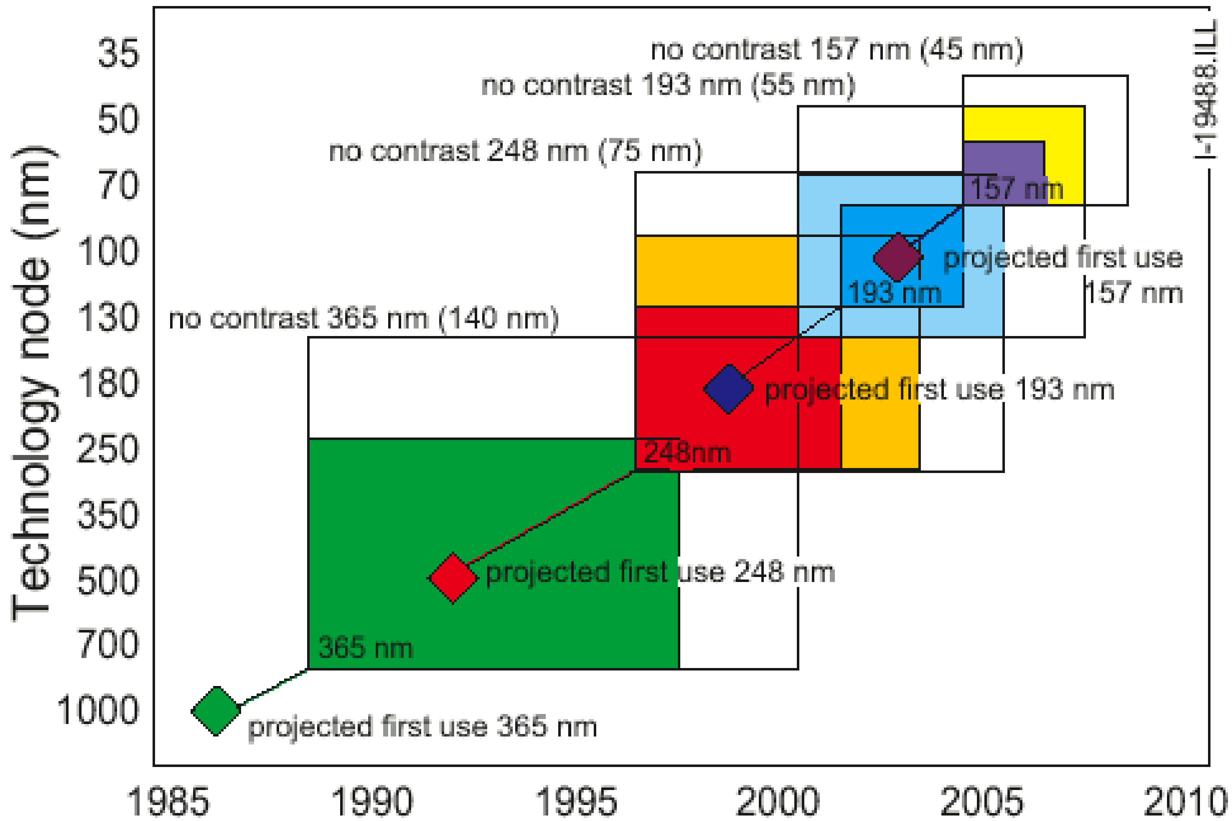
Exposure Tools

- 1. Exposure Tool types
- 2. Alignment systems
- 3. Focus/Leveling systems
- 4. Illumination and Projection Optics Designs
- 5. Wafer Stages

Exposure Tools

reference: **157 nm Technology: Where Are We Today?**

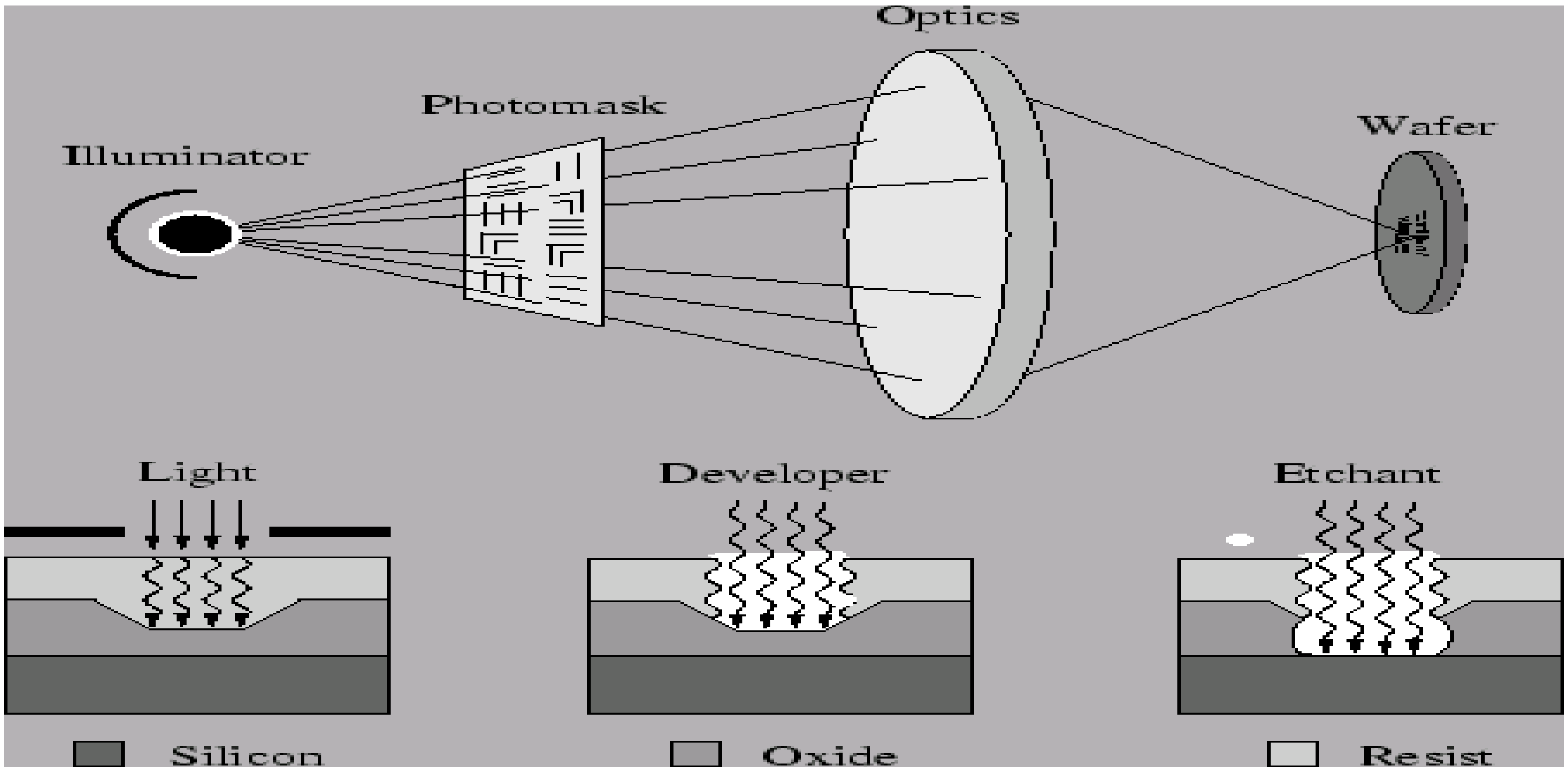
Jan Mulkens, Tom Fahey, James McClay, Judon Stoeldraijer, Patrick Wong, Martin Brunotte, Birgit Mecking



1, Exposure Tools : Microlithography Topics

http://www.iue.tuwien.ac.at/publications/PhD%20Theses/kirchauer/node17.html#fig::PRprosys

Figure 2.3: An optical lithography tool generally consists of an illuminator, a photomask, an optical system, and the photoresist spinned on top of the wafer. The lithography process is based on the ability of the photoresist to store a replica of the photomask that is used for subsequent processing steps, e.g., etching, deposition or implantation.

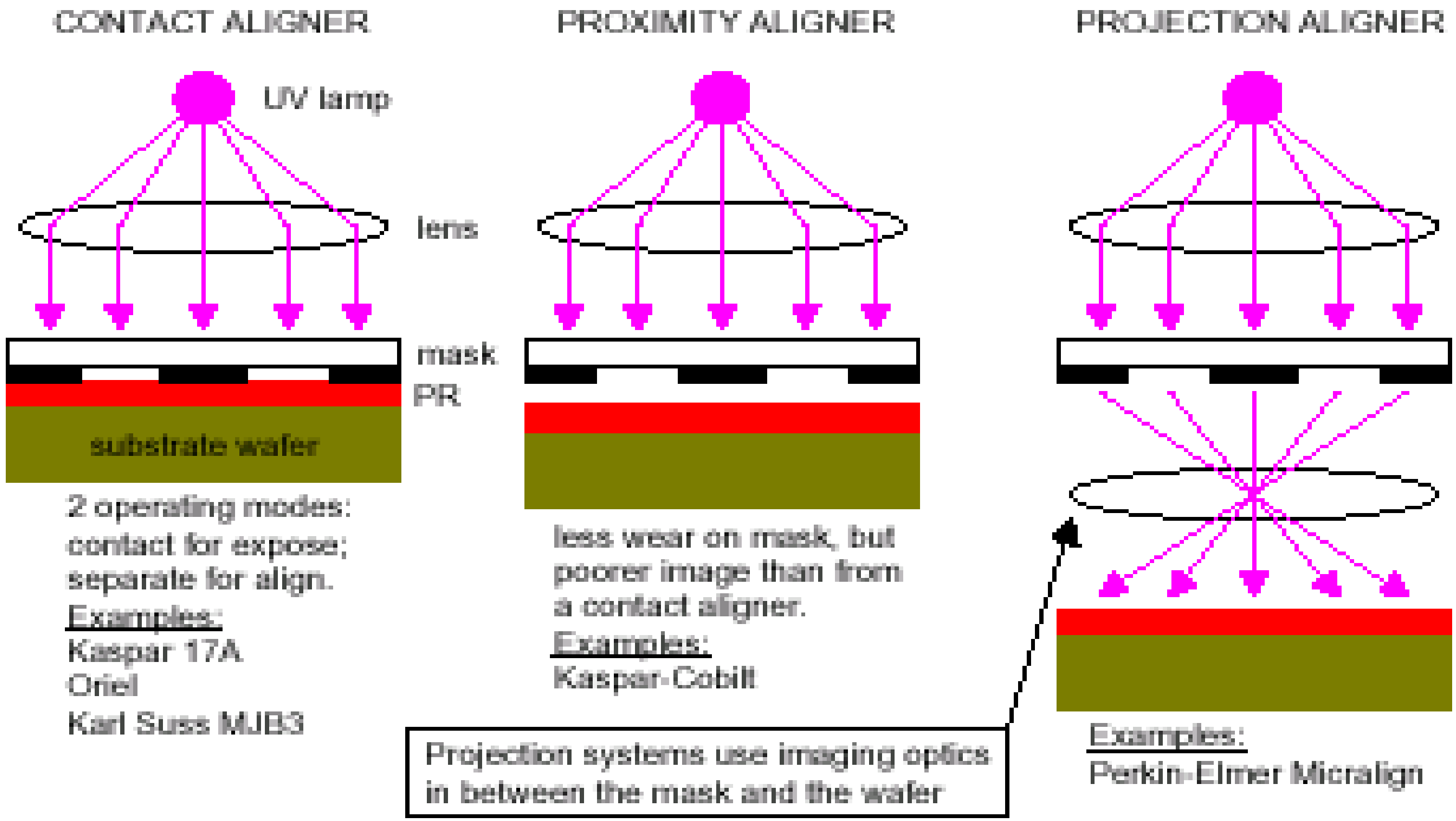


1. Exposure Tools : Contact/Proximity/Projection Printing History

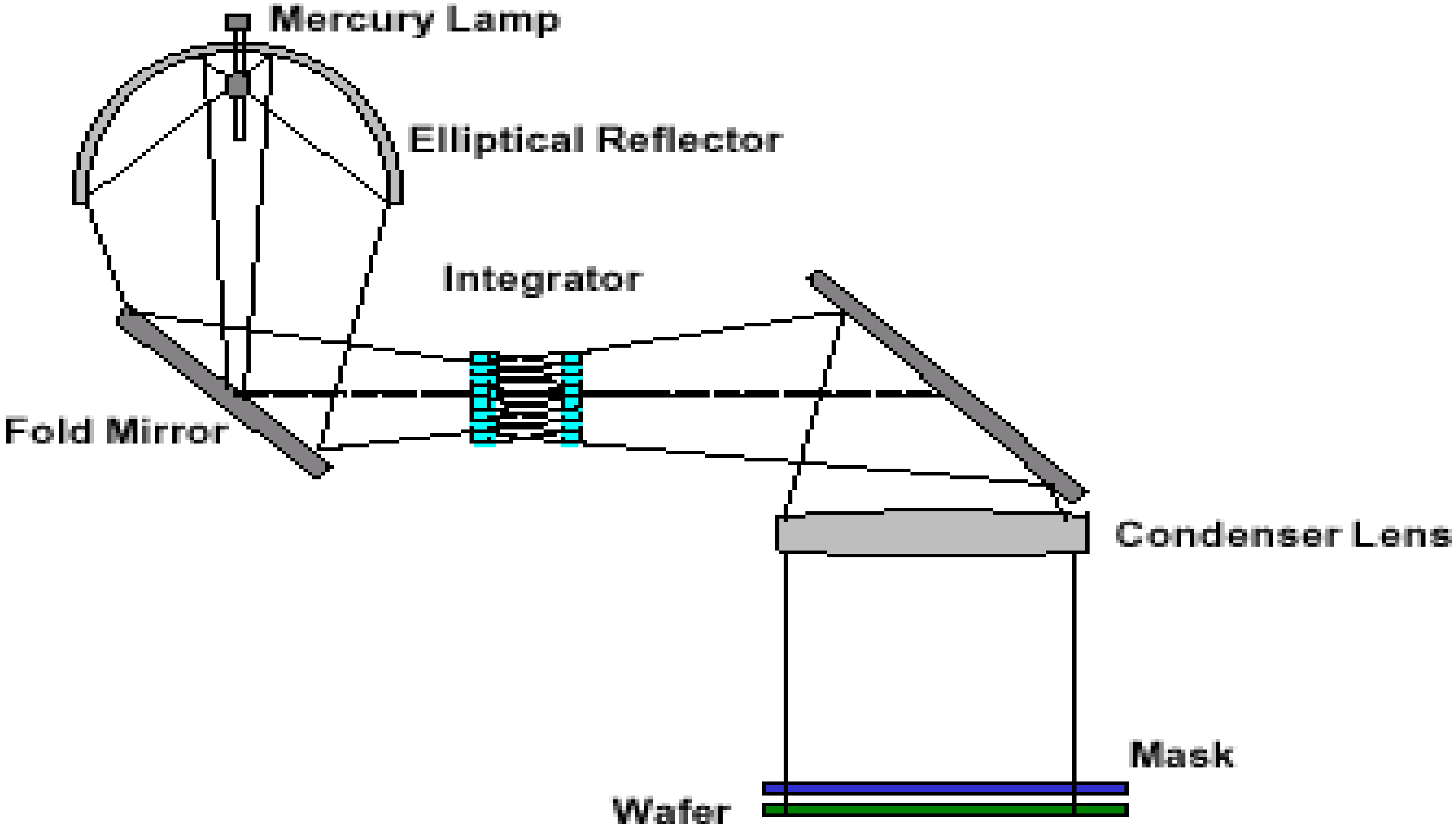
- 1x Full Wafer Contact/ Proximity Printing
- 1x Full Wafer Scan Projection Printing
- 10x Reduction Step-and-Repeat Projection Printing
- 1x Step-and-Repeat Projection Printing
- 5x Reduction Step-and-Repeat Projection Printing
- 4x Reduction Step-and-Scan Projection Printing

J. C. Langgston, G. T. Dao, Solid State Technol., p. 57 (March 1995)

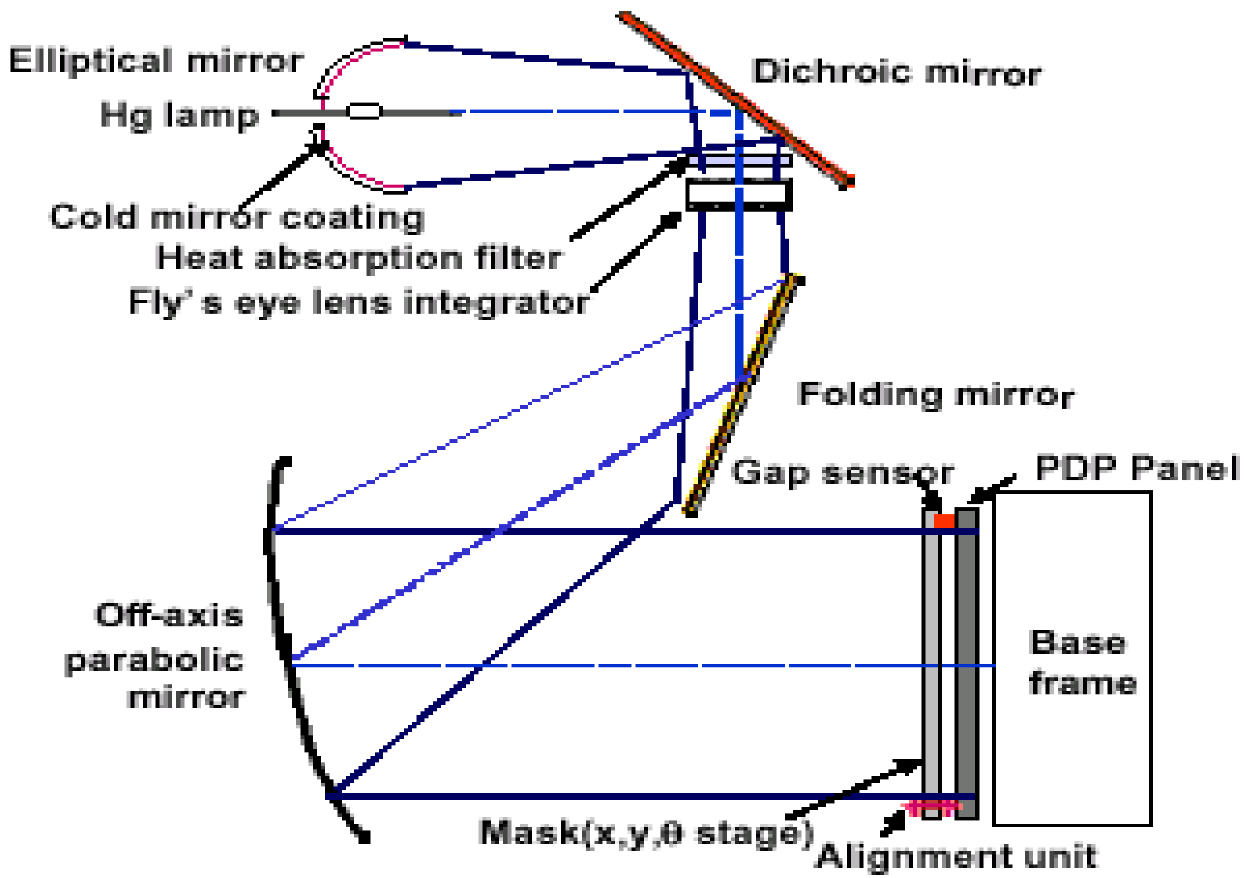
1. Exposure Tools : Contact/Proximity/Projection printing



1. Exposure Tools : Contact Printing Tool



1. Exposure Tools : Proximity Printing Tool

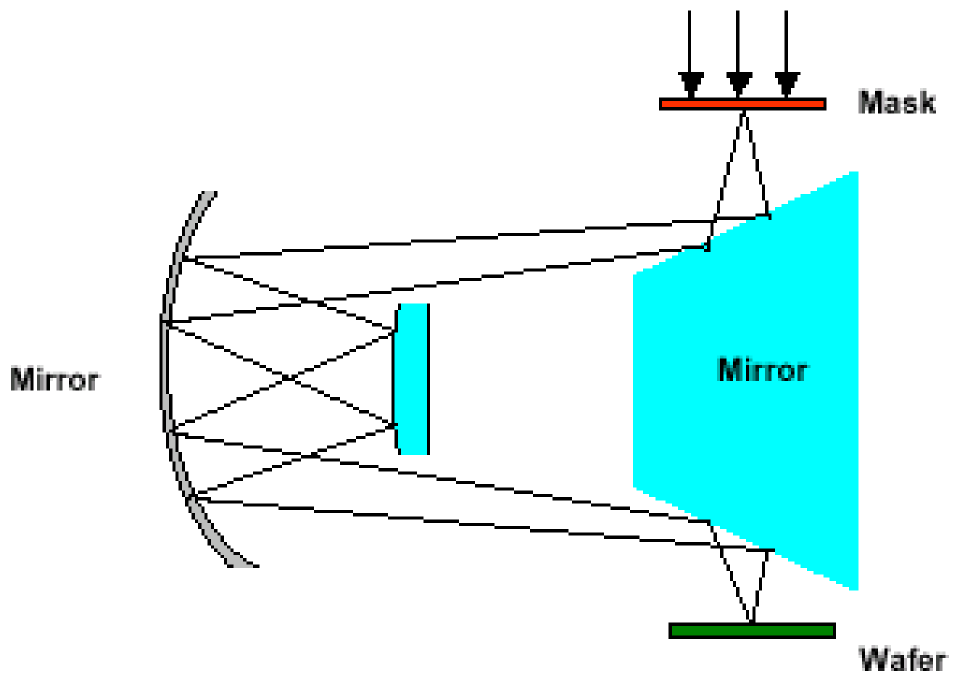


1. Exposure Tools : 1X Projection printing

- **The first projection printing systems were 1:1 systems introduced by Perkin-Elmer ≈ 20 years ago.**
- **These systems require full wafer 1X masks which become more difficult to manufacture as wafers get larger and device dimensions smaller.**
- **Today's steppers are almost all reducing machines - 2X to 5X.**
- **This makes the masks a lot easier to make and the optics are required to be "perfect" over a smaller area.**

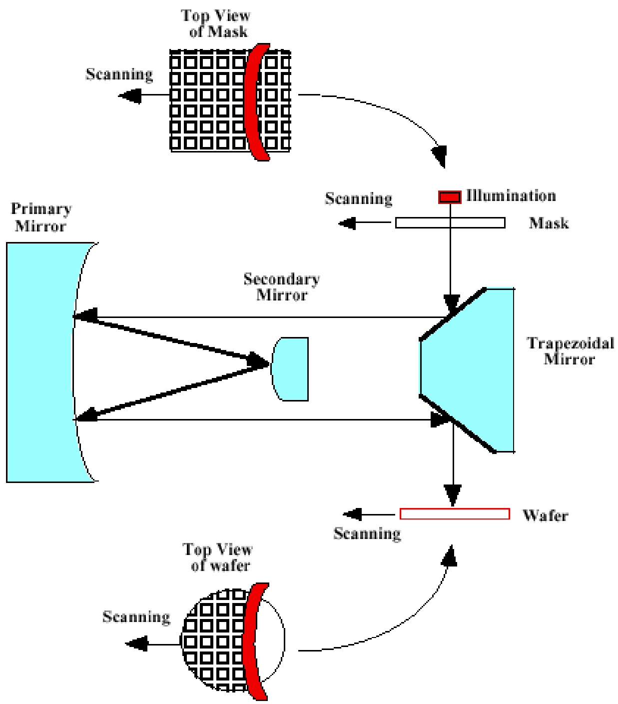
1. Exposure Tools :
1X Projection printing

- Perkin Elmer Abe Offner Design (1973) (top view) 1 X system



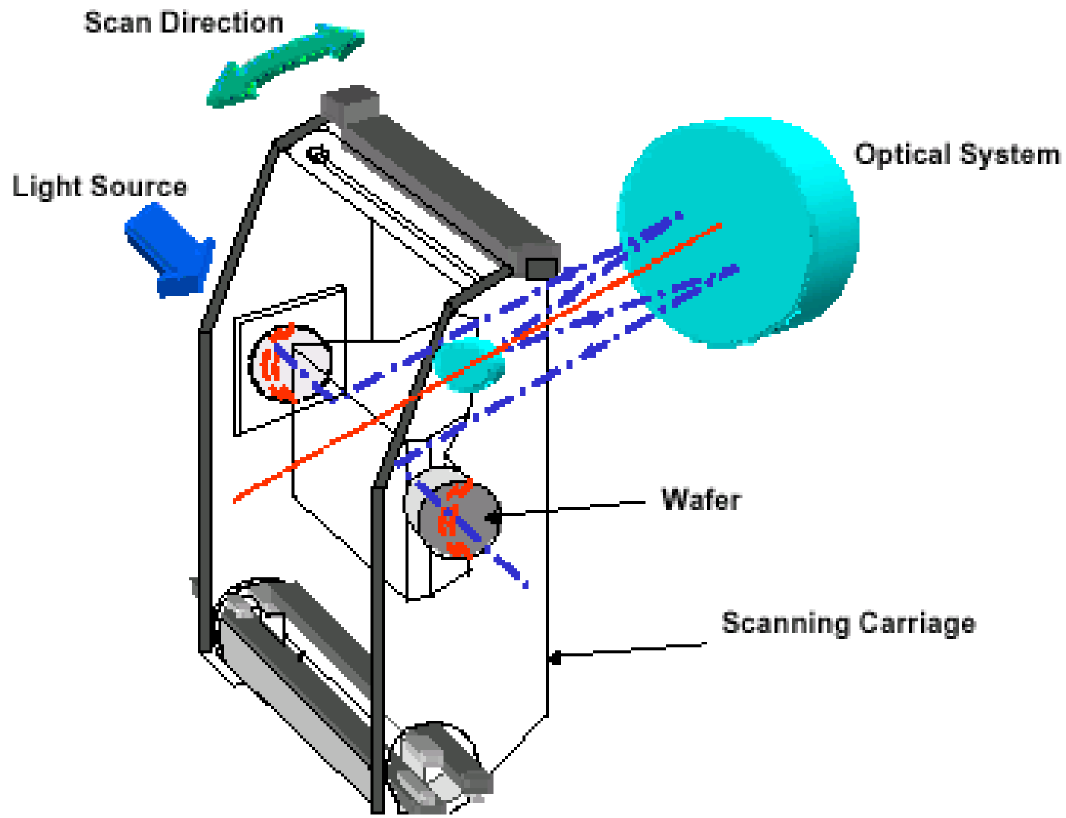
1. Exposure Tools :
1X Projection printing

- Perkin Elmer Micralign scanner Design (1975) (top view)



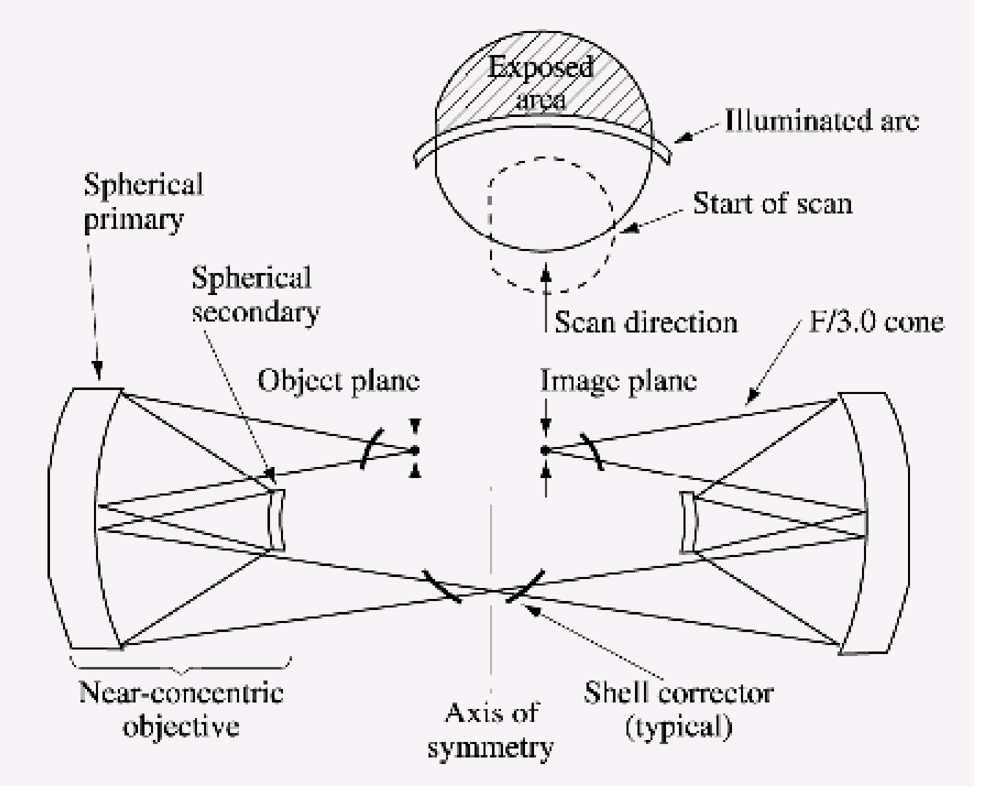
1. Exposure Tools : 1X Projection printing

- Perkin Elmer Micralign 1X scanning system



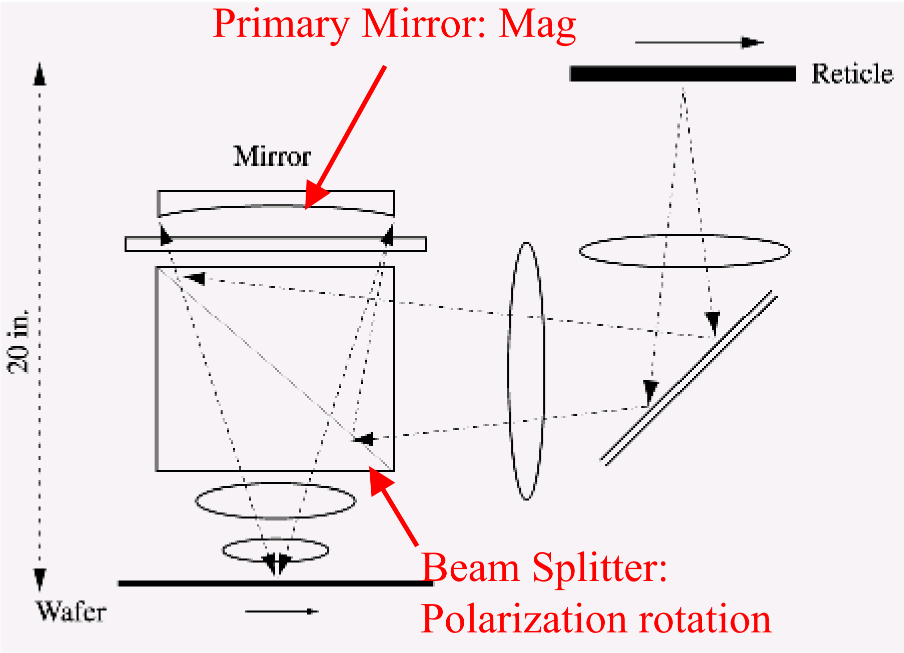
1. Exposure Tools : 1X Projection printing

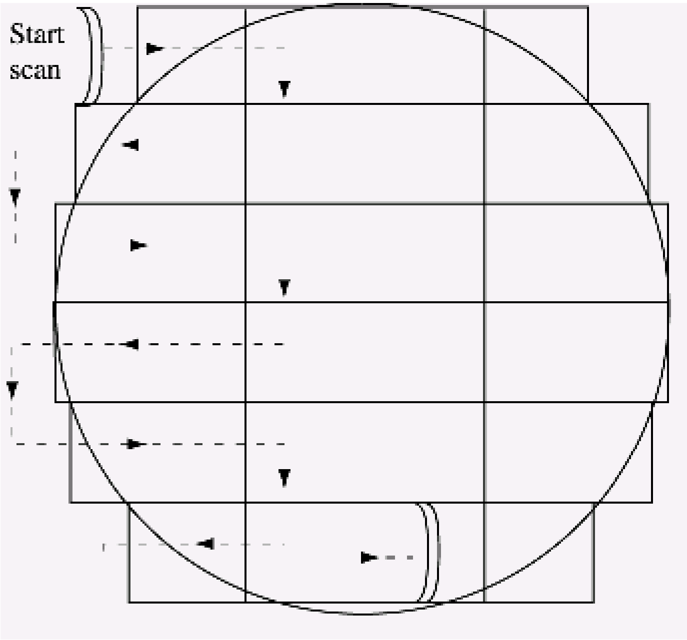
- Catoptric all Mirrors: Perkin Elmer Micralign 1X scanning system PE500



1. Exposure Tools : 1X Projection printing

- 1995 step and scan: SVGL scanner Micrascan: Catadioptric Projection optics (mirrors and lens)





1. Exposure Tools : 1X Projection printing

- ***1980: Ultratech 1X step and repeat system(Wynne-Dyson Optical design (Wynne 1959)***
- (R. Hershel modifications to catadioptric design: achromat and fine tuning 1981)
- **Optical design setup to “cancel” Aberrations!! (symmetrical!**
- **Broadband illumination called gh line**

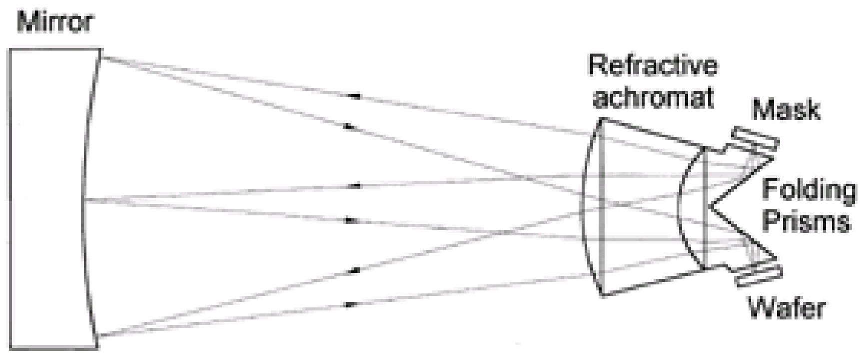


Figure 4. Catadioptric projection lens used for step-and-repeat. This low-aberration system allows for a much broader band of wavelengths, is simple in design with very few elements, and is symmetrical.

1. Exposure Tools

Projection printing: Example 2: Typical stepper GCA 1979

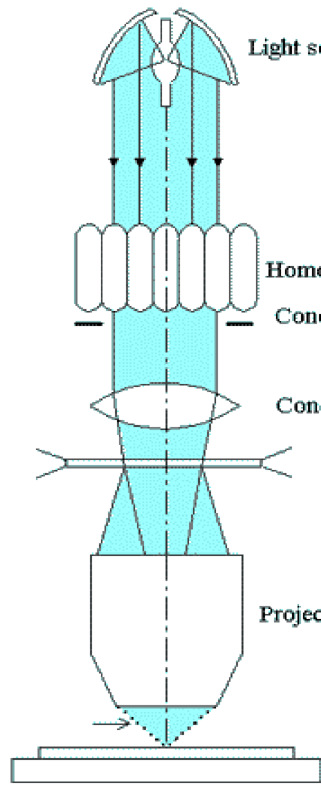
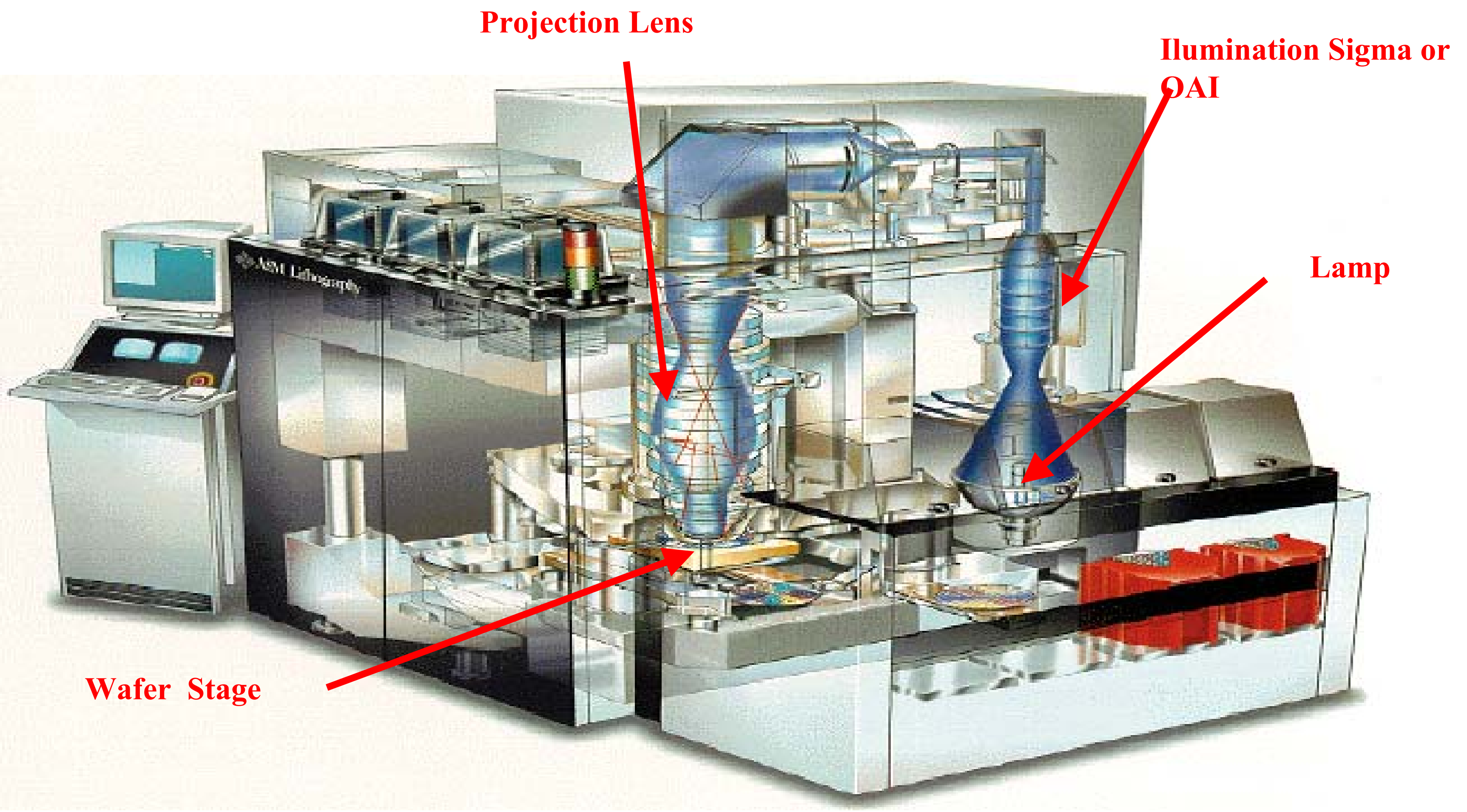


Figure 1. Essential elements of a photolithographic "stepper" used for exposing semiconductor wafers. The condenser stop controls the degree of coherence of the illumination. The numerical aperture NA_o of the projection lens is defined as $\sin \theta$, where θ is the half-angle of the cone subtended by the clear aperture of the projection lens at the wafer. The uniformly illuminated mask is imaged onto the wafer with a magnification M that is typically around 1/5. (Adopted from [1].)

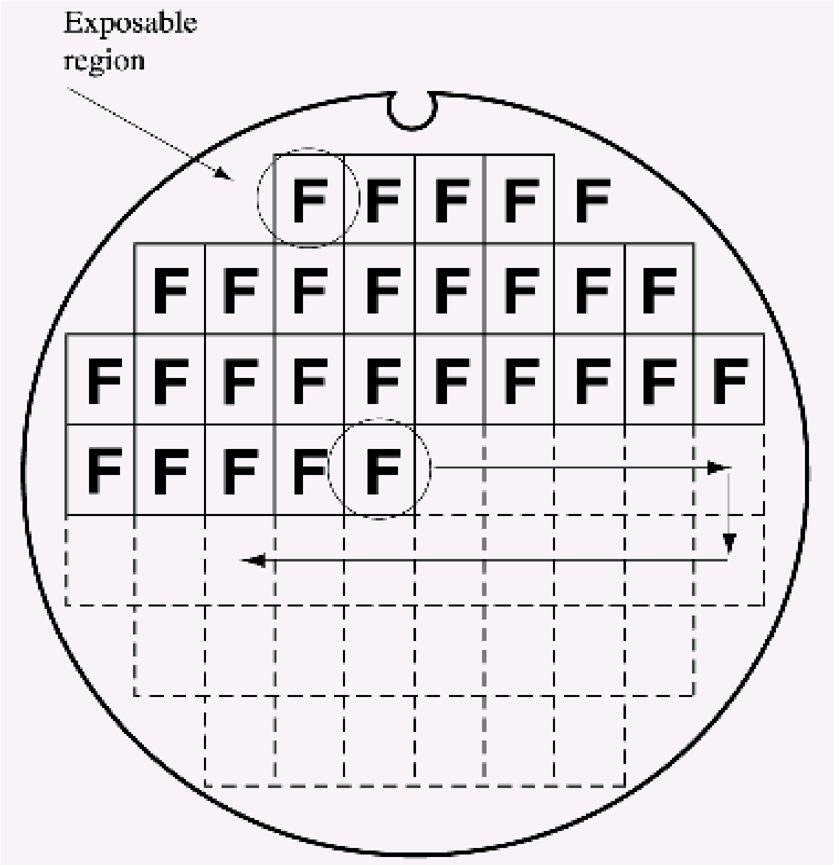
1. Exposure Tools
Projection printing: ASML 5500/XXX stepper: I-line



1. Exposure Tools
Projection printing: Typical stepper

Step and repeat camera: Typically a reduction tool: i.e. mag <1.0X

- 10:1 system Mag = 0.10
- 5:1 system Mag = 0.20
- 4:1 system Mag = 0.25

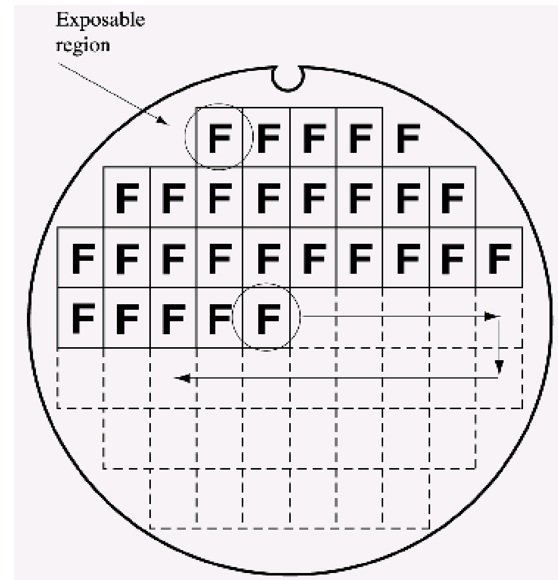


Projection printing: Typical stepper Wafer Stages: The stepping pattern

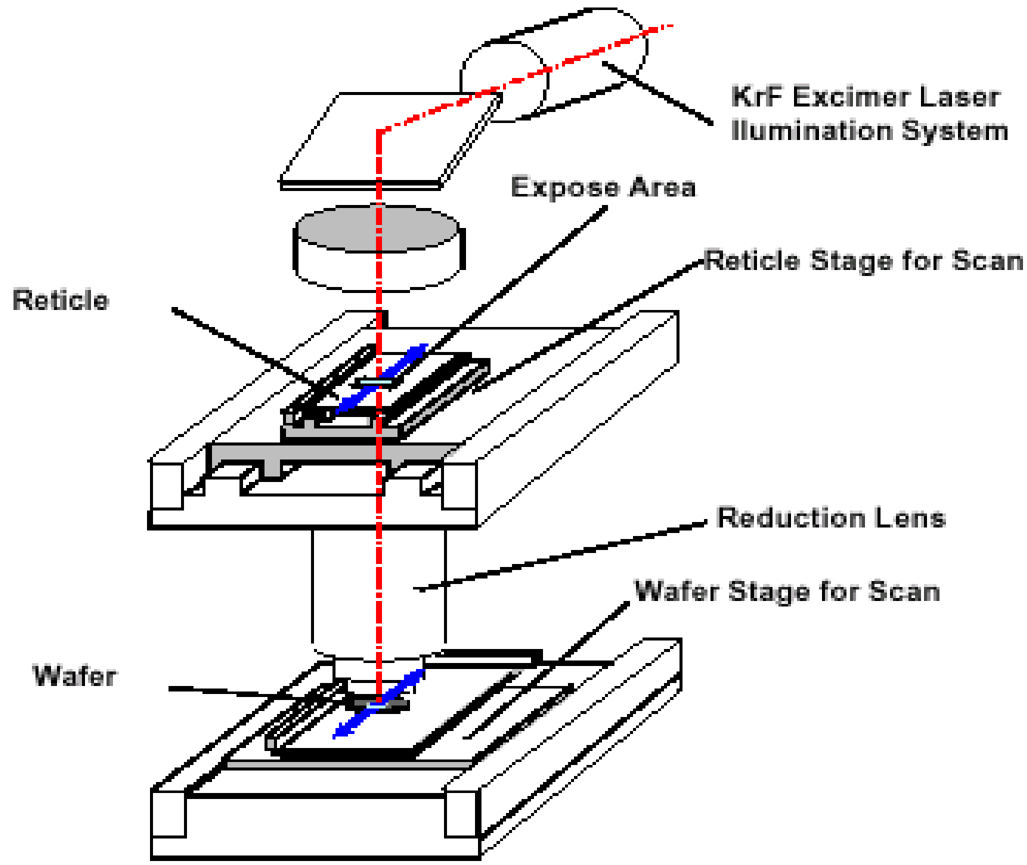
Basic Step pattern: **BOUSTROPHEDONIC**

Of or relating to text written from left to right and right to left in alternate lines.

Mainly of interest to paleographers, this is a form of writing which occurs principally in very ancient or rare texts. Examples are the rongo-rongo script of Easter Island, some of those in the Etruscan language, a few early Latin inscriptions and some ancient Greek texts created in a transitional period at about 500BC before which writing ran from right to left but afterwards from left to right. The word is itself from the Greek meaning "as the ox ploughs". It is sometimes used by computer specialists for a form of optimization in typesetting software or printer drivers.

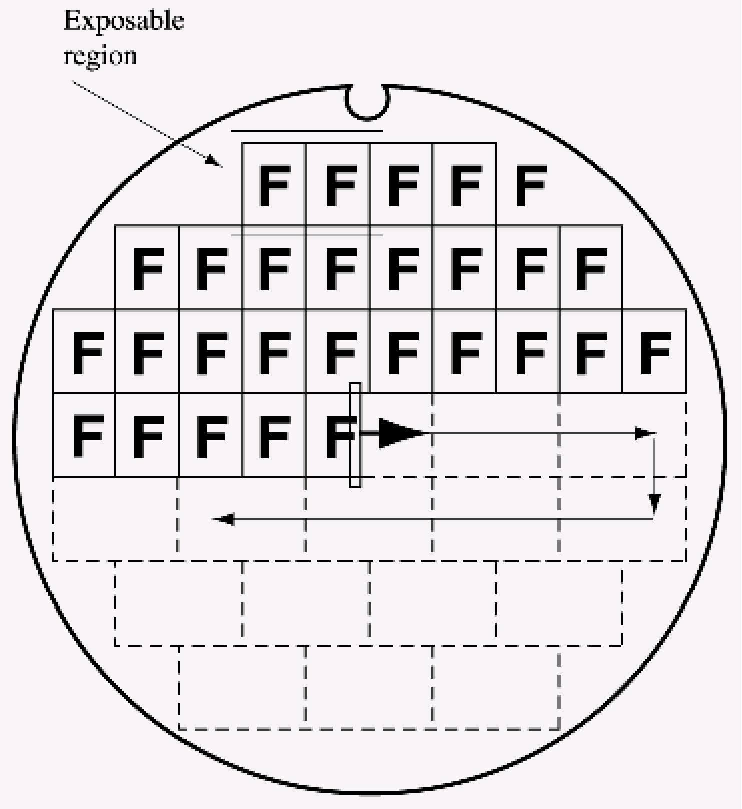


1. Exposure Tools
Projection scanning printing: reticle and wafer move through slit of light Nikon scanner



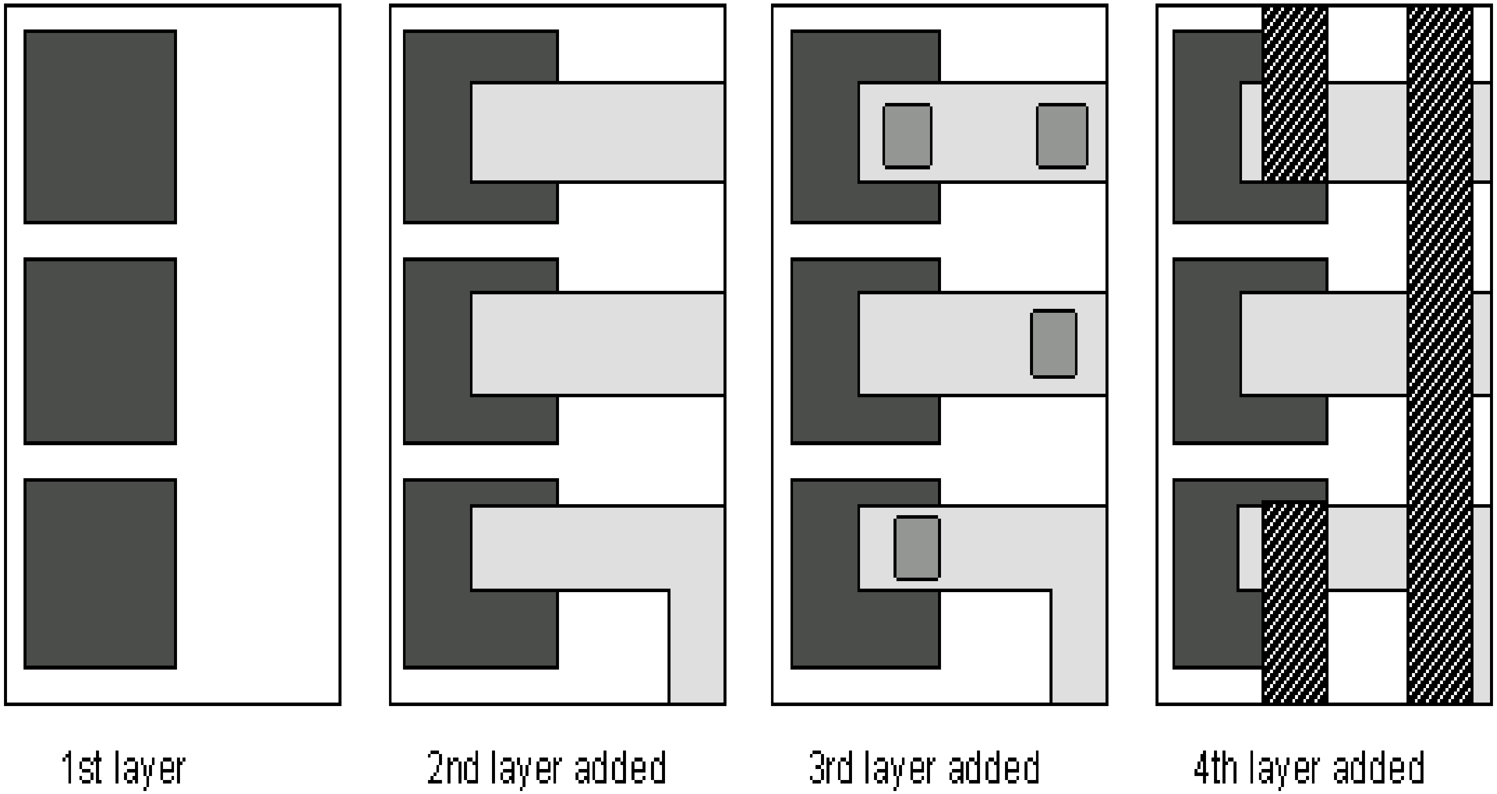
1. Exposure Tools
Projection printing: Step and Scan

- Step and scan camera: Typically a reduction tool: i.e. mag <1.0X .
- During exposure: Reticle moves through slit of light while wafer moves
- Speed of wafer movement is X times slower than reticle
- Ratio Wafer stage speed /Reticle stage speed = X mag
- More uniform CDs and registration



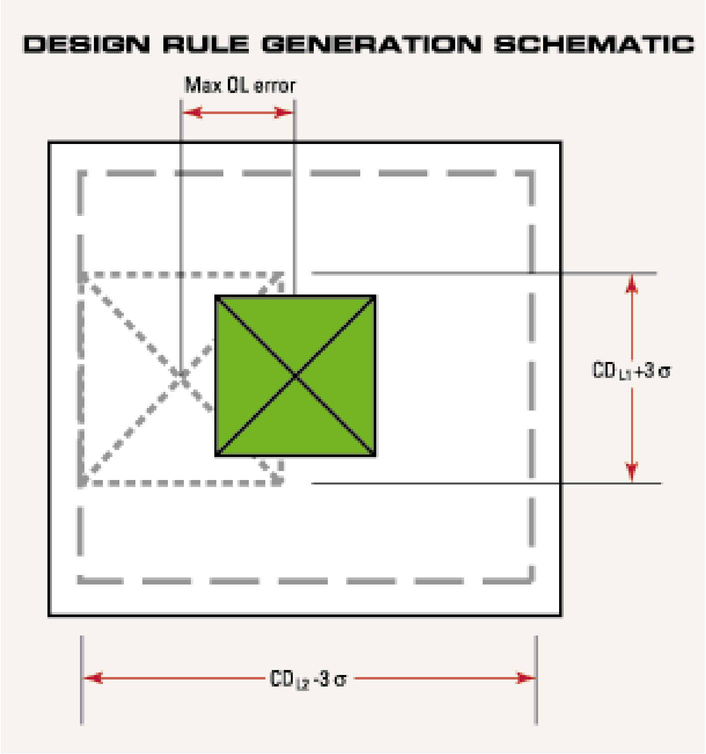
2. Alignment Systems

Registration = Result of Alignment



2. Alignment Systems

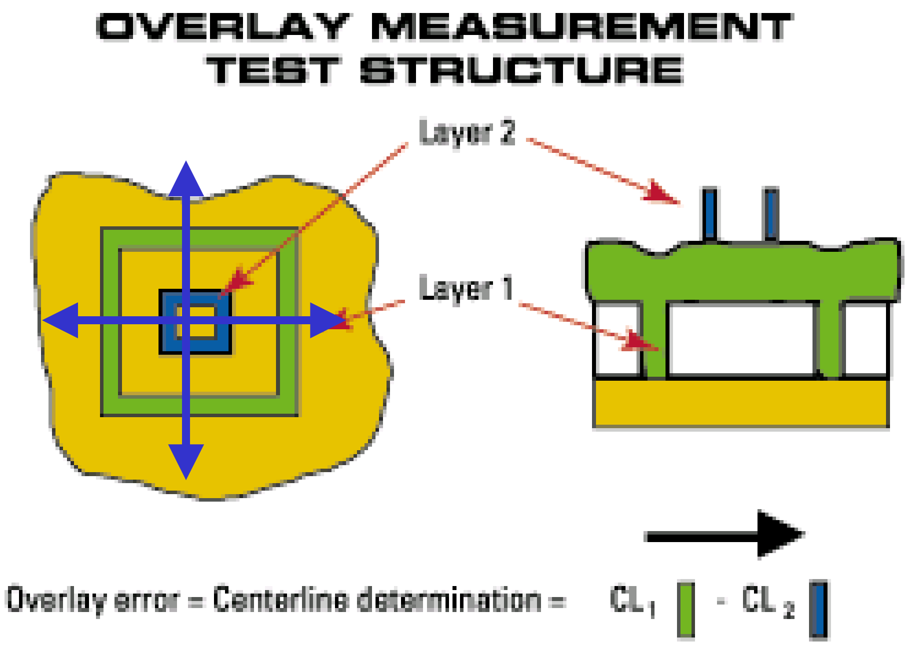
- *Alignment:* Optical mechanical system that locates a reference feature and positions the wafer for the "correct location exposure".
- *Registration:* Measurement of how well alignment performed.
- *Overlay* is the edge to edge placement of two patterns which is a function of registration and CDs



1. The maximum allowable overlay shift shown as the center-to-center distance.

2. Alignment Systems

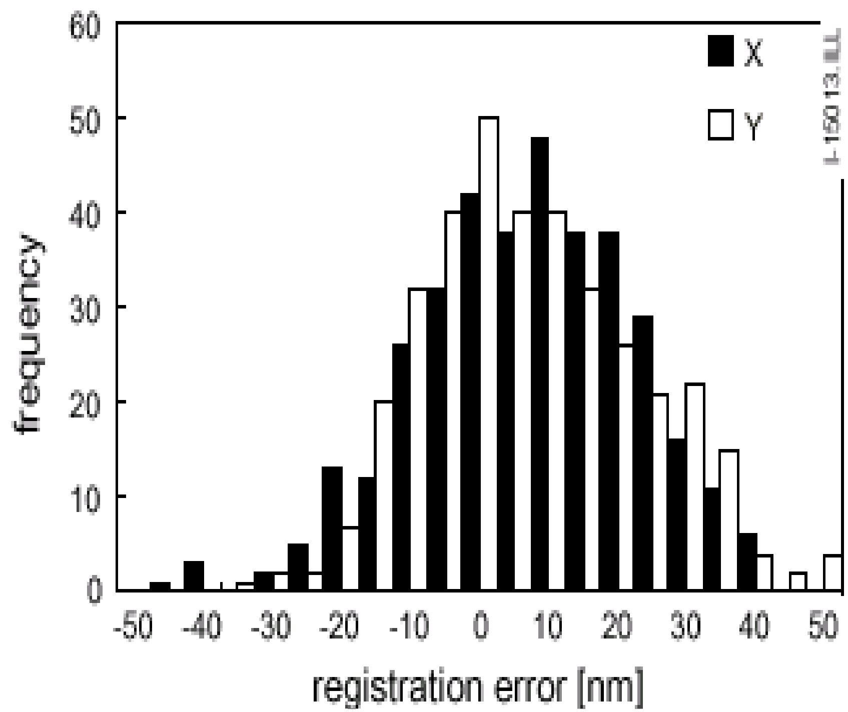
- Registration Measurements:
- Require special test structures to measure registration errors in X,Y displacements.
- Remember the goal is 0.0 nm error!!



2. A box-in-box test structure is commonly used to measure overlay error.

2. Alignment Systems

Registration Error is presented as a distribution.
The Goal is 0.0 error

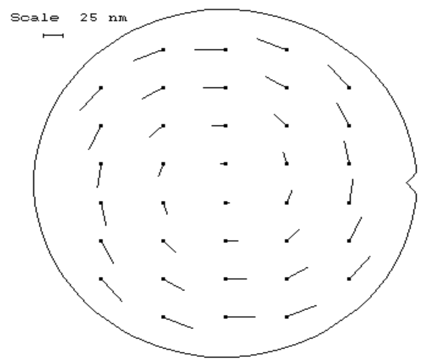


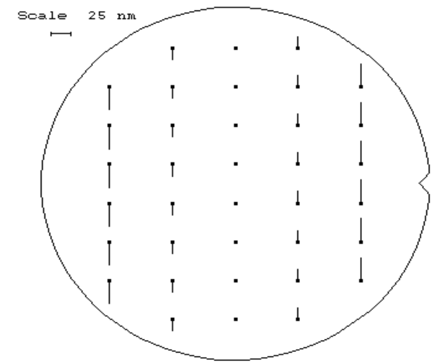
Registration error terms (these are all Grid Terms)

Translation X [3σ, nm]	Translation Y [3σ, nm]	Wafer scaling X [3σ, ppm]	Wafer scaling Y [3σ, ppm]	Wafer rotation [3σ, urad]	Non-ortho [3σ, urad]	Mean + 3σ X [nm]	Mean + 3σ Y [nm]
15	15	0.159	0.15	0.099	0.15	48	48

2. Alignment Systems
Registration Error Terms: Grid: Wafer Terms

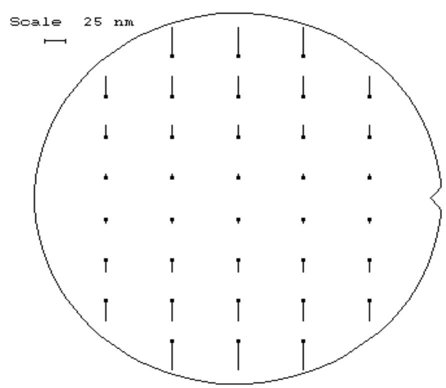
Grid Rotation

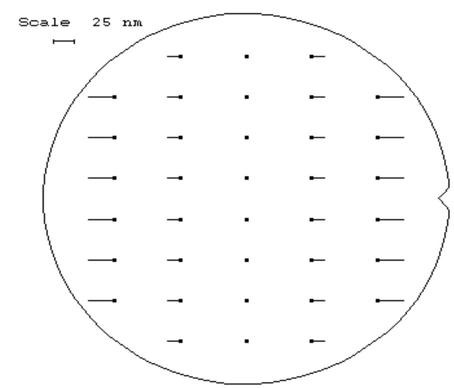




Grid Skew

Grid Y Mag



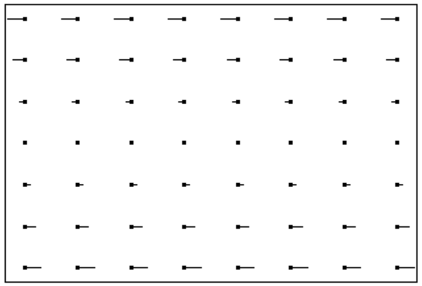


Grid X Mag

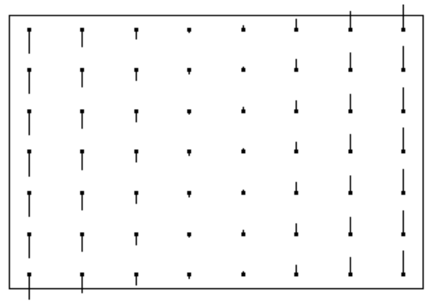
0.50 PPM scale

2. Alignment Systems

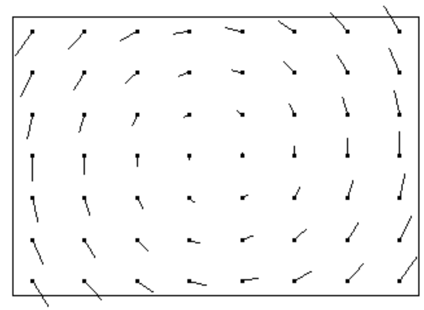
Registration Error Terms: Field: IFD Terms



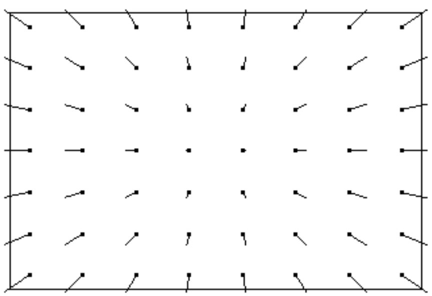
System Skew



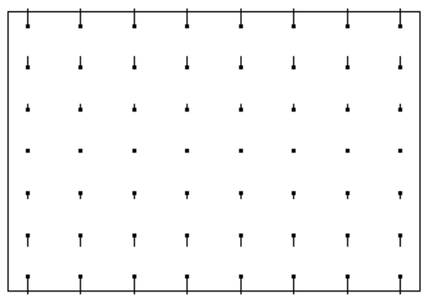
Field Skew



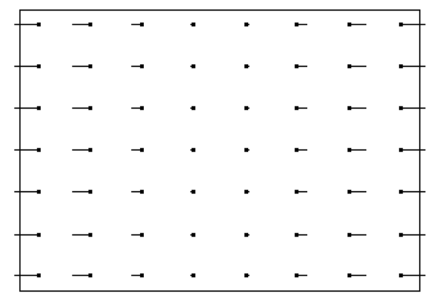
Field Rotation



Field IsoMag



Field Y (optical) Mag

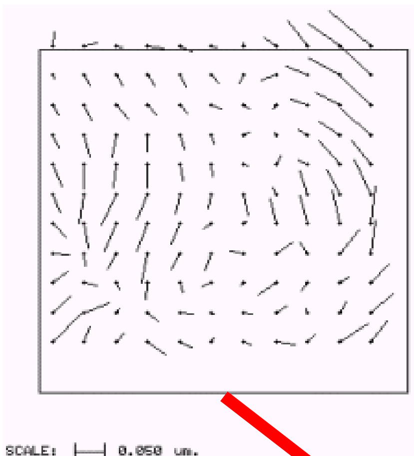


Field X (scan) Mag

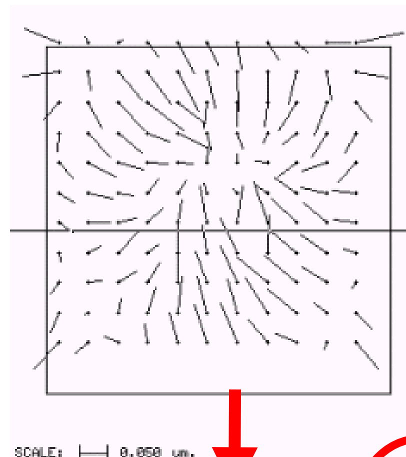
2 PPM scale

Registration Error Terms: Field: Lens Matching

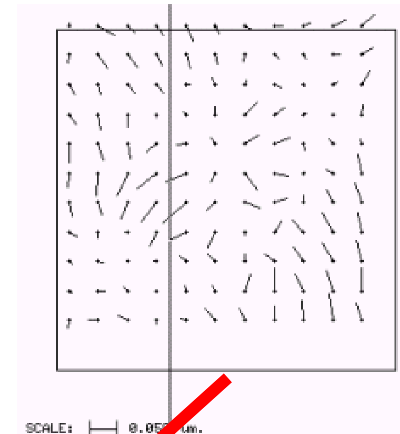
Stepper A

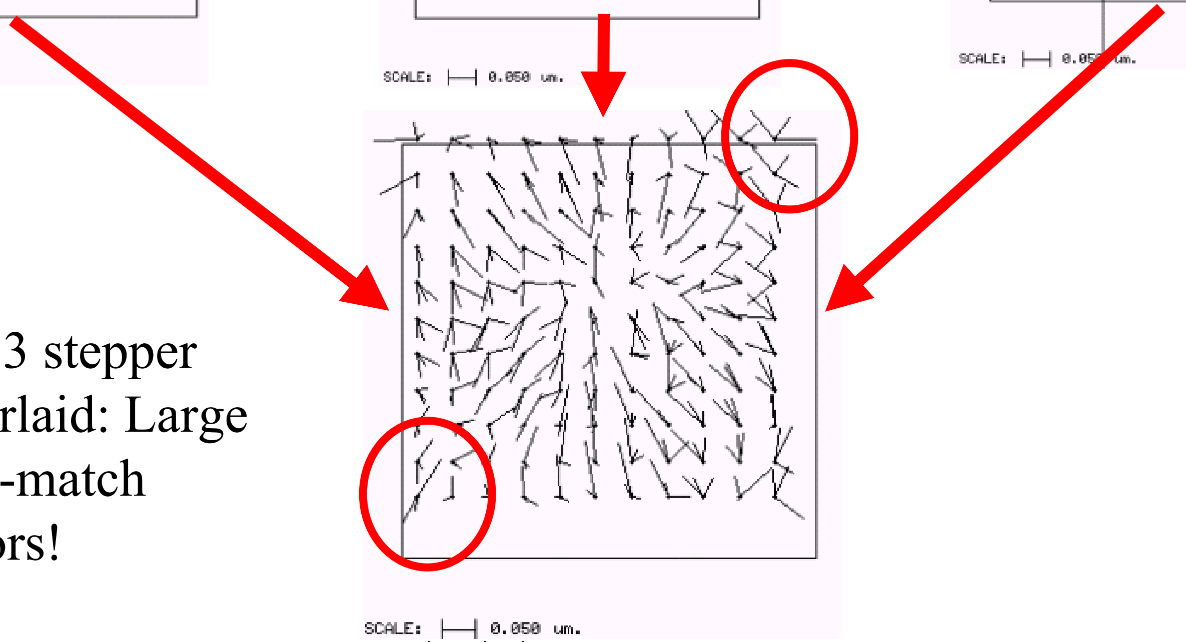


Stepper B



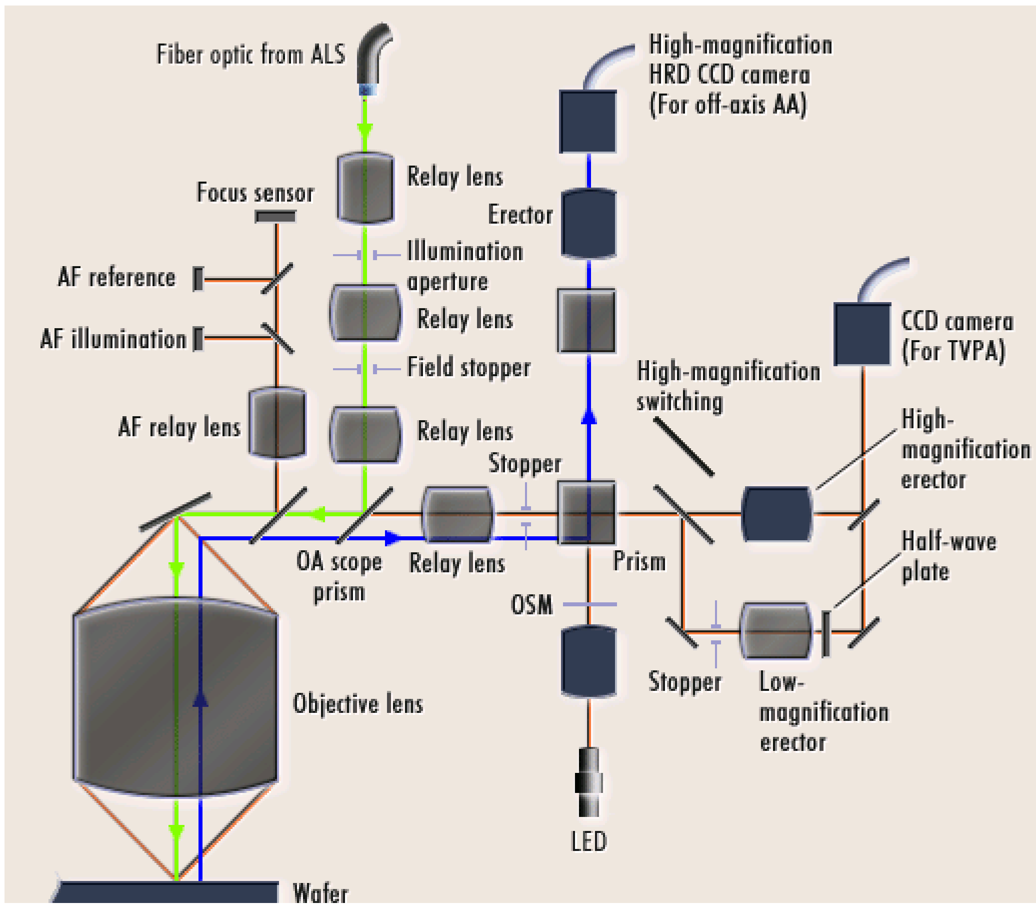
Stepper C





All 3 stepper overlaid: Large mis-match errors!

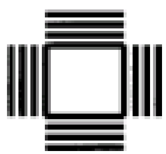
2. Alignment Systems
Canon ES-3 Off Axis Alignment OAS-AGA

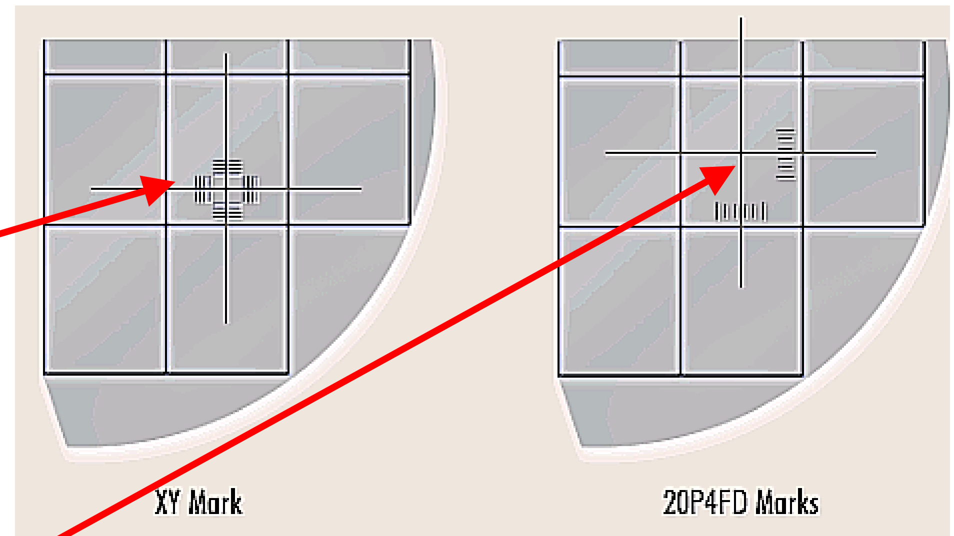


2. Alignment Systems
Canon ES-3 Off Axis Alignment OAS-AGA

Alignment system locates marker and finds center of gravity for each axis. Wafer alignment markers located in wafer scribelines 2 types

XY8: 80 x 80u

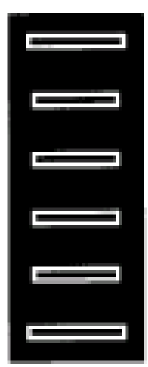




20P-4FD

100 x 120 u

Need an X and Y marker



2. Alignment Systems
Canon ES-3 4X Scanner Wafer Alignment System Description

There are 5 bright field alignment illumination Modes on a Canon ES-3 UV Scanner:

1 [B-B/W] broadband 590+/- 60nm

2 HeNe/ Normal 632.8 nm

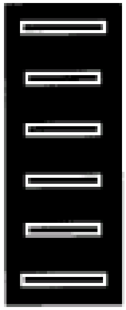
3 HeNe/ High 632.8 nm high coherence

4 [B-B/S] broadband narrow 560 +/- 35nm

5 [B-B/W] High broadband high coherence 590+/- 60nm (Only on ES-3)

There are different align marker illuminations designed to improve marker signal to noise ratio for various wafer thin films.

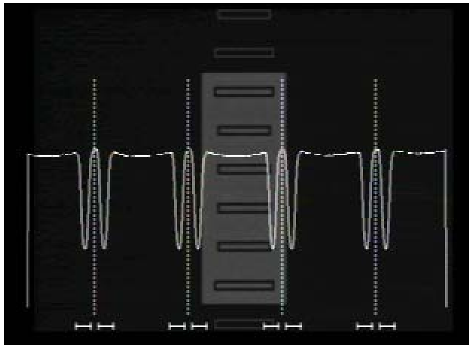
2. Alignment Systems
Canon ES-3 Off Axis Alignment OAS-AGA



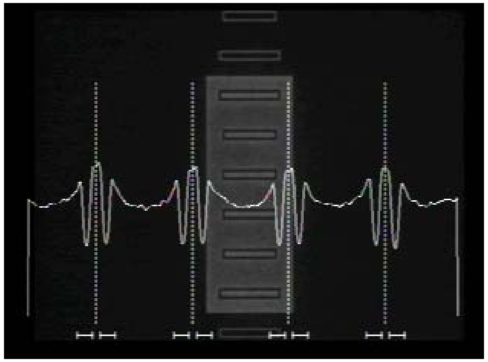
Alignment signals for various alignment illuminations

20P-4FD

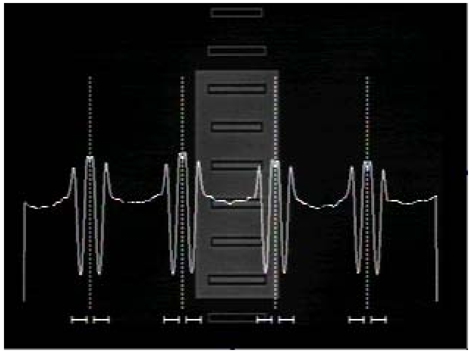
Align Marker



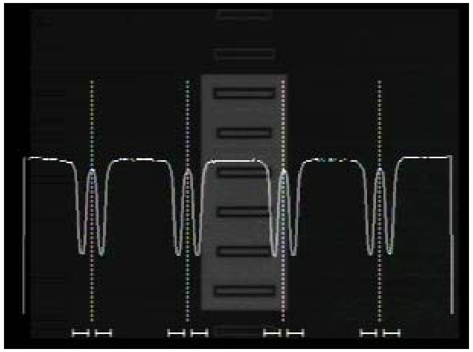
Mode 1



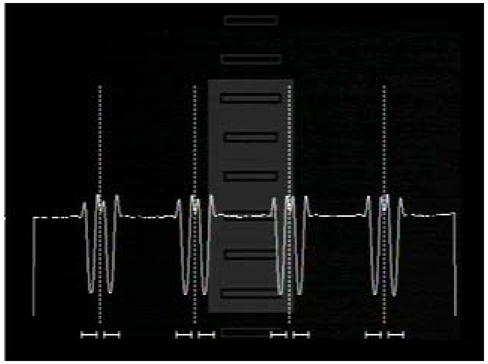
Mode 2



Mode 3



Mode 4

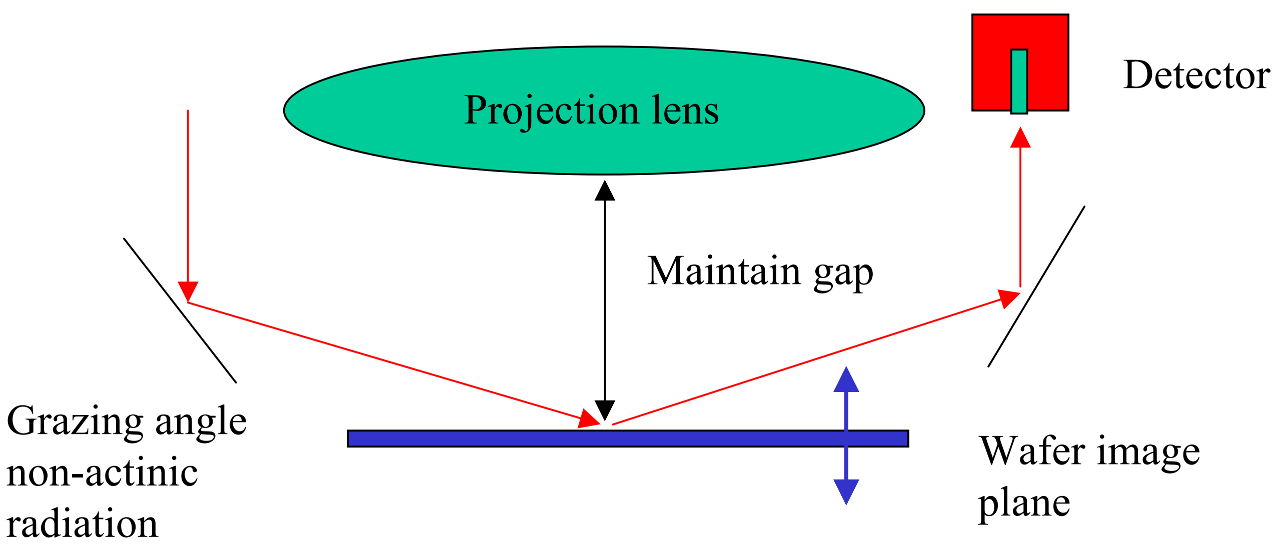


Mode 5

3. Focus and leveling control

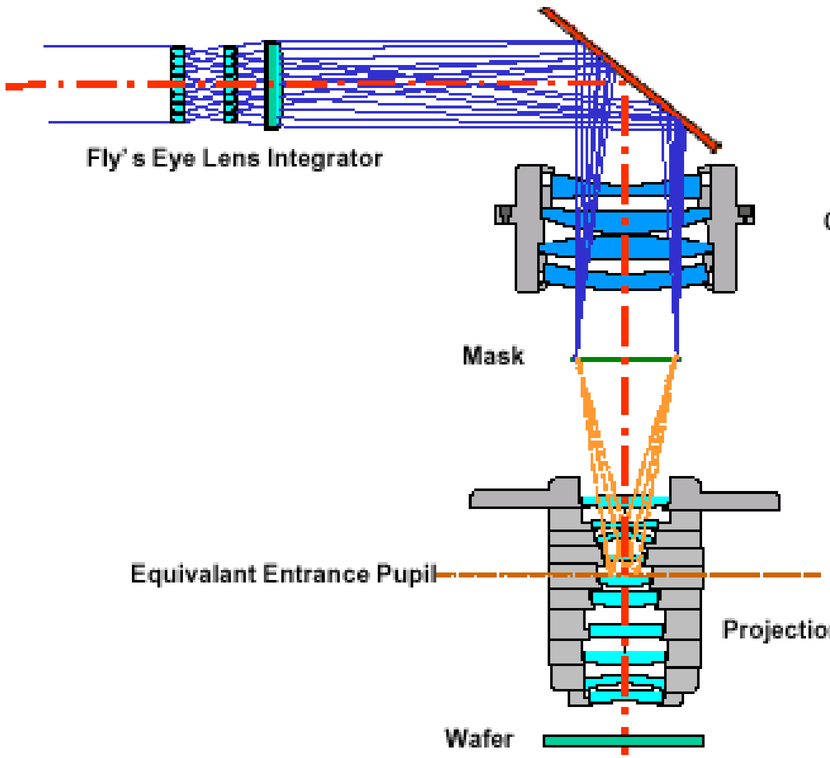
Goal: Maintain set distance between lens and wafer There are 3 types:

1. ***Grazing angle:*** ASML, Nikon, and Canon
2. ***Capacitance:*** SVGL and Optimetrix
3. ***Air Probe:*** Ultratech 1X



4. Illumination Systems: Partially Coherent (On-Axis)

Kohler illumination σ (sigma) is the so-called *partial coherence factor or fill factor*.
Sigma = NA_c/NA_p



4. Illumination and Exposure Systems

reference: http://www.asml.com/support/94086.pdfG.

A High Throughput DUV Wafer Stepper with Flexible Illumination Source

J. Stoeldraijer, SEMICON Japan 6

- **ASML 5500/300 4X scanner:248 nm KrF; 0.57NA 250nm node: refractive optics: variable illumination!**

Off-axis illumination
OAI

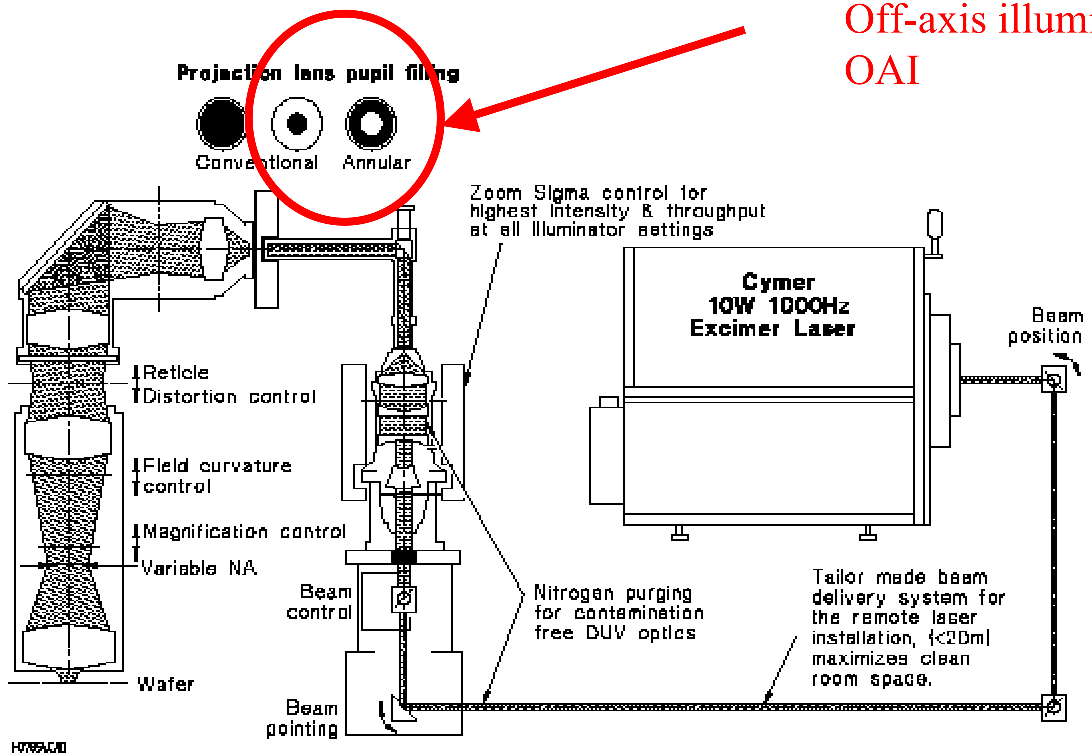


Figure 3 Optical light path in the PAS 5500/300

4. Illumination and Exposure Systems

reference: http://www.asml.com/support/94109.pdf
Christian Wagner etal, Advanced Technology for extending Optical Lithography, SPIE 2000 Santa Clara, CA

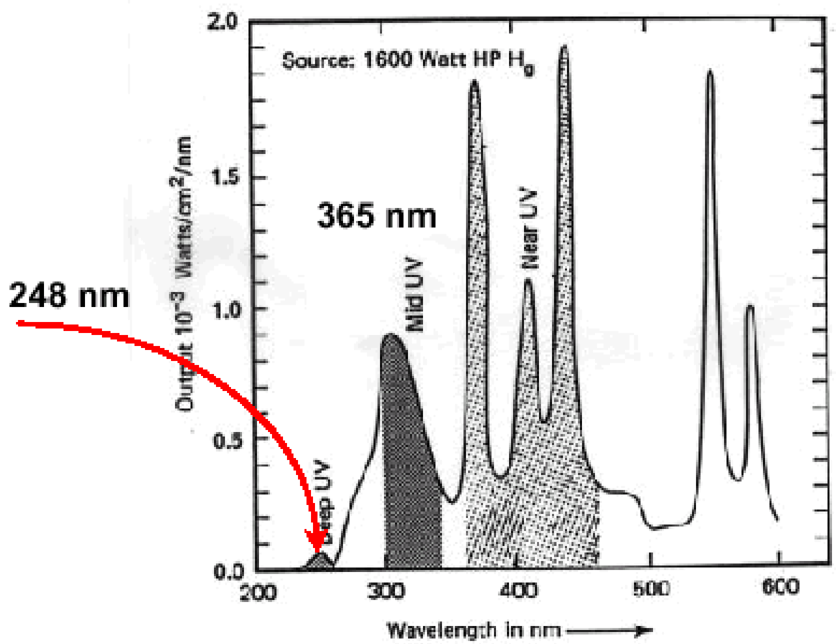
	Laser	Optics	Resist	Mask Technology	System Issues
248 nm	KrF laser available	high-NA optics with fused silica	supports evolution to <130 nm	workable	
193 nm	ArF laser available	high-NA optics with fused silica and calcium fluoride	contrast, production worthiness	need material for attPSM	
157 nm	F_2 laser under development	high-NA optics with calcium fluoride and possibly alternative fluorides	high absorption	modified fused silica substrate, develop pellicle	purging, contamination
126 nm	no laser	catoptric has limited NA, catadioptric needs lens material	to be developed	no material (?), reflective masks	purging with He

Table 1: The issues concerning wavelength reduction.

4. Illumination and Exposure Systems DUV

Output Spectrum of Hg Arc Lamp

$$R = k_1 \lambda / NA$$



Changing Wavelengths

248 nm → 193 nm → 157 nm → EUV (13 nm) → X-ray

4. Illumination and Exposure Systems ***DUV***

reference: http://www.asml.com/support/94109.pdf

Christian Wagner etal, Advanced Technology for extending Optical Lithography, SPIE 2000 Santa Clara, CA

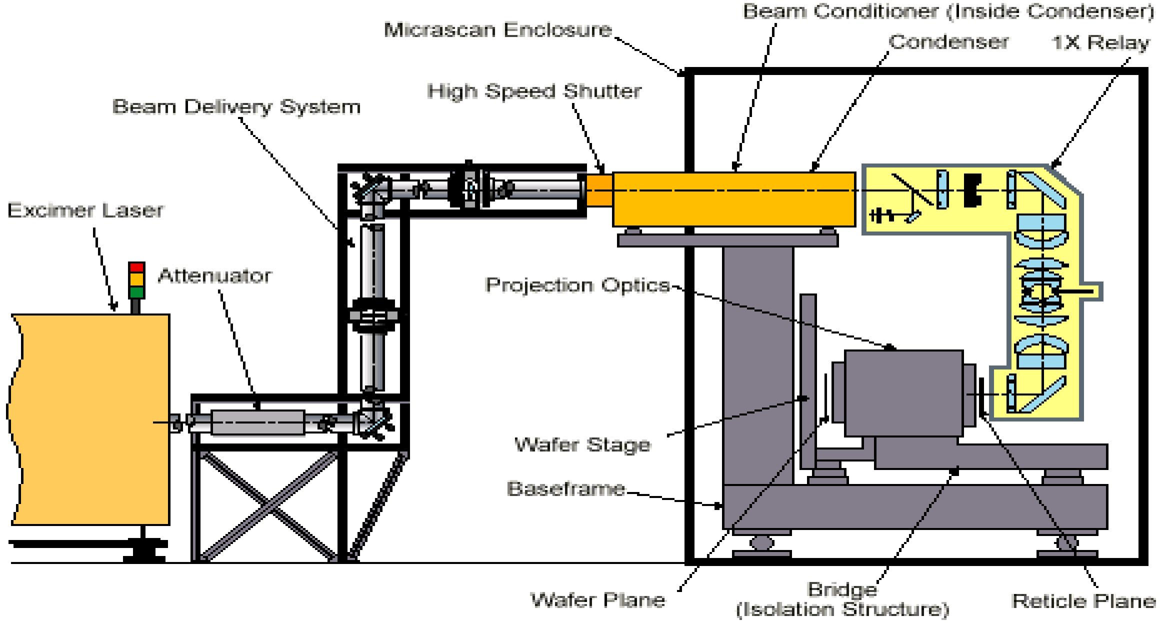
	Preferred High NA-Design Option	Coatings	Materials	Laser	System Integration
248 nm	Refractive	evolution	fused silica available, larger blank sizes needed	0.5 pm to 0.3 pm bandwidth	standard
193 nm	Refractive	development for higher NA	fused silica available, larger blank sizes needed, CaF_2 volume and quality	0.5 pm to 0.3 pm under development	standard
157 nm	Beam splitter, Catadioptric w/o beam splitter	additional HR coating development	CaF_2 volume and quality	>1 pm bandwidth available	solution with either off-axis field or obscuration
	Refractive	AR coatings under development	2nd material for color correction	<1pm bandwidth under development	standard

Table 2: Preferred design options for 248 nm, 193 nm and 157 nm.

4. Illumination and Exposure Systems

reference: SVGL Micrascan III and III+ manual

SVGL MS III+ scanner: Layout



4. Illumination and Exposure Systems

reference: SVGL Micrascan III and III+ manual

SVGL MS III+ scanner: KrF Laser requirements

Table 1. Excimer Laser Specifications

Item	Specification
Wavelength setpoint Range	248.356 nm ± 0.125 nm
Wavelength setpoint Stability	± 0.010 nm
Spectral bandwidth	50 pm < BW < 300 pm*
Pulse Frequency	1000 hertz
Minimum delivered pulse energy	15 mJ
Maximum 30-pulse average variation	± 0.7%
Polarization	≥ 97.5% linearly polarized along the short axis
Average polarized output power	15 watts
Output beam dimensions	4 ± 1 mm x 15 ± 4 mm
Safety compliance	CDRH Class IV and S2-93
Maximum electrical consumption	9 kVA

* pm = picometers or 10^{-12} meters.

4. Illumination and Exposure Systems

reference: SVGL Micrascan III and III+ manual

SVGL MS III+ scanner: **Dose Control: mj/cm2 = mw/cm2*(slit widthin mm)/(stage speed mm/sec)**

Note Polarization Orientations

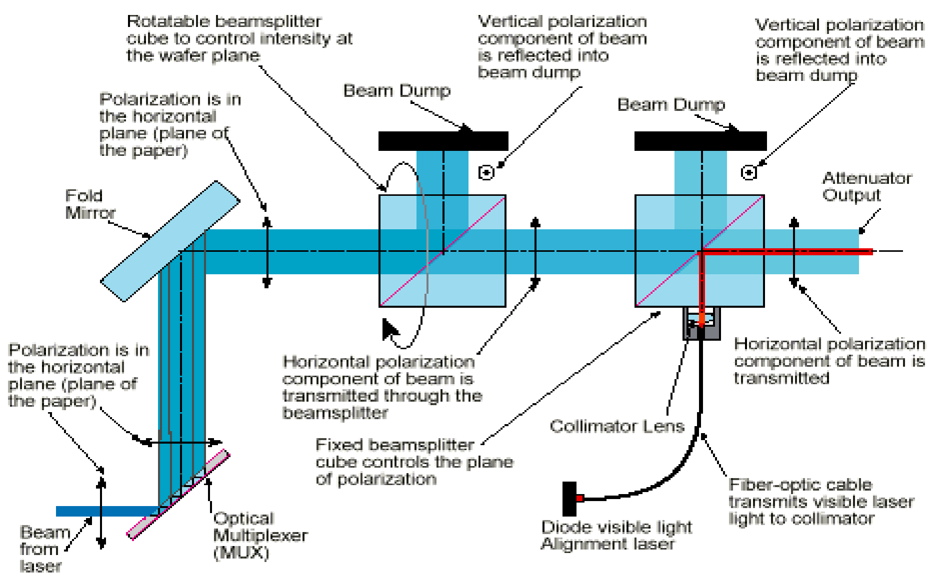
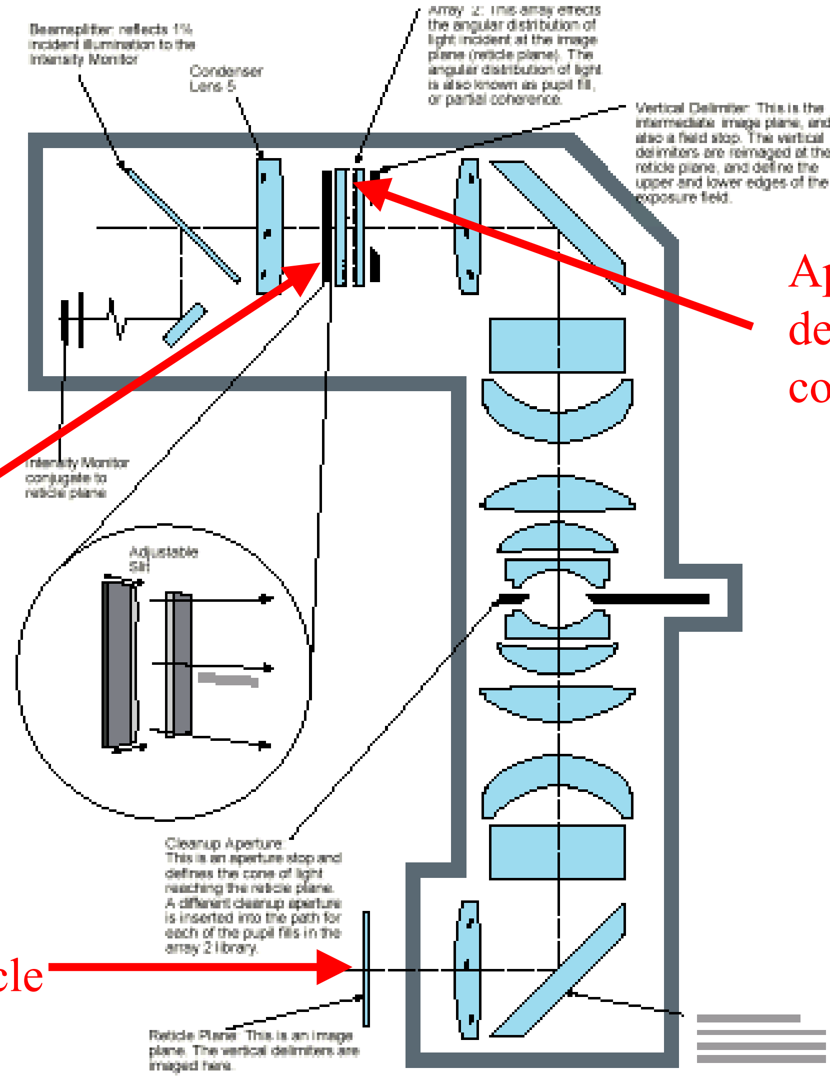


Figure 2. Optical Diagram of the Attenuator

4. Illumination and Exposure Systems

reference: SVGL Micrascan III and III+ manual

SVGL MS III+ scanner: Optics Relay Optics: Bringing illumination to reticle plane



4. Illumination and Exposure Systems

reference: SVGL Micrascan III and III+ manual

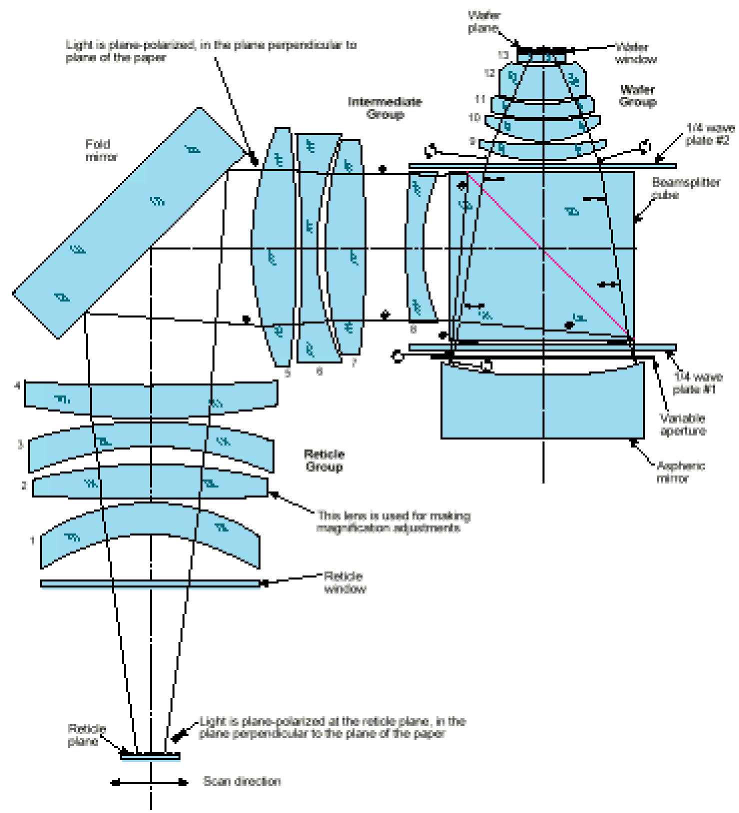
SVGL scanner: catadioptric Projection optics (mirrors and lens)

Wavelength: 248nm:

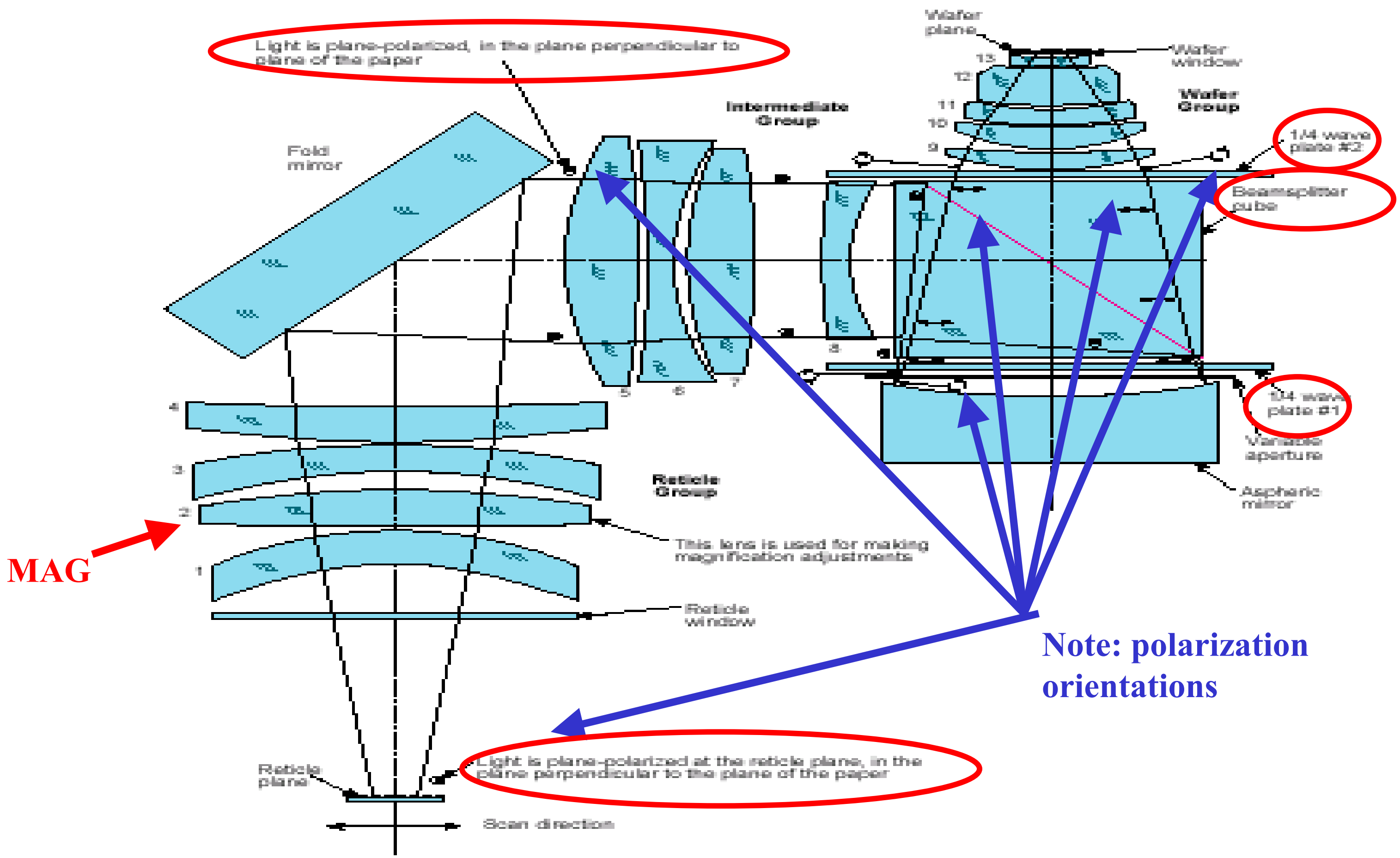
Resolution: 180nm

Adjustable slit: CD control

Overlay: 45nm



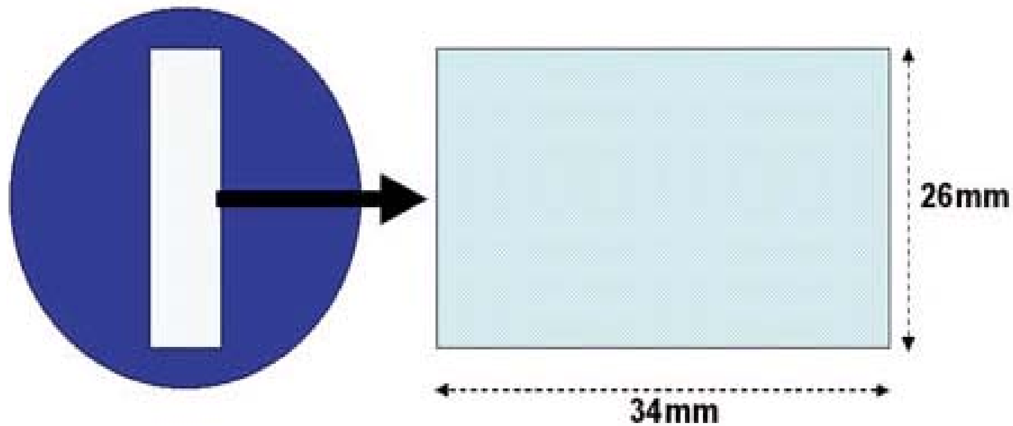
4. Illumination and Exposure Systems Projection printing: SVGL Micrascan MSIII+scanner



4. Illumination and Exposure Systems

reference:http://www.semiconductorfabtech.com/features/lithography/articles/edition9/ed9_a2_2.shtml

- 4X scanner: Reticle and wafer stage move in synchronization using an illuminated slit:
- **Reticle moved through illuminated slit of light**
  ADVANTAGES:
- Larger field Size
- Improved overlay and CD: aberrations and field distortions averaged out

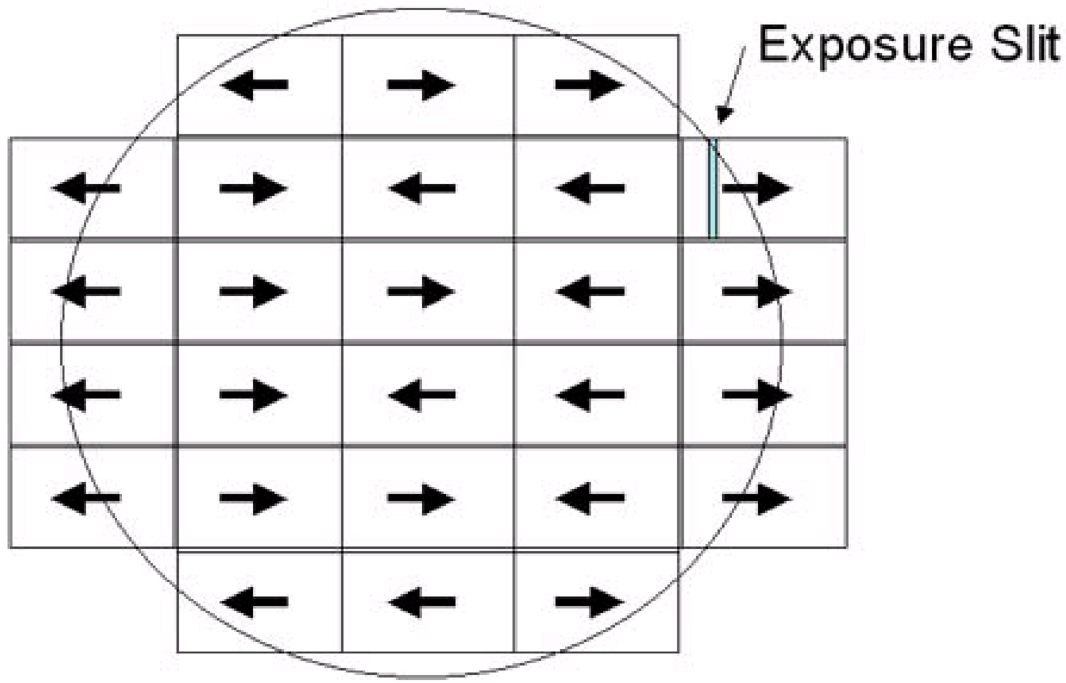


Scanned Field Length limited by the reticle (up to 52mm with 9" reticle).

4. Illumination and Exposure Systems

reference:http://www.semiconductorfabtech.com/features/lithography/articles/edition9/ed9_a2_2.shtml

- **4X scanner: Wafer: step and scan pattern**



4. Illumination and Exposure Systems

reference: http://www.asml.com/support/94109.pdf
Christian Wagner etal, Advanced Technology for extending Optical Lithography, SPIE 2000 Santa Clara, CA

Focus control across scanned field is called contour or terrain focus control.

CD uniformity across the slit

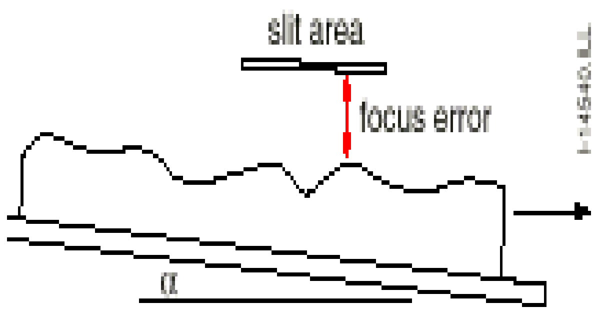


Figure 12: Impact of wafer topography on MA and MSD focus behavior.

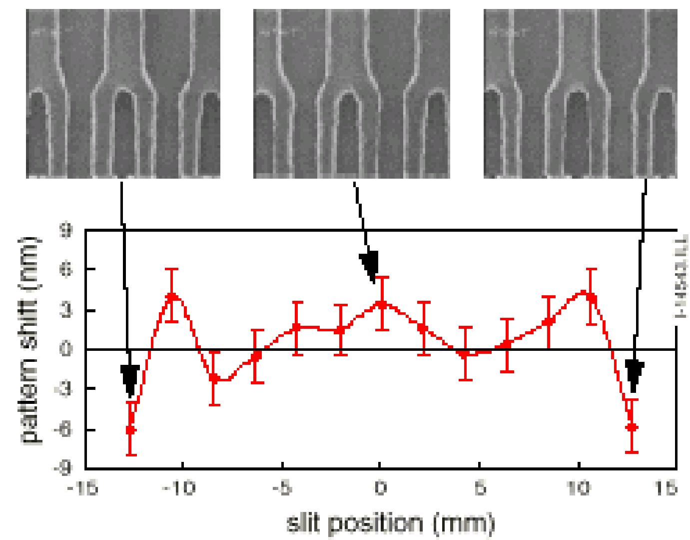
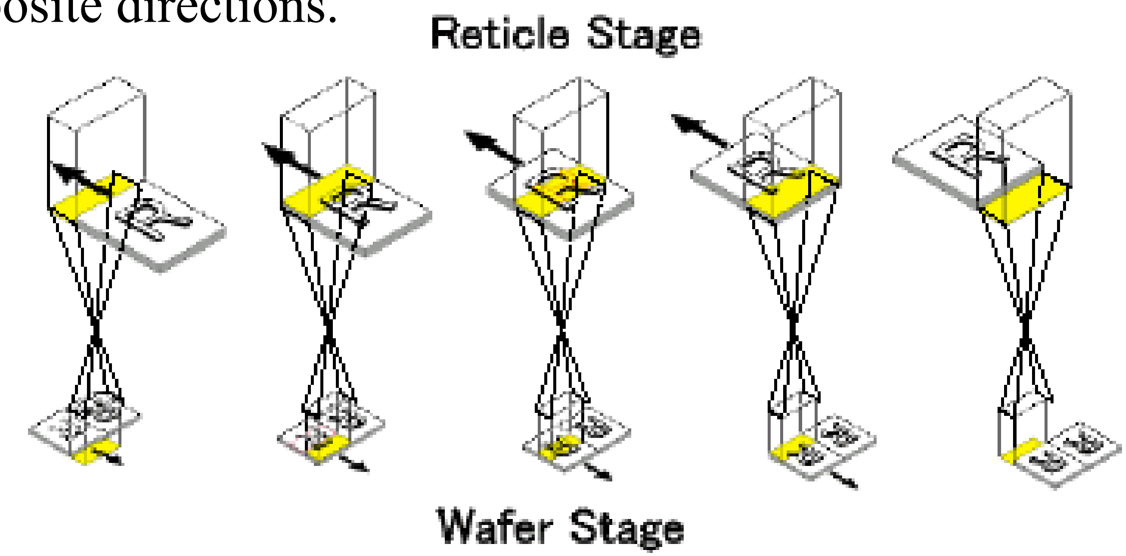


Figure 14: Critical pattern extension experiment with double exposure. Pattern shift for 0.15 μm dense lines relative to 0.30 μm dense lines, obtained with a double exposure using a annular and conventional illumination setting respectively.

5. Wafer and Reticle Stages: Scanners

<u>Basic Step & Scan Operation</u> After stepping to each field position the image is exposed (through an 8 x 26 mm slit) while scanning the reticle and wafer in opposite directions.



<u>Scanner advantages</u> (compared to steppers):
1. Uses only the 'sweet spot' of the lens - less distortion, astigmatism, coma, field curvature, etc. and lens errors averaged across 8mm slit width.
2. Reduced impact of wafer non-flatness since system dynamically focuses (height and tilt) over the slit area while scanning.
3. Larger field size (through-scan dimension only limited by mask size).
(#1 & 2 $\rightarrow$ better CD control and overlay; #3 $\rightarrow$ increased throughput)

5. Wafer Stages: Scanners

reference: http://www.asml.com/support/94086.pdfG.
de Zwart etal, Performance of a Step & Scan System for DUV Lithography, SPIE March 1997 Santa Clara, CA

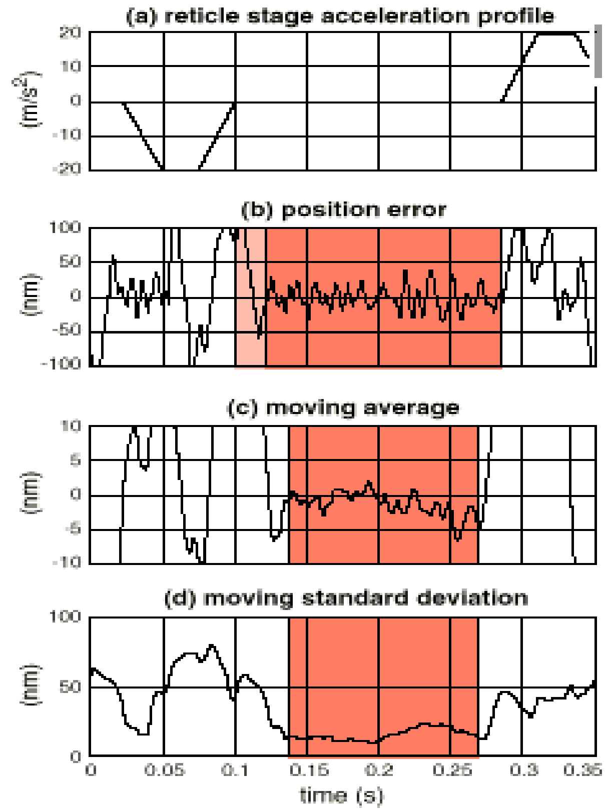
- Scanner Advantages: More degrees of freedom in Overlay Correction

Adjustment	Step and Repeat		Step & Scan	
Translation in X	1	0	1	0
Translation in Y	0	1	0	1
Magnification M	x	y	x'	0
Rotation R	-y	x	0	x'
scan scale β	-	-	0	y'
scan skew α	-	-	-y'	0

5. Wafer Stages: Scanners

reference: http://www.asml.com/support/94086.pdfG.
de Zwart etal, Performance of a Step & Scan System for DUV Lithography, SPIE March 1997 Santa Clara, CA

- Scanner Reticle and Wafer Stage synchronization is Key to CDs and registration
- Moving Average (MA): Average differences between reticle and wafer stage speeds: (for 4X tool 4:1 RS/WS speeds)
- Moving Standard deviation (MSD): standard deviation of Average differences between reticle and wafer stage speeds
- ASML wafer stage 250 mm/sec



5. Wafer Stages: Scanners

reference: http://www.asml.com/support/94086.pdfG.
Jan van Schoot etal, 0.7 NA DUV Step & Scan System for 150nm Imaging with Improved Overlay, SPIE March 1999 Santa Clara, CA

- CD Impact: Moving Average (MA): Moving Standard deviation (MSD)

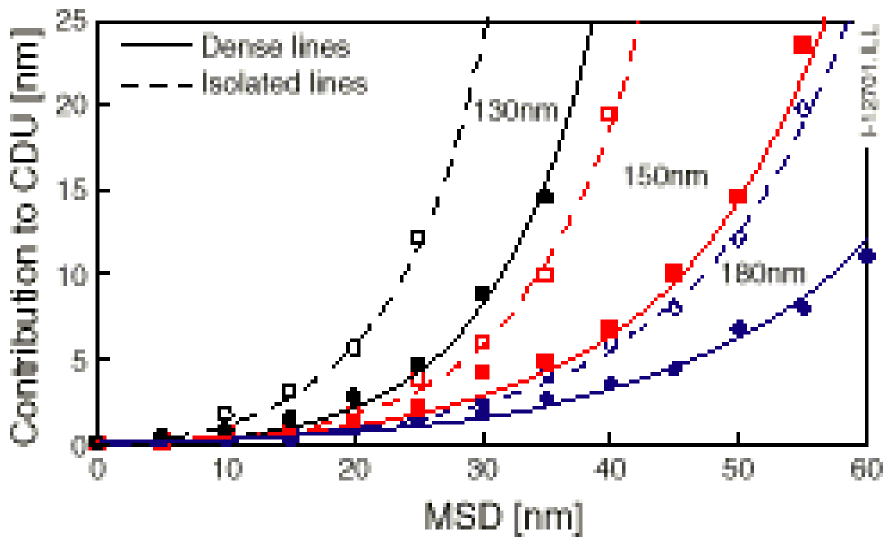


Figure 4 MSD contribution to CD-uniformity. For features below 180nm, MSD values greater than 20nm have a severe impact on the CD-uniformity.

5. Wafer Stages: Scanners

reference:ASML: **Step & Scan and Step & Repeat, A Technology Comparison**

Martin van den Brink,Hans Jasper,Steve Slonaker,Peter Wijnhovenand Frans Klaassen,PSIE 1996

- Scanner exposure Calculation: **mj/cm2 = mw/cm2*(slit width mm)/(stage speed mm/sec)**

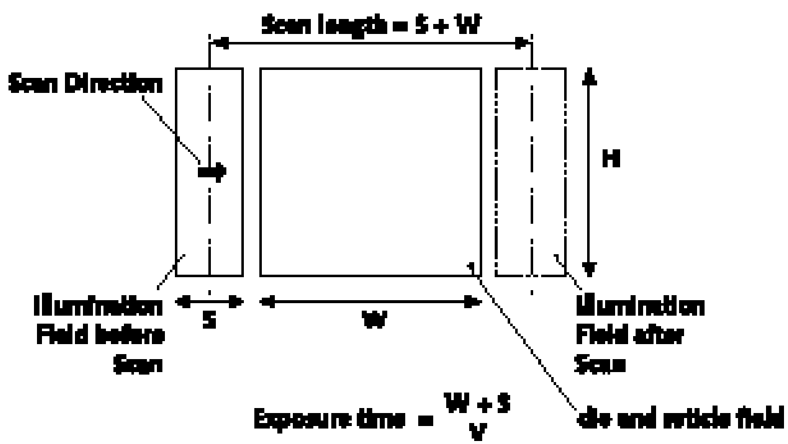


Figure 4 The die needs to move in and out of the scanning field; overscan per die

Overscan means that the mask needs to be scanned in and out of the illuminated scan slit. In doing this, the fundamental difference between the scanner and stepper exposure time is equal to the scan slit divided by the scan speed. The scanner exposure time is given by:

$$T_{ss} = \frac{W + S}{V} \qquad (1)$$

Where:

T_{ss}	: Step-and-scan exposure time	[s]
W	: Die width	[mm]
S	: Slit width	[mm]
V	: Scan speed	[mm/s]

6. Stepper Thermal materials

- Lens, mirrors, and mounting or holding materials

Material	Type	dn/dt x 10^{-6}/dgC	Expansion Coefficient x 10^{-6}/dg. C
Optical Glass	BK7	4	71
	FK5	-1.5	9.2
	Fused Silica	15	0.51
	Calicium Fluoride	-11	18.85
Glass Ceramic	Zerodur	16	0.05
Mounting	Aluminum 356		21.4
Materials	Brass		20
	Stainless Steel 440		10.1
	Cast Iron		11.9
	Invar 35		0.56
	Super Invar		-0.18
	Graphite Epoxy		0.2

6. Stepper Systems Environmental Sensitivities

Table from David Williamson SVGL

	DIOPTRIC			CATADIOPTRIC		
Term	**delta Pressure 50 mm**	**delta Temo 1o C**	**delta Temo 1o C**	**delta Pressure 50 mm**	**delta Temo 1o C**	**delta Temo 1o C**
		Aluminum mounts	**Invar 35 mounts**		**Aluminum mounts**	**Invar 35 mounts**
δ focus nm	-11770	-8062	-6681	7	-766	-40
δ MAG nm	333	152	190	0	-40	0
δ Z5 Astig RMS	0.0403	0.0245	0.0229	-0.0005	0.0004	-0.0003
δ Z8 Coma RMS	-0.0368	-0.0231	-0.021	0	0.0004	0
δ Z9 Spherical RMS	0.0469	0.0313	0.0273	0	0.0008	0.0002
δ Field Curvature nm	-319	-191	-184	-11	-11	-6
δ Distortion nm	48	36	28	0	1	1