to 0.60 variable
σ= 0.35 to 0.85 variable
With Variable Kohler, or
Variable Annular illumination
Resolution = K1 λ/NA
= ~ 0.35µm
for NA=0.6, σ =0.85
Depth of Focus = k_2 $\lambda/(NA)^2$
= > 1.0 µm for NA = 0.6



i-Line Stepper λ = 365 nm
22 x 27 mm Field Size

ASML5500/200 SPECIFICATIONS

Lens Specifications	PAS 5500/100D	PAS 5500/200
Wavelength (nm)	365	365
Reduction	5x	5x
NA	0.48 to 0.6	0.48 to 0.6
Linear resolution (µm)	≤ 0.35	≤ 0.32
UDOF (m) @ 0.56 NA, 0.75 σ	≥1.0	≥1.0
@feature size (line / space)	@0.4 µm	@0.35 µm
Field size diameter	31.11	31.11
Max X (mm)	22.0	22.0
Max Y (mm)	27.4	27.4
Distortion (nm)	<55	<55

Illumination specifications		
Intensity (mW/cm^2) with annular illum. N/A	>900	>1500 >900
Uniformity (±%)	<1.5	≤1.2
Partial Coherence NA max NA min	 0.3 to 0.5 0.4 to 0.7	 0.35 to 0.85 0.44 to 0.85
Annular Illum. inner sigma N/A		0.1 to 0.5
Throughput specifications		
200 mm wafers (70 shots)	>72	>80
Overlay specifications		
Single machine overlay (nm)	<60	<50
Matched overlay (nm)	<110	<110

ASML

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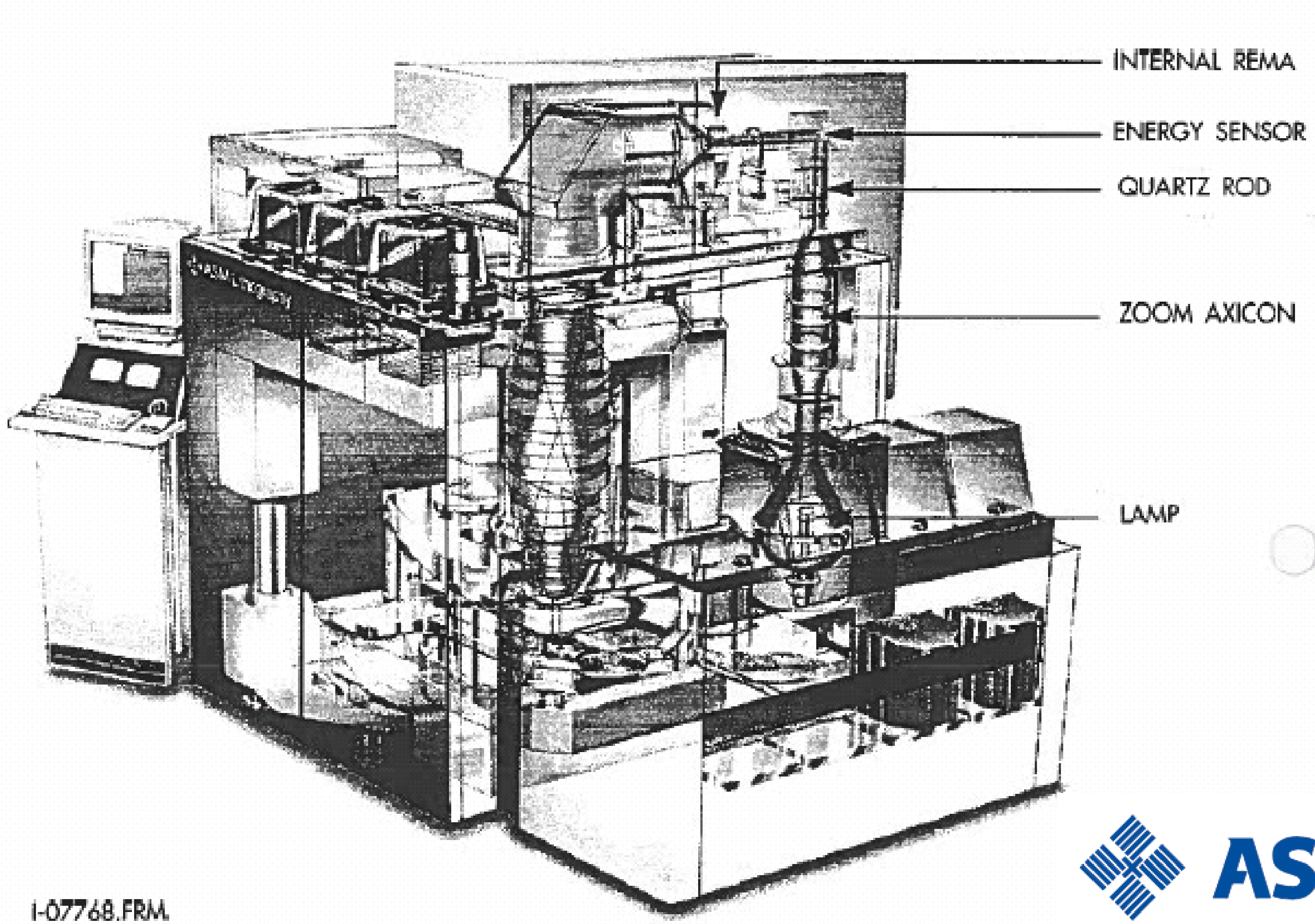
ASML PAS 5500 ILLUMINATION SYSTEM



ASML PAS 5500 ILLUMINATION SYSTEM

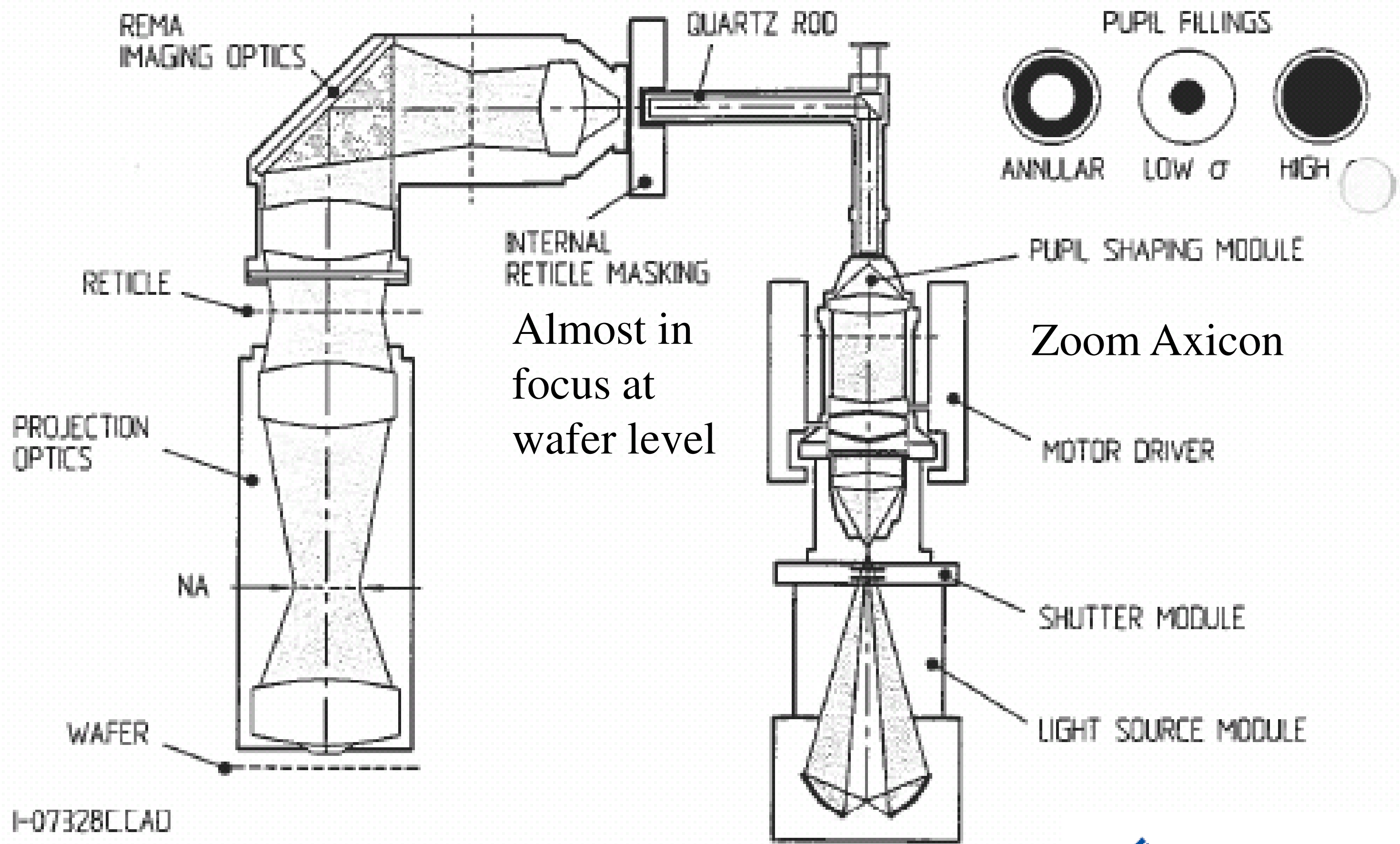


Figure 5 Schematic diagram showing how an illumination setting is chan...

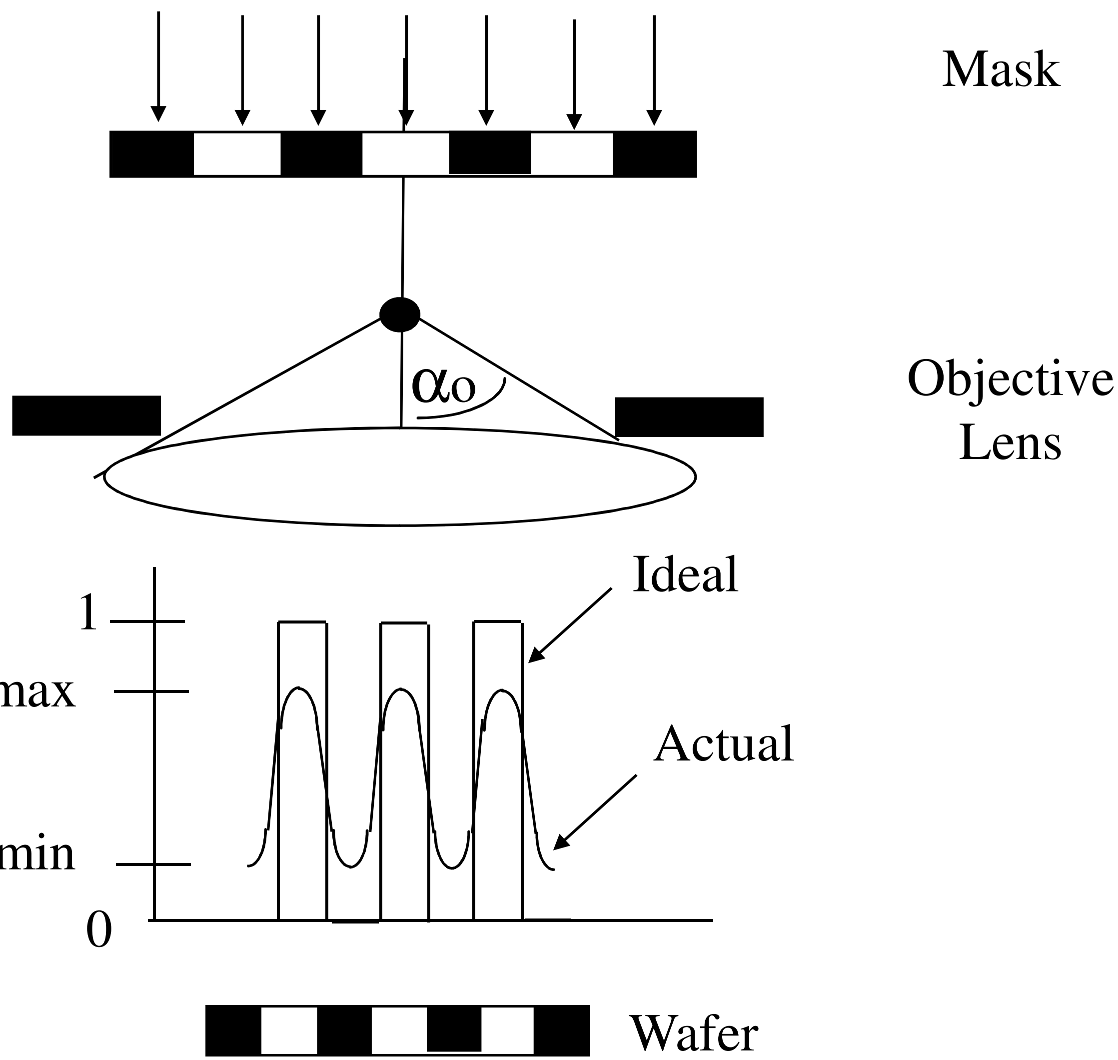
Almost in focus at wafer level

Zoom Axicon

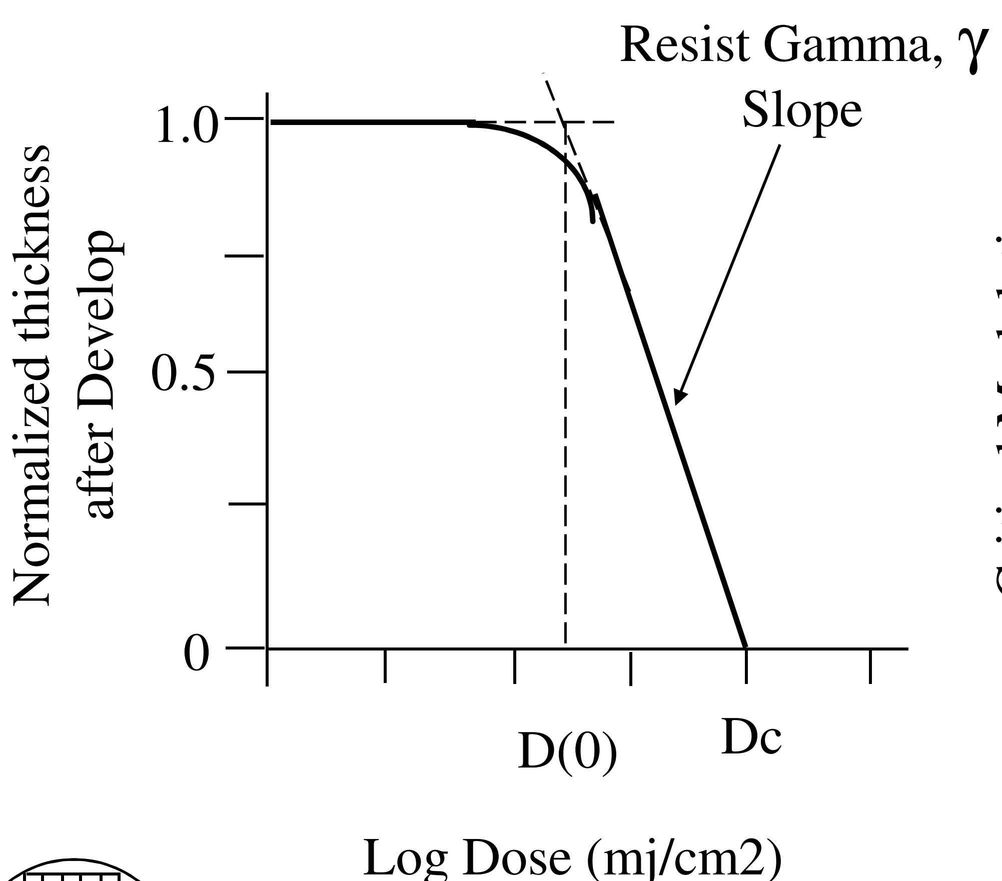
MODULATION OF AERIAL IMAGE

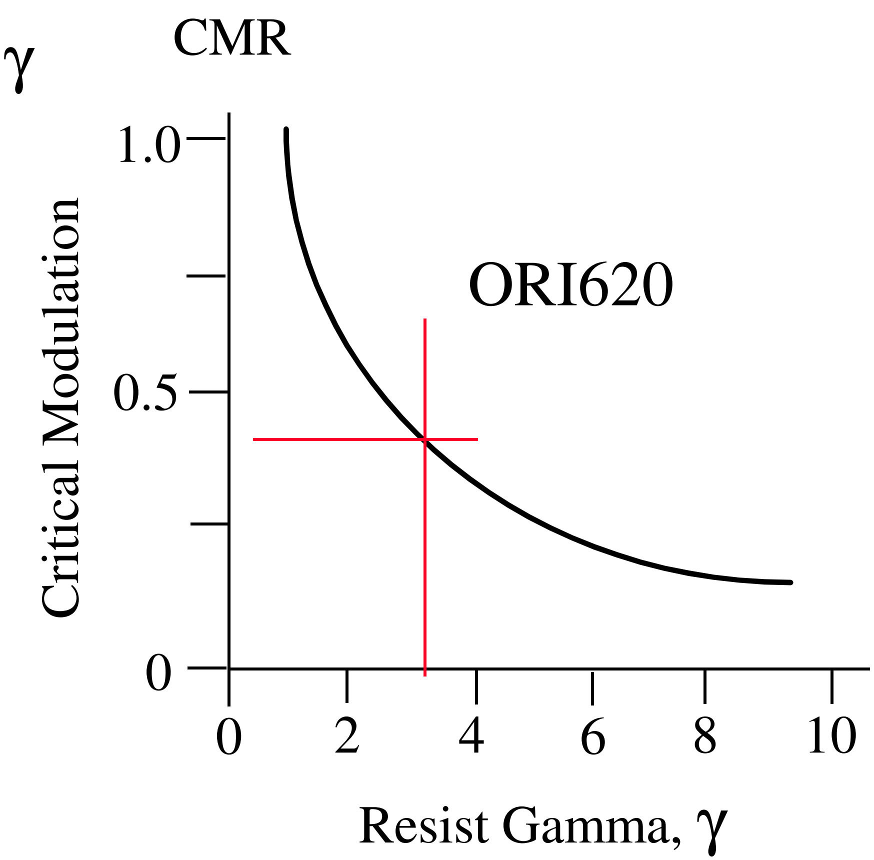
Modulation:

$$M = \frac{Imax - Imin}{Imax + Imin}$$



CRITICAL MODULATION FOR RESIST (CMR)





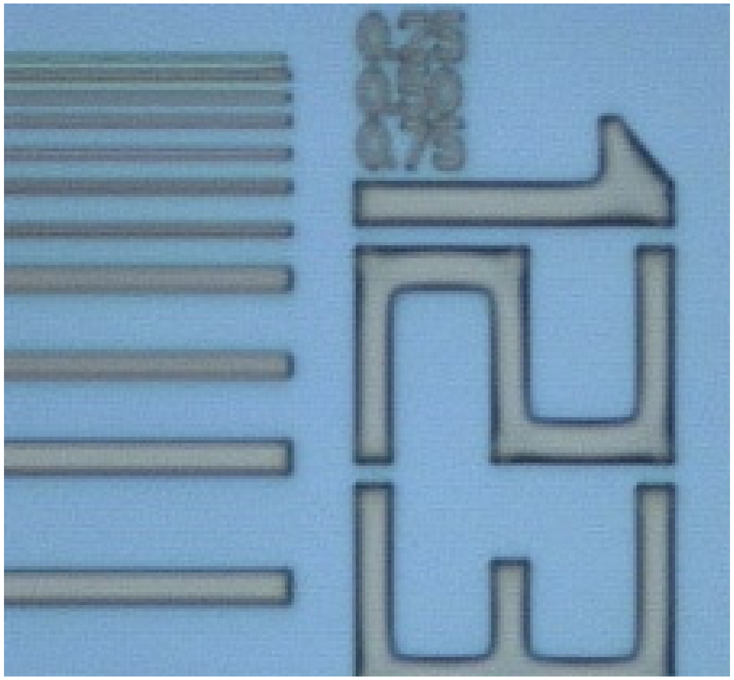
$$CMR = (10^{1/\gamma} - 1)/(10^{1/\gamma} + 1)$$

EXPOSURE DOSE

Dose to clear = Dc

Dose to size Ds = ~ 2.5 x Dc

Today we are working on finding Dc and Ds for each layer in our process. It appears that Dc is ~100mj/cm2 and Ds is ~ 250 mj/cm2



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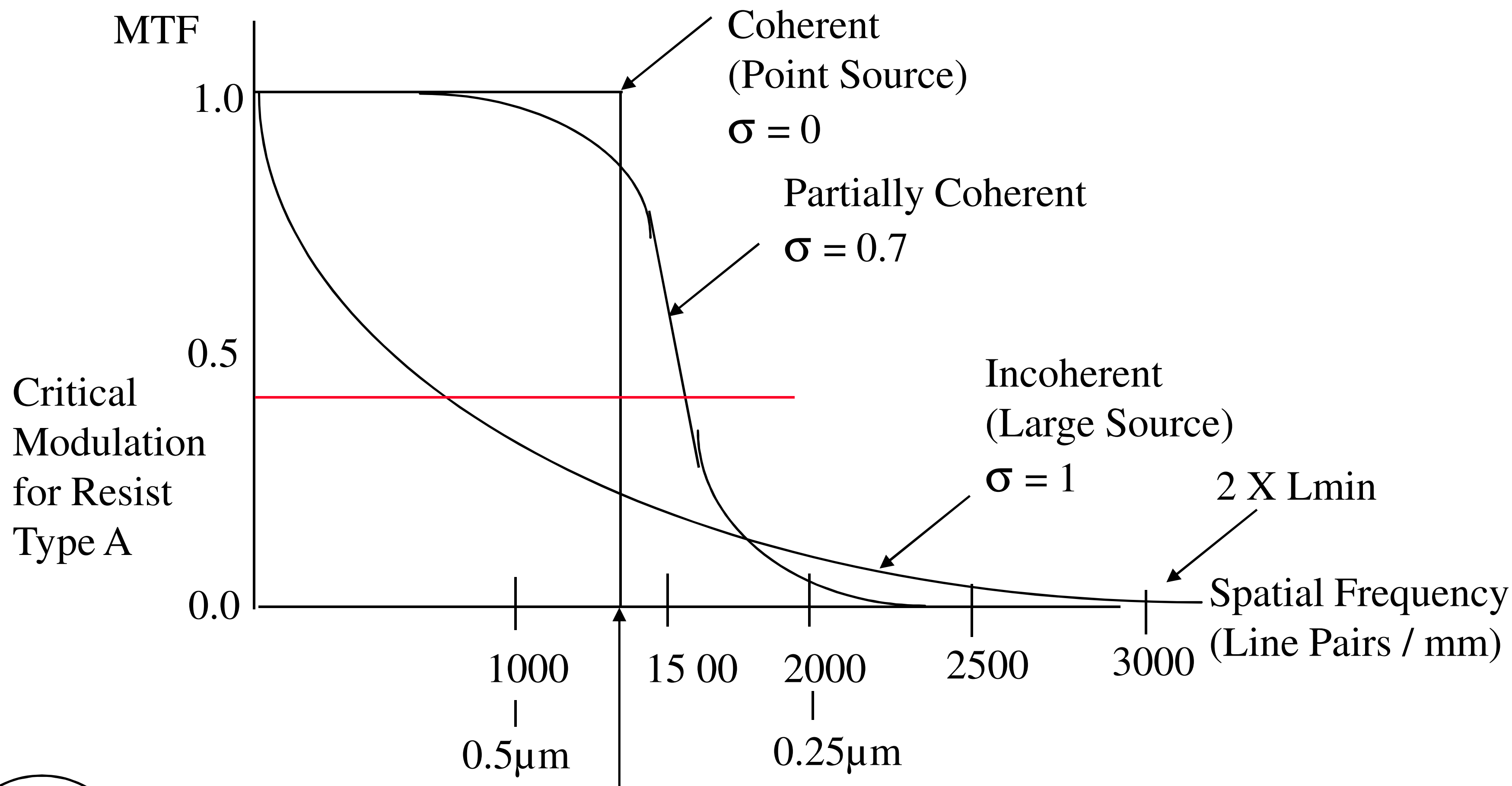
MODULATION TRANSFER FUNCTION (MTF)

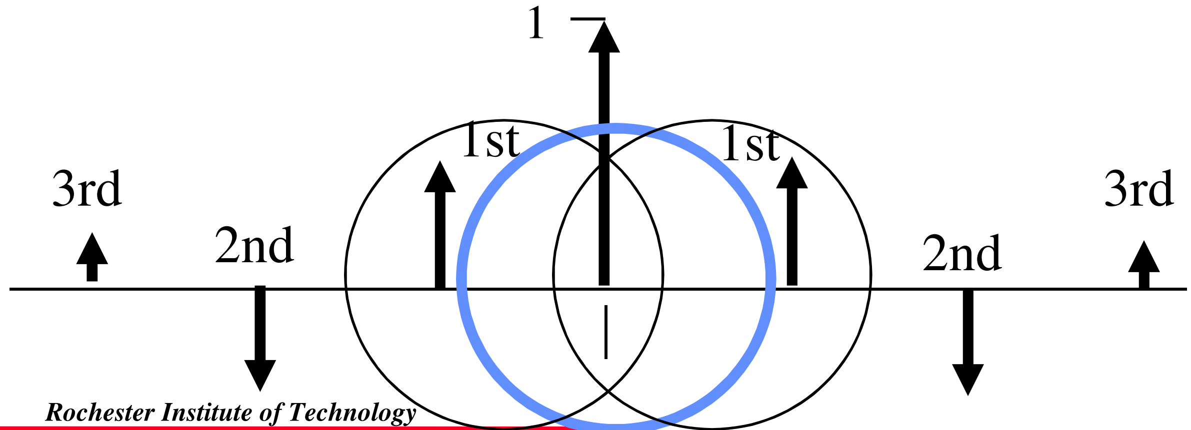


$$L_{min} = 0.61\ \lambda\ /\ NA$$

COHERENCY

Coherent - Normally incident plane wave illumination (point source)
Incoherent - a continuous spectrum of plane waves with incident angles ranging from +/- 90 degrees (infinite size source)
Partially Coherent - A finite range of incident Angles of the plane waves
Coherency - σ = NAc/NAo Numerical Aperture of Condenser Lens divided by Numerical Aperture of the Objective Lens.
Illumination techniques include variable pupil (Kohler) and gaussian illumination.

Off Axis illumination allows images to be formed from the + or - 1st diffraction order. Techniques include ring illumination, quadrapole illumination, and dipole illumination



SUMMARY

This table lists the tradeoffs for numerical aperture, NA, coherency, σ, and type of illumination as it relates to resolution, Lmin, Depth of Focus, DOF, modulation of aerial image, M, and time to expose, throughput.

	Lmin	DOF	Modulation	Throughput
Increasing NA	↓	↓	↑	↑
Increasing σ	↓		↓	↓
Off Axis vs. Kohler	↓		↓	↓

Increasing NA, σ and using off axis illumination can give higher resolution but will be offset by poorer DOF, Modulation and throughput.

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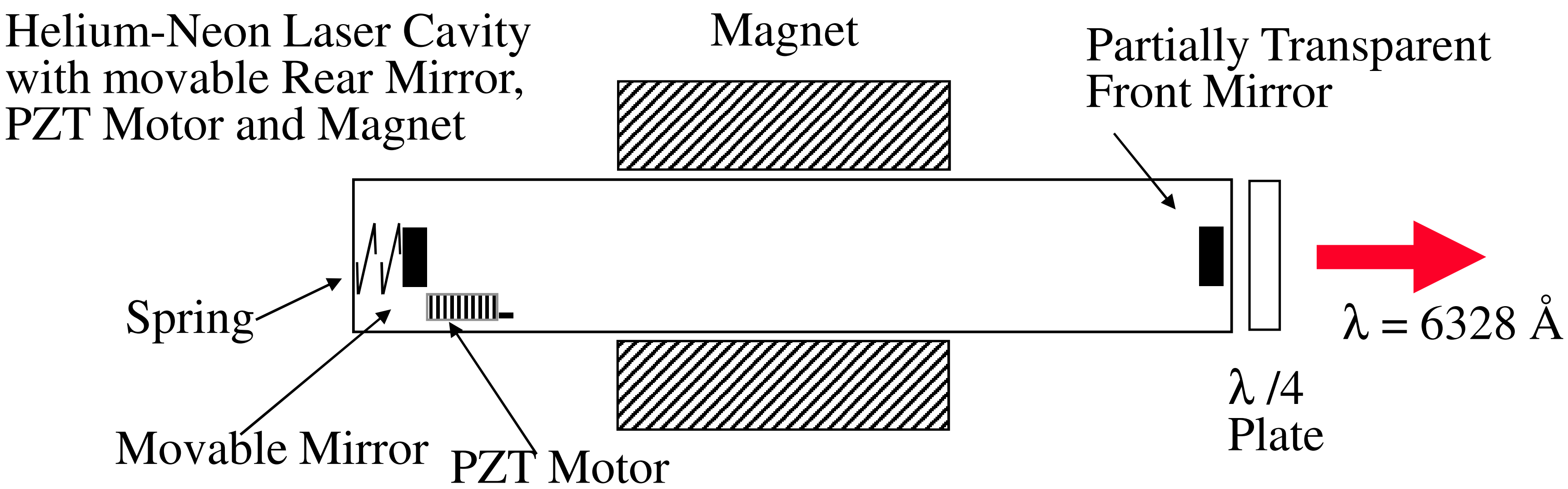
STAGE ACCURACY

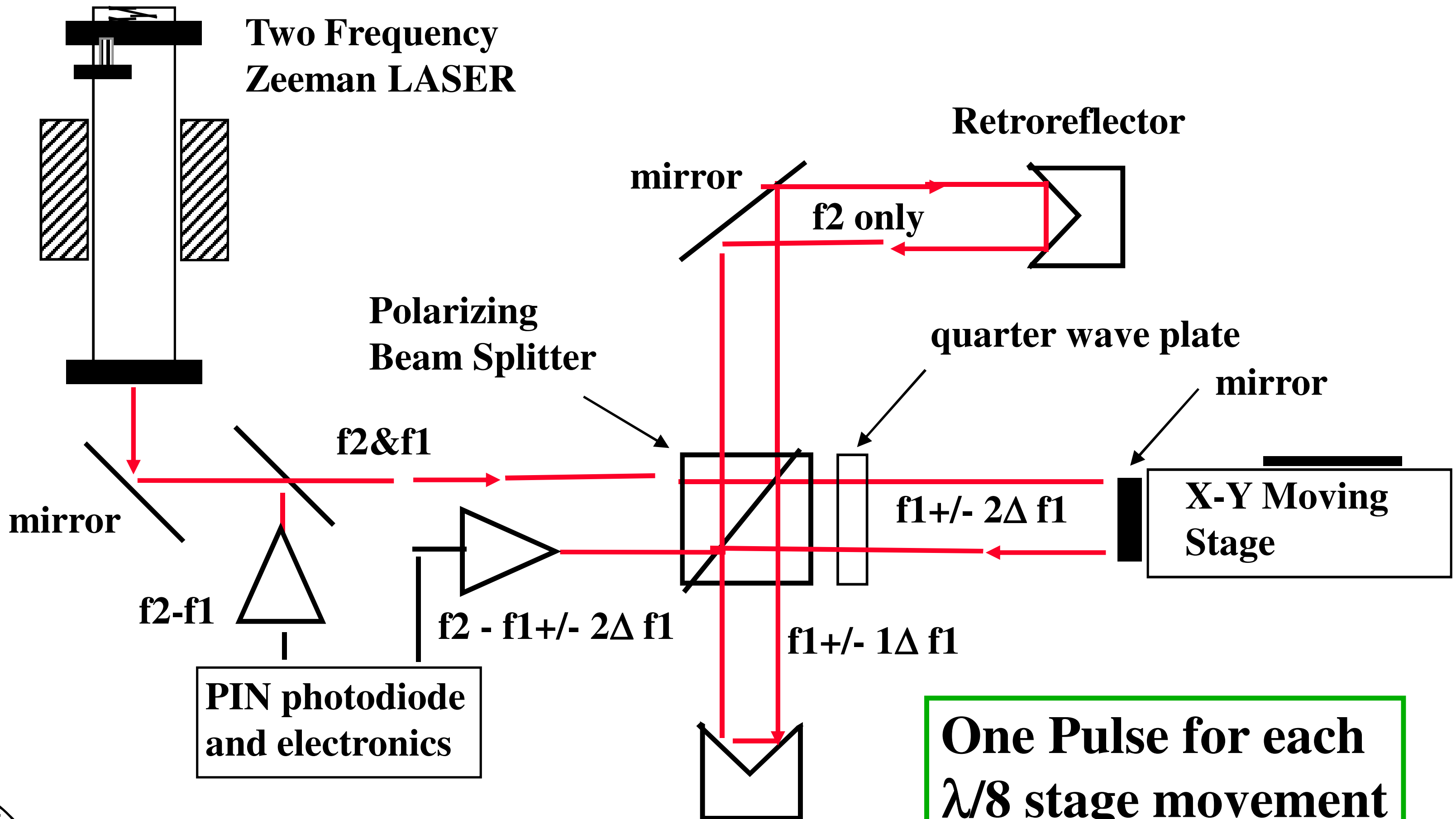
The stage position is very accurate. Its position is measured using a laser interferometer that has a fundamental accuracy of $\lambda/8 \sim 0.08\mu m$. The interferometer measures the position of the mirrors on the x and y stages while the wafer is some distance from the mirrors on the stage. If the temperature inside the environmental chamber is kept constant then the errors caused by the thermal coefficient of expansion for the stage can be minimized. The stage accuracy is monitored periodically to ensure that the interferometer is working correctly. However, in most modes of operation, including alignment, the stepper stage measured position is assumed to be perfect.

LASER FOR STAGE POSITION MEASUREMENT



The magnet causes Zeeman splitting of the LASER frequency resulting in two circularly polarized frequency components. One left-hand circularly polarized (LHCP) the other RHCP and about 1 M Hz above and below the center frequency, fo. By applying a voltage between 270 and 1800 Volts to the piezoelectric transducer (PZT), the rear mirror can be moved, giving a small amount of resonate cavity length tuning. Tuning makes the strength of LHCP and RHCP components equal. A quarter wave plate makes the output beam have two equal strength, linearly polarized, mutually perpendicular beams.

PLANE MIRROR INTERFEROMETR



One Pulse for each
$\lambda/8$ stage movement
$\lambda/8 = 0.08\ \mu m$

ALIGNMENT

Alignment involves placing the wafer /stage in a position such that the wafer/stage marks can be illuminated by the HeNe laser. The reflected diffraction pattern goes back through the lens and the wafer image is reconstructed from the +/-1st order components of the diffraction pattern (the zero order is returned to the laser, higher orders are blocked). The electric and magnetic fields are transferred through the lens as in a linear system resulting in a sinusoidal field image. The intensity is the square of the field doubling the frequency of the diffraction grating on the wafer when viewed at the mask level. This image is superimposed on the fiducial marks on the reticle and a light detector measures the brightness as the stage is moved to find best alignment of the wafer to the mask.

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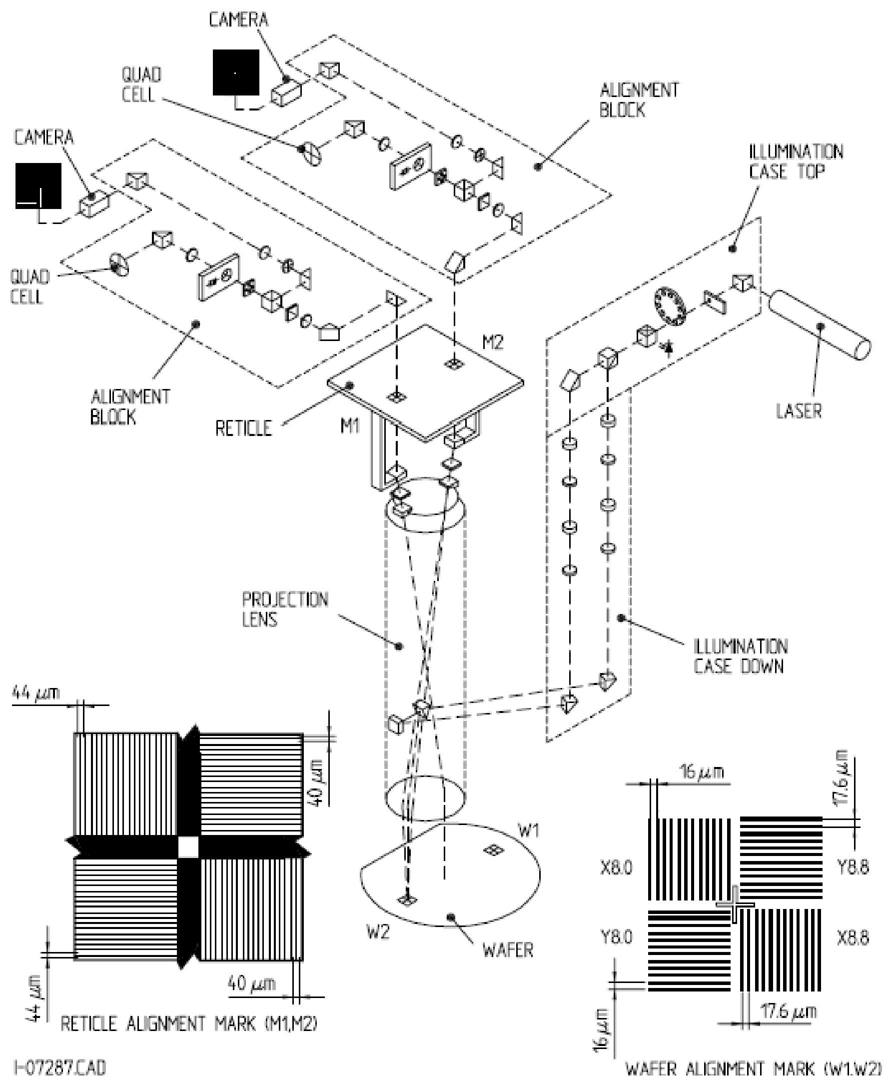
OPTICAL PATH FOR WAFER ALIGNMENT



The red laser is split into two beams one directed toward the left side of the wafer and the other directed toward the right side of the wafer, for alignment marks on the left or right side respectively. Only one alignment mark is illuminated at a time.

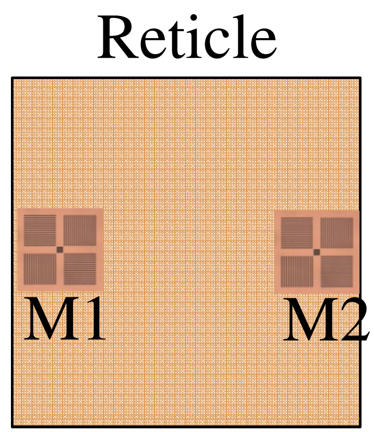
TYPES OF ALIGNMENT

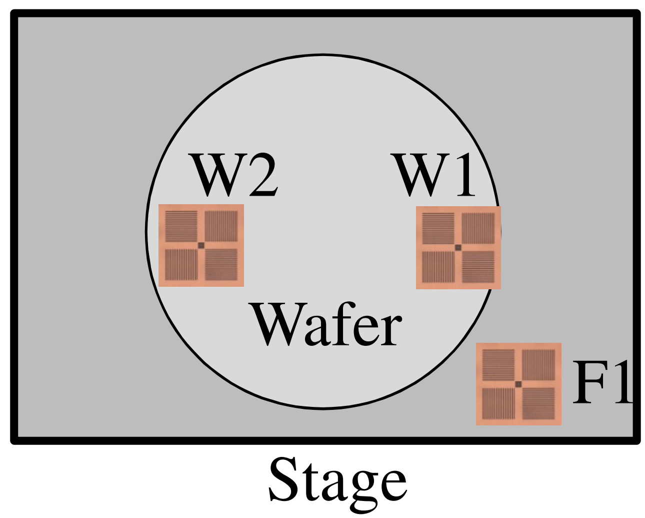
Fiducial – Reticle alignment when there are no alignment marks on the wafer (zero or 1st level)
F1 aligned to M1 and F1 to M2

Global – After both reticle and wafer exchange
F1 aligned to M1, W1 to M2, and W2 to M1

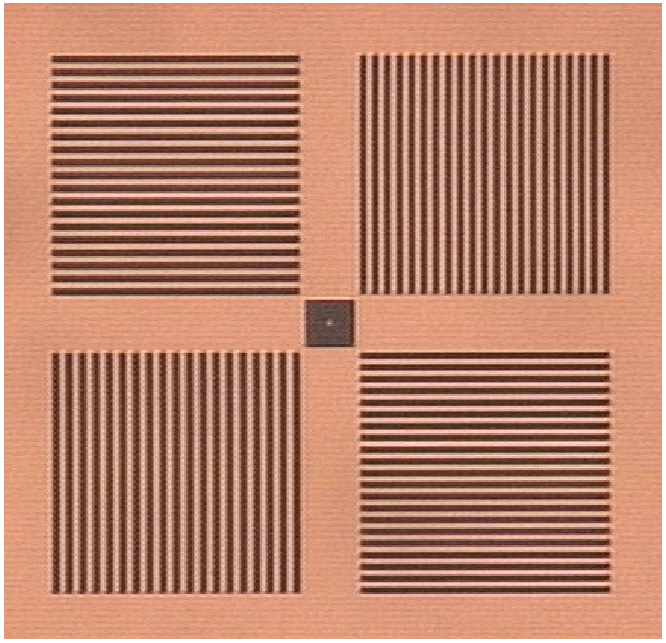
Wafer – After wafer exchange
W1 aligned to M1 and W2 to M1

Reticle – After reticle exchange
W1aligned to M1 and W1 to M2





ASML RETICLE ALIGNMENT MARKS



44 um L/S 40 um L/S

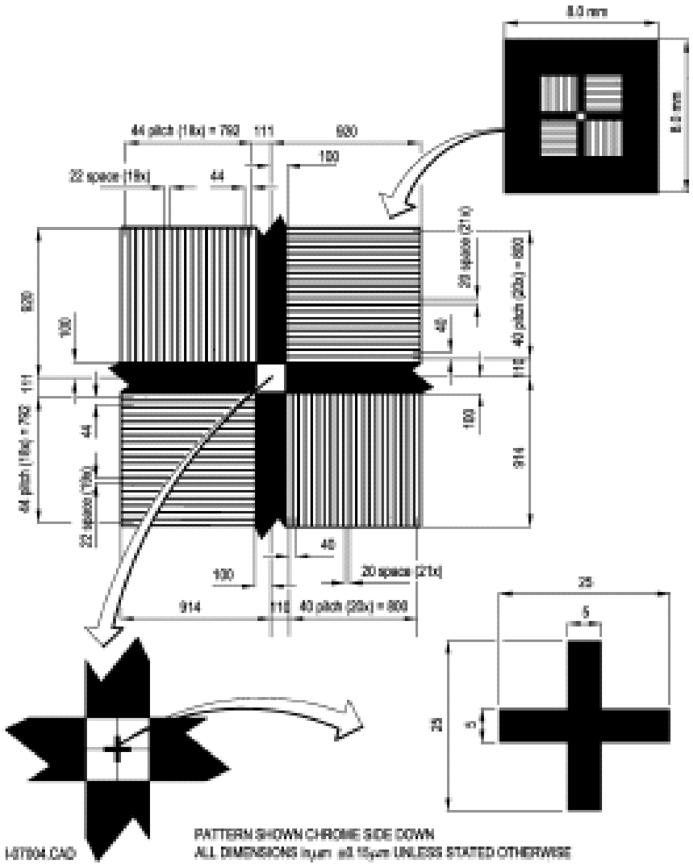


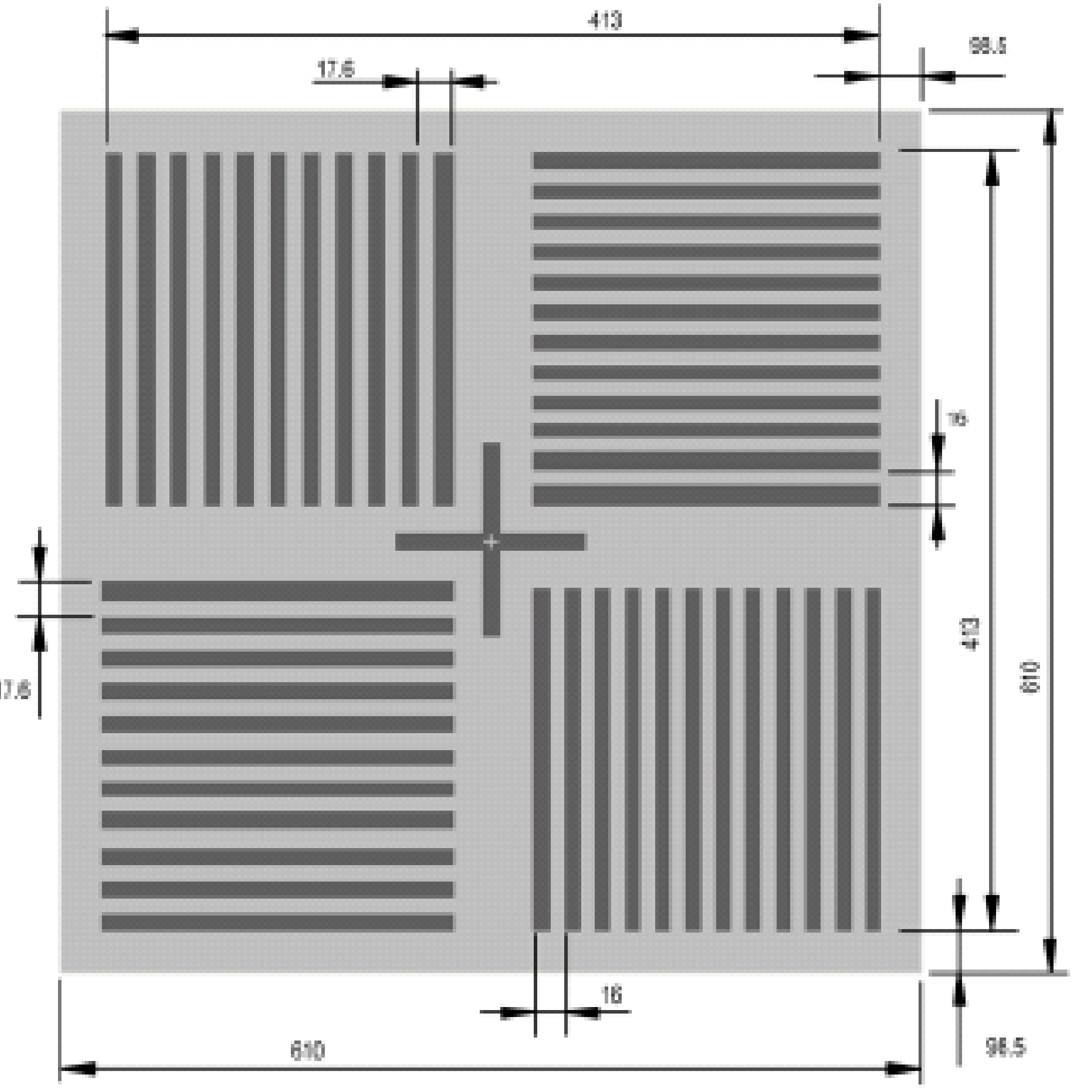
Figure 3.2 The reticle alignment mark

Two reticle alignment marks are used for Through The Lens (TTL) alignment of the reticle to the wafer in global and/or field by field alignment mode. The nominal distance between the marks depends on the distance at reticle level between the alignment branches in the stepper (see Table 3.1).

ASML WAFER OR STAGE PM MARKS

17.6um L/S

16um L/S



17.6um L/S

16um L/S

WAFER ALIGNMENT CONTINUED

The 16um L/S wafer marks are transferred to the mask at 5X for the lens magnification divided by two for the frequency doubling. This is 40um L/S equal to the period on the reticle alignment marks. (the 17.6um L/S becomes 44um L/S at the reticle) The light from the wafer goes through the lens and through the reticle alignment marks to the detector. The stage moves to determine the best alignment. Thus the wafer is aligned to the reticle.

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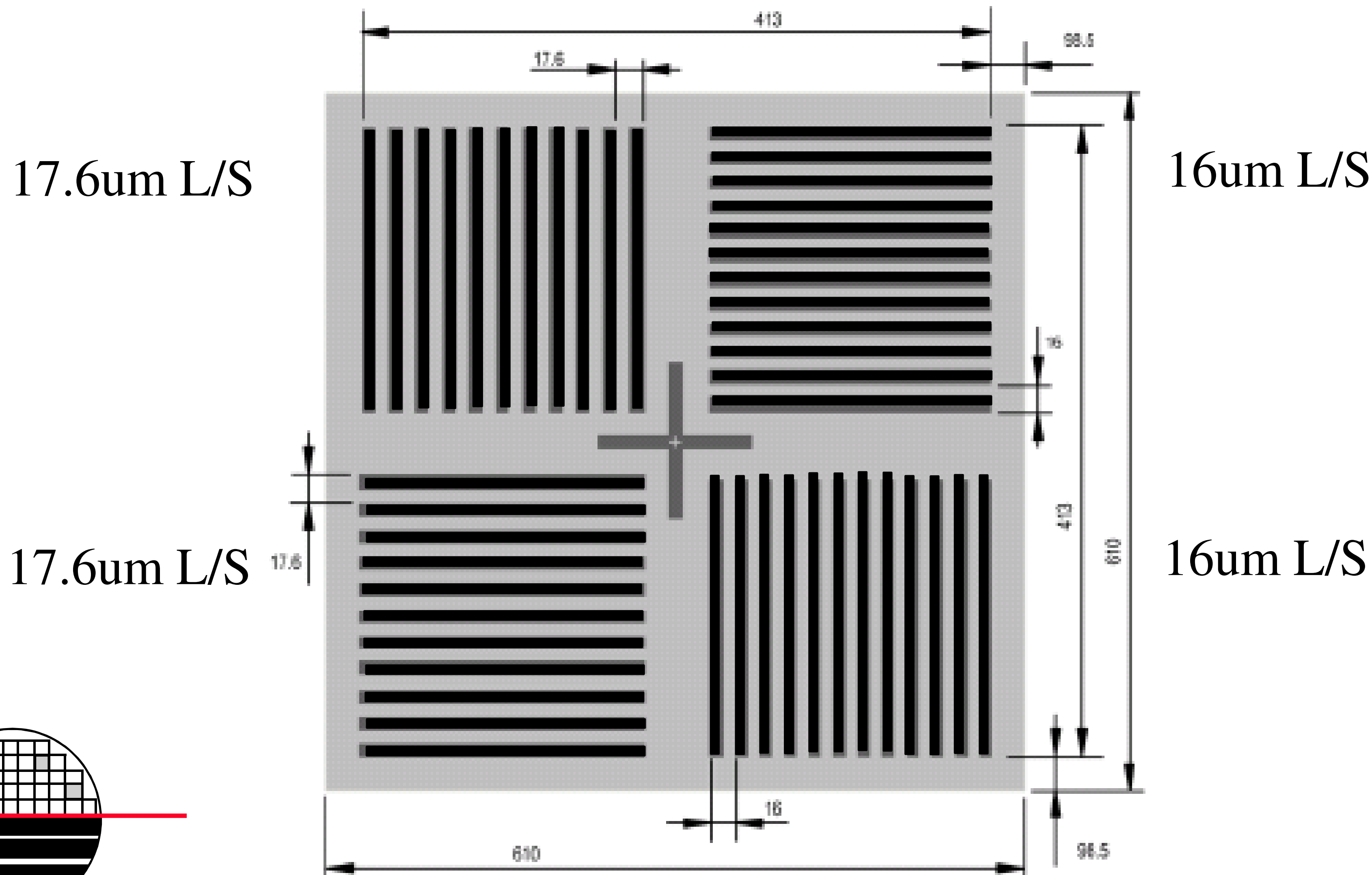
ANIMATION OF WAFER ALIGNMENT TO RETICLE



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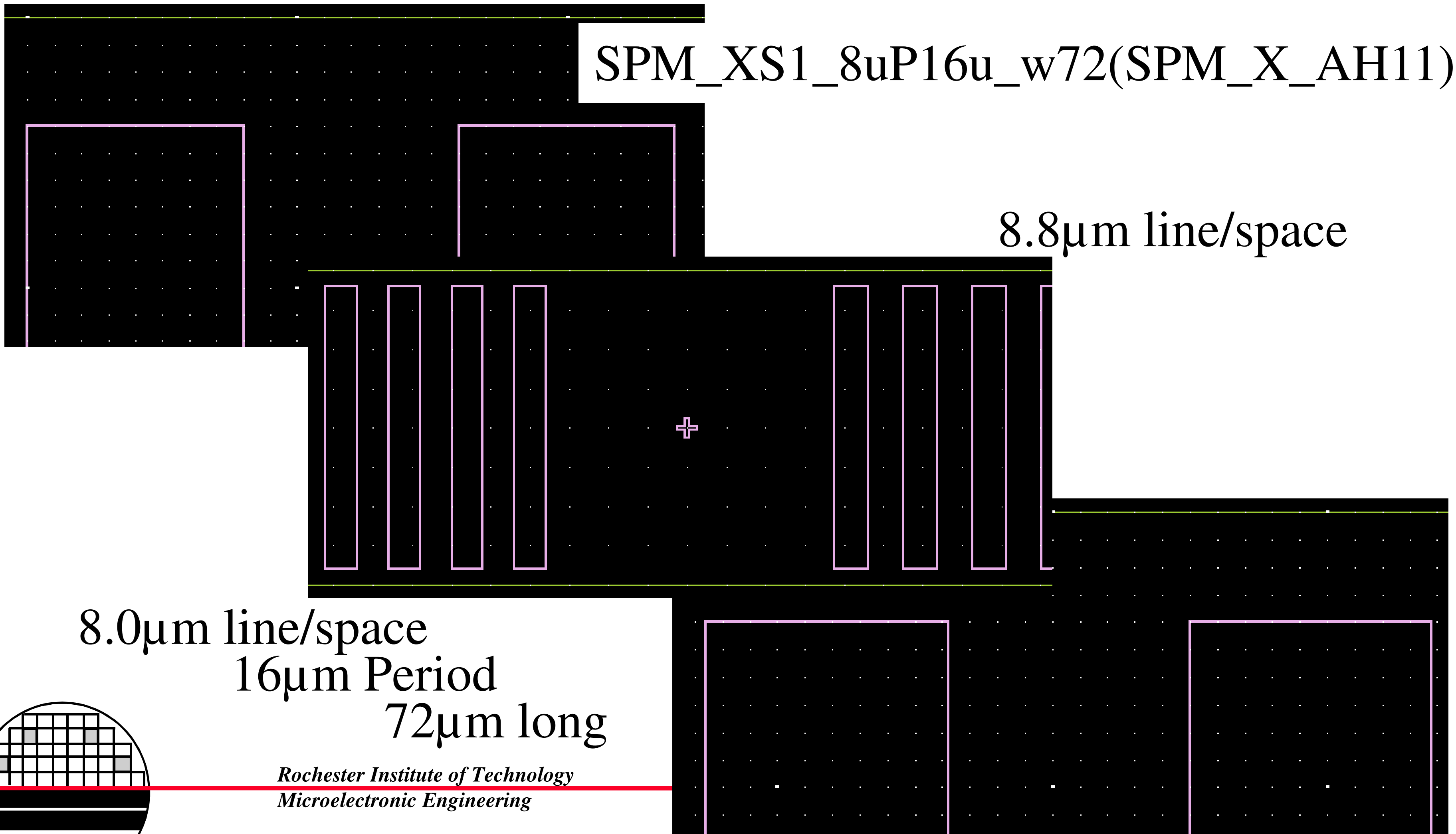
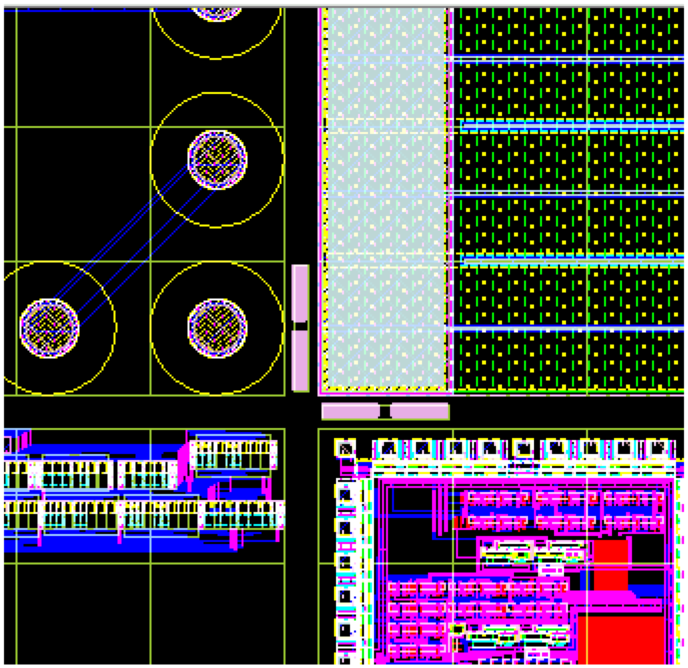
ASML STREET PRIMARY MARKS (SPM MARKS)



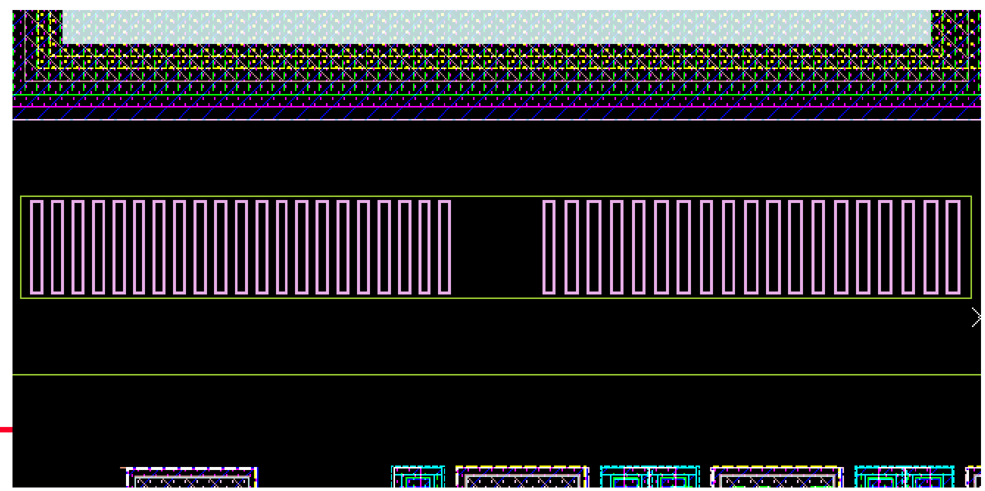
ASML STREET PRIMARY MARKS (SPM MARKS)

SPM_YS1_8uP16u_w72(SPM_Y_AH11)



Street Primary Marks (SPM)

SPM_XS1_8uP16u_w72(SPM_X_AH11)



RETICLE ALIGNMENT

In order to align a reticle to the stepper, the reticle must have fiducial marks at given locations near the edge of the mask. The ASML fiducial marks are shown on the following pages. They are automatically included in any stepper job written in the RIT maskshop. If your mask is made outside of RIT you will need to request fiducial marks and specify type and possibly the exact location on the mask.

You can use reticles with no fiducial marks but only in a non production mode such as exposure matrix. To do this press alignment and change alignment mode to N (none).

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RETICLE ALIGNMENT (continued)

Once the mask is placed on the platen. The reticle prealignment marks are used to position the reticle in the approximate correct location. The stage is moved to position special alignment marks attached to the stage in the correct position to do the reticle fine alignment. Just like wafer alignment the marks are illuminated with a HeNe laser and the reticle is moved to give the best alignment position and then held in that position until removed from the stepper.

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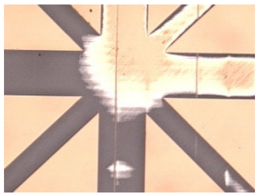
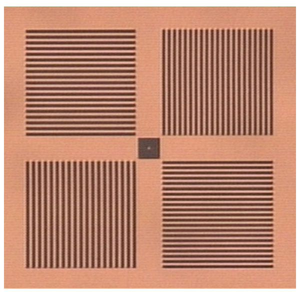
ASML MASK SPECIFICATION



PrealignmentMarks



Reticle Alignment Marks

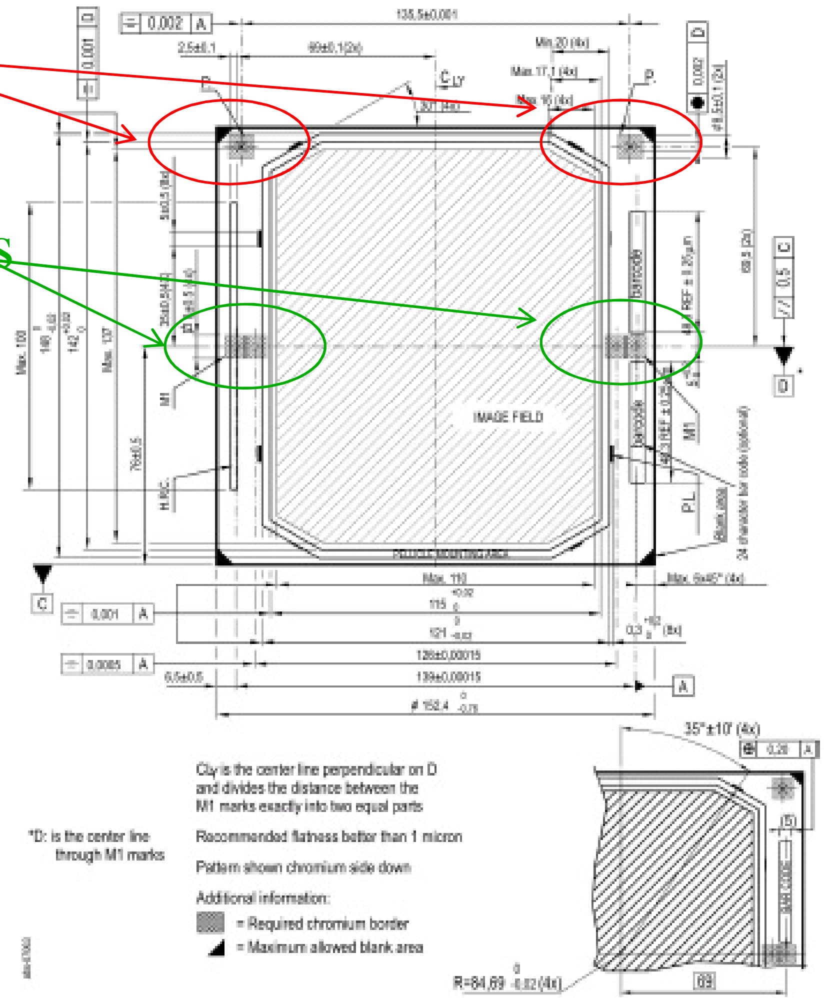


Figure 4.1 PAS 5500/22 reticle layout

RIT SPECIFICATIONS

6" x 6" x .125" Quartz

Chrome

Write Area 22 x 27.4 mm

ASML RETICLE PREALIGNMENT AND FIDUCIAL MARKS

Fiducial Marks

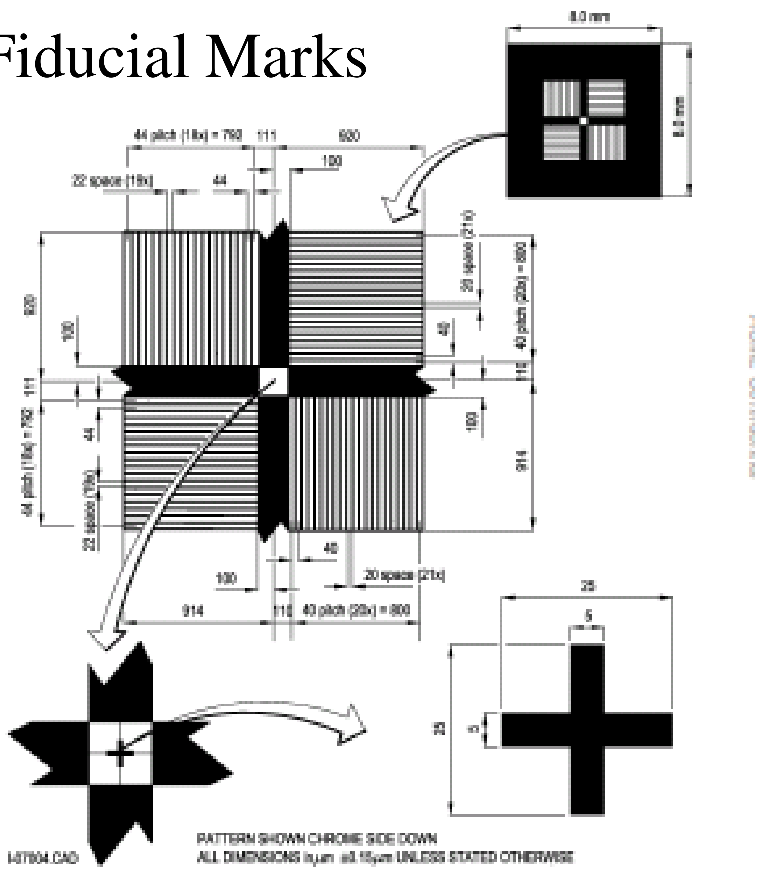


Figure 3.2 The reticle alignment mark

Two reticle alignment marks are used for Through The Lens (TTL) alignment of the reticle to the wafer in global and/or field by field alignment mode. The nominal distance between the marks depends on the distance at reticle level between the alignment branches in the stepper (see Table 3.1).

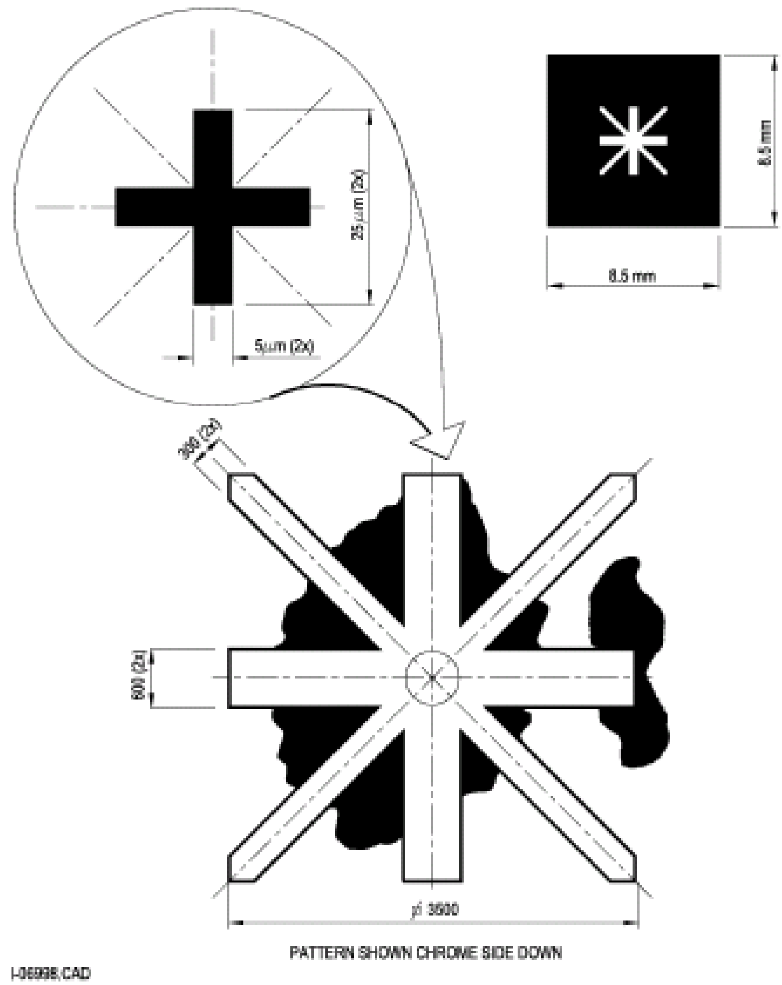
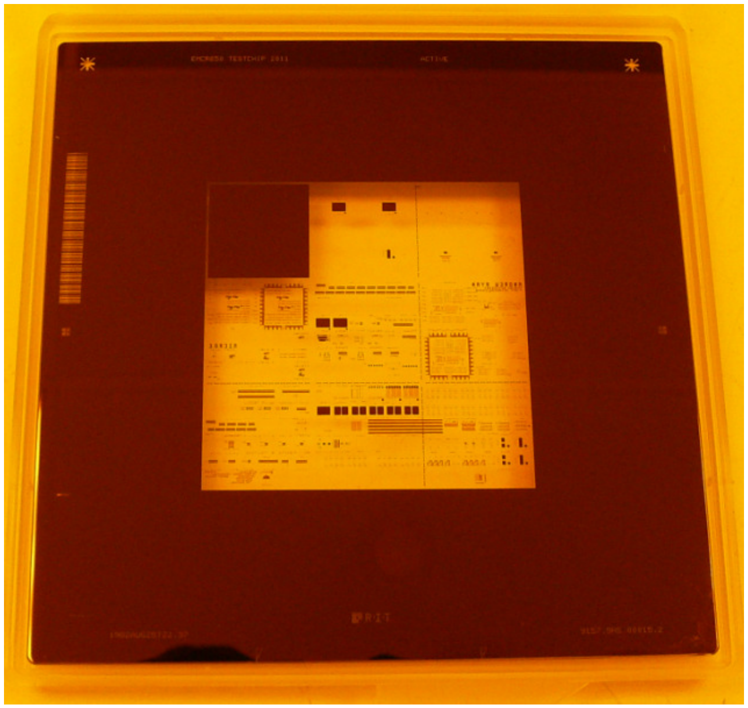


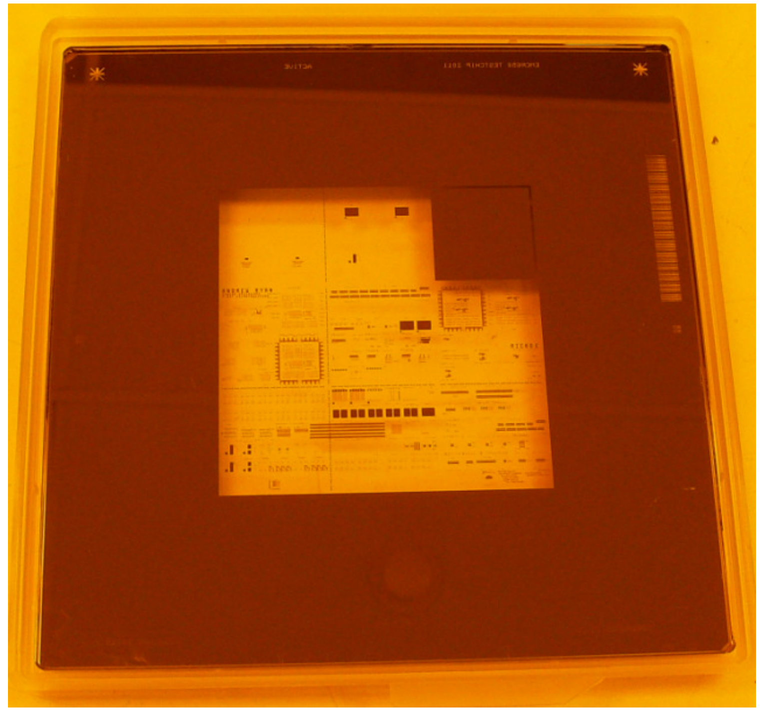
Figure 3.1 The r

Pre Alignment Marks

ASML RETICLE

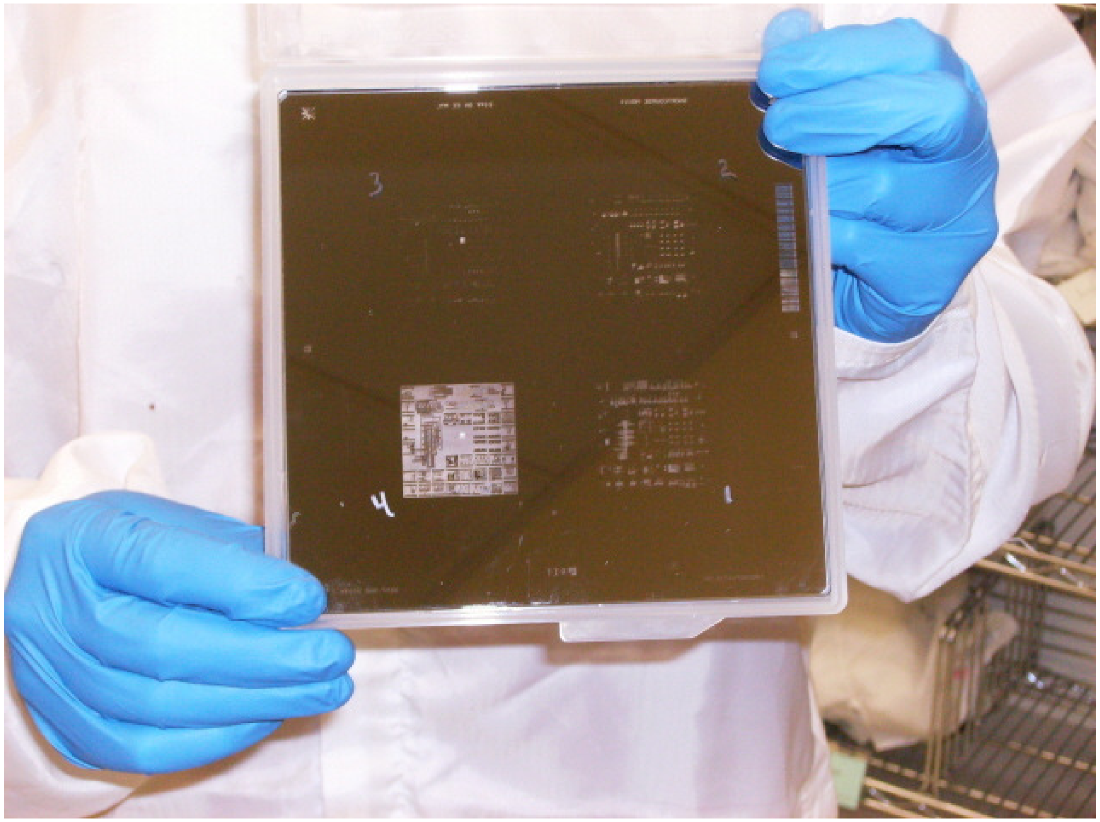


Chrome Side
Mirrored 90°
Chip Bottom at Bottom



Non Chrome Side
As loaded into Reticle Pod, Chrome Down, Reticle Pre-Alignment Stars Sticking out of Pod

ASML 4 LEVELS PER PLATE RETICLE



Stepper Job Name = PMOS

Masks with 4 levels per plate
- Saves money, time, inventory
- Max Chip size 10mm by 10mm

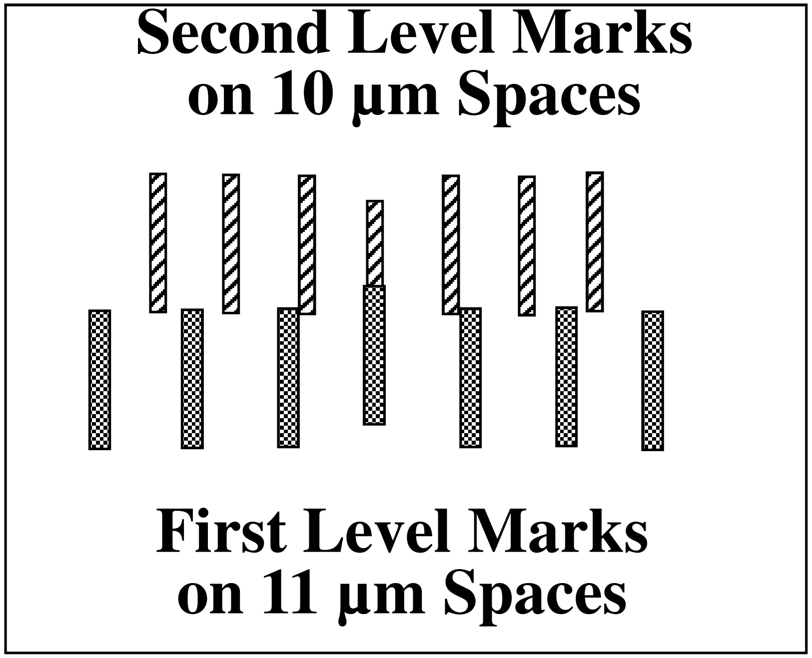
COMBINED ZERO AND FIRST LEVEL WAFER MARKS

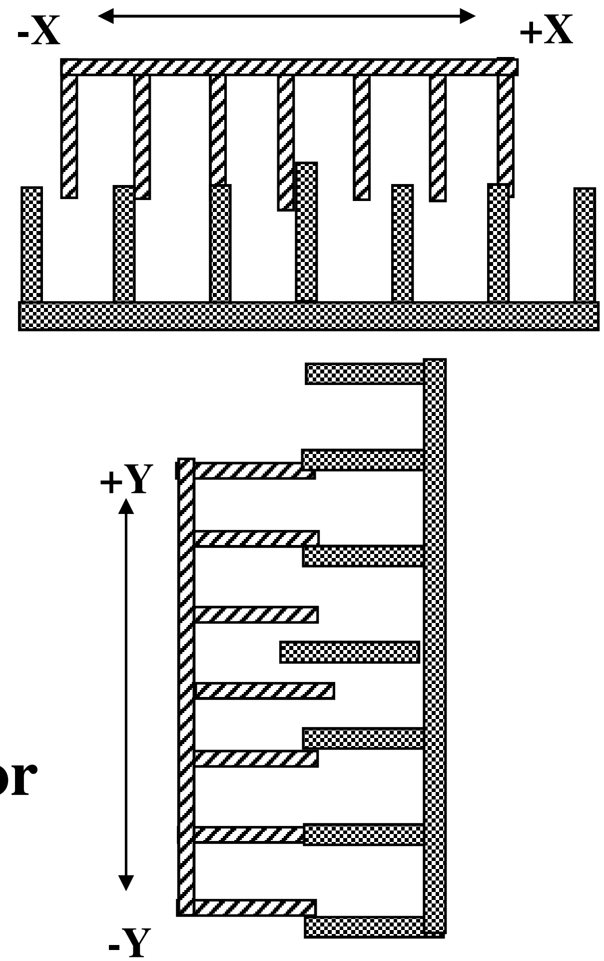
The wafer marks can be etched to the calculated depth or created by differential oxide growth.

For example a wafer with 500nm of oxide on it can be patterned and etched with the wafer marks followed by another 500nm oxide growth resulting in a 120nm step in the silicon. One could also use LOCOS or shallow trench processes to create steps in the silicon.

Drytek Quad, Recipe ZEROETCH
Chamber3, Step 1, 100 mTorr, 200w
CF_4=25, CHF_3=50, O_2=10sccm,
Max Etch Time = 2 min for 1300Å

BASIC OVERLAY VERNIERS

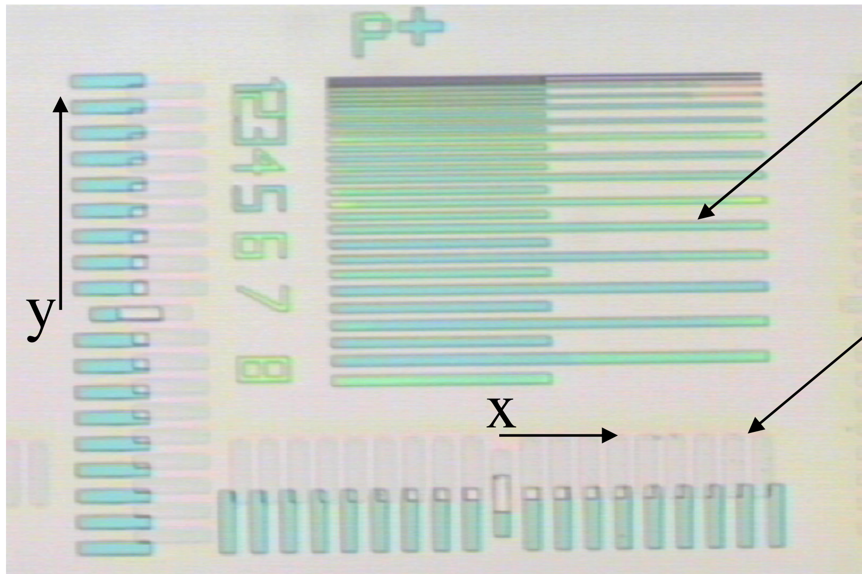




Example shows alignment error of -1 µm in X and -2 µm in Y

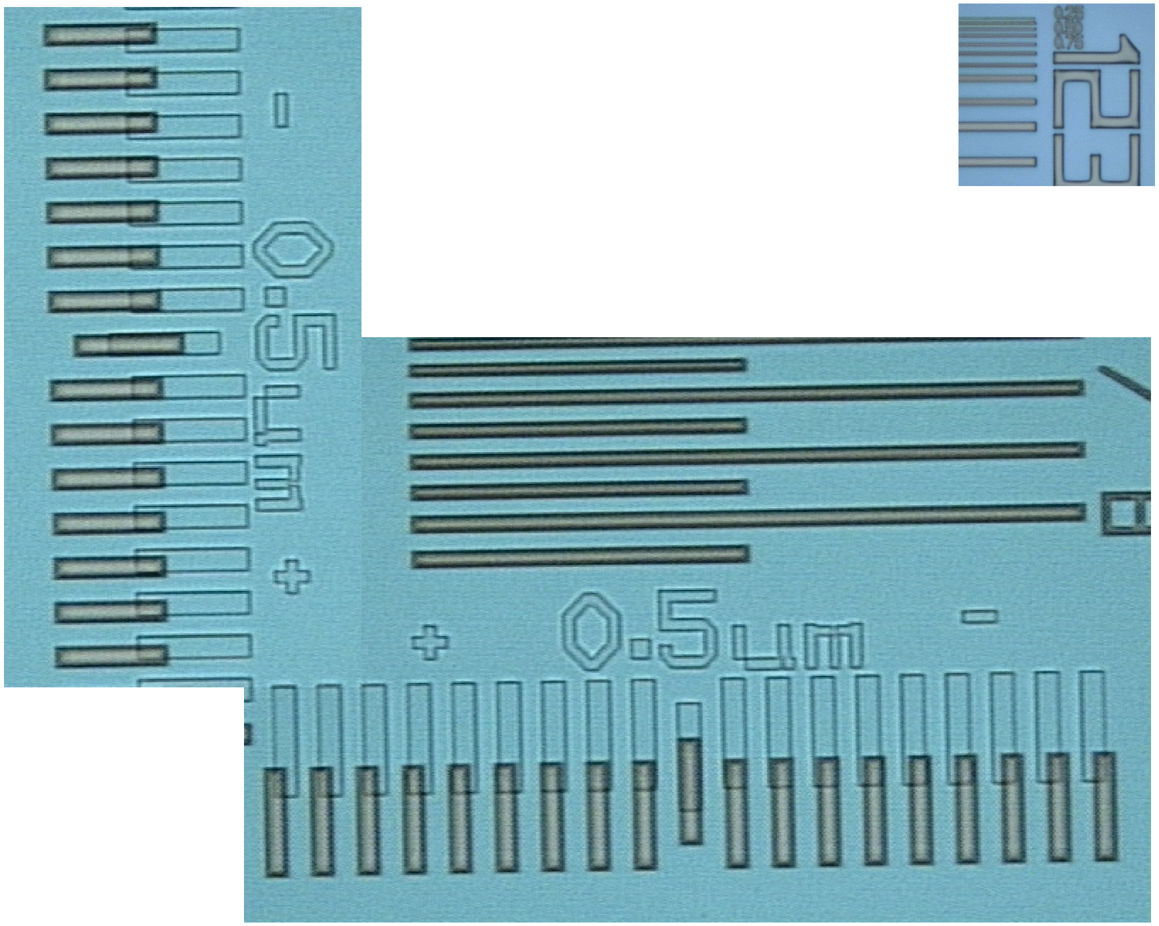
RIT 1 µm OVERLAY VERNIERS

This picture shows perfect alignment in x and y



Note: in this picture the lines and spaces and the outer set of marks for x and y overlay are the result of the most recent photolithography. The inner set of overlay marks are from a previous layer. Some RIT designs use the inner set of bars with the lines and spaces. Be careful when determining and specifying alignment directions. (A precise specification for example is: the 2^{nd} layer pattern needs to shift 1µm in the –y direction (down toward wafer flat) and 0.5µm in +x direction to give correct alignment with the previous layer)

RIT 0.5 µm OVERLAY VERNIERS



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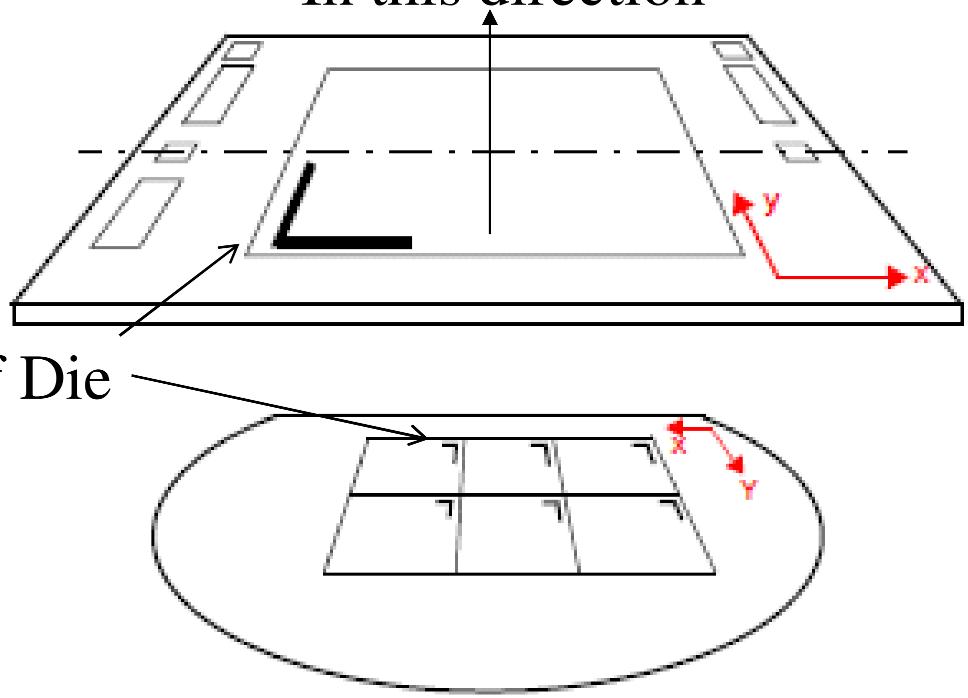
RETICLE AND WAFER ORIENTATION

Mask is loaded into Machine
In this direction

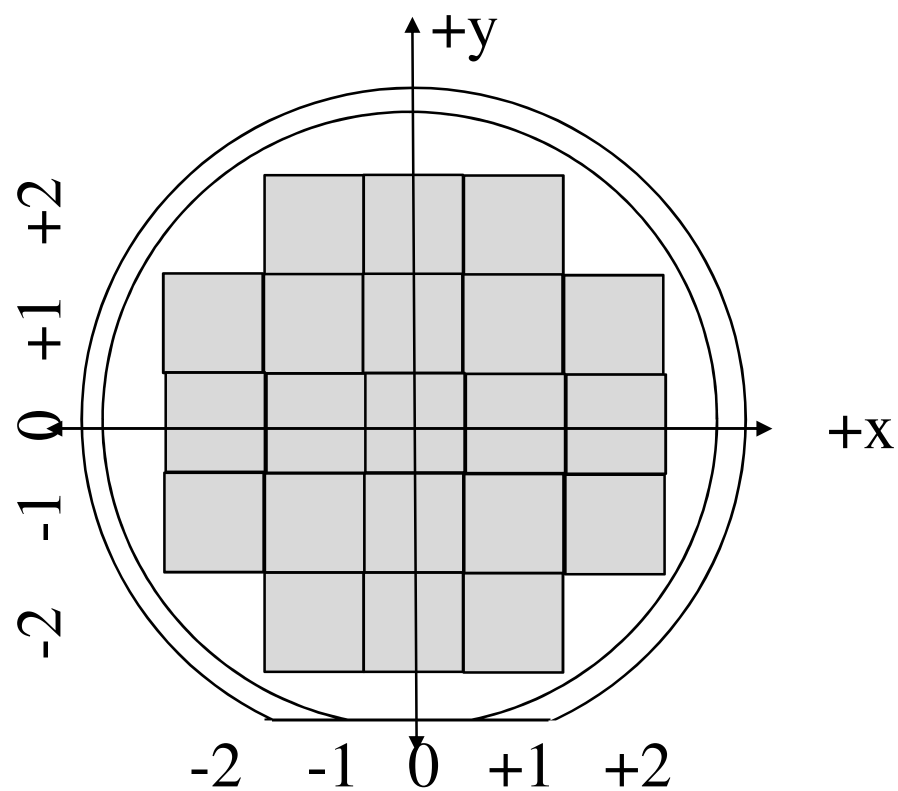


Bottom Left Corner of Die

Figure 1.1 Relationship between reticle and wafer coordinate system

Figure 1.2 shows the schematic layout of a PAS 55(
shows all the required reticle patterns.

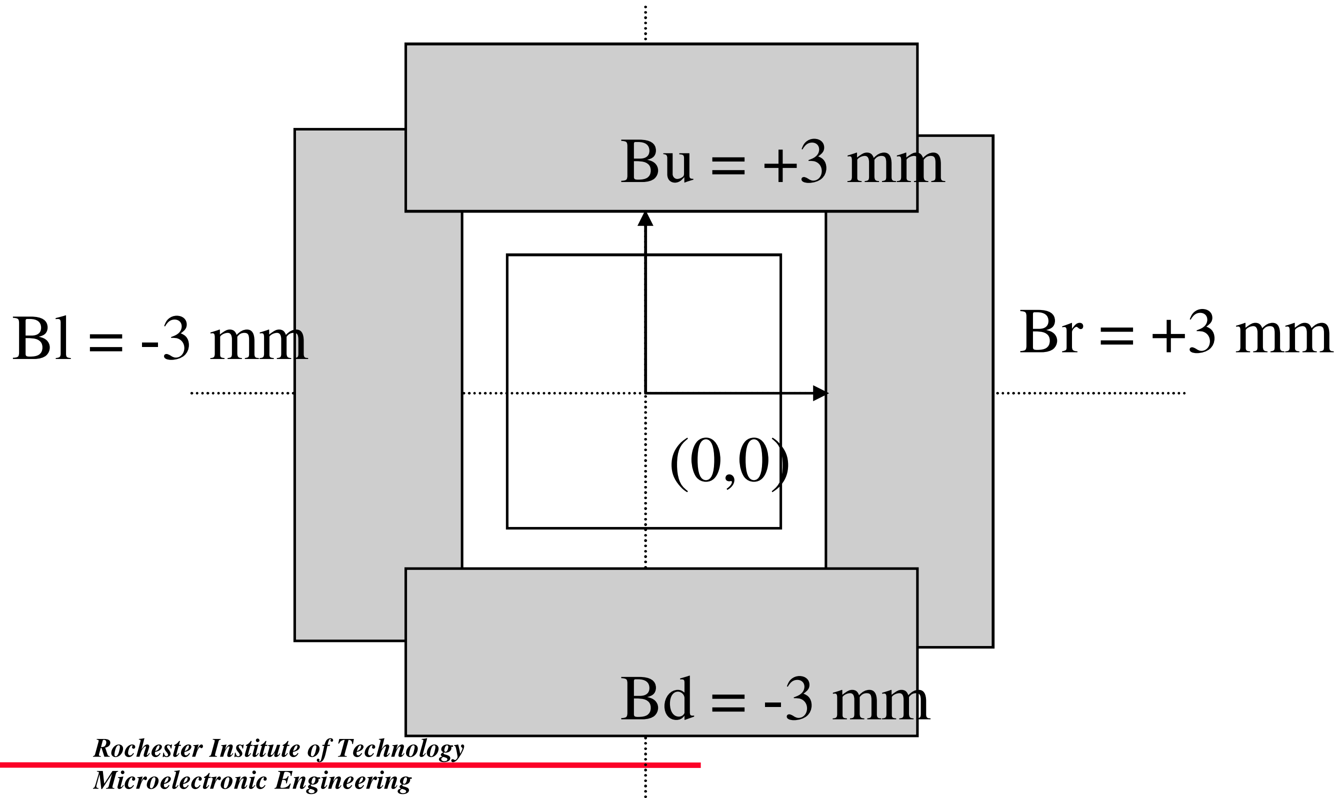
DIRECTIONS ON THE WAFER



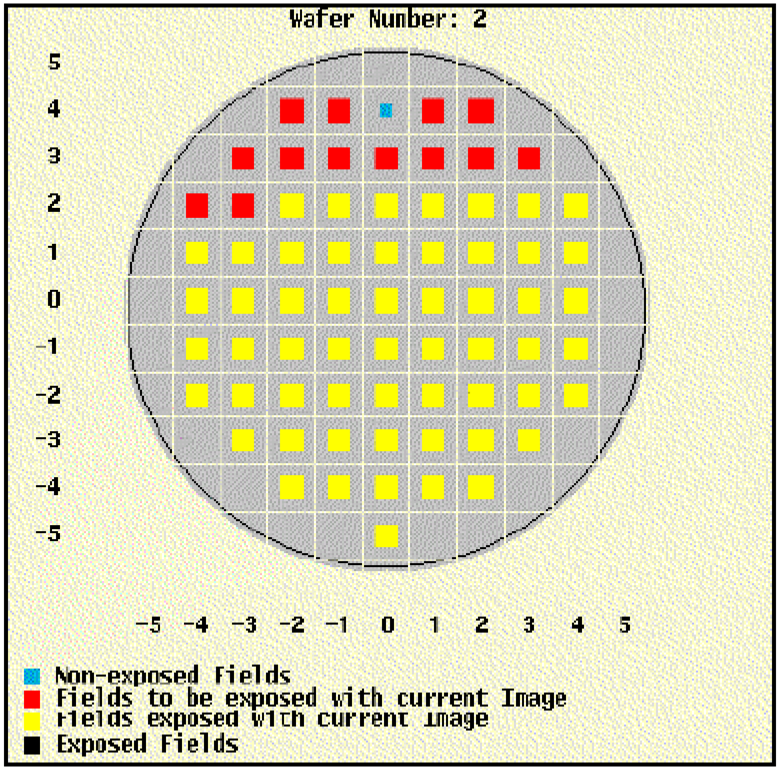
Die should be correct reading with bottom of the chip design toward the wafer flat. Some microscopes invert the image so be careful determining directions of alignment errors. (For example: 2^{nd} layer pattern needs to shift 1µm in –y direction and 0.5µm in +x direction to give correct alignment)

BLADE POSITION CALCULATION

Note: Assume the Reticle is opaque outside the chip area. The blade opening should be a little larger than the chip size so divide by 2. For example a 5mm square chip should have blades open a little more than 2.5 mm in each direction. Pick 3 mm. Blade openings should be less than ½ step size, for 6 mm step size that is 3 mm.

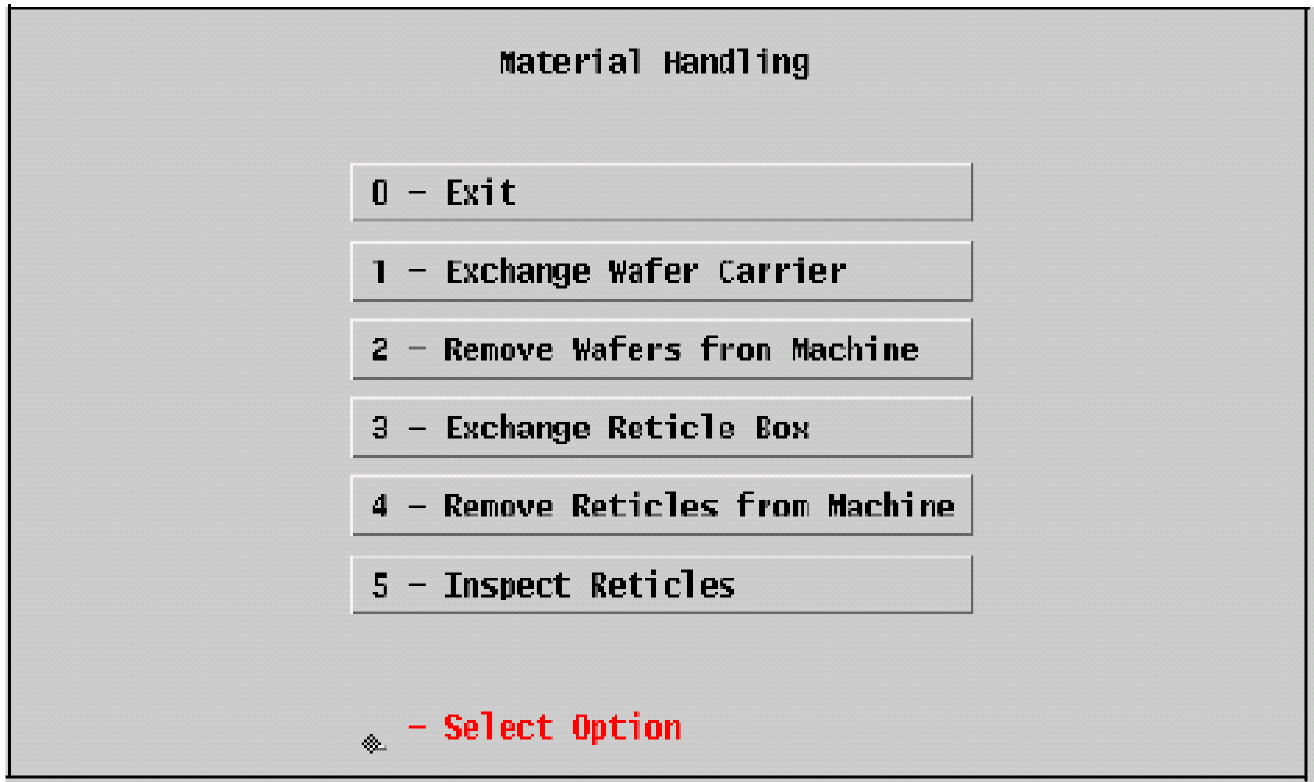


ASML PAS 5500 USER INTERFACE MAIN MENU



MATERIAL HANDLING

Handling of Wafers and Reticles



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BATCH CONTROL

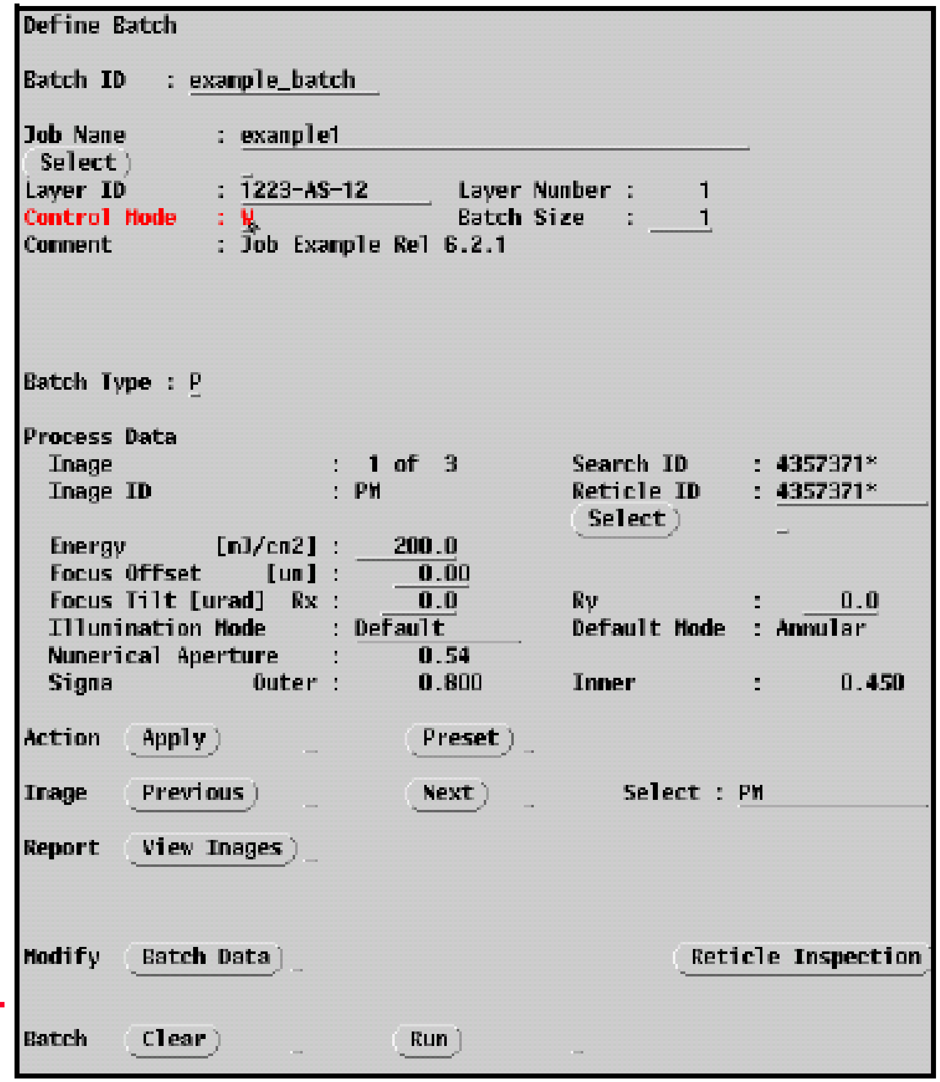
Range for coherence value

Conventional Illumination

	NA=0.48	0.54	0.60
Min	0.42	0.37	0.34
Max	0.85	0.85	0.85

Annular

	NA=0.48	0.54	0.60
Outer	0.34 to 0.56	0.57	0.58
Inner	0.18	0.16	0.14



SSI COAT AND DEVELOP TRACK FOR 6" WAFERS

PHOTORESIST PROCESSING

COAT.RCP

DEHYDRATE BAKE/ HMDS PRIMING	SPIN COAT	SOFT BAKE
HMDS Vapor Prime 140 °C, 60 sec.	OIR 620-10 Resist 3250rpm, 30 sec.	90 °C 60 sec.

DEVELOP.RCP

POST EXPOSURE BAKE	DEVELOP	HARD BAKE
110 °C, 60 sec.	DI Wet CD-26 Developer 48sec. Puddle, 30sec. Rinse, 30sec., 3750rpm Spin Dry	120 °C, 60 sec.

HOMEWORK – ASML ALIGNMENT

1. What is the difference between fiducial marks and alignment marks?
2. What is the definition of alignment key offset? How is the alignment key offset, left alignment die and right alignment die (row and column) used in a stepper job?
3. How accurate can a stepper overlay images? What determines this accuracy?
4. Why are four levels placed on a single mask at RIT? What are the advantages and disadvantages of this approach? Can this be done on the ASML stepper?

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COPY JOB FILES TO FLOPPY

Main Menu -> Job Definition -> View Job (click 4 times to highlight all text)
Press Copy Button (at left side of keyboard)
Open Command Window (right click somewhere on background screen)
Click on ASML
Type textedit
Press Paste button (on left side of keyboard – text should appear)
Right Click on file -> save as
Double click "Go up one Folder" (until you can't anymore)
Click mnt
Type in a filename under save as:_______________
Click save

Remove Floppy, go to another computer, open using Wordpad