ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

Introduction to ASML PAS 5500 Wafer Alignment and Exposure

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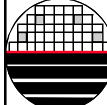

Revision Date: 4-28-2014 Lithography-ASML.PPT

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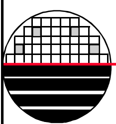
DEFINITIONS

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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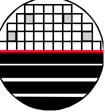
OUTLINE

Introduction
PAS 5500 Specifications
Stage Accuracy
Reticle Specifications and Alignment
Exposure Dose
Wafer Alignment
Overlay Measurement
Reticle and Wafer Orientation
User Interface
Material Handling
Batch Control
Coat and Develop Track
Stepper Jobs
References



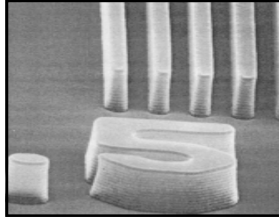
INTRODUCTION

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.

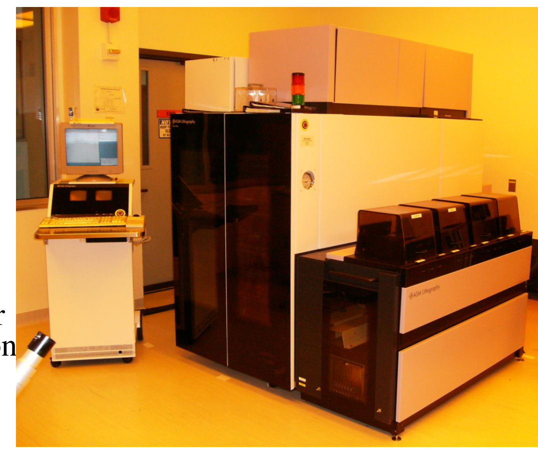
INTRODUCTION (cont.)

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)

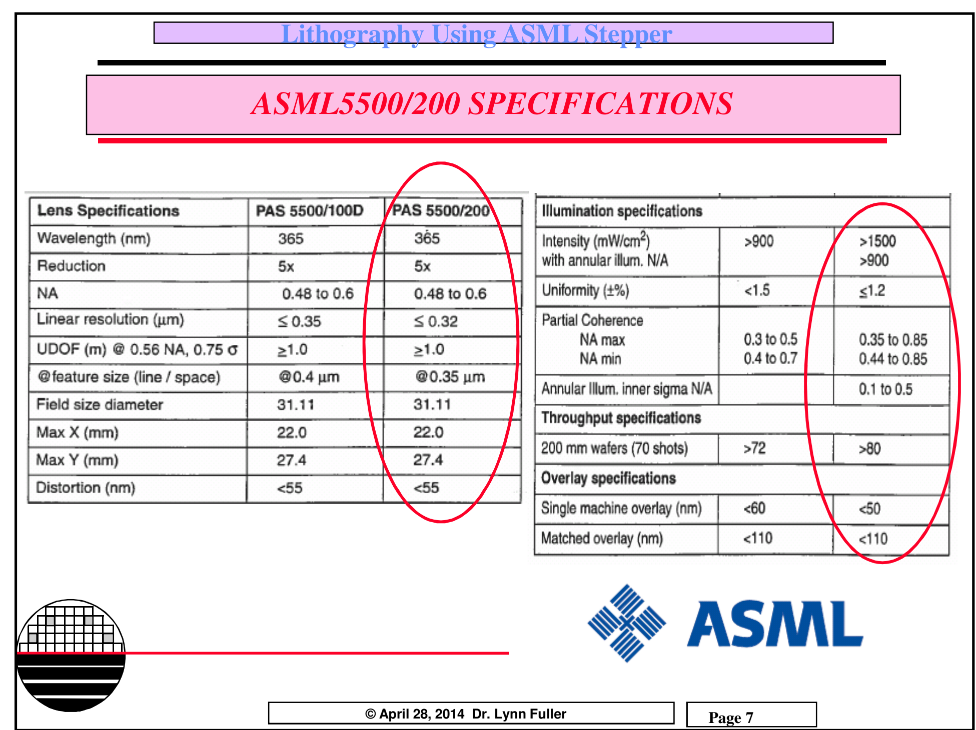
RIT's - ASML PAS 5500/200



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

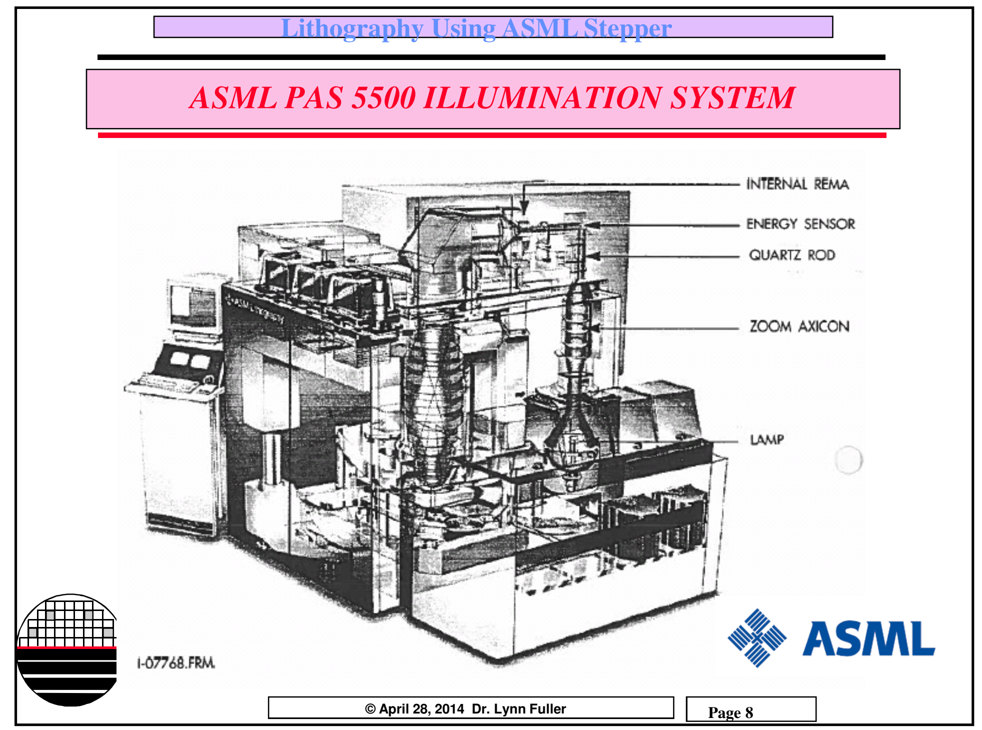


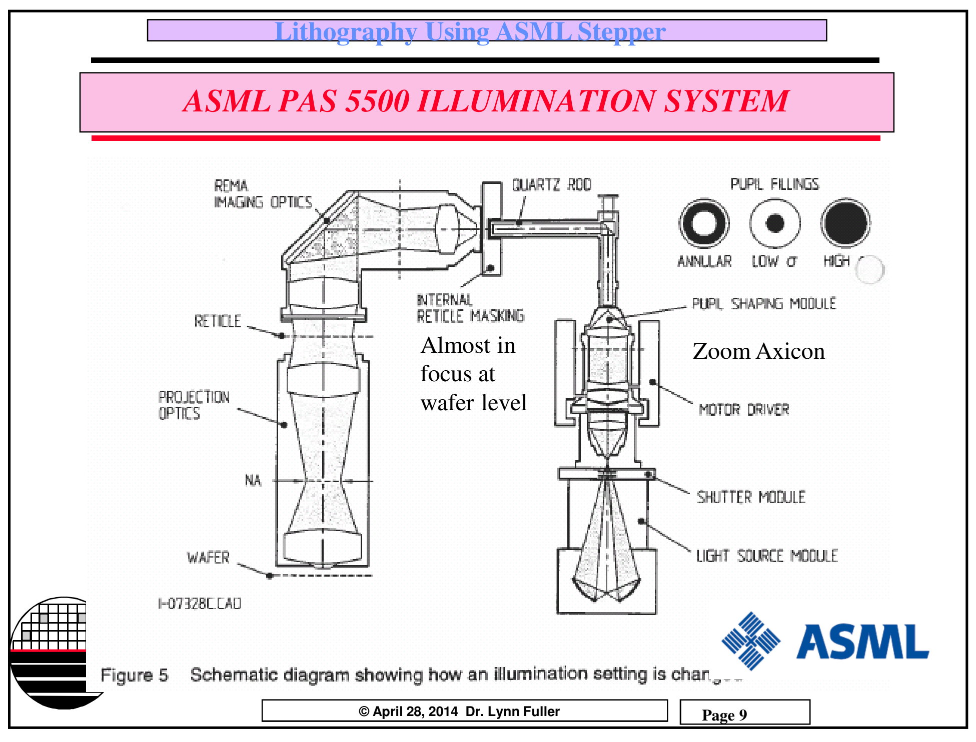
i-Line Stepper λ = 365 nm
22 x 27 mm Field Size



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




Lithography Using ASML Stepper
ASML PAS 5500 ILLUMINATION SYSTEM
REMA
IMAGING OPTICS
QUARTZ ROD
PUPIL FILLINGS
ANNULAR
LOW σ
HIGH
RETICLE
INTERNAL
RETICLE MASKING
PUPIL SHAPING MODULE
Almost in
focus at
wafer level
Zoom Axicon
PROJECTION
OPTICS
MOTOR DRIVER
NA
SHUTTER MODULE
WAFER
LIGHT SOURCE MODULE
I-07328C.CAD
ASML
Figure 5 Schematic diagram showing how an illumination setting is chan
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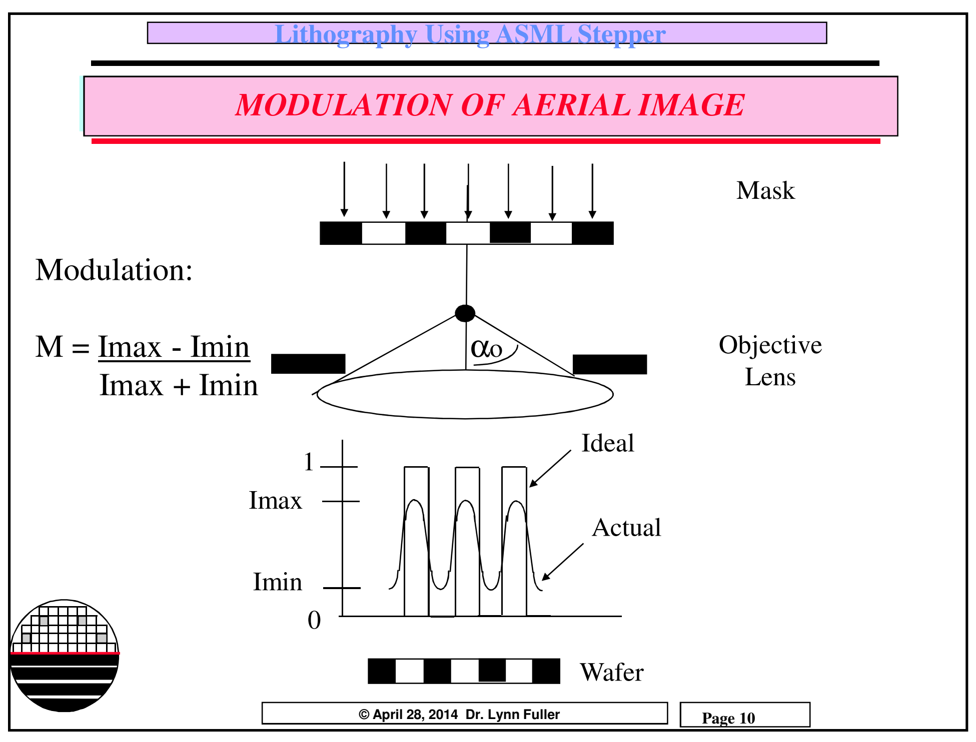
Page 9


Lithography Using ASML Stepper
MODULATION OF AERIAL IMAGE
Mask
Modulation:
M = Imax - Imin / Imax + Imin
αo
Objective
Lens
1
Imax
Imin
0
Ideal
Actual
Wafer
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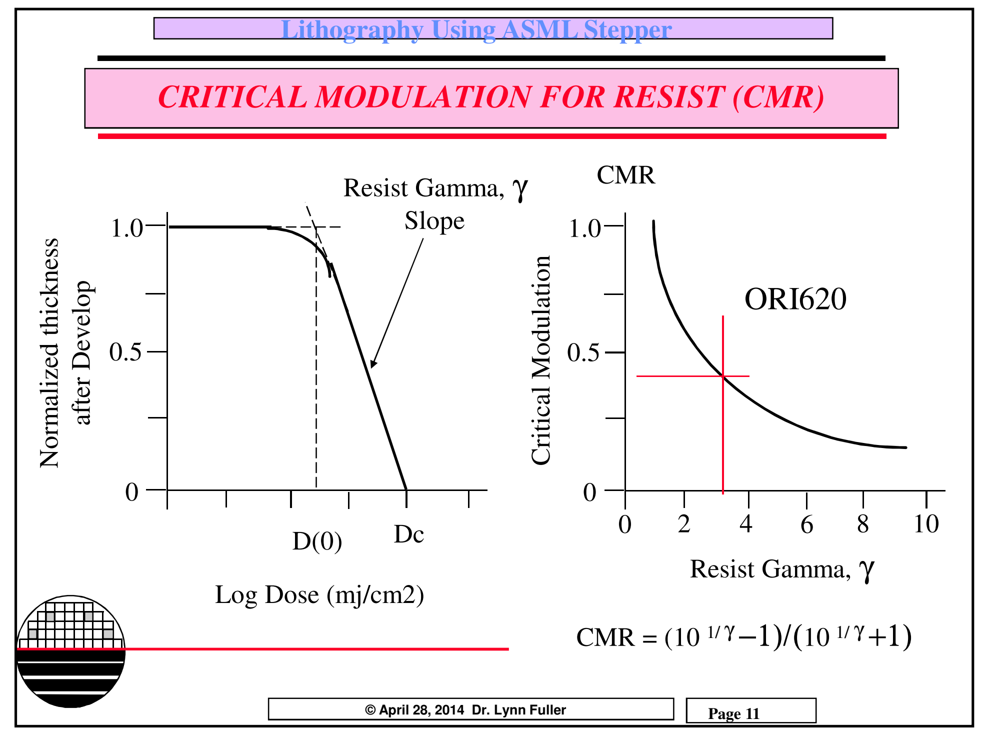
Page 10


Lithography Using ASML Stepper
CRITICAL MODULATION FOR RESIST (CMR)
Resist Gamma, γ
Slope
CMR
1.0
0.5
0
Normalized thickness after Develop
D(0)
Dc
Log Dose (mj/cm2)
Critical Modulation
ORI620
0 2 4 6 8 10
Resist Gamma, γ
CMR = (10 1/γ−1)/(10 1/γ+1)
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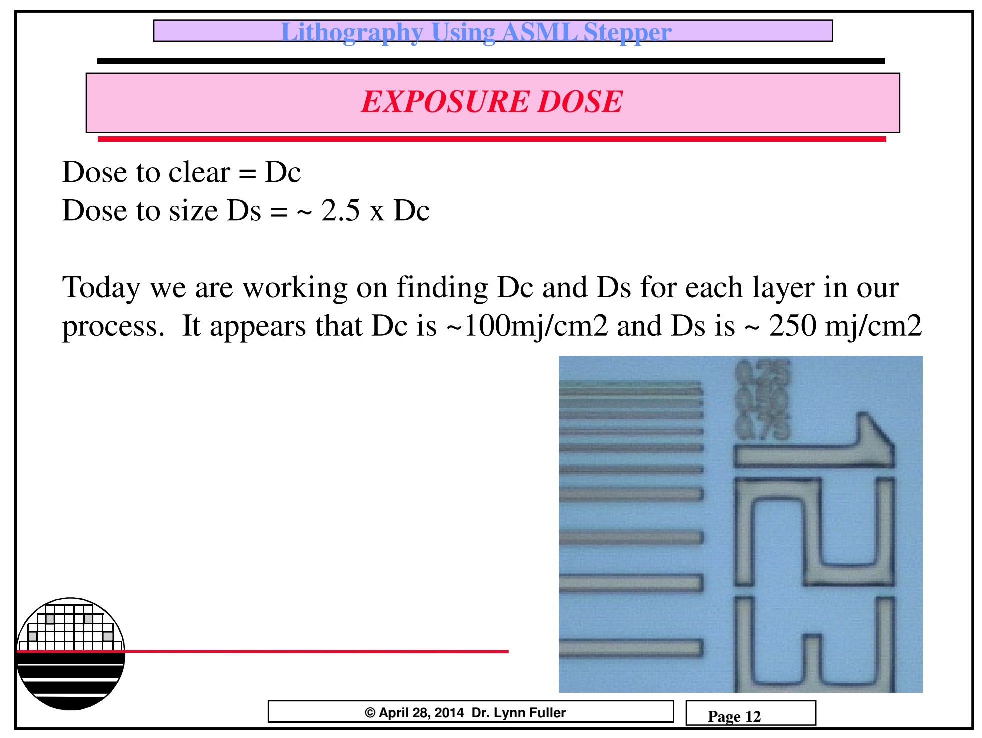
Page 11


Lithography Using ASML Stepper
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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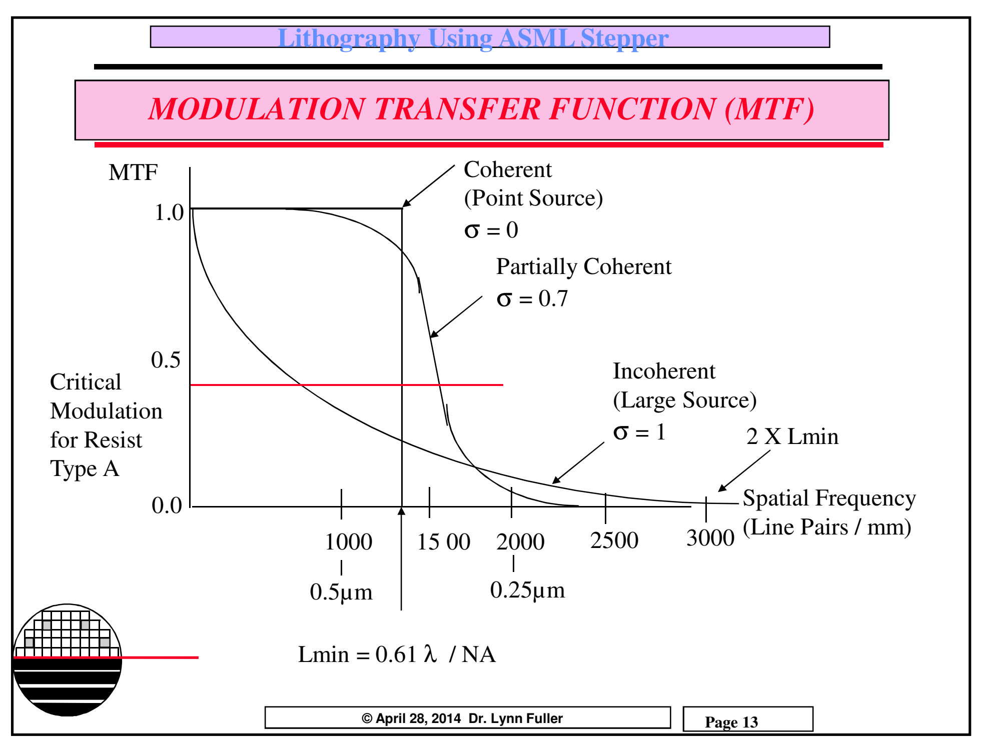
Page 12


Lithography Using ASML Stepper
MODULATION TRANSFER FUNCTION (MTF)
MTF
1.0
0.5
0.0
Coherent
(Point Source)
σ = 0
Partially Coherent
σ = 0.7
Incoherent
(Large Source)
σ = 1
2 X Lmin
Critical
Modulation
for Resist
Type A
Spatial Frequency
(Line Pairs / mm)
1000
15 00
2000
2500
3000
0.5µm
0.25µm
Lmin = 0.61 λ / NA
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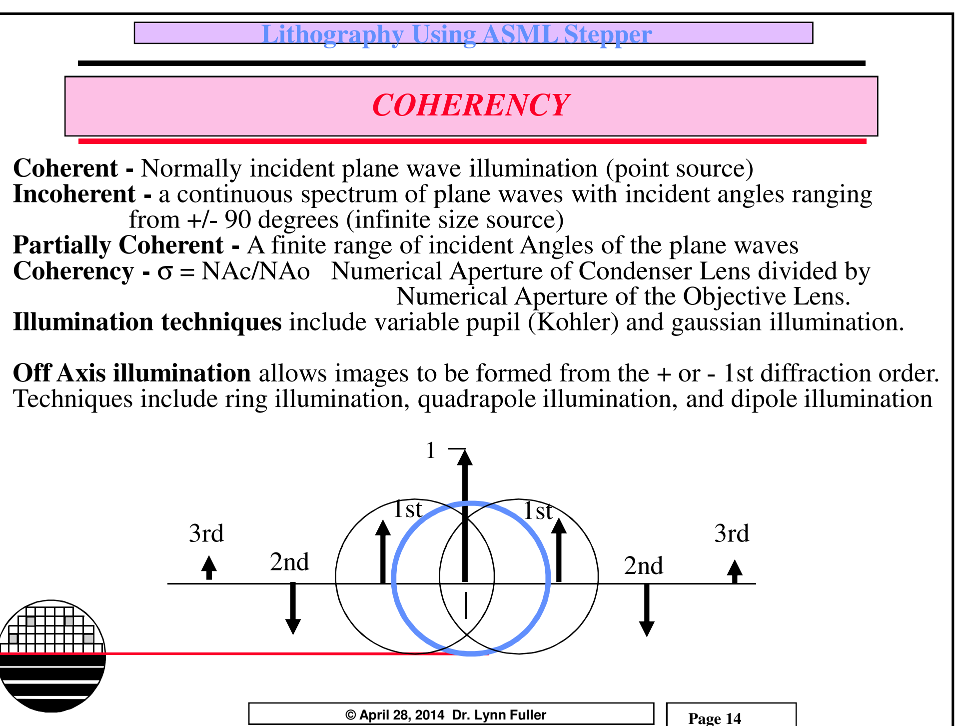
Page 13


Lithography Using ASML Stepper
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
1
1st
1st
3rd
2nd
2nd
3rd
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Page 14

SUMMARY

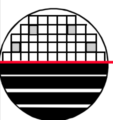
This table lists the tradeoffs for numerical aperture, NA, coherency, σ, and type of illumination as it relates to resolution, Lmin, Depth of Focus, DOF, modulation of aerial image, M, and time to expose, throughput.

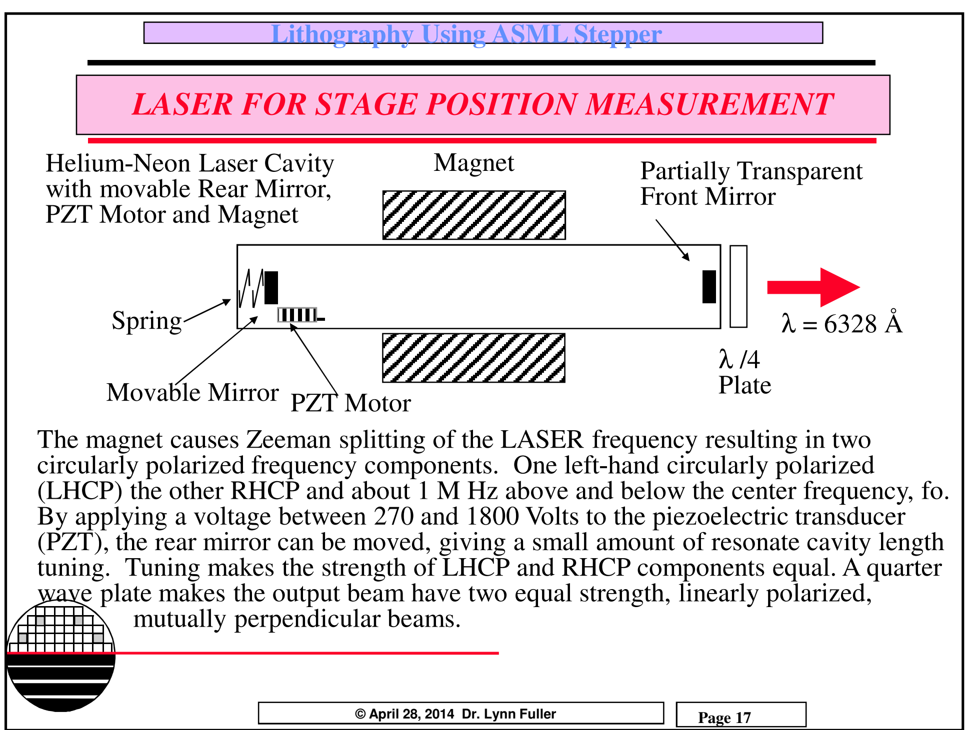
	Lmin	DOF	Modulation	Throughput
Increasing NA	⇩	⇩	⇧	⇧
Increasing σ	⇩		⇩	⇩
Off Axis vs. Kohler	⇩		⇩	⇩

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

STAGE ACCURACY

The stage position is very accurate. Its position is measured using a laser interferometer that has a fundamental accuracy of λ/8 ~0.08μm. 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.




Lithography Using ASML Stepper
LASER FOR STAGE POSITION MEASUREMENT
Helium-Neon Laser Cavity
with movable Rear Mirror,
PZT Motor and Magnet
Magnet
Partially Transparent
Front Mirror
Spring
λ = 6328 Å
λ /4
Plate
Movable Mirror
PZT Motor
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.
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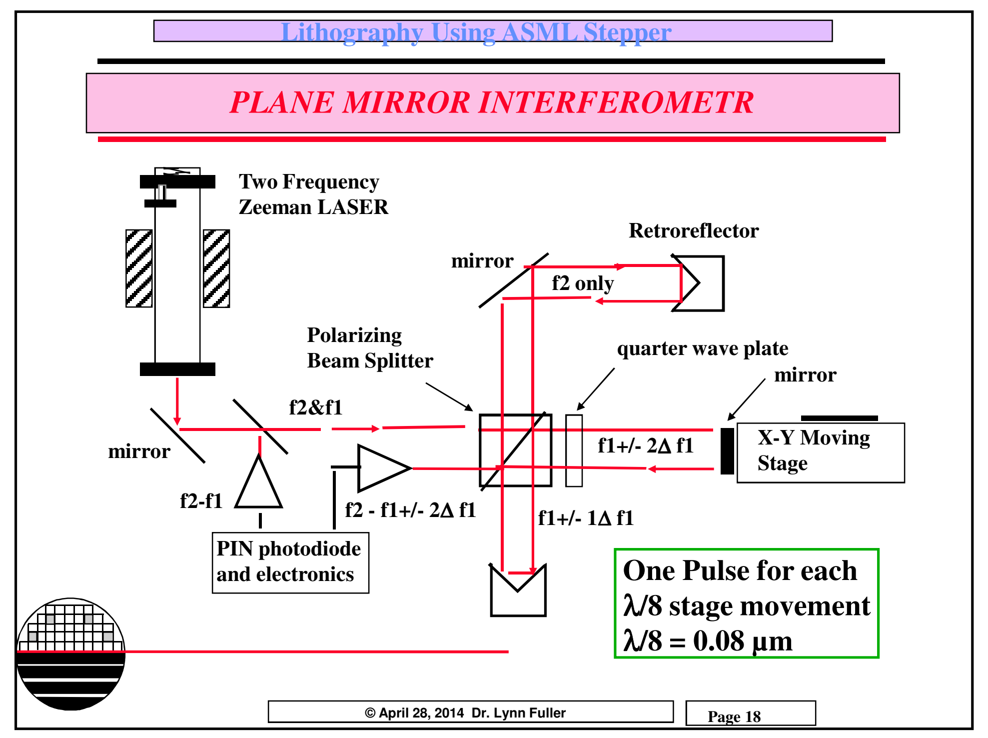
Page 17


Lithography Using ASML Stepper
PLANE MIRROR INTERFEROMETR
Two Frequency
Zeeman LASER
Retroreflector
mirror
f2 only
Polarizing
Beam Splitter
quarter wave plate
mirror
f2&f1
X-Y Moving
Stage
f1+/- 2Δ f1
mirror
f2-f1
f2 - f1+/- 2Δ f1
f1+/- 1Δ f1
PIN photodiode
and electronics
One Pulse for each
λ/8 stage movement
λ/8 = 0.08 µm
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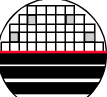
Page 18

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.



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

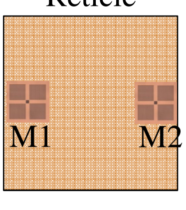
Fiducial – Reticle alignment when there are no alignment marks on the wafer (zero or 1st level)
F1 aligned to M1 and F1 to M2

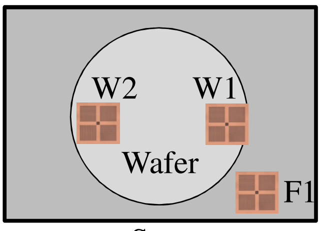
Global – After both reticle and wafer exchange
F1 aligned to M1, W1 to M2, and W2 to M1

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

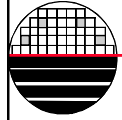
Reticle – After reticle exchange
W1aligned to M1 and W1 to M2

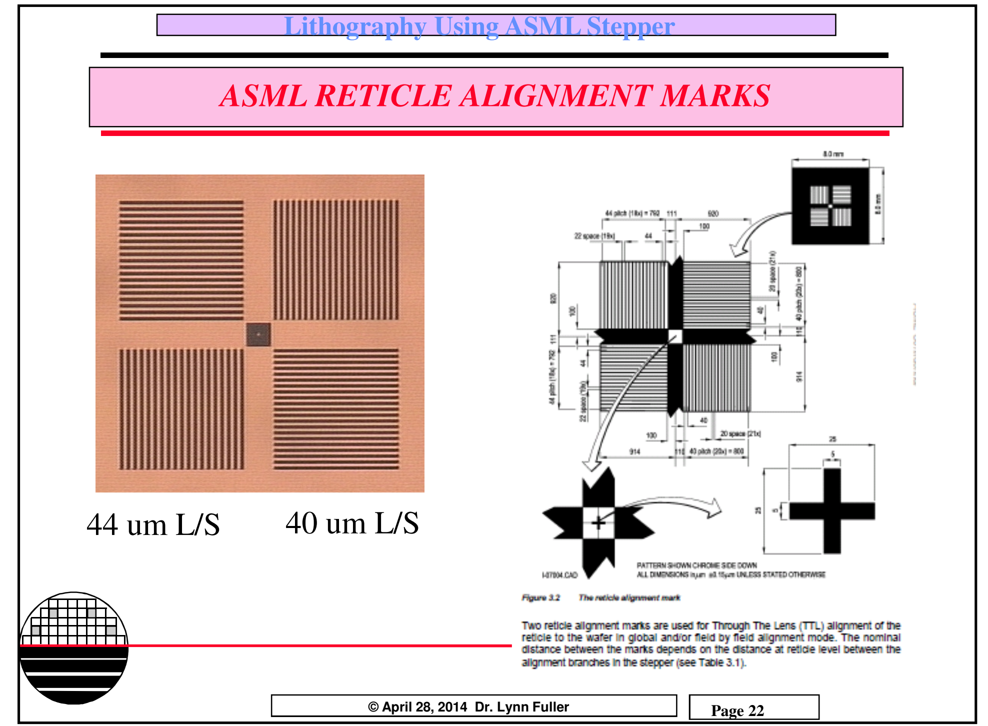
Reticle

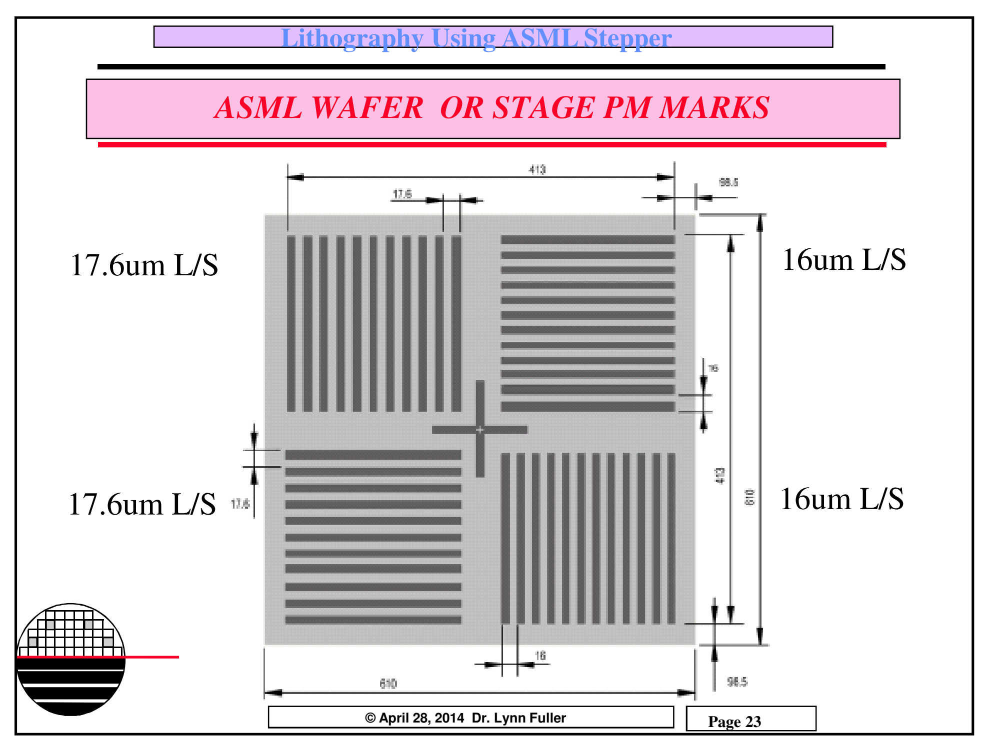




Stage

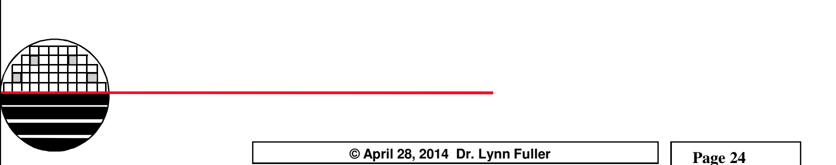






WAFER ALIGNMENT CONTINUED

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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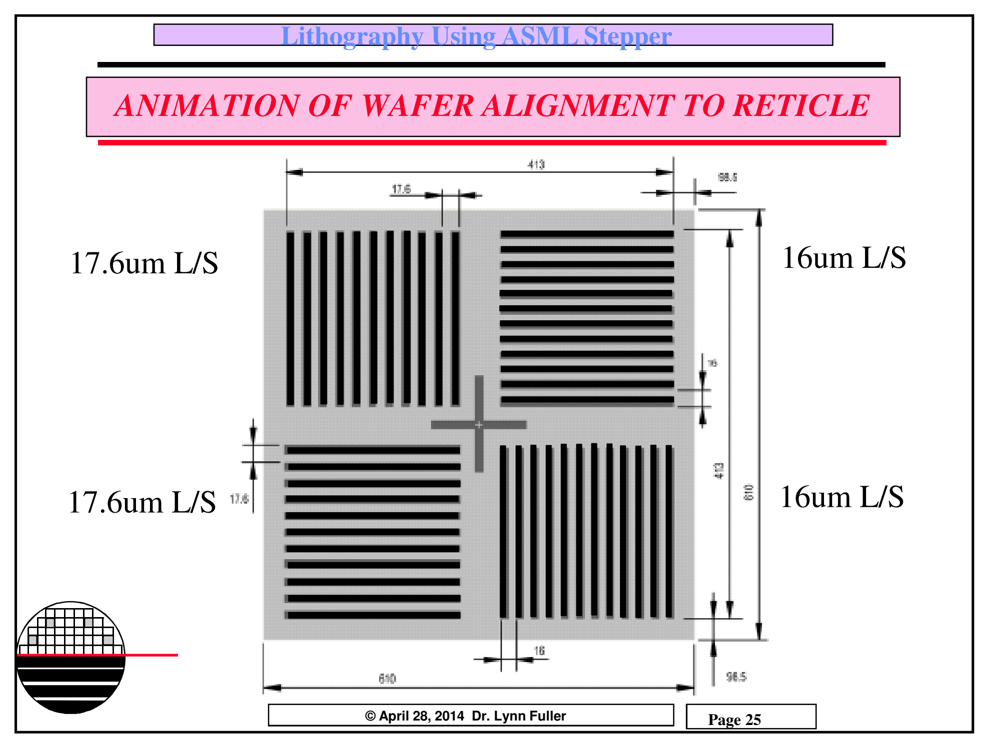
Lithography Using ASML Stepper
ANIMATION OF WAFER ALIGNMENT TO RETICLE
17.6um L/S
16um L/S
17.6um L/S
16um L/S
413
17.6
98.5
16
610
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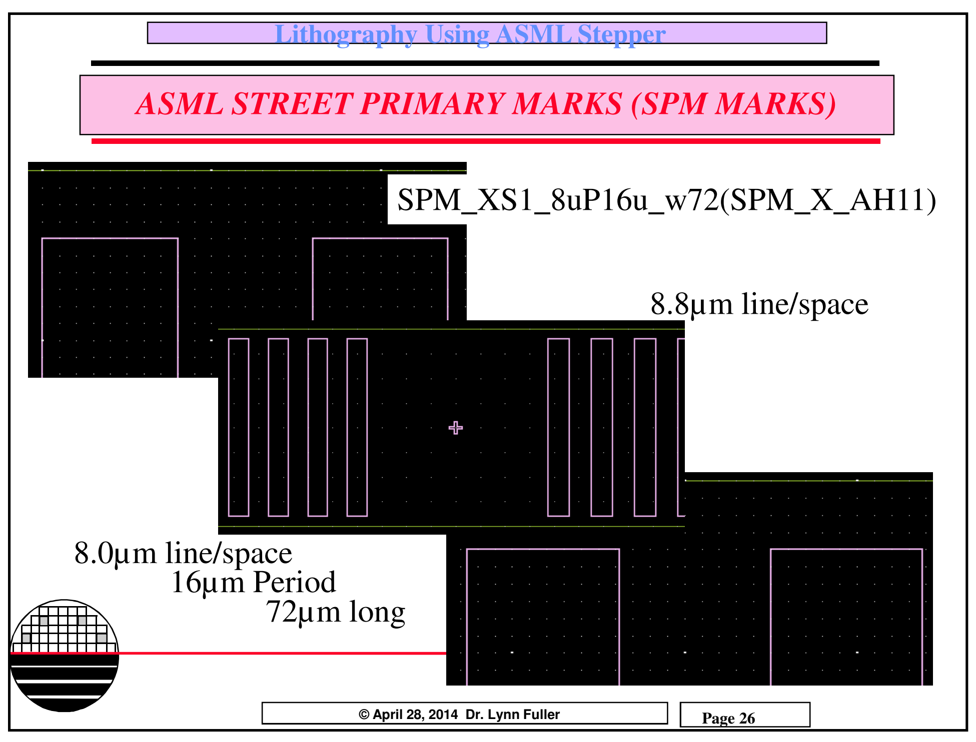
Page 25


Lithography Using ASML Stepper
ASML STREET PRIMARY MARKS (SPM MARKS)
SPM_XS1_8uP16u_w72(SPM_X_AH11)
8.8µm line/space
8.0µm line/space
16µm Period
72µm long
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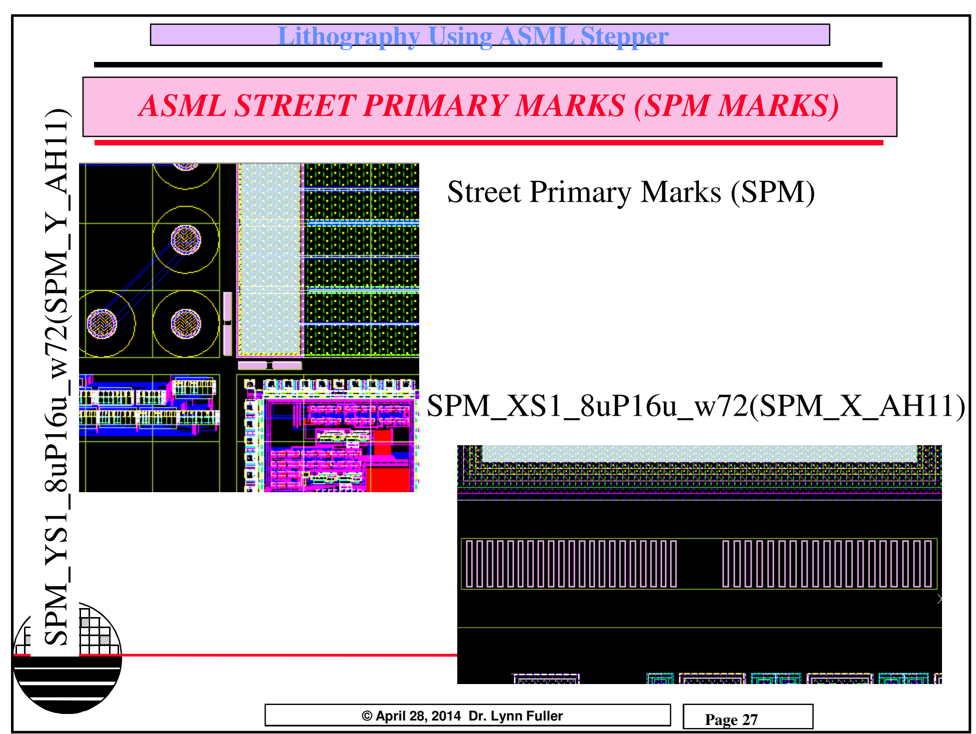
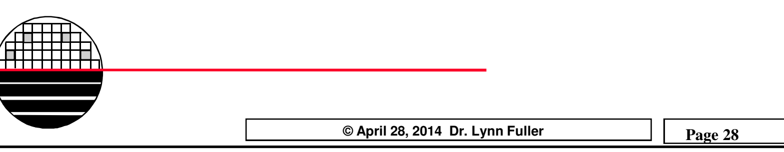
Page 26



RETICLE ALIGNMENT

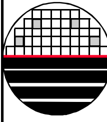
In order to align a reticle to the stepper, the reticle must have fiducial marks at given locations near the edge of the mask. The ASML fiducial marks are shown on the following pages. They are automatically included in any stepper job written in the RIT maskshop. If your mask is made outside of RIT 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).

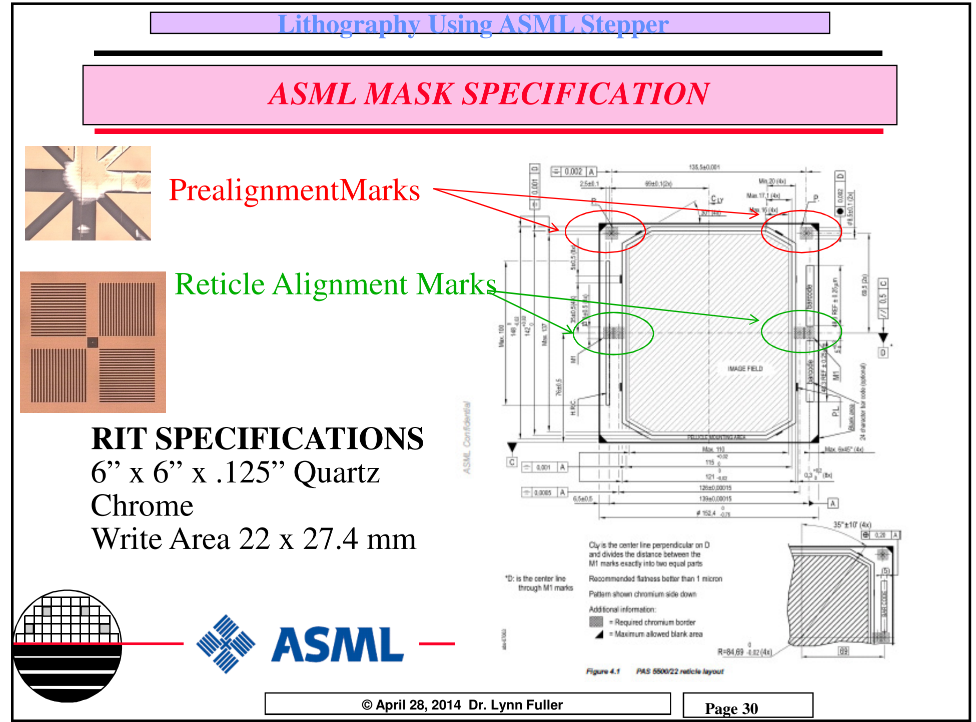


RETICLE ALIGNMENT (continued)

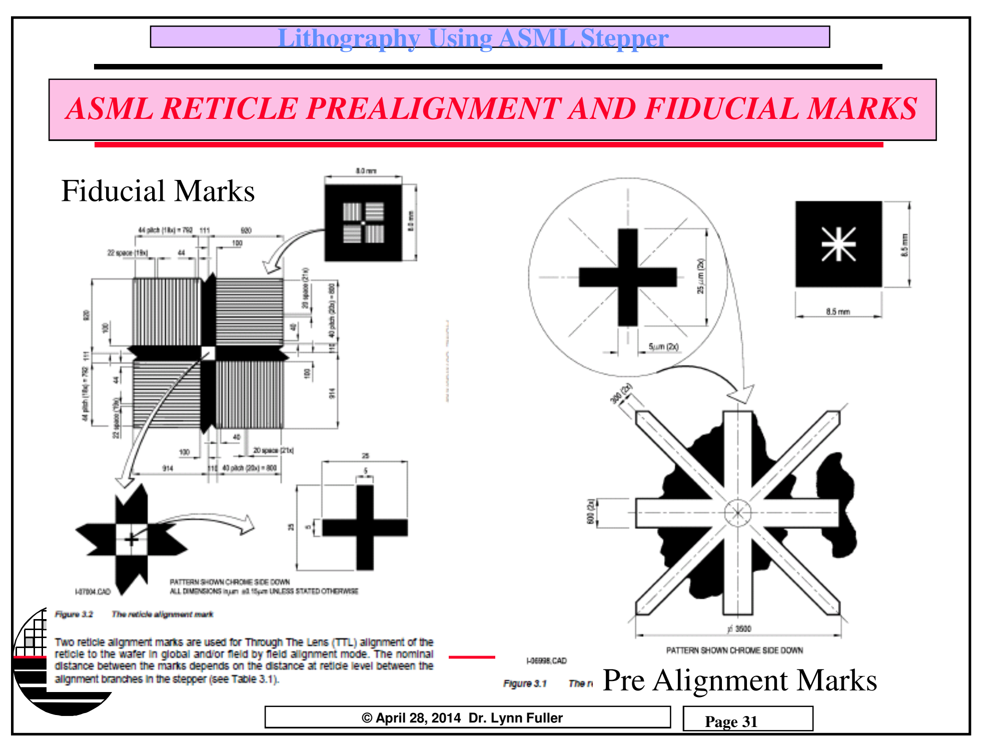
Once the mask is placed on the platen. The reticle prealignment marks are used to position the reticle in the approximate correct location. The stage is moved to position special alignment marks attached to the stage in the correct position to do the reticle fine alignment. Just like wafer alignment 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.



ASML MASK SPECIFICATION



RIT SPECIFICATIONS
6” x 6” x .125” Quartz
Chrome
Write Area 22 x 27.4 mm


Lithography Using ASML Stepper
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).
PATTERN SHOWN CHROME SIDE DOWN
Figure 3.1
Pre Alignment Marks
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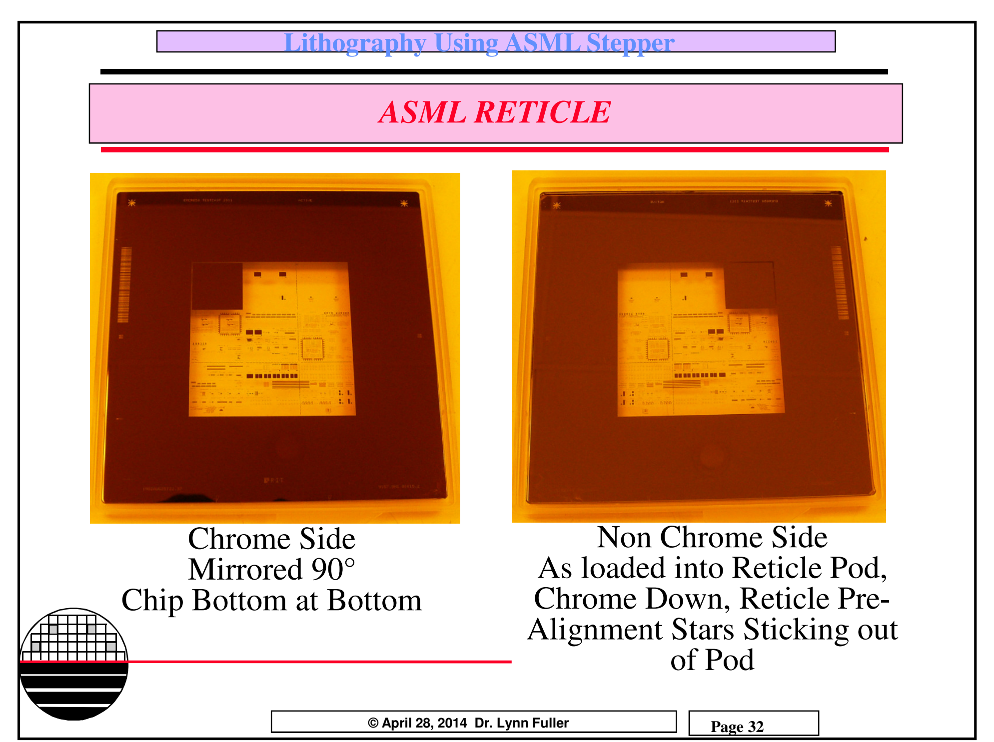
Page 31


Lithography Using ASML Stepper
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
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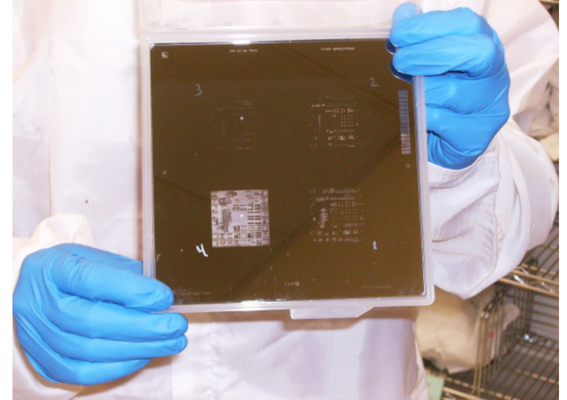
Page 32

ASML 4 LEVELS PER PLATE RETICLE

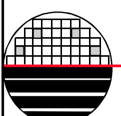


Stepper Job Name = PMOS

Masks with 4 levels per plate

Saves money, time, inventory

Max Chip size 10mm by 10mm

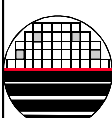


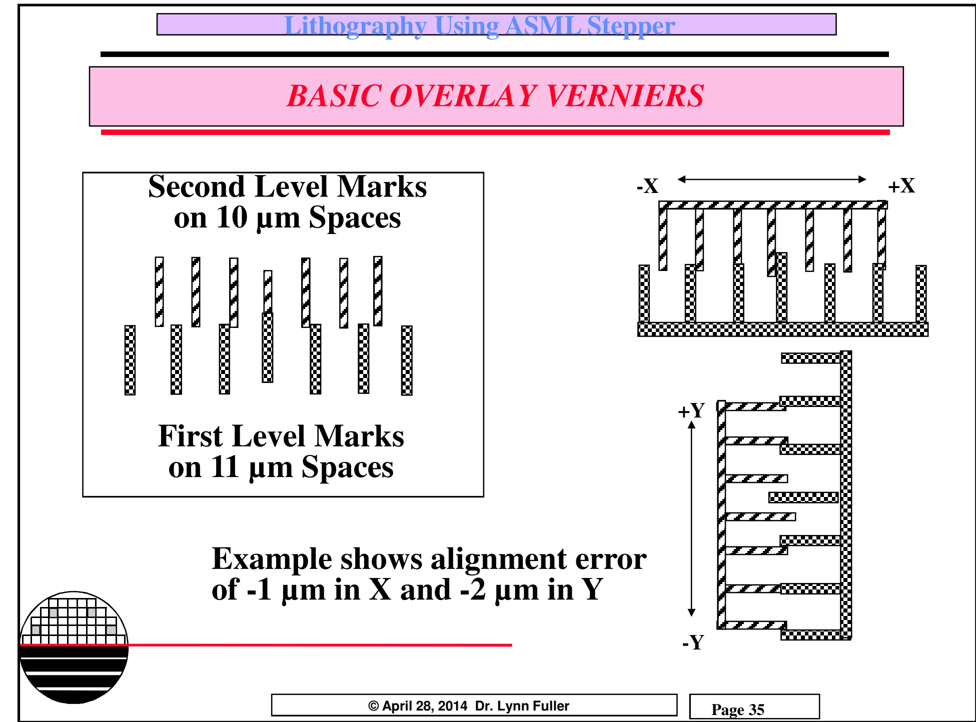
COMBINED ZERO AND FIRST LEVEL WAFER MARKS

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
CF4=25, CHF3=50, O2=10sccm,
Max Etch Time = 2 min for 1300Å




Lithography Using ASML Stepper
BASIC OVERLAY VERNIERS
Second Level Marks
on 10 µm Spaces
First Level Marks
on 11 µm Spaces
-X
+X
+Y
-Y
Example shows alignment error
of -1 µm in X and -2 µm in Y
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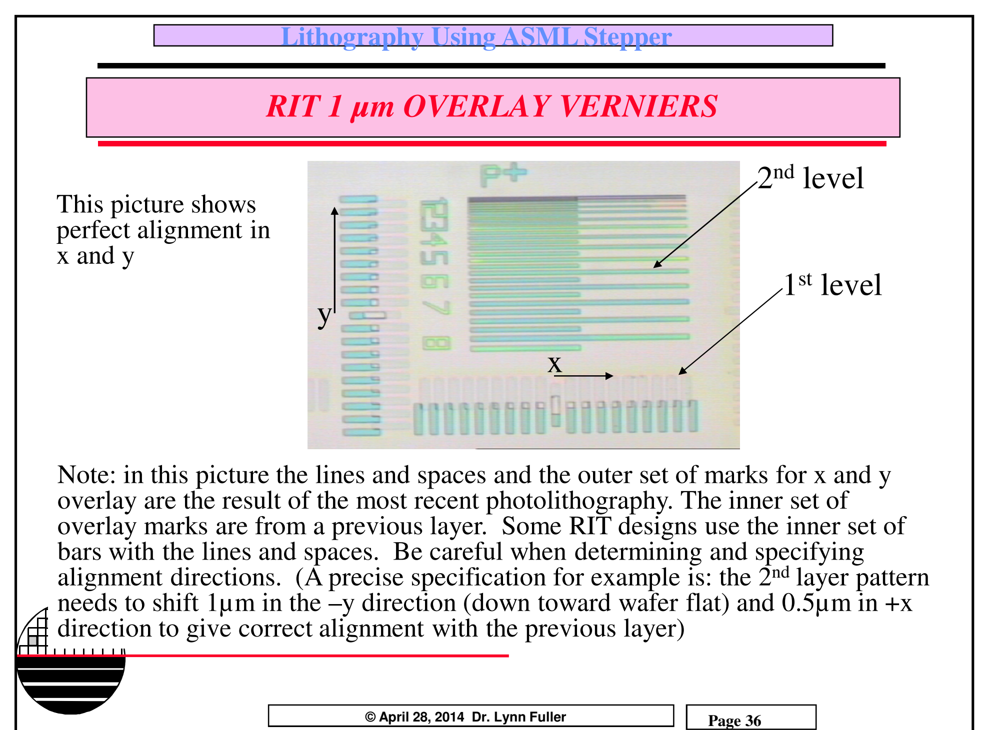
Page 35


Lithography Using ASML Stepper
RIT 1 µm OVERLAY VERNIERS
This picture shows
perfect alignment in
x and y
2nd level
1st level
y
x
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 2nd 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)
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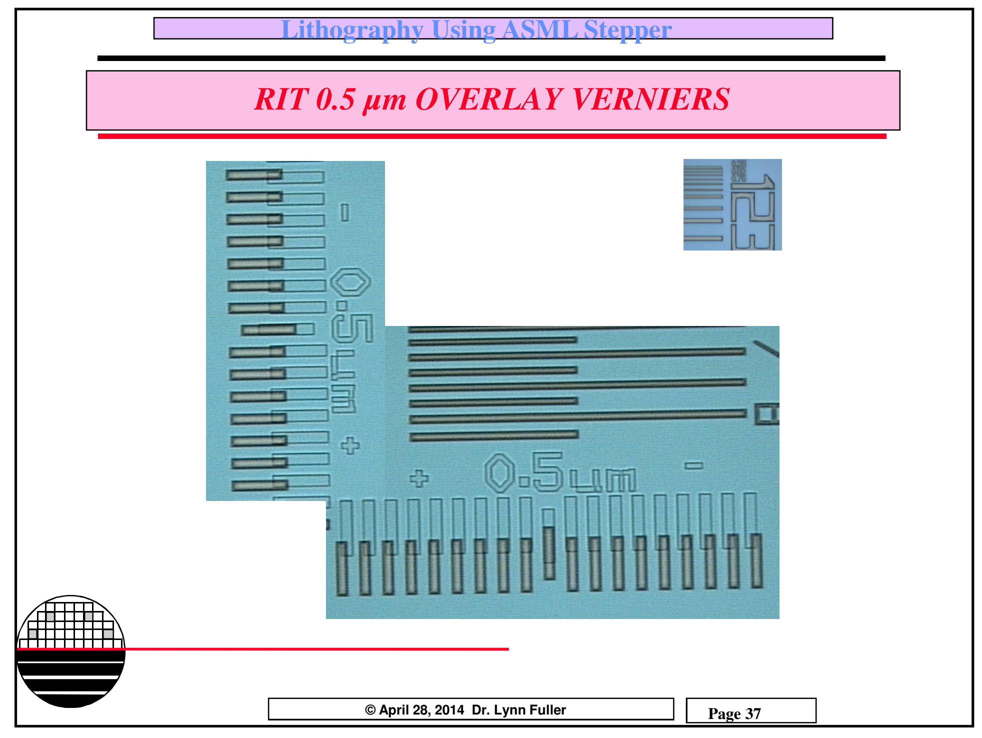
Page 36


Lithography Using ASML Stepper
RIT 0.5 µm OVERLAY VERNIERS
0.5 um
0.5um
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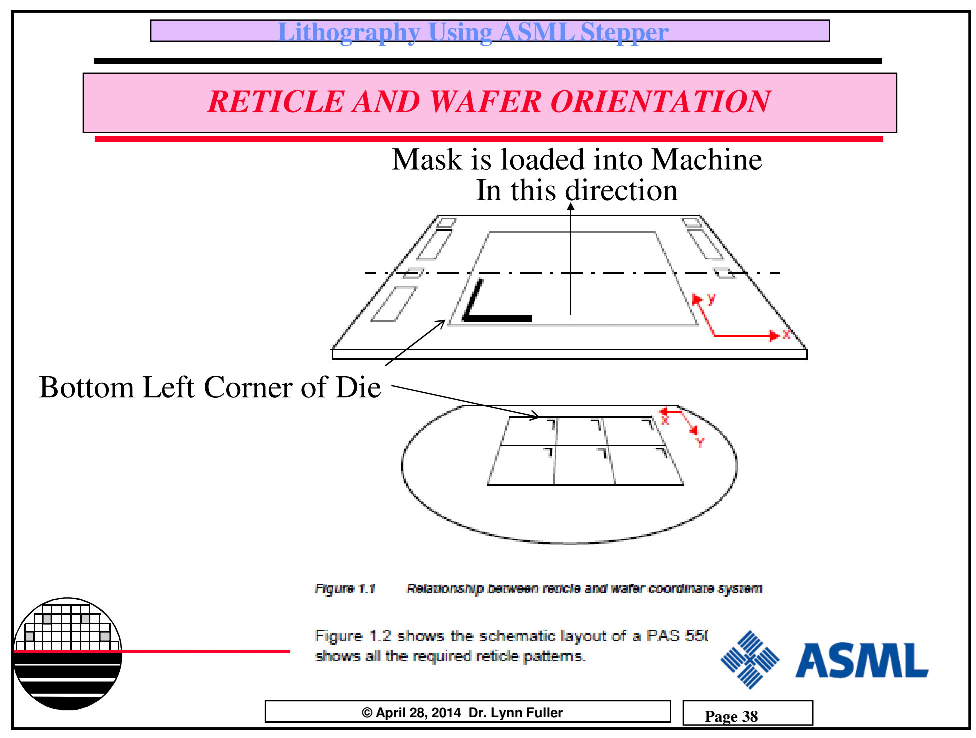
Page 37


Lithography Using ASML Stepper
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.
ASML
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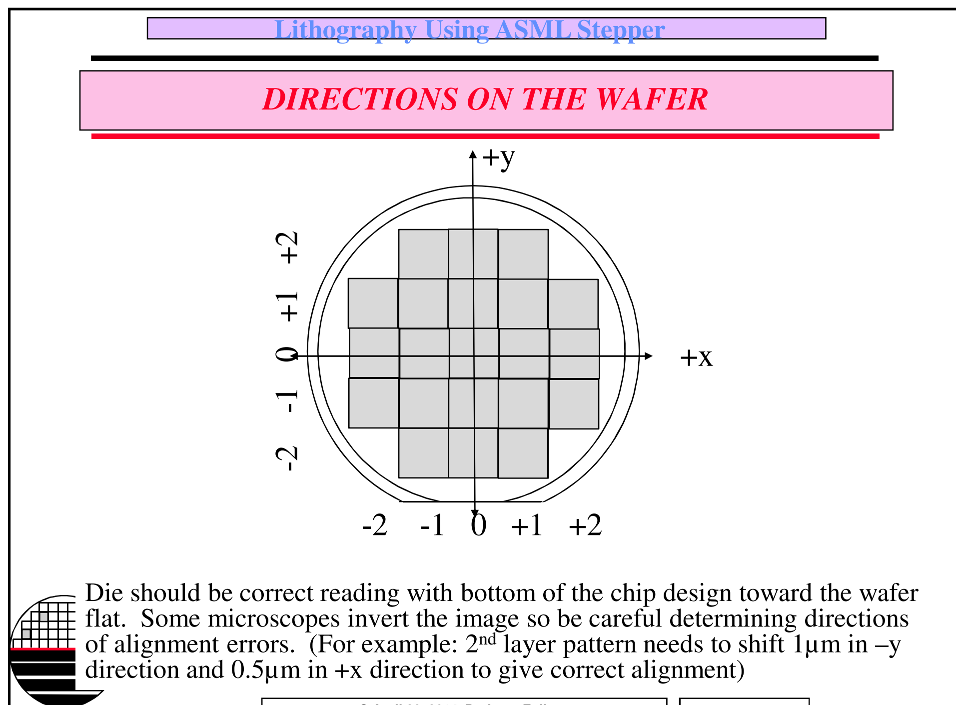
Page 38



Lithography Using ASML Stepper
DIRECTIONS ON THE WAFER
+y
+x
-2 -1 0 +1 +2
-2 -1 0 +1 +2
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: 2nd layer pattern needs to shift 1µm in –y direction and 0.5µm in +x direction to give correct alignment)
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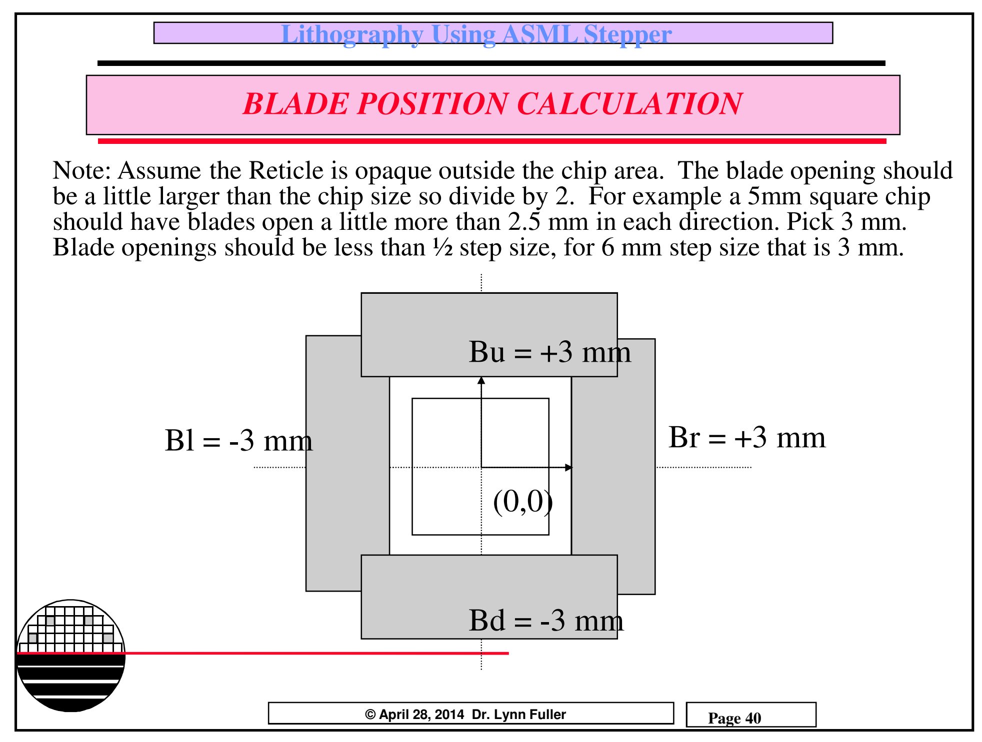
Page 39



Lithography Using ASML Stepper
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.
Bu = +3 mm
Bl = -3 mm
Br = +3 mm
(0,0)
Bd = -3 mm
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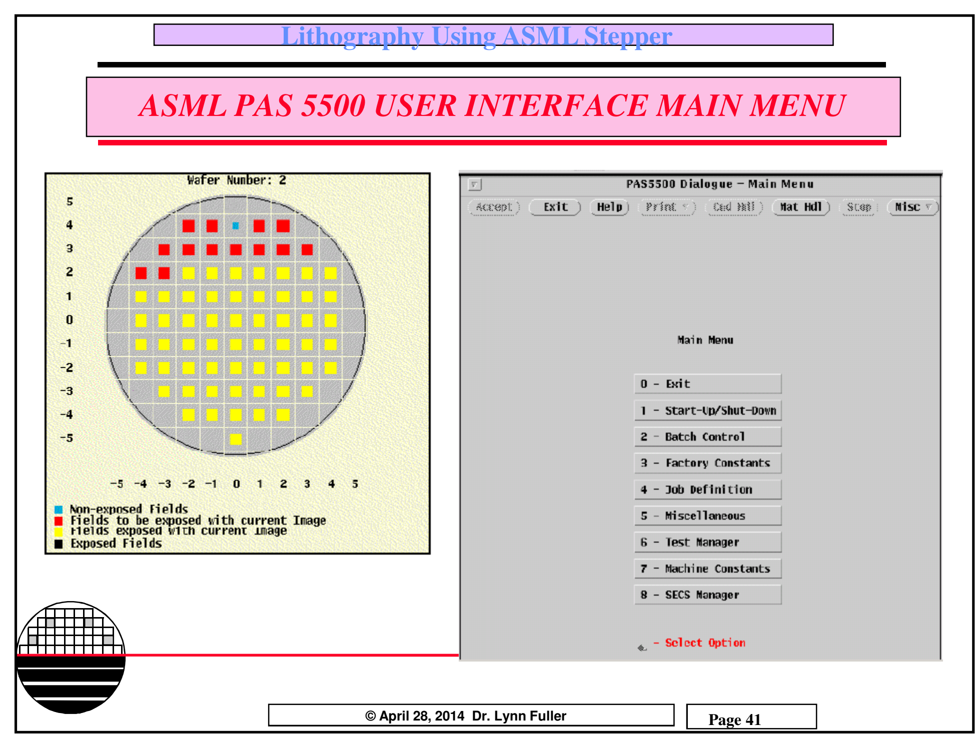
Page 40


Lithography Using ASML Stepper
ASML PAS 5500 USER INTERFACE MAIN MENU
Wafer Number: 2
Non-exposed Fields
Fields to be exposed with current Image
Fields exposed with current image
Exposed Fields
PAS5500 Dialogue – Main Menu
Accept
Exit
Help
Print
Cmd Hdl
Mat Hdl
Stop
Misc
Main Menu
0 – Exit
1 – Start-Up/Shut-Down
2 – Batch Control
3 – Factory Constants
4 – Job Definition
5 – Miscellaneous
6 – Test Manager
7 – Machine Constants
8 – SECS Manager
– Select Option
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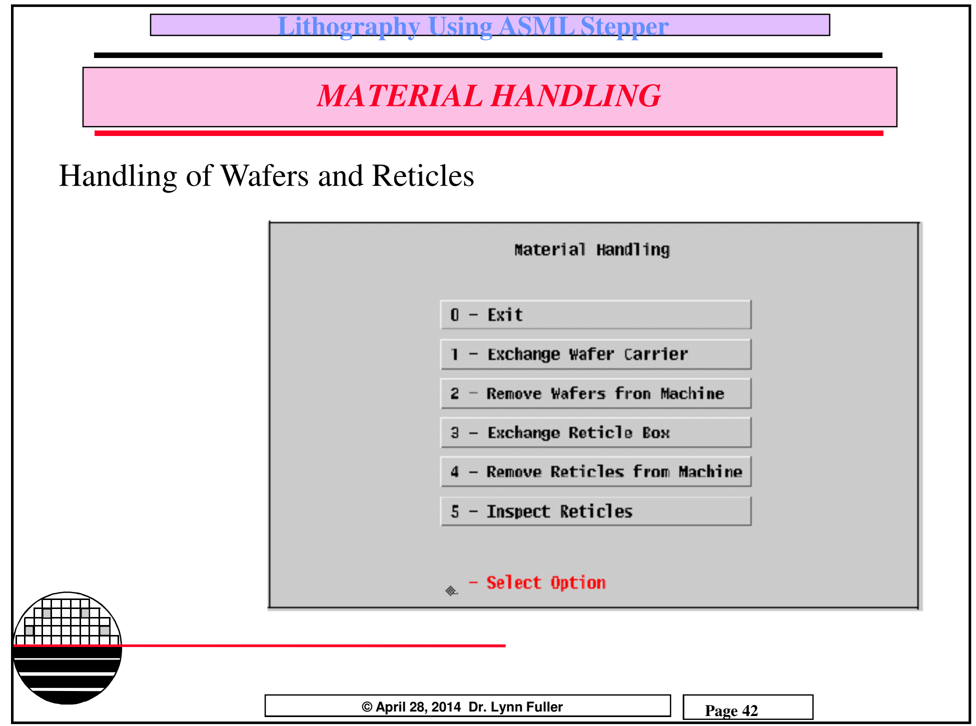
Page 41


Lithography Using ASML Stepper
MATERIAL HANDLING
Handling of Wafers and Reticles
Material Handling
0 – Exit
1 – Exchange Wafer Carrier
2 – Remove Wafers from Machine
3 – Exchange Reticle Box
4 – Remove Reticles from Machine
5 – Inspect Reticles
– Select Option
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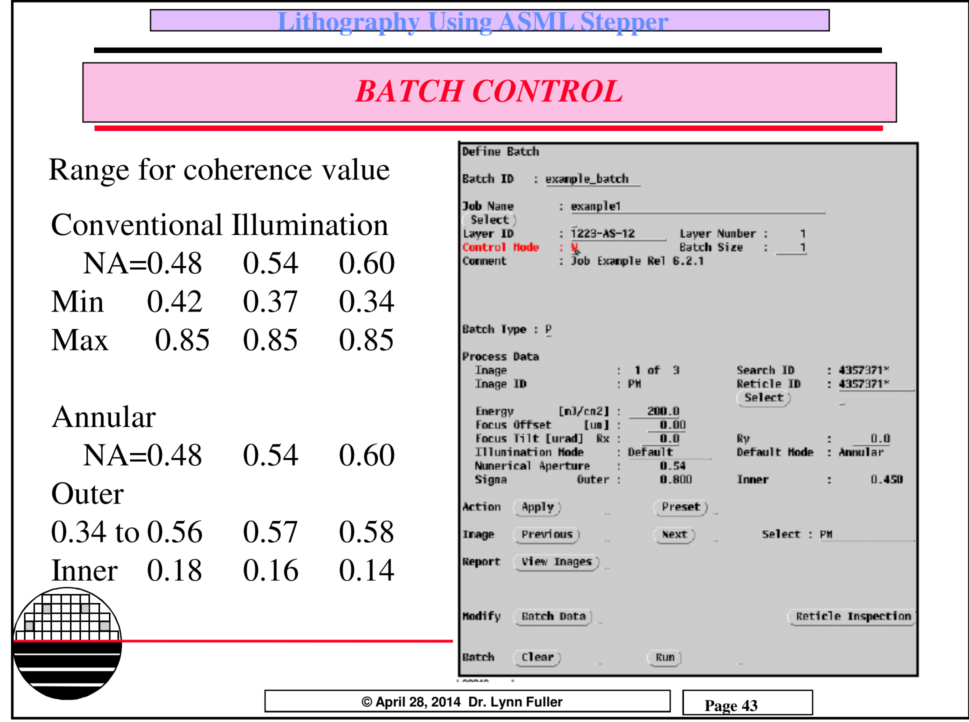
Page 42


Lithography Using ASML Stepper
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
Define Batch
Batch ID : example_batch
Job Name : example1
Select
Layer ID : 1223-AS-12
Layer Number : 1
Control Mode
Batch Size : 1
Comment : Job Example Rel 6.2.1
Batch Type : P
Process Data
Image : 1 of 3
Image ID : PM
Search ID
Reticle ID
Select
Energy [mJ/cm2] : 200.0
Focus Offset [um] : 0.00
Focus Tilt [urad] Rx : 0.0
Ry : 0.0
Illumination Mode : Default
Default Mode : Annular
Numerical Aperture : 0.54
Sigma Outer : 0.800
Inner : 0.450
Action Apply Preset
Image Previous Next
Select : PM
Report View Images
Modify Batch Data
Reticle Inspection
Batch Clear Run
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Page 43

Lithography Using ASML Stepper
SSI COAT AND DEVELOP TRACK FOR 6" WAFERS
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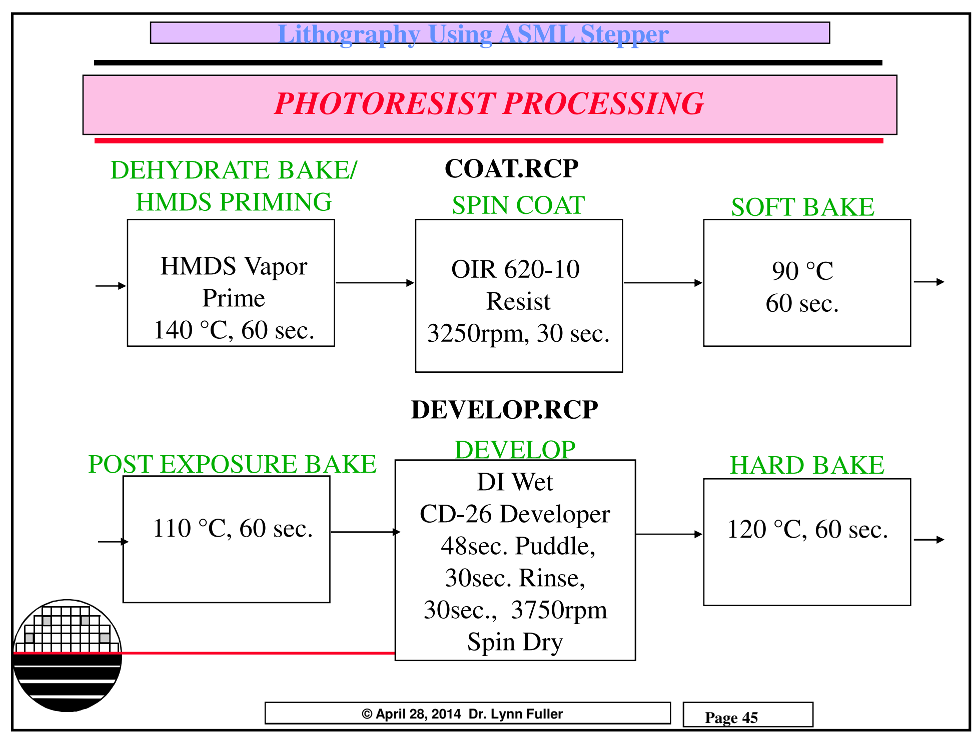
Page 44


Lithography Using ASML Stepper
PHOTORESIST PROCESSING
DEHYDRATE BAKE/
HMDS PRIMING
HMDS Vapor
Prime
140 °C, 60 sec.
COAT.RCP
SPIN COAT
OIR 620-10
Resist
3250rpm, 30 sec.
SOFT BAKE
90 °C
60 sec.
DEVELOP.RCP
POST EXPOSURE BAKE
110 °C, 60 sec.
DEVELOP
DI Wet
CD-26 Developer
48sec. Puddle,
30sec. Rinse,
30sec., 3750rpm
Spin Dry
HARD BAKE
120 °C, 60 sec.
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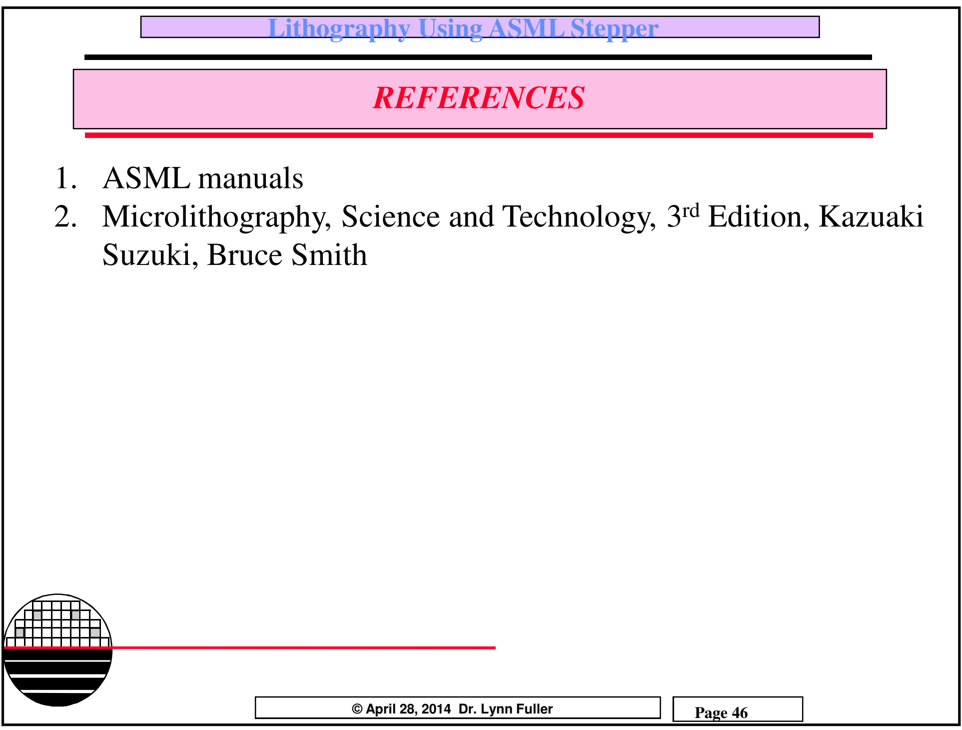
Page 45


Lithography Using ASML Stepper
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2. Microlithography, Science and Technology, 3rd Edition, Kazuaki Suzuki, Bruce Smith
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Page 46