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Nano Team / R&D

DongbuAnam Semi

- What is Lithography …
- Resolution Limit and DOF
- Equipment
- Optical Extension
- Simulation in Lithography
- Next Generation of Lithography

Lithography 의미

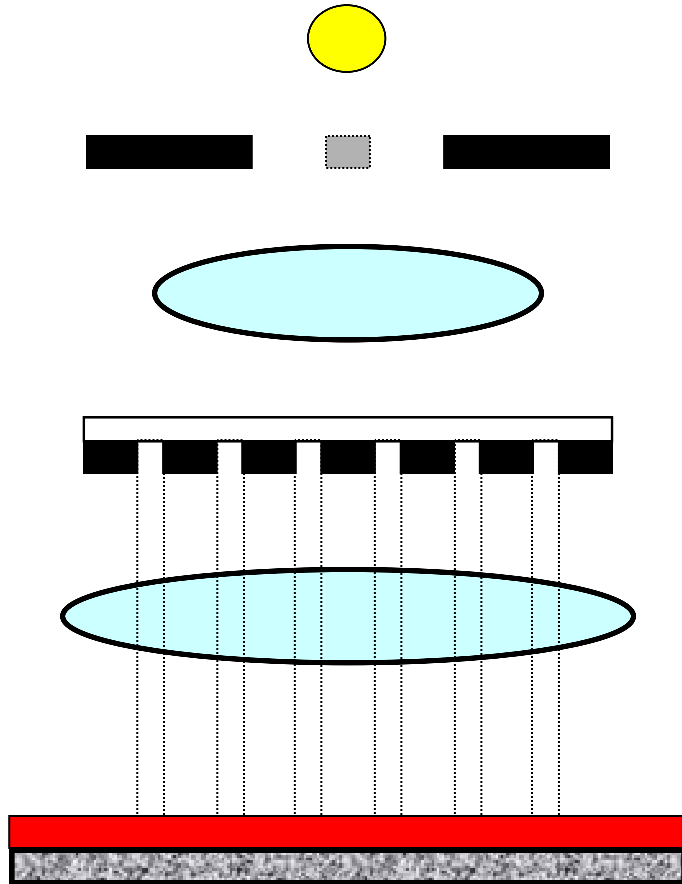
- 석판화 기술, 인쇄 기술 : litho(돌) + graphy(그림, 글자)

- **Semiconductor manufacturing** :

microlithography = transfer the pattern of circuitry from a photomask (a quartz plate containing the "master copy" of microscopic integrated circuitry) to a wafer (a thin slice of silicon or other semiconductor material on which chips are made)

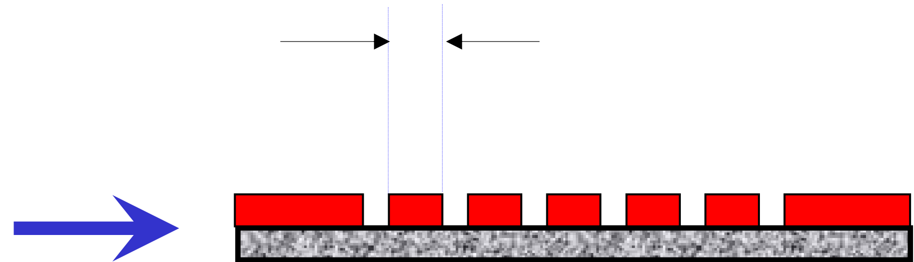
- Today's approach : use a combination of shorter wavelengths of light, larger lenses and RET to create smaller, more precise circuit patterns.

Lithography = Photolithography = Optical Lithography



Exposure

CD : Critical Dimension



Resist Pattern

after
Development

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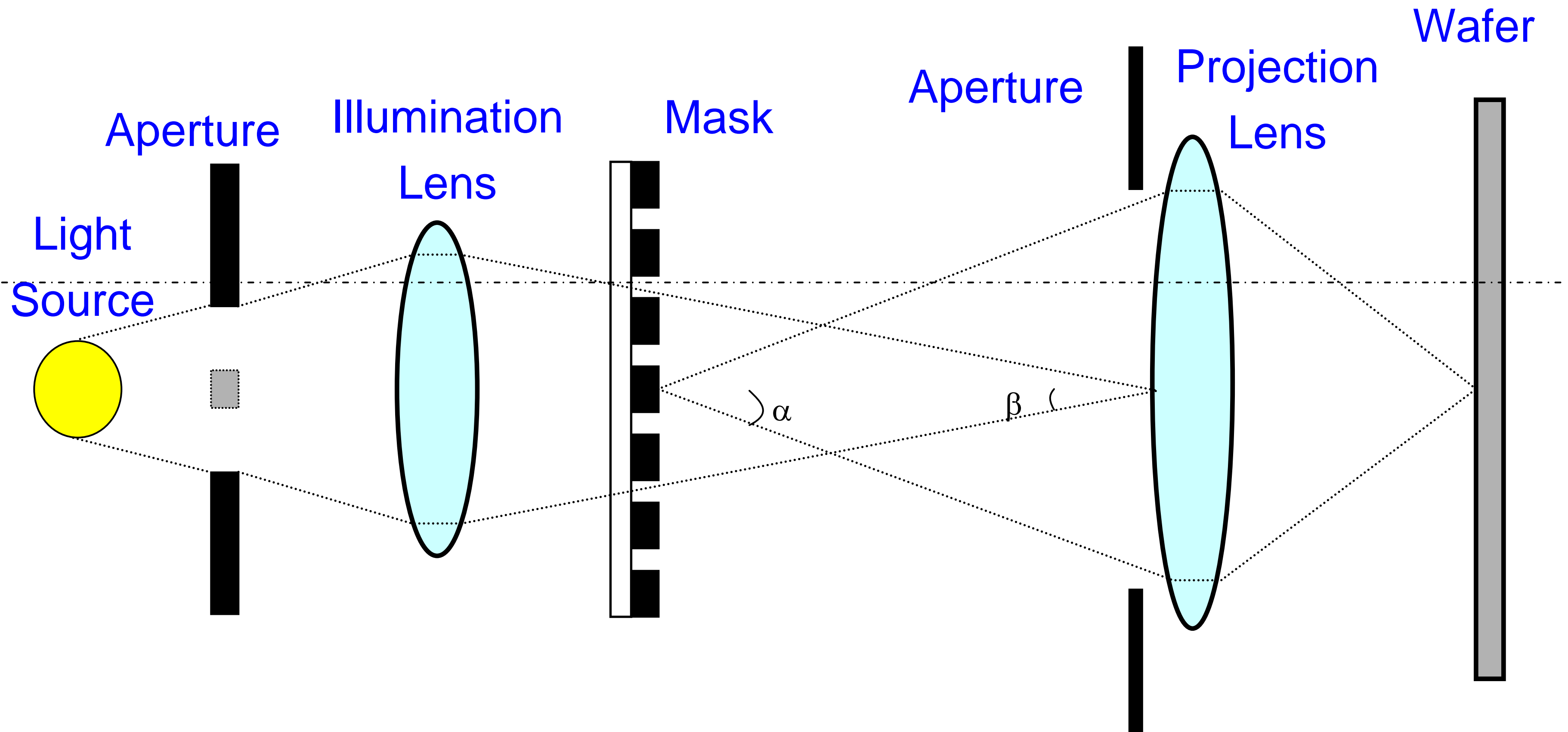
Optical Imaging System

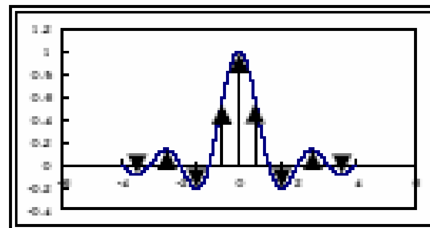


Imaging Mechanism (1)

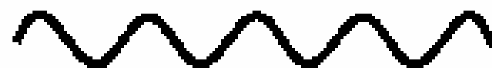
Fourier Optics

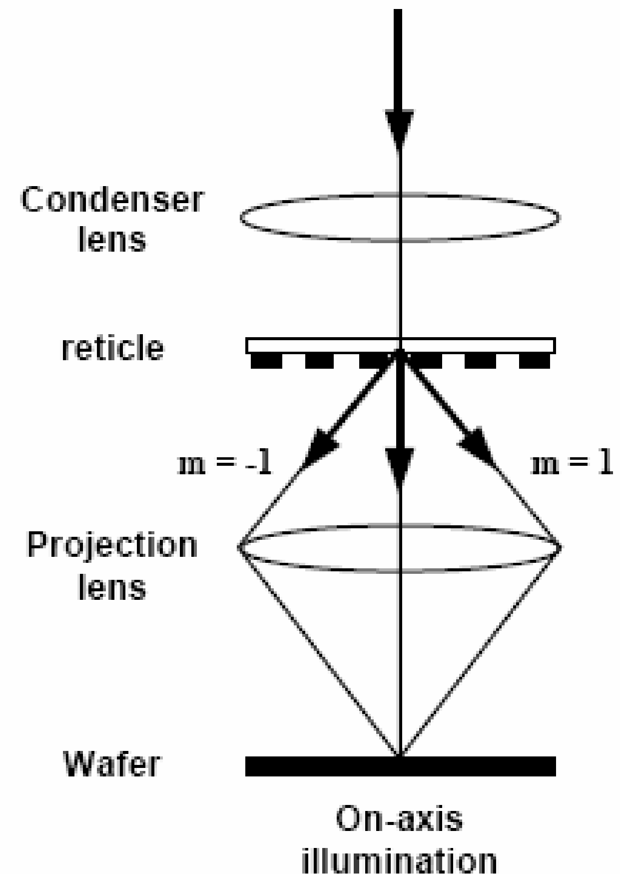
$f(x)$

$g(k) = F\{f(x)\}$



$f'(x) = F^{-1}\{g'(k)\}$





Imaging Mechanism (2)

A lens limits the number of diffraction order that can be used for image reconstruction

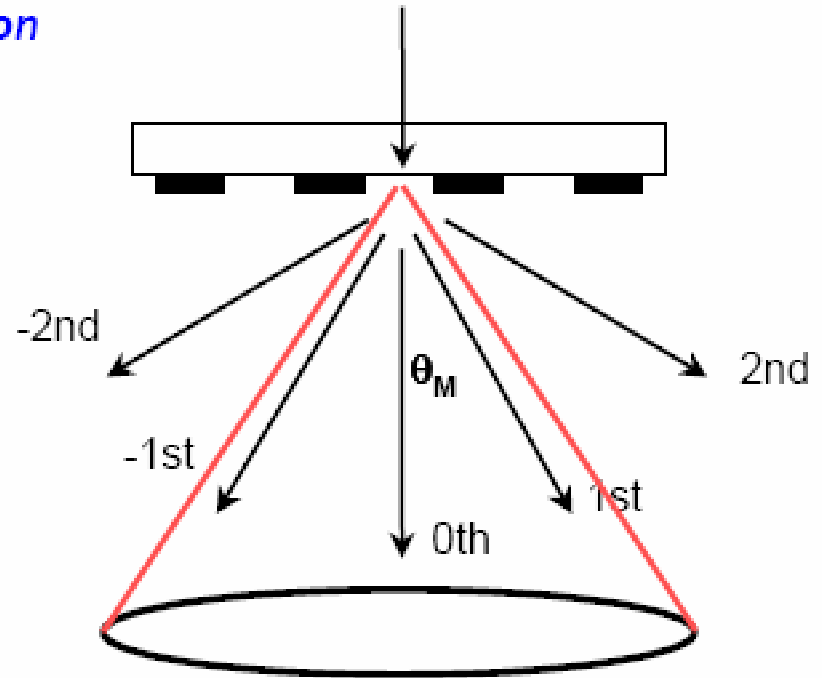
➡ Low frequency pass filter

$$p \sin q = n \lambda$$

$$2R \sin q = \lambda \qquad \because p=2R \ \& \ n=1$$

$$Res. = \frac{\lambda}{2NA} = 0.5\frac{\lambda}{NA}$$

$$= k_1 \frac{\lambda}{NA}$$

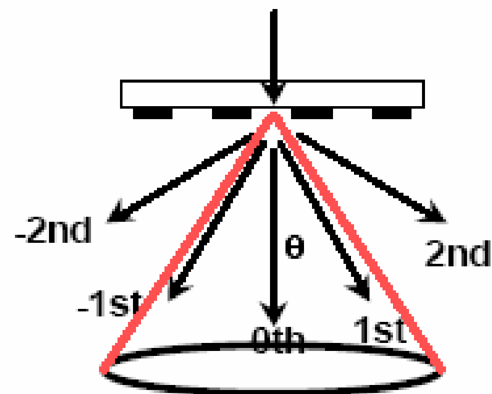


Effect of Partial Coherence to Imaging (1)

1. Coherent case

$$Res. = \frac{\lambda}{2NA} = 0.5\frac{\lambda}{NA}$$

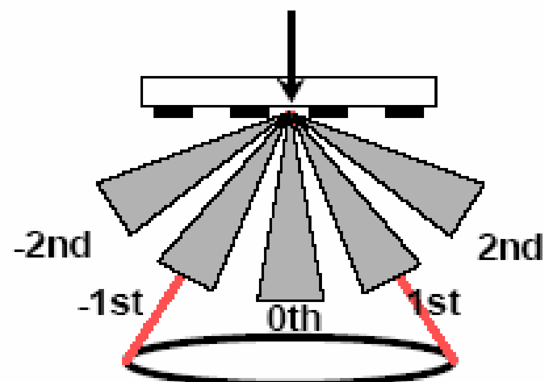
$$= k_1 \frac{\lambda}{NA}$$



2. Partially Coherent case

$$Res. = \frac{\lambda}{2(\sigma+1)NA} = 0.5\frac{\lambda}{(\sigma+1)NA}$$

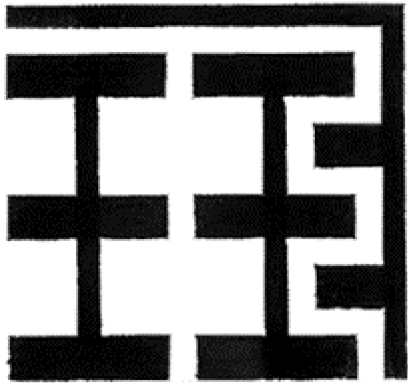
$$= k_1 \frac{\lambda}{(\sigma+1)NA}$$

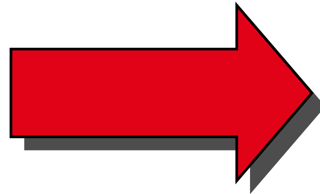


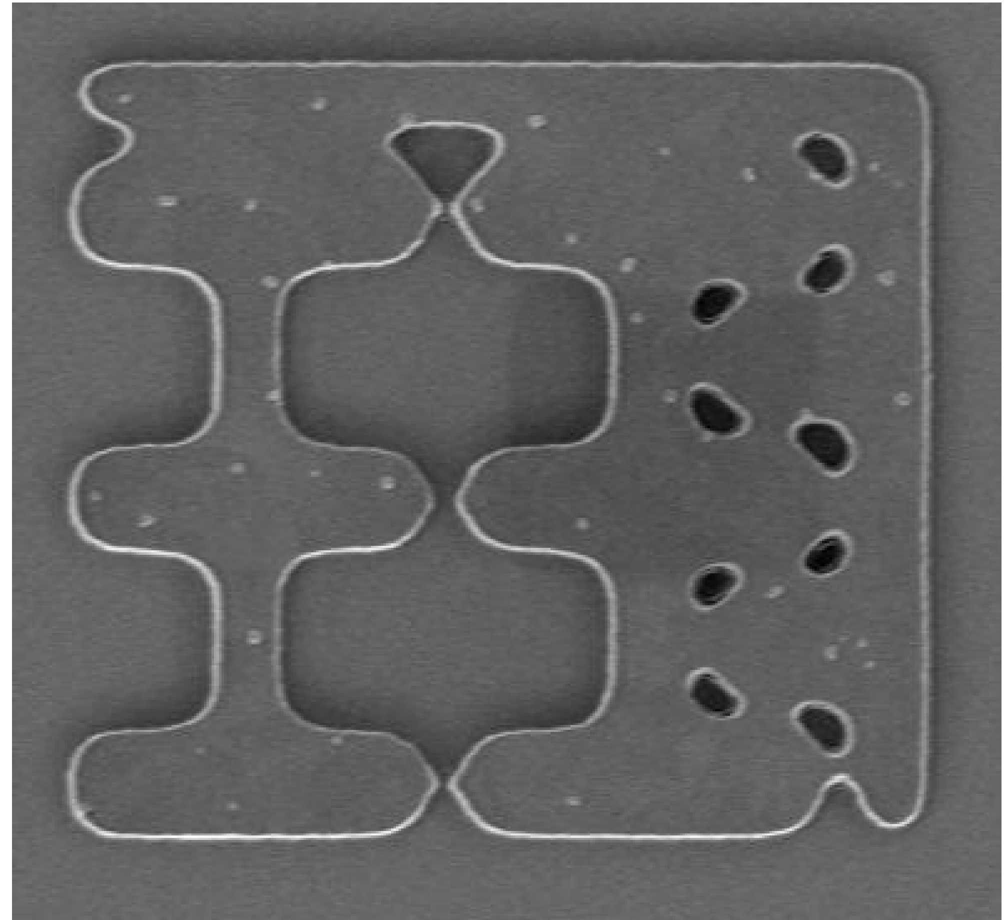
Resolution Limit

Mask

Final Pattern after Lithography







Depth of Focus

Depth of Focus

If $OPD = \lambda/2$
$= \delta\, NA^2,$

$$\text{then } \delta = \frac{\lambda}{2NA^2} = 0.5\frac{\lambda}{NA^2}$$

$$= k_2\,\frac{\lambda}{NA^2}$$

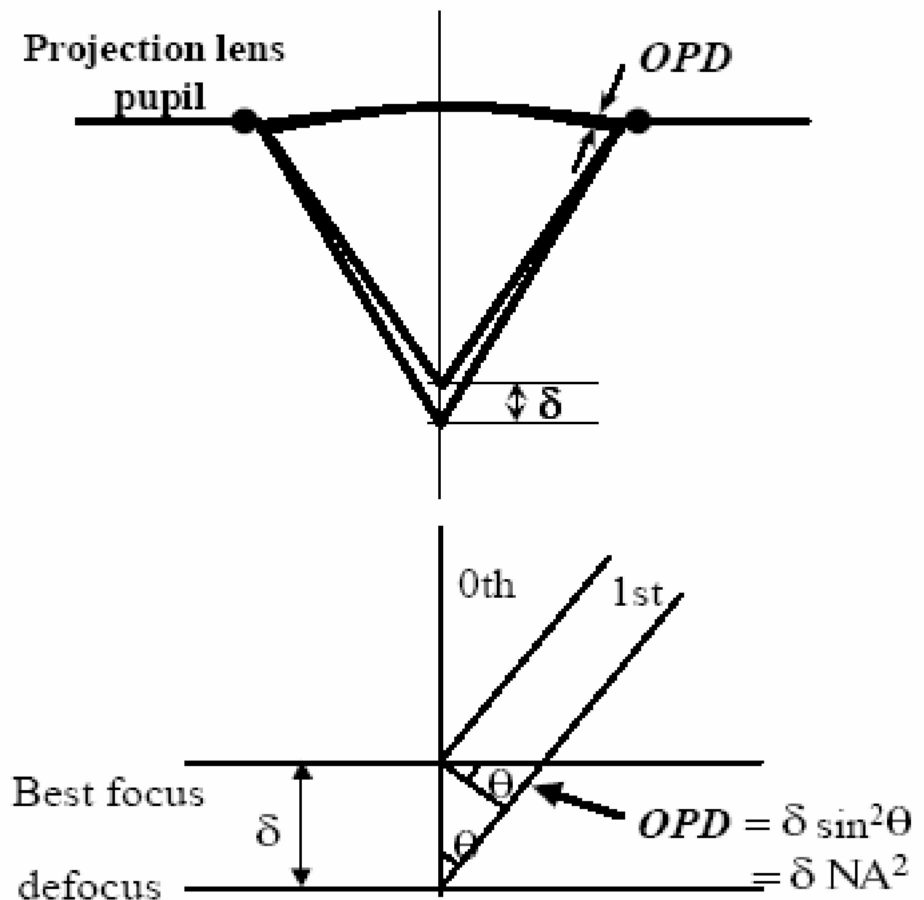
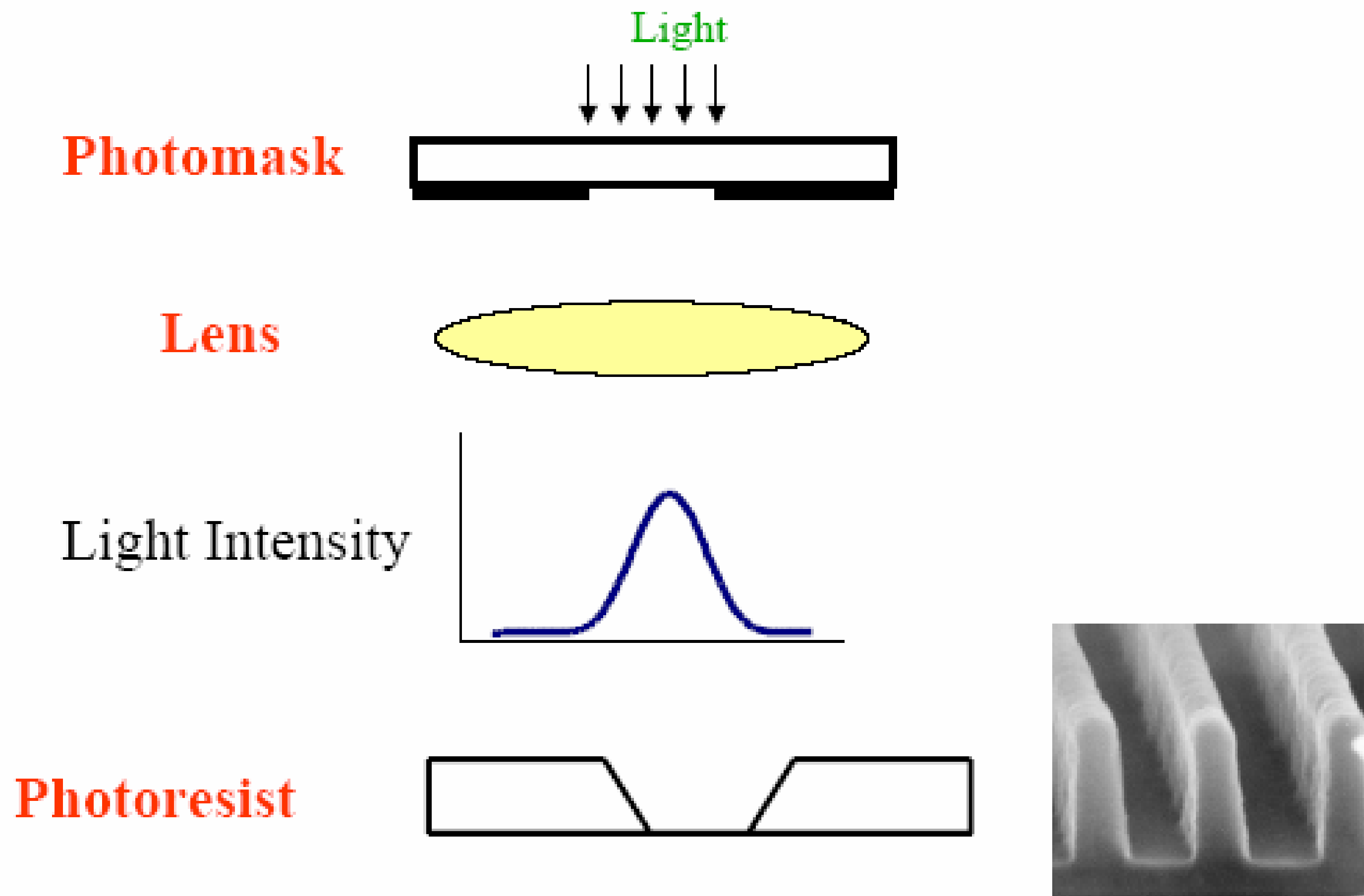
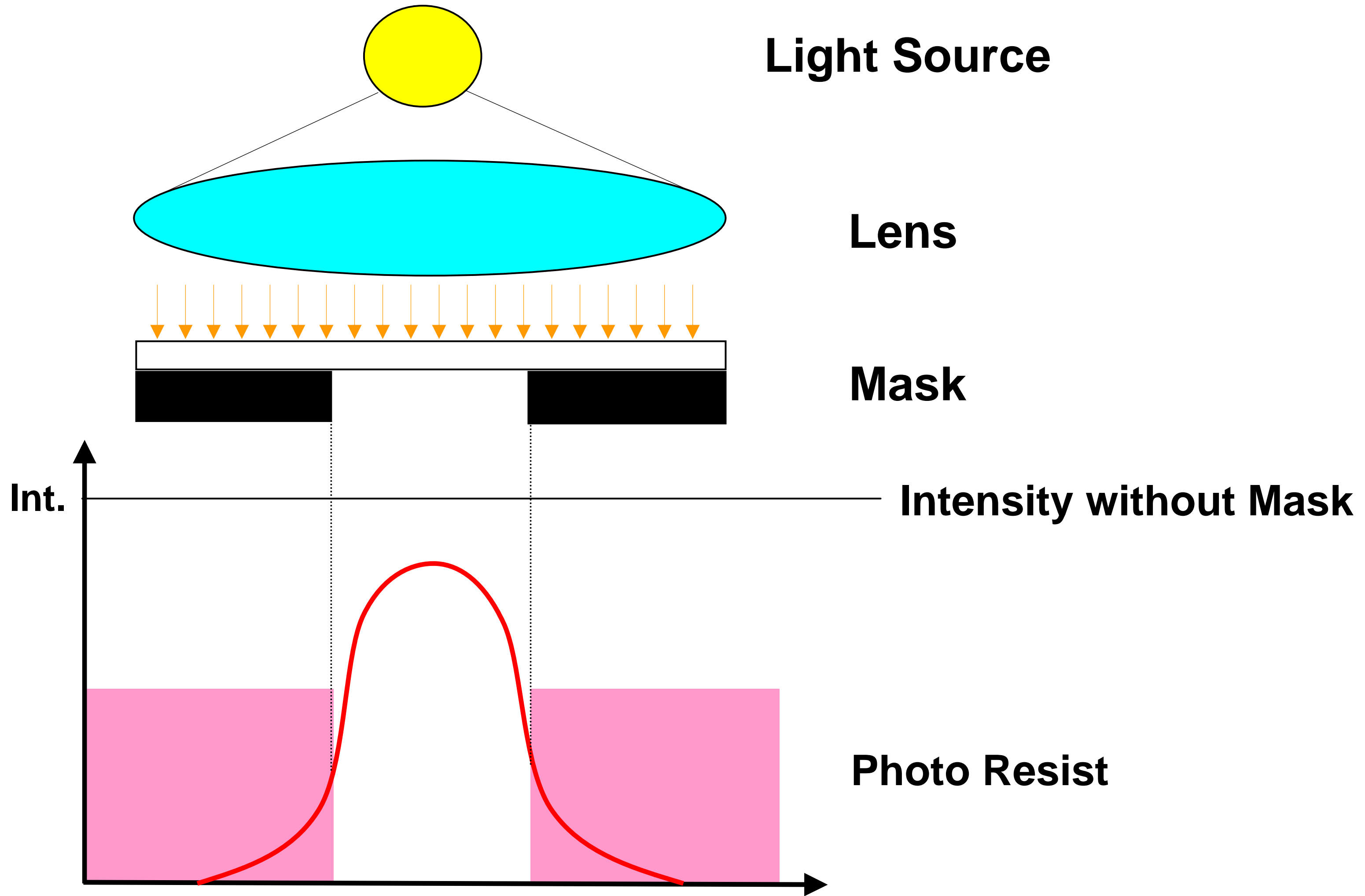


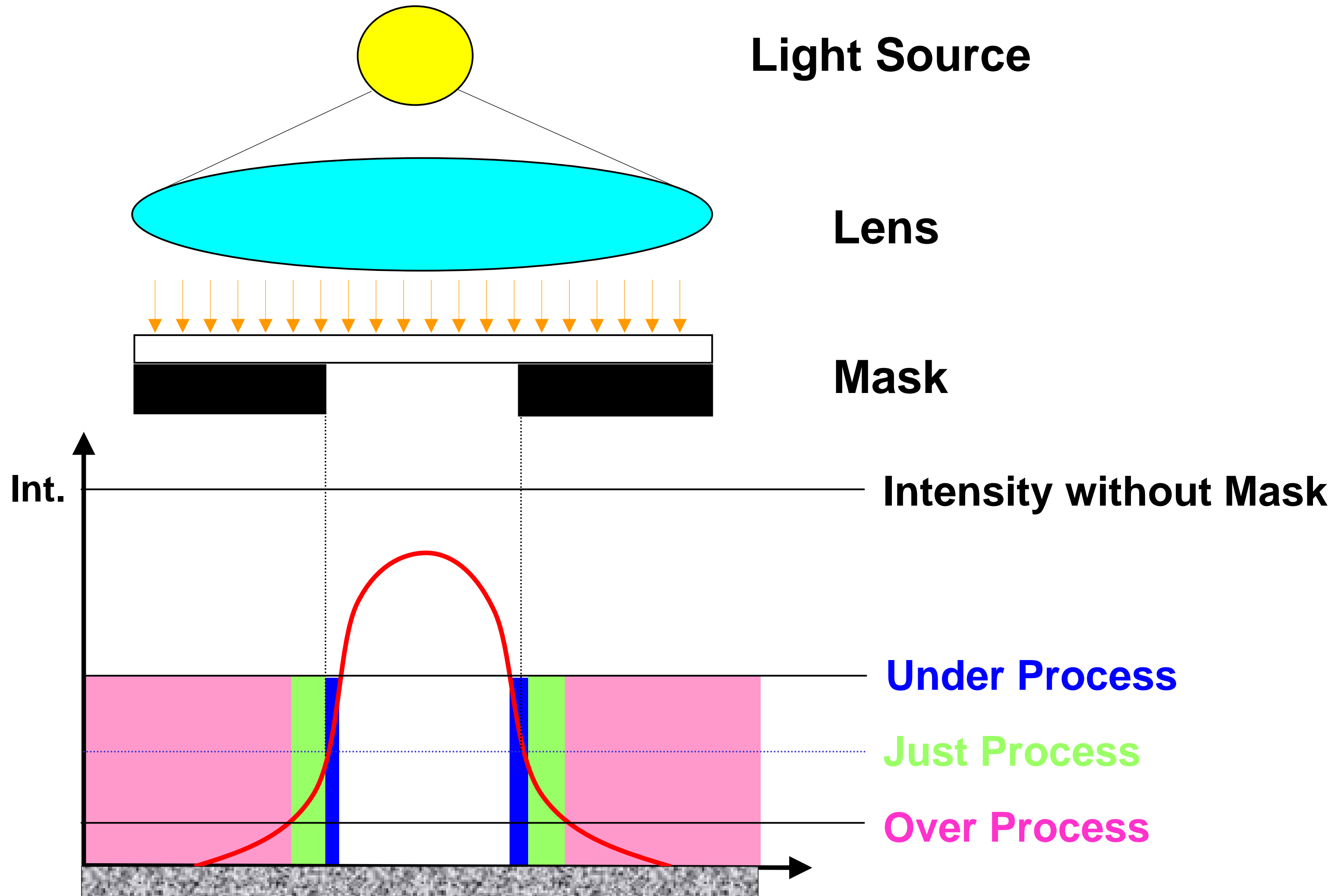
Diagram of Pattern Formation



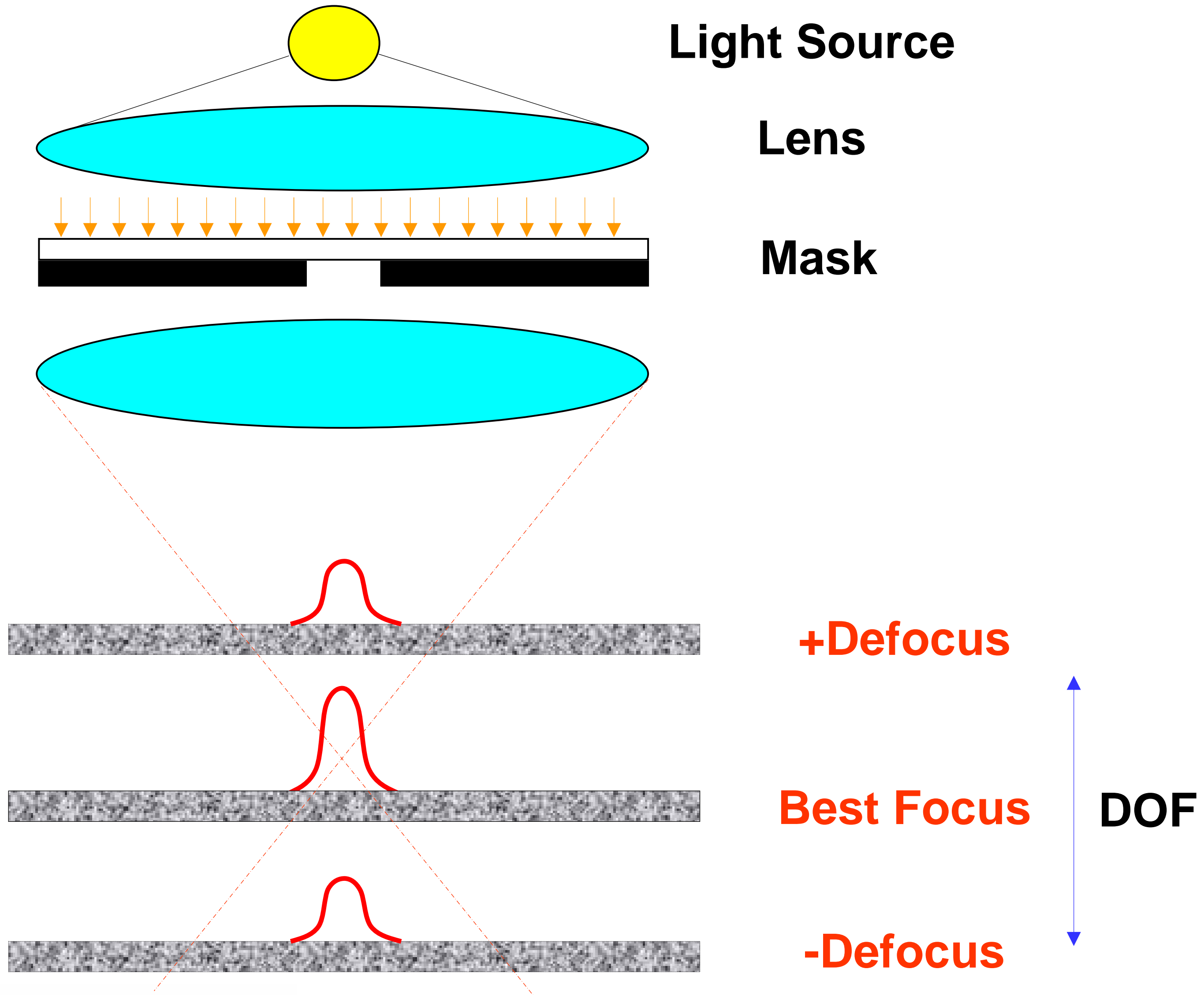
Light Intensity



Light Intensity



Focus & DOF



Lithography Resolution & Depth of Focus

$$\text{Resolution} = K_1 \frac{\lambda}{NA}$$

λ = Wavelength of illuminating light

K_1 = Process constant

NA = Numerical aperture

Smaller λ → light source & optics

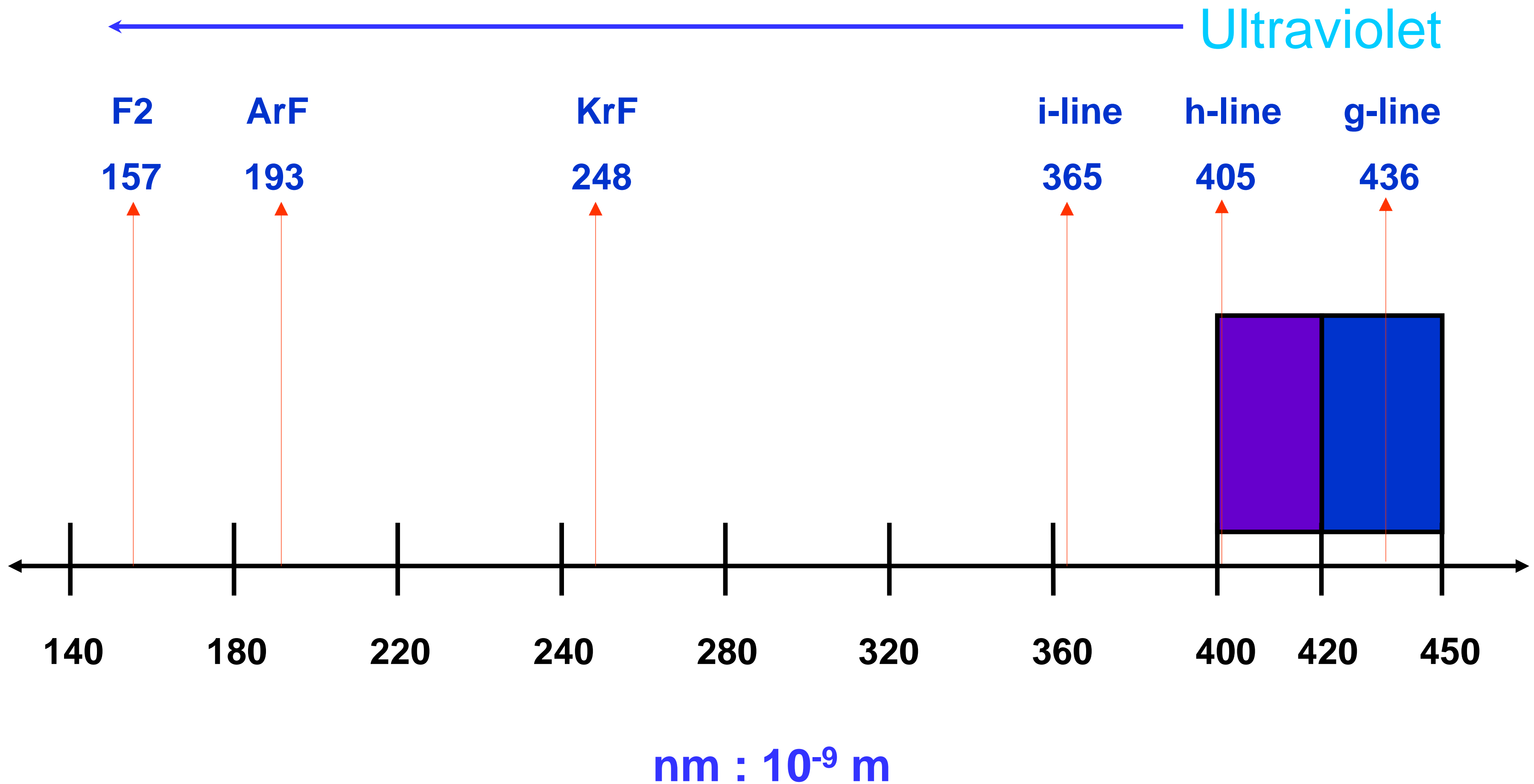
Lower K_1 → process/resist improvements
improved optical schemes

Higher NA → lens design improvements

$$\text{DOF} = K_2 \frac{\lambda}{NA^2}$$

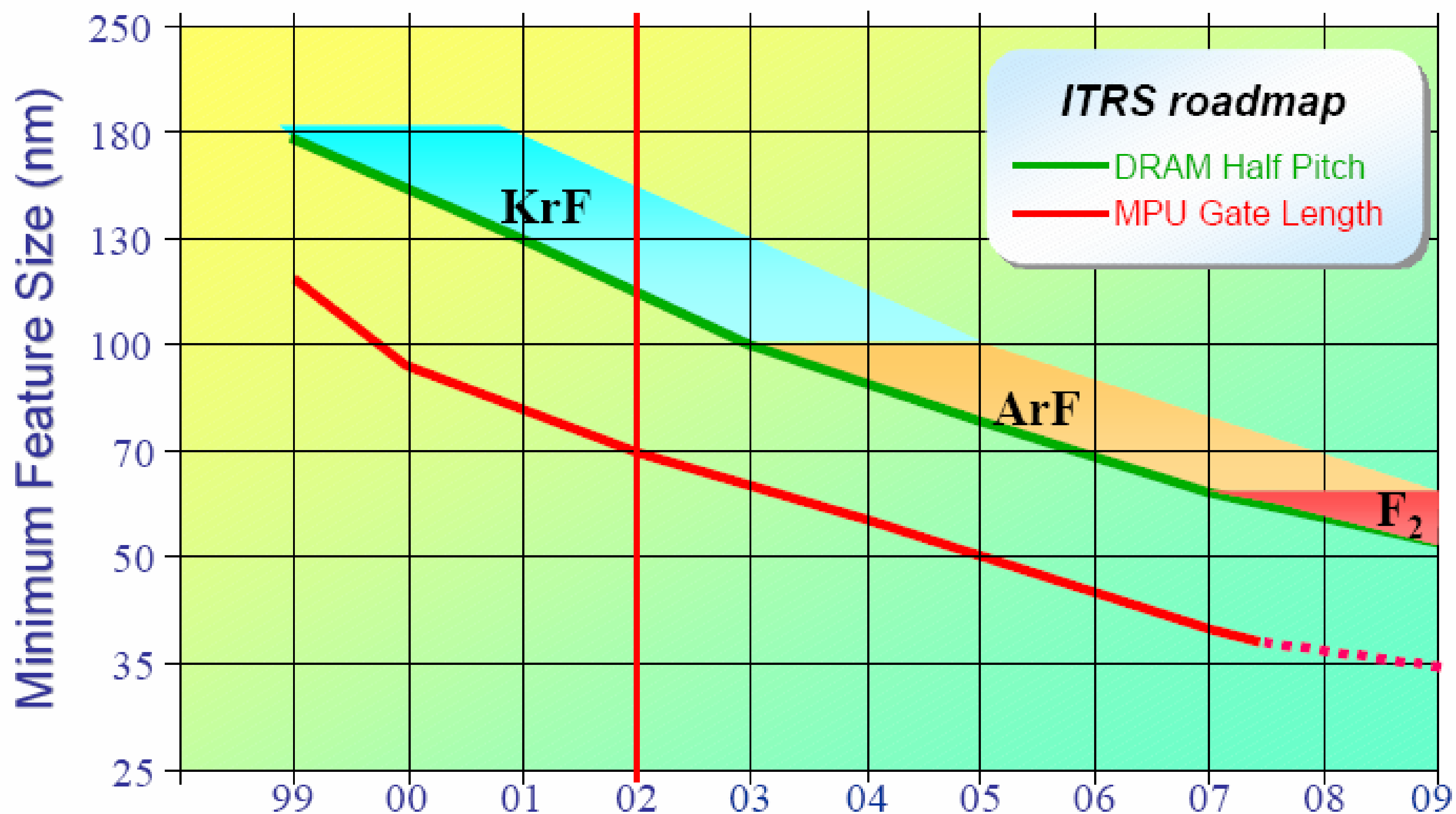
K_2 : depending on the criteria used to define acceptable imaging & on the type of feature

Wavelength of Lithography System

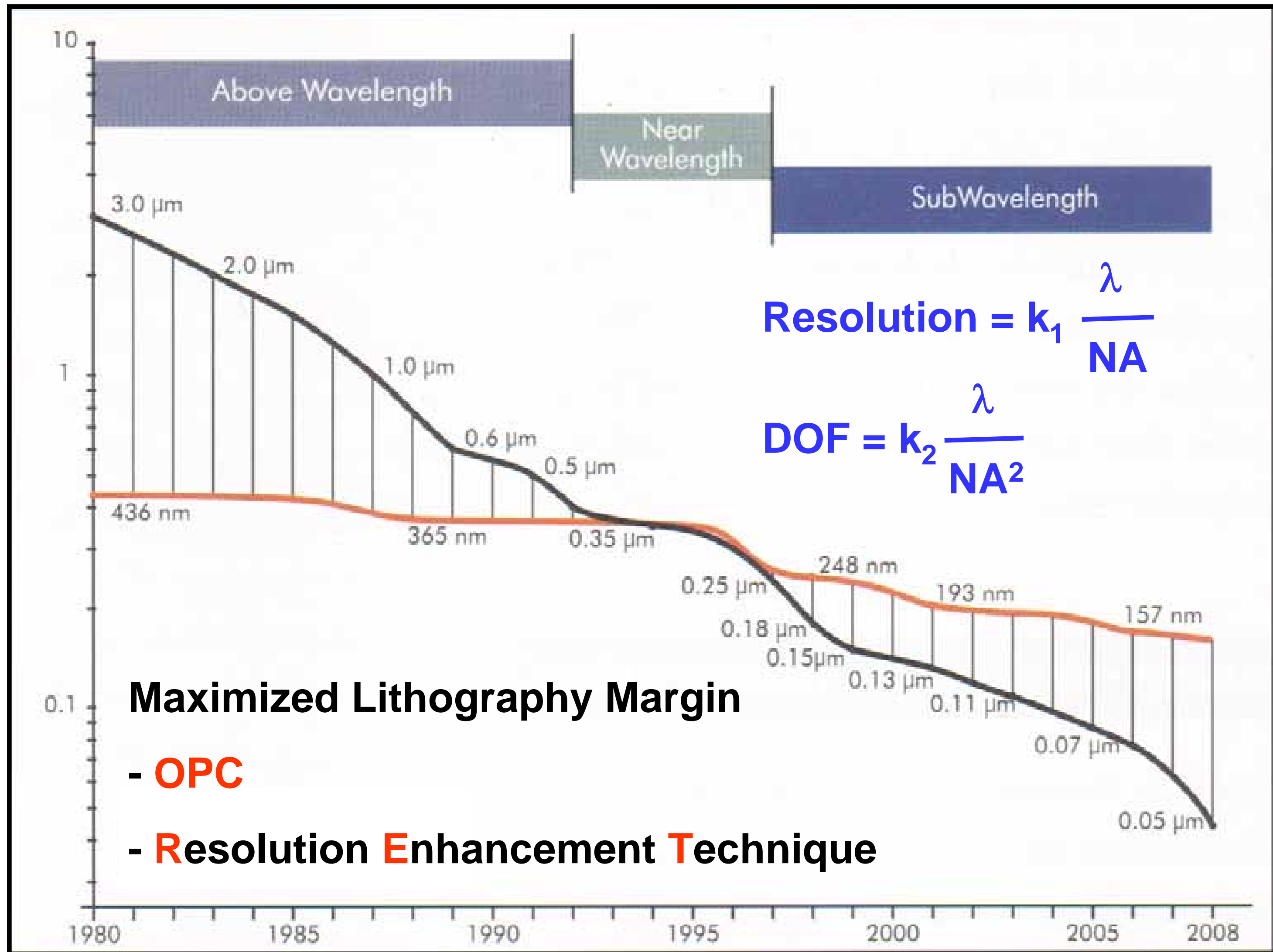


nm : 10^{-9} m

Roadmap for DRAM / MPU



Optical Lithography



$$\text{Resolution} = k_1 \frac{\lambda}{NA}$$

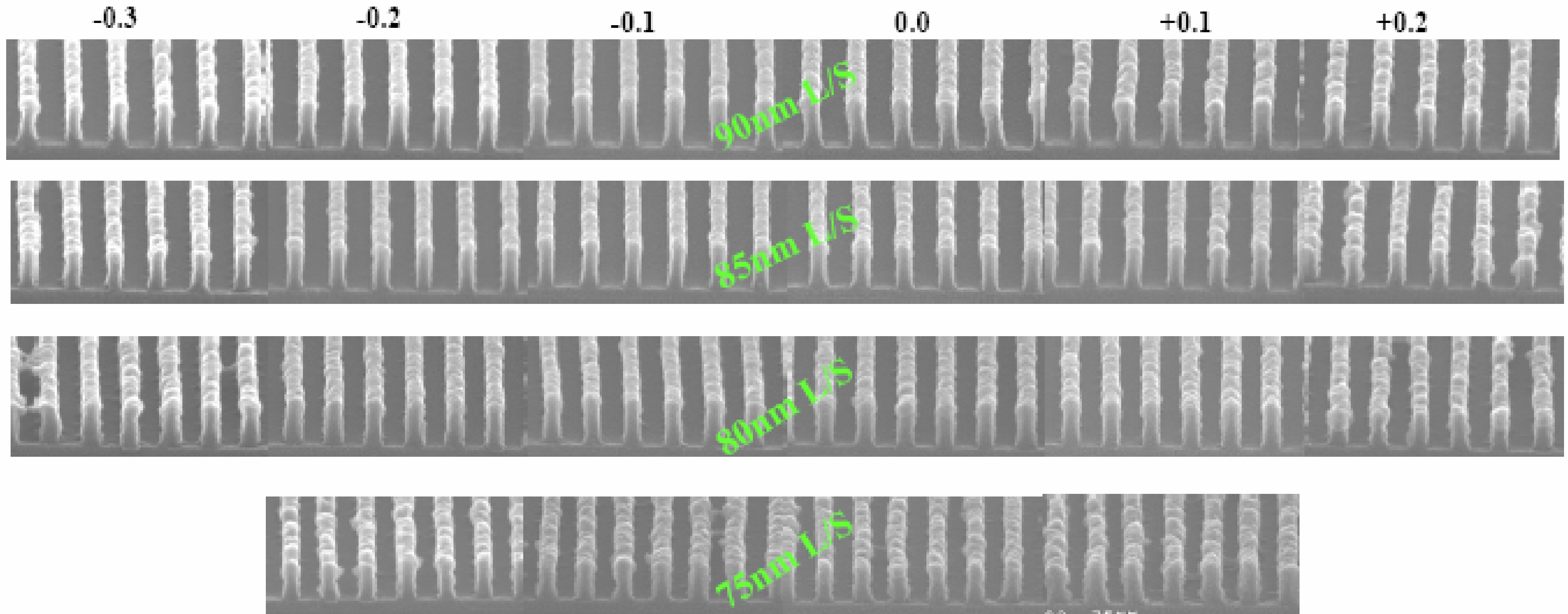
$$\text{DOF} = k_2 \frac{\lambda}{NA^2}$$

Maximized Lithography Margin

- **OPC**
- **Resolution Enhancement Technique**

NTI

Optical Lithography



State of the Art ArF Resolution ☞ 75nm Line & Space

Optical Lithography

Wavelength

g-line : 436nm, Hg-Xe Lamp + Optical Filter

i-line : 365nm, Hg-Xe Lamp + Optical Filter

DUV : 248nm, KrF Excimer Laser

193nm, ArF Excimer Laser

F_2 : 157nm, F_2 Laser

EUV : 13.4nm, Soft X-ray

Exposure Type (Nikon, Cannon, ASML)

Step and Repeat : Stepper

Step and Scan : Scanner

Reduction Ratio

1X(UT), 4X(Scanner), 5X(Stepper), 10X

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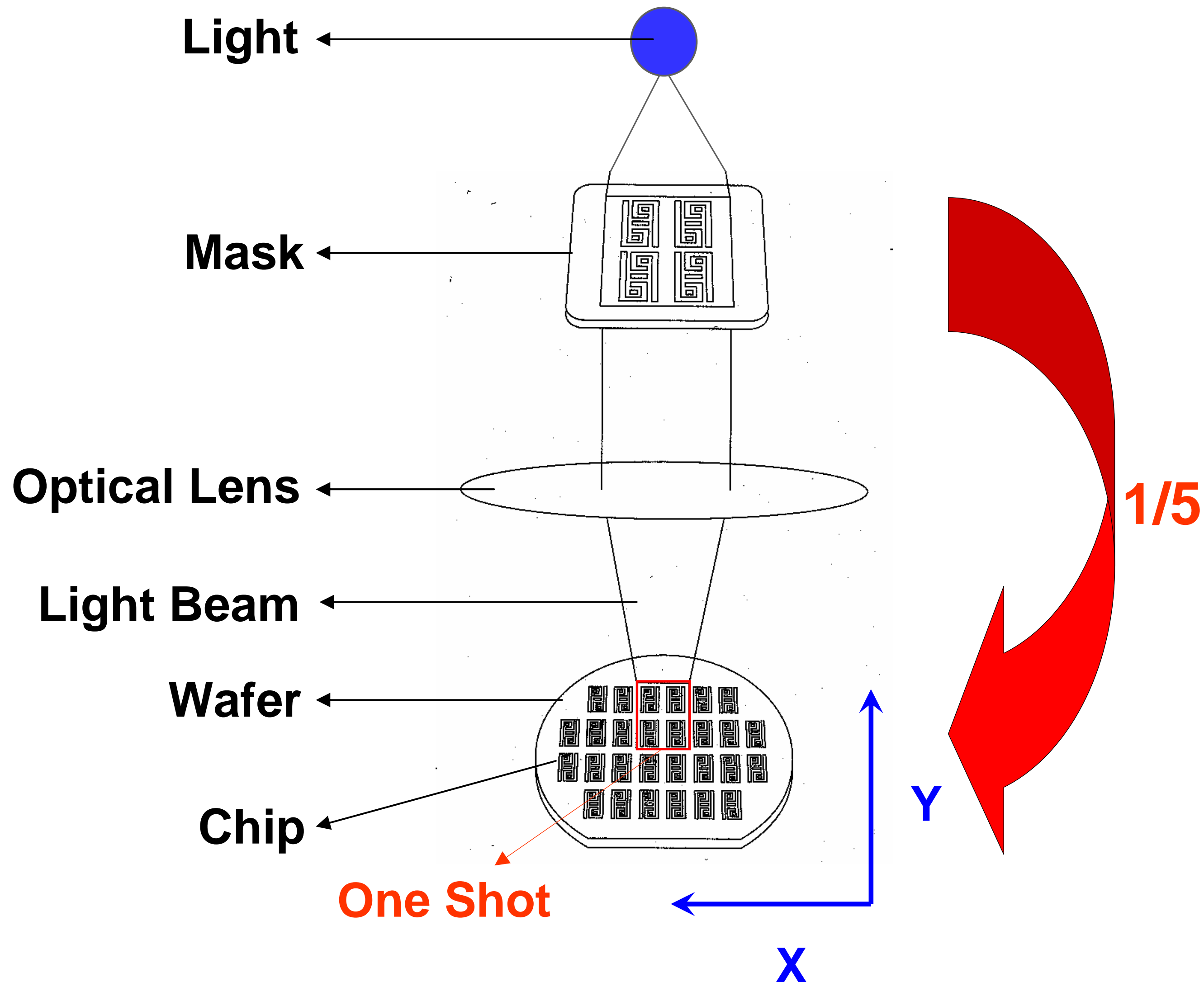
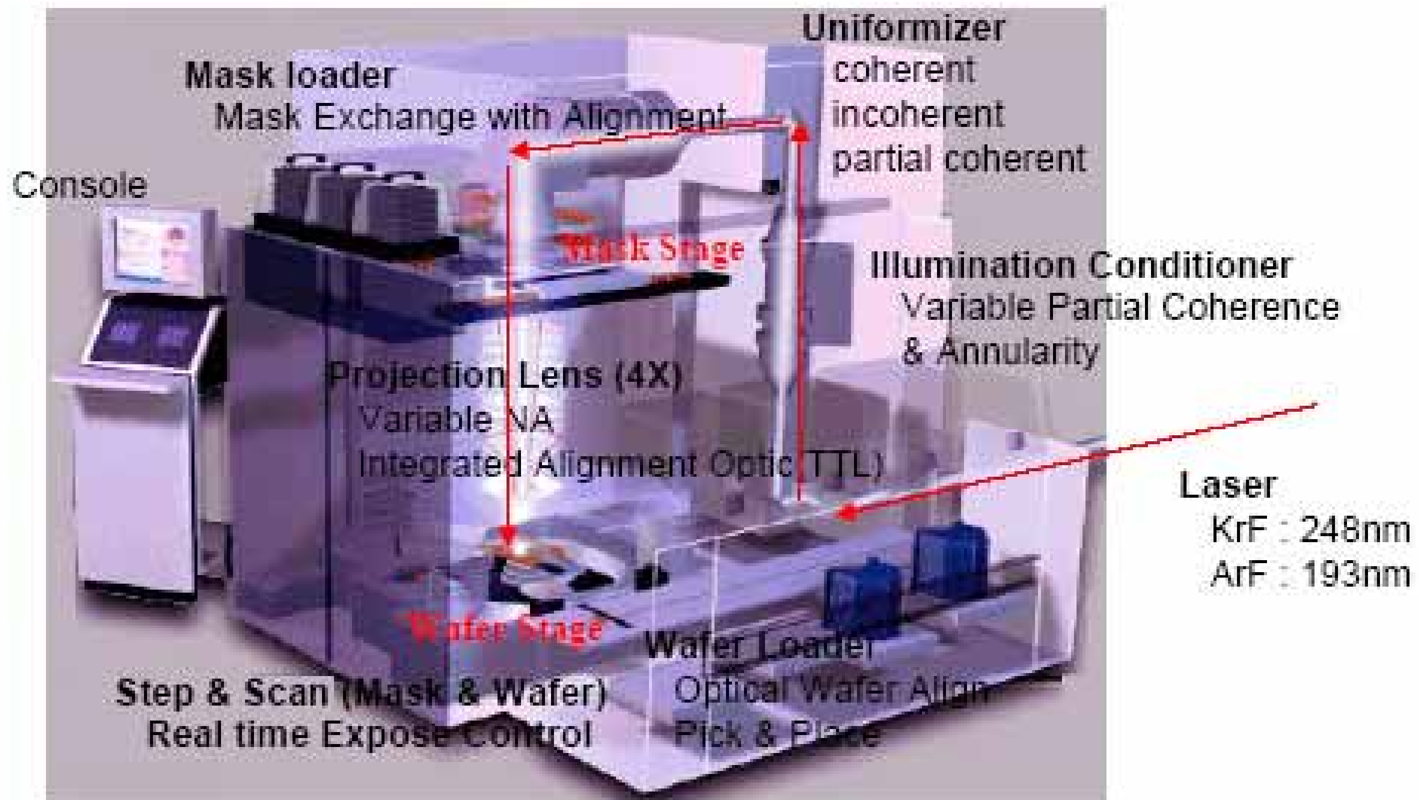
Stepper (Step and Repeat)

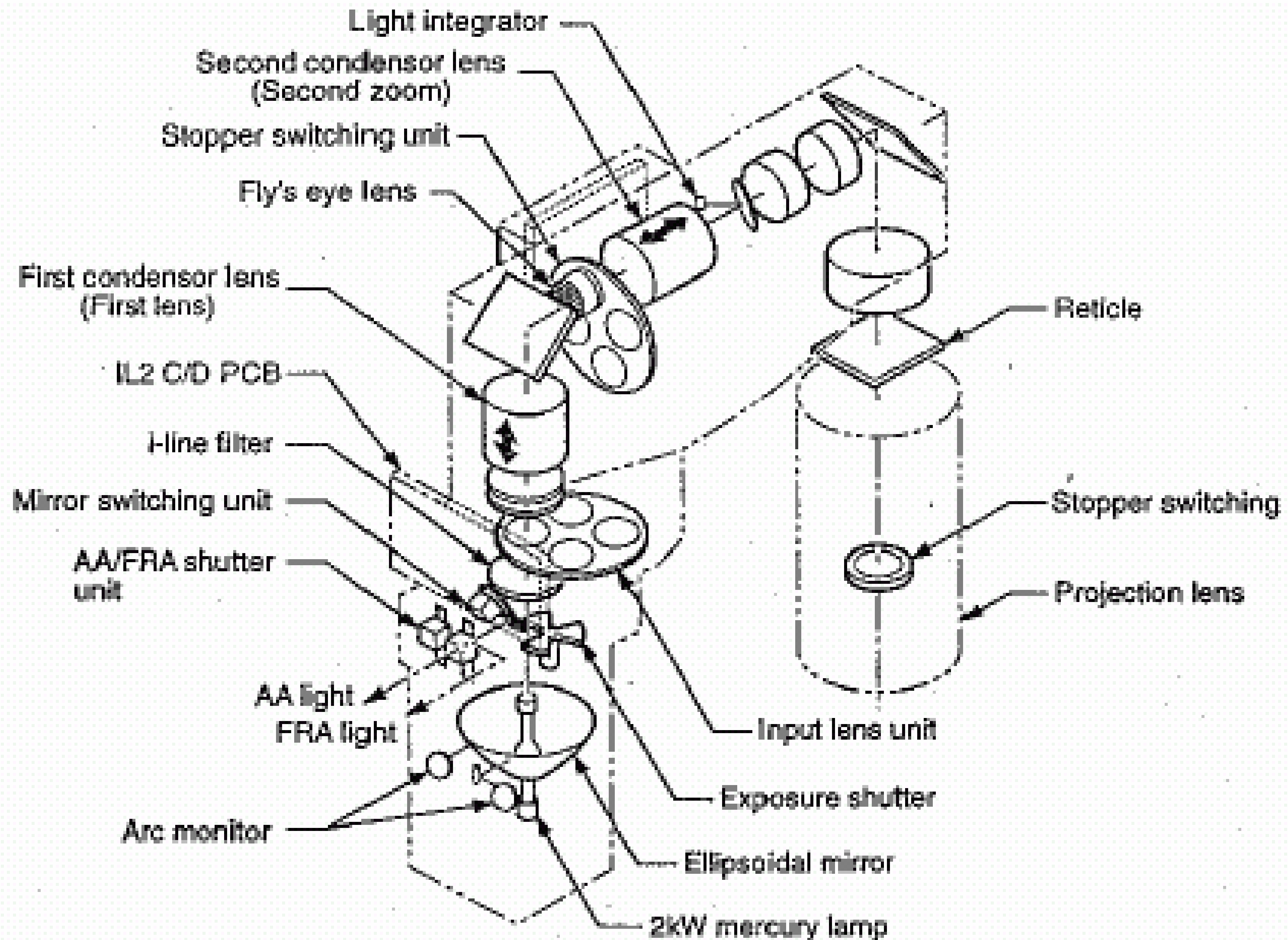


Exposure System

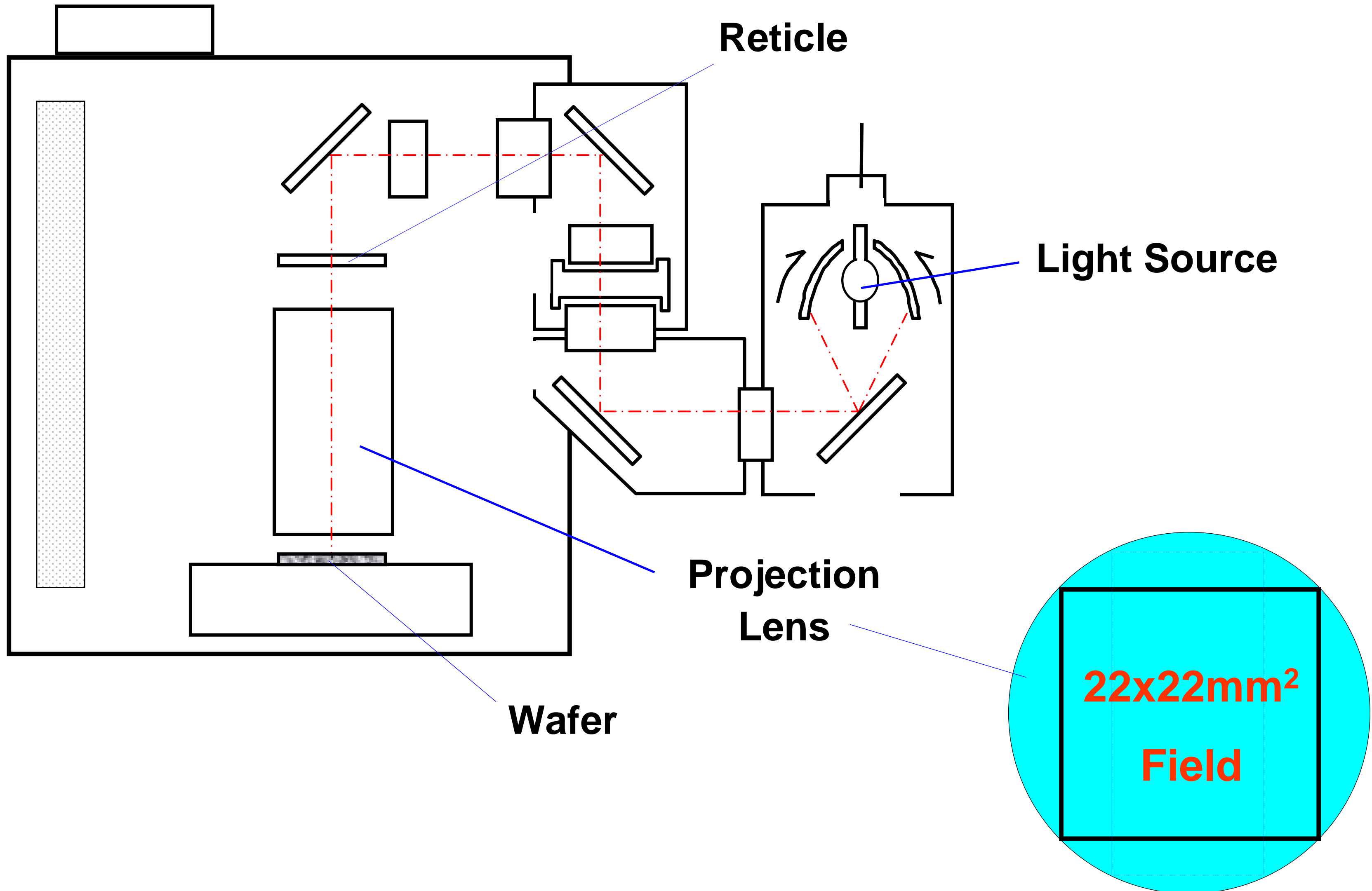


Wafer Exposure System ☞ Step & Scan with Alignment

Optic System of Stepper (Canon)

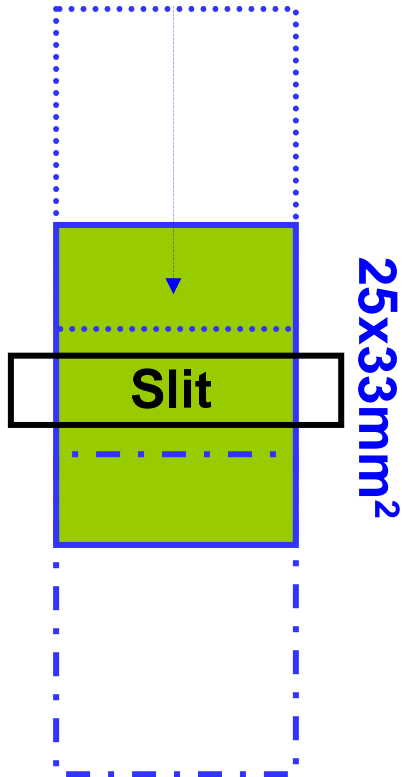


Nikon Stepper Structure



Nikon Scanner

Slit : 8x26mm²



Illumination System

Reticle Scanning Stage

Projection Lens (Slit)

Wafer Scanning Stage

Scanner and Stepper

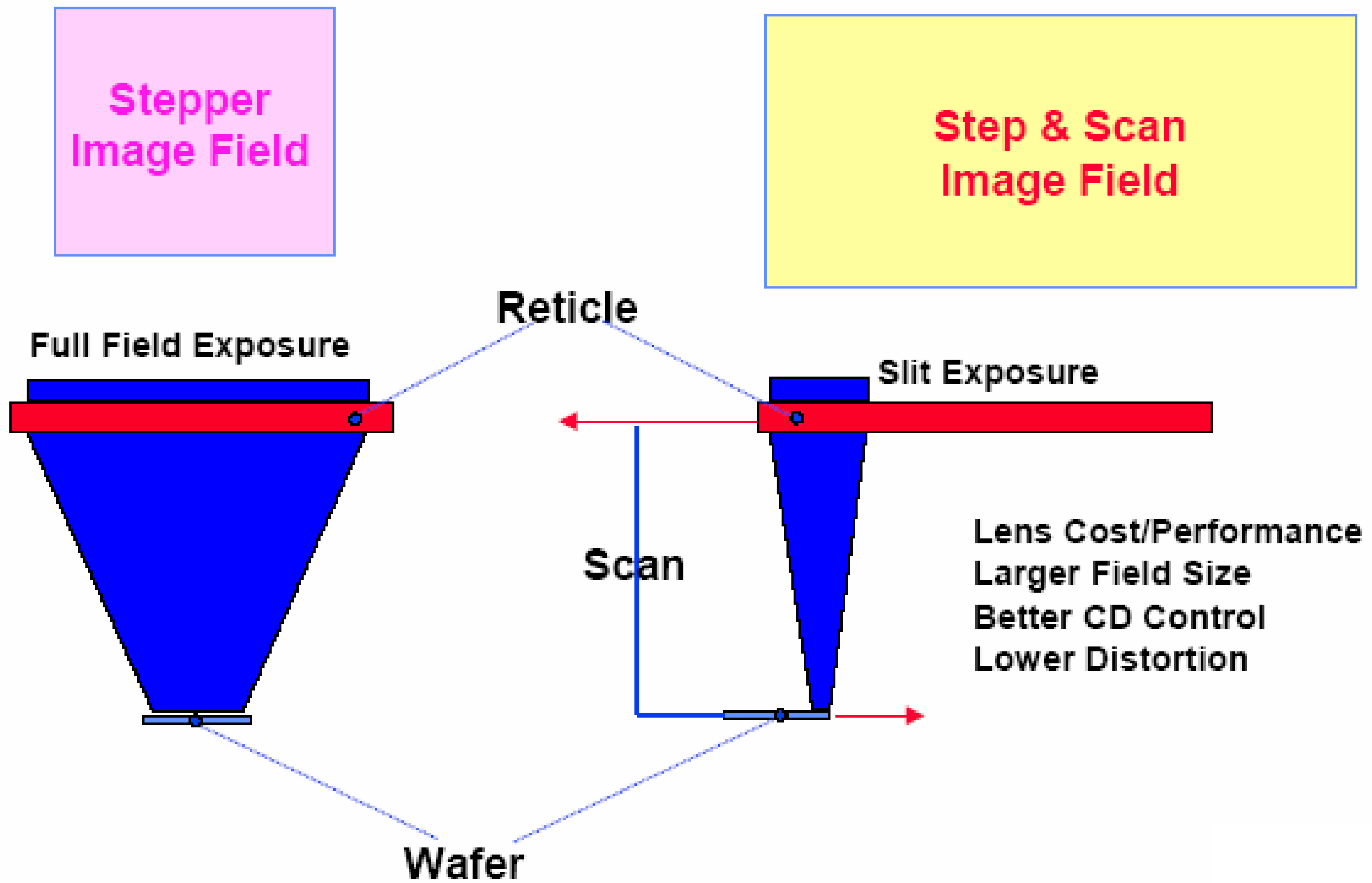


Photo Resist

Resist Tone

Click here

Positive : Exposed Resist (Decomposition)

=> Removed after Development

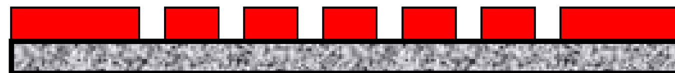
Mask Tone == Resist Pattern Tone

Negative : Exposed Resist (Cross Link)

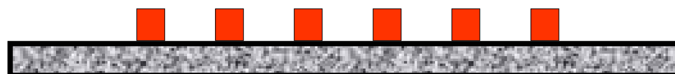
=> Remains after Development

Mask Tone <=> Resist Pattern Tone

Mask



Positive



Negative

Photo Resist

Resist Component (Sumitomo, TOK, JSR, Shin-Etsu)

Sensitizer : Reaction to Light

Resin : Masking to Etching

Solvent : Viscosity Adjustment for Coating

Thickness = Thickness(Spin Speed, Viscosity, Others)

i-line Resist

PAC(Photo Acid Compound) + Novolac + Solvent

Exposed PAC => Decomposition => Higher Dissolution Rate

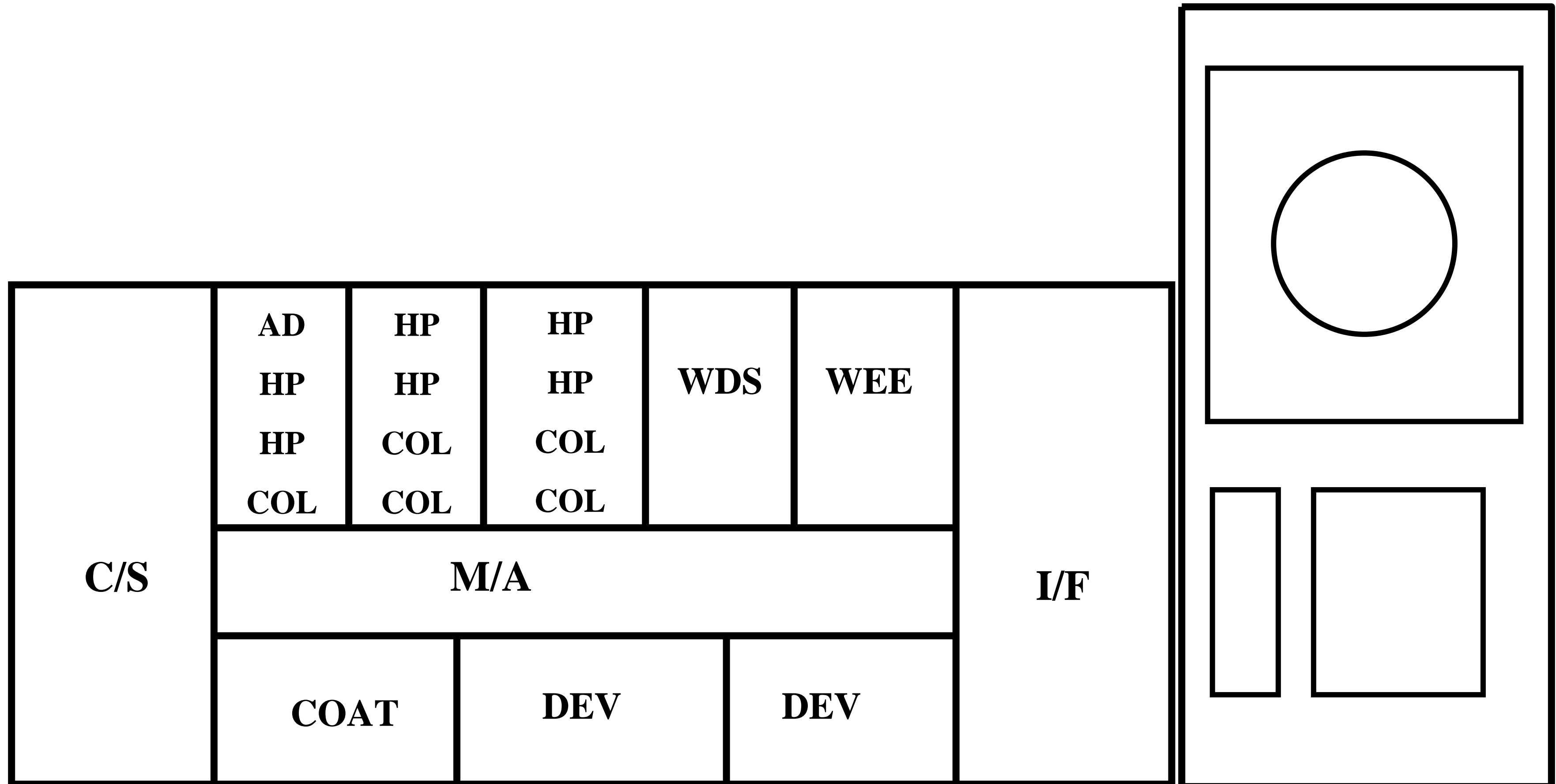
DUV (KrF) Resist (Chemically Amplified Resist)

PAG(Photo Acid Generator : Proton-Catalyst) + PHS + Solvent

Proton Catalyze Decomposition or Cross-linking

PHS => Acetal(Low Temp) / t-BOC / Acrylate(High Temp)

In-line Process



Nikon Stepper & Scanner

NSR-2205i14E

NSR-S203B

NSR-S204B

ASML Scanner

Click Here

TEL Track System

Mark-8

ACT-8

CD-SEM System

PCD001 : S-9220 (Hitachi)

PCD003 : S-9260 (Hitachi)

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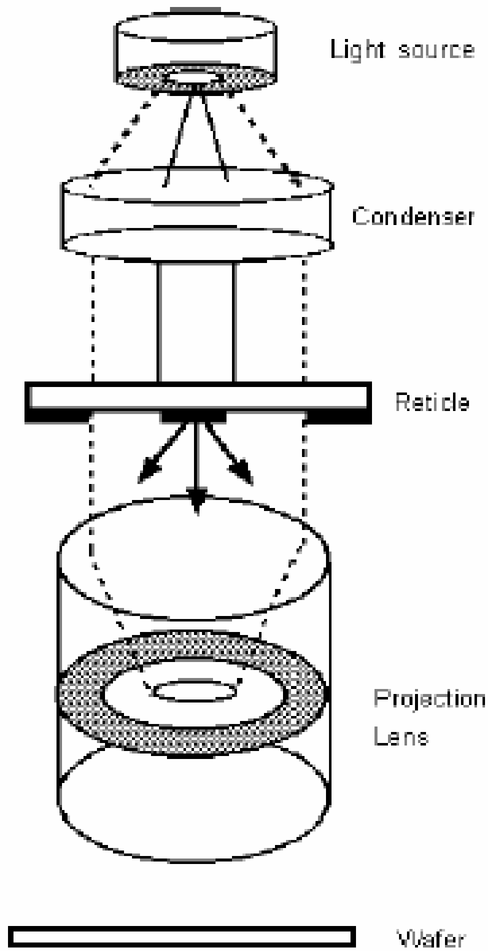
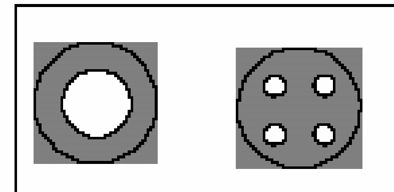
Exposure 원리 개념도



Light source
- shorter wavelength(i-line, KrF, ArF)

Illumination: OAI
- **annular**
- **dipole**
- **quadrupole**

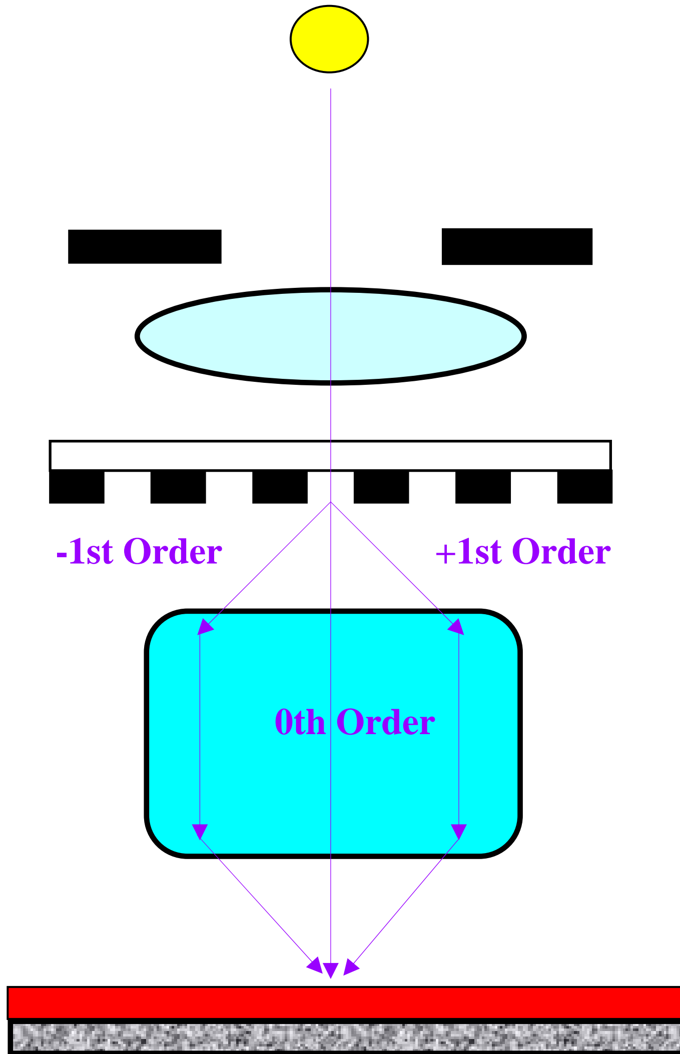


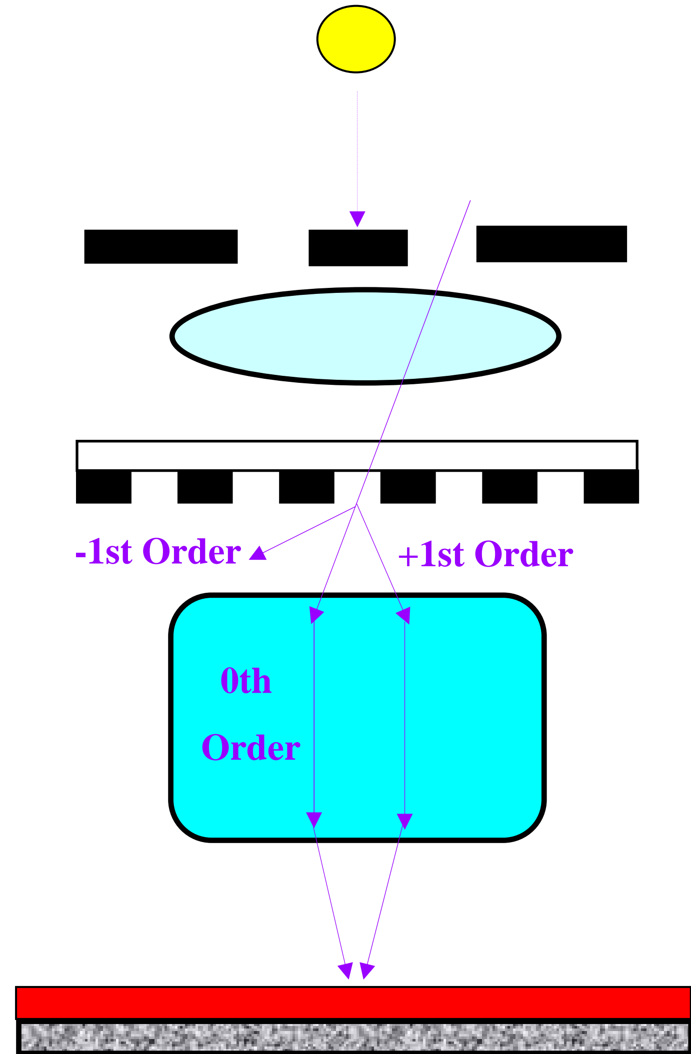
Mask
- **PSM**
- **OPC mask**

Projection lens
- high NA
- pupil filtering

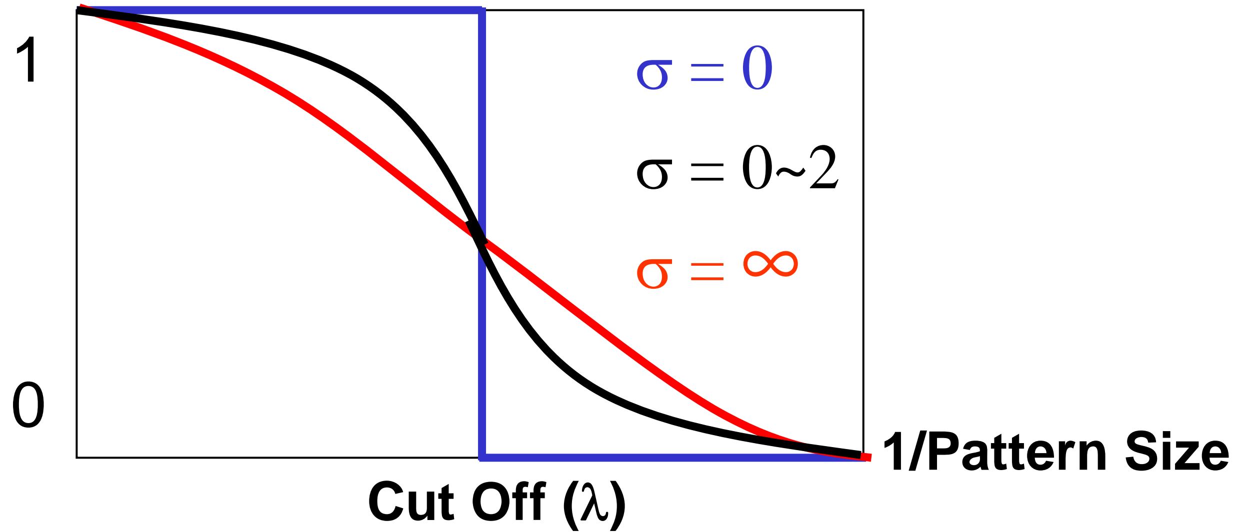
Wafer
- high resolution resist
- TSI
- FLEX(Focus Latitude Enhancement Exposure)

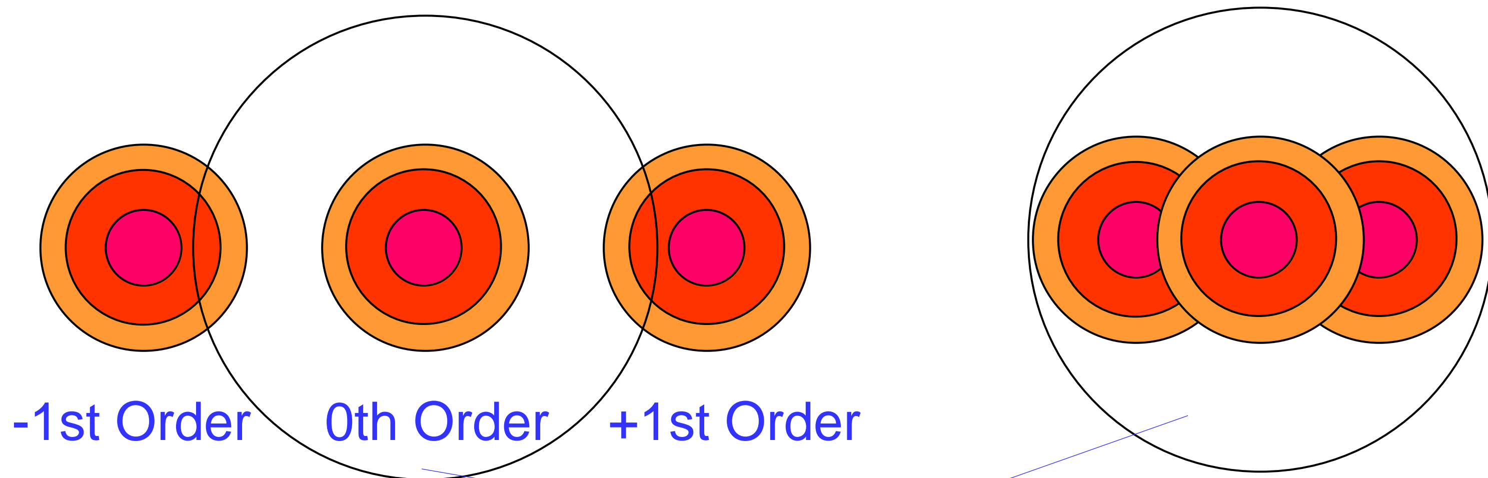
Off-axis Illumination





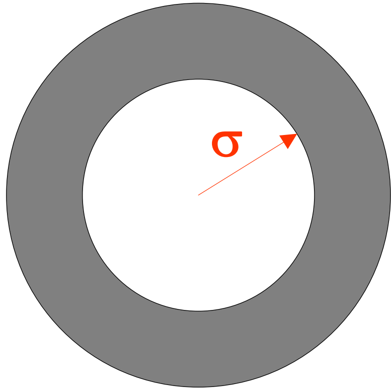
Coherence Factor (σ) Effect



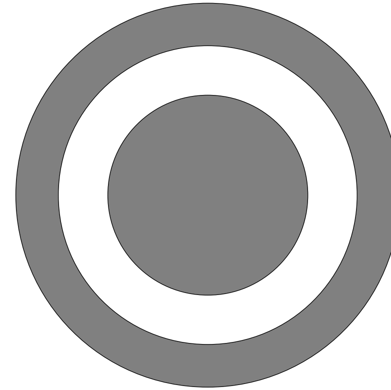


Projection Lens (Diameter ~ NA)

Apertures for Off-axis Illumination

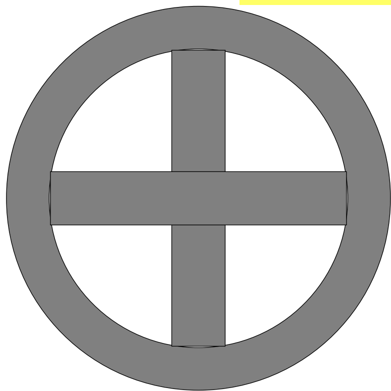


Conventional

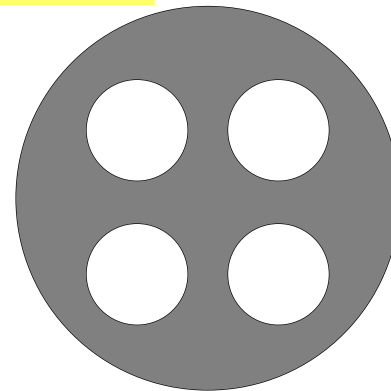


Annular

Modified Illum. / OAI?

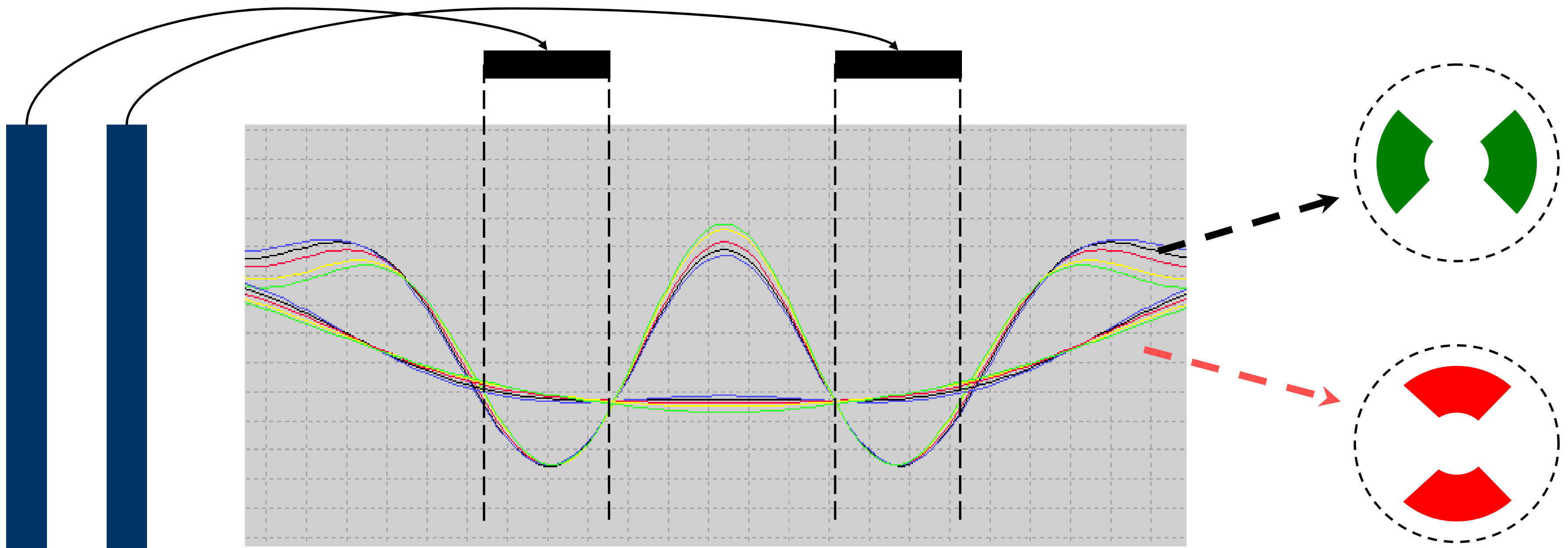


SHRINC

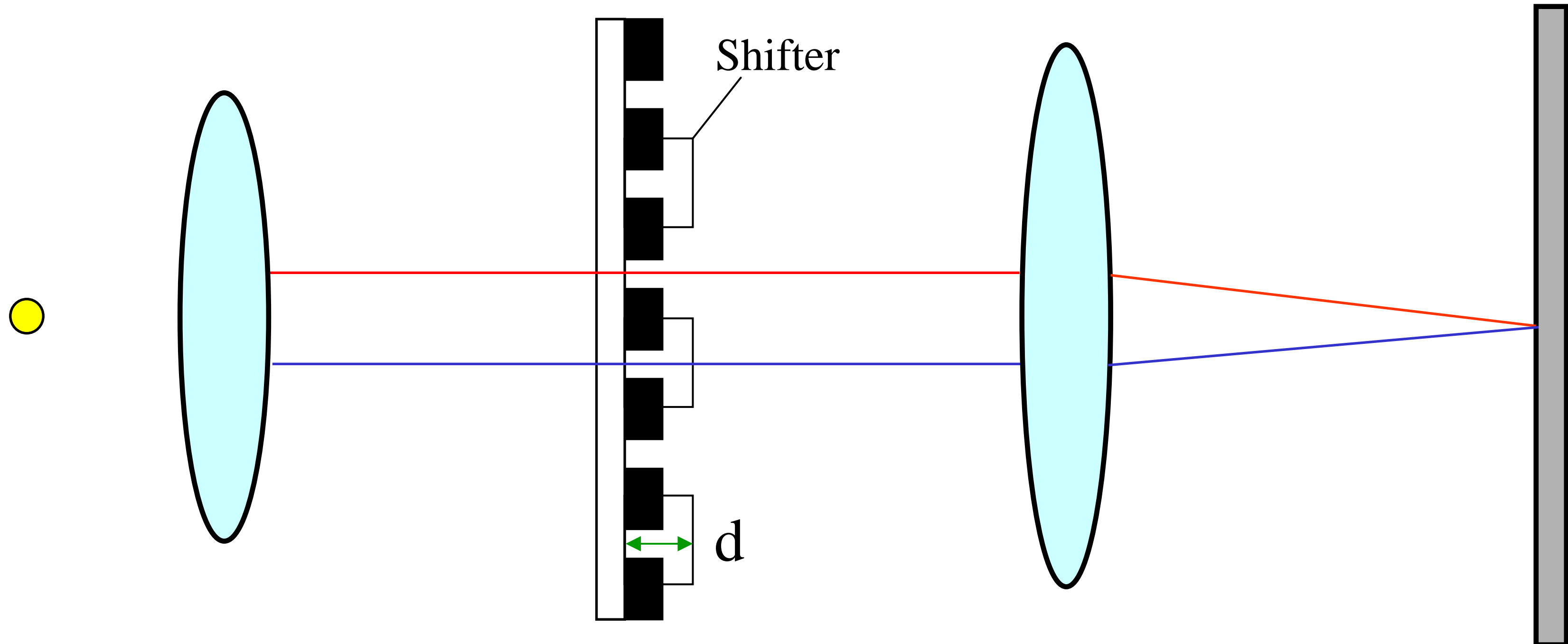


Quadruple

Dipole



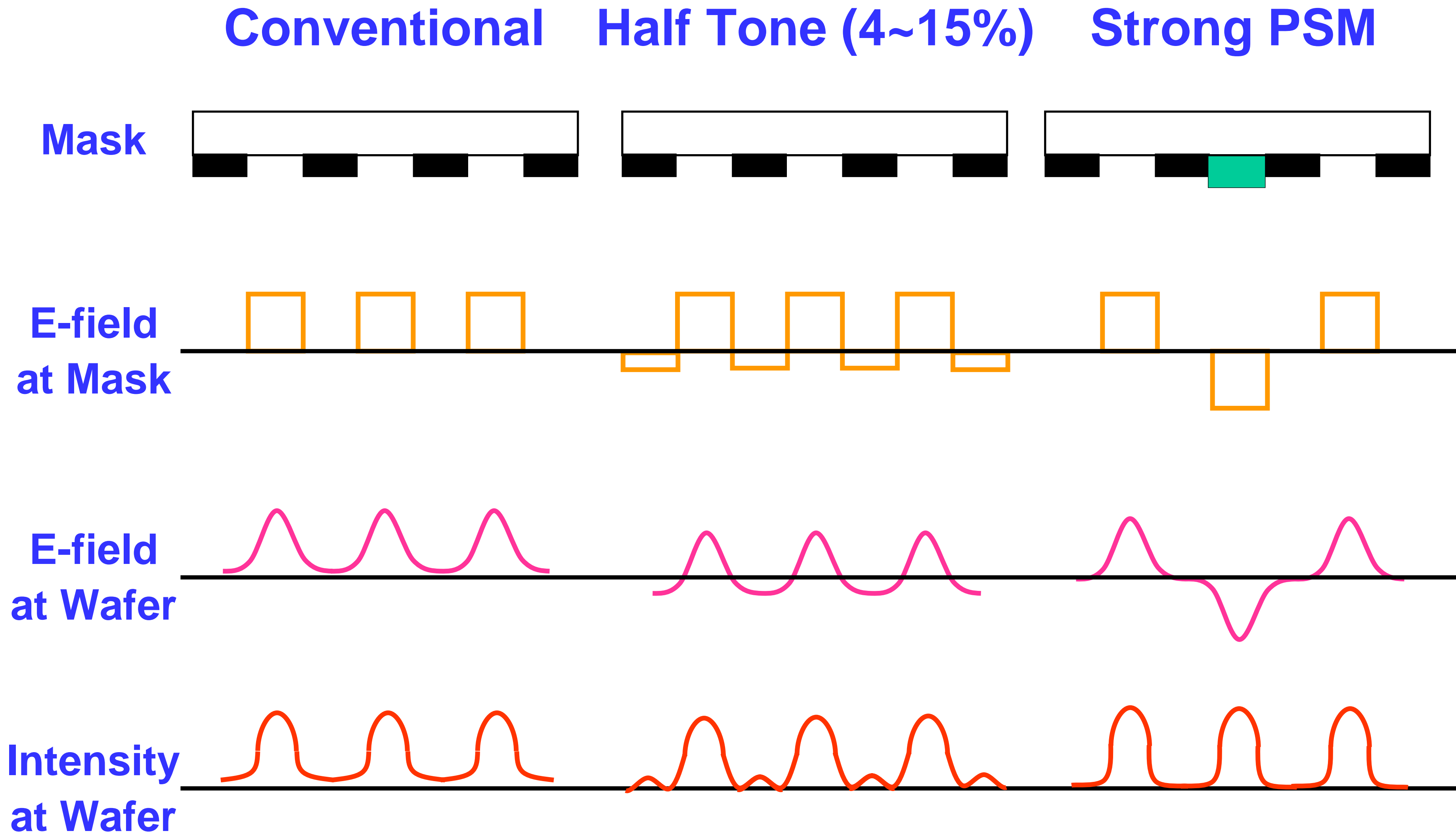
Phase Shift Mask Making Formula



$$\textbf{OPD} = d(n_{shifter} - n_{air})$$

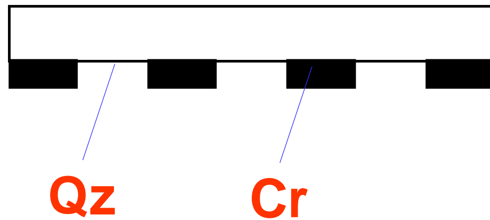
$$= \frac{1}{2}\lambda$$

Phase Shift Mask

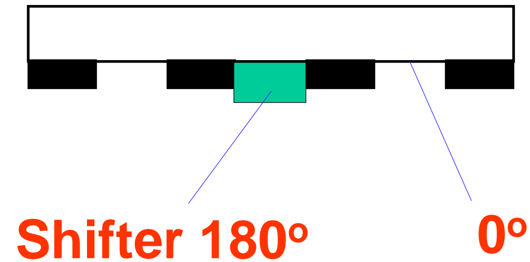


Strong PSM

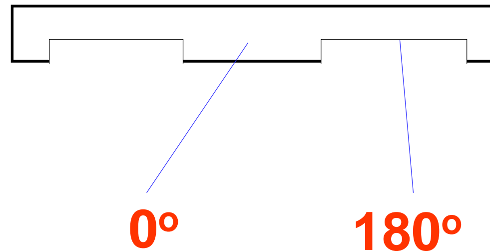
Conventional



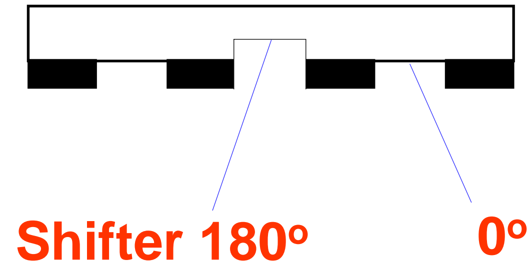
Alternating (Old)



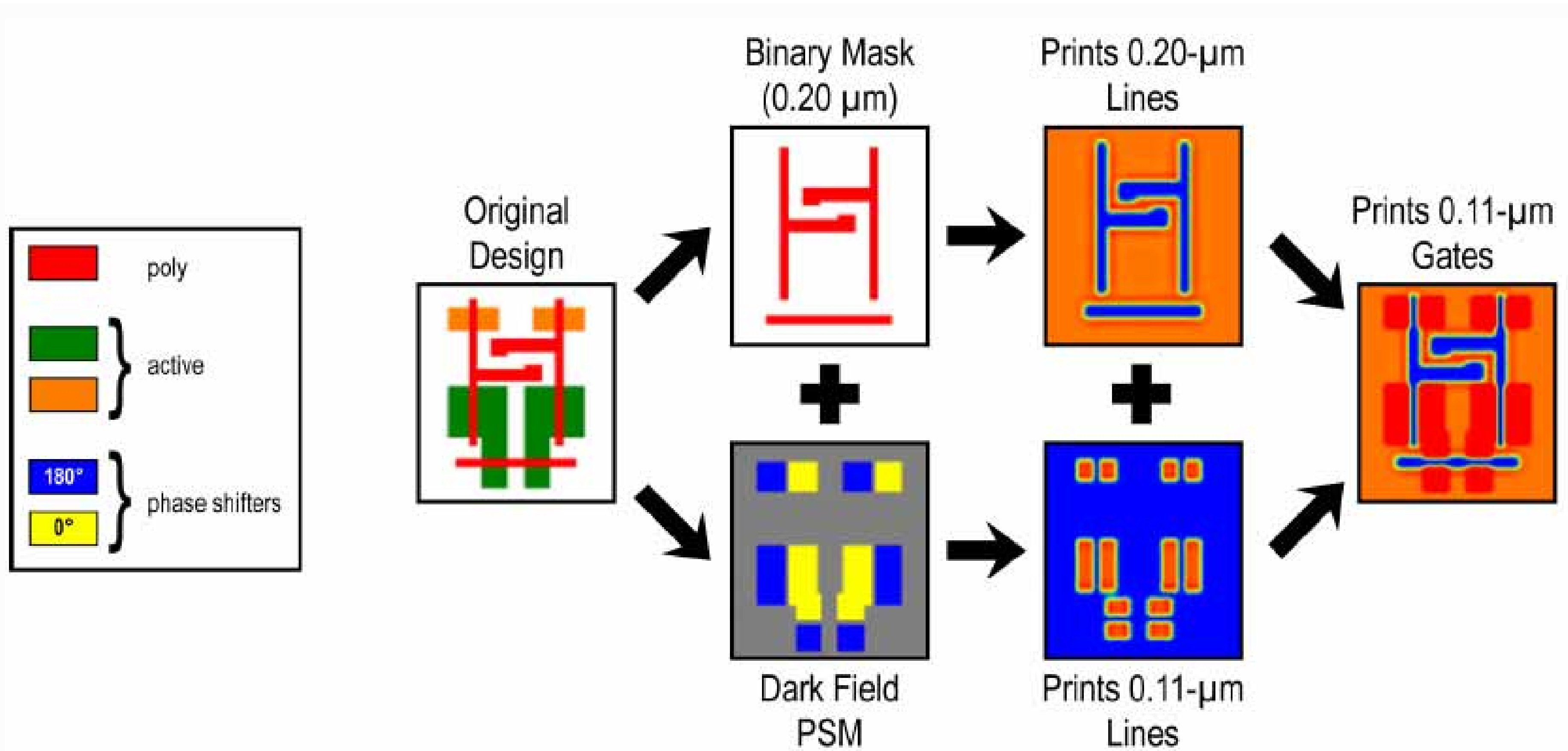
Cr-less (Qz Etch)



Alternating

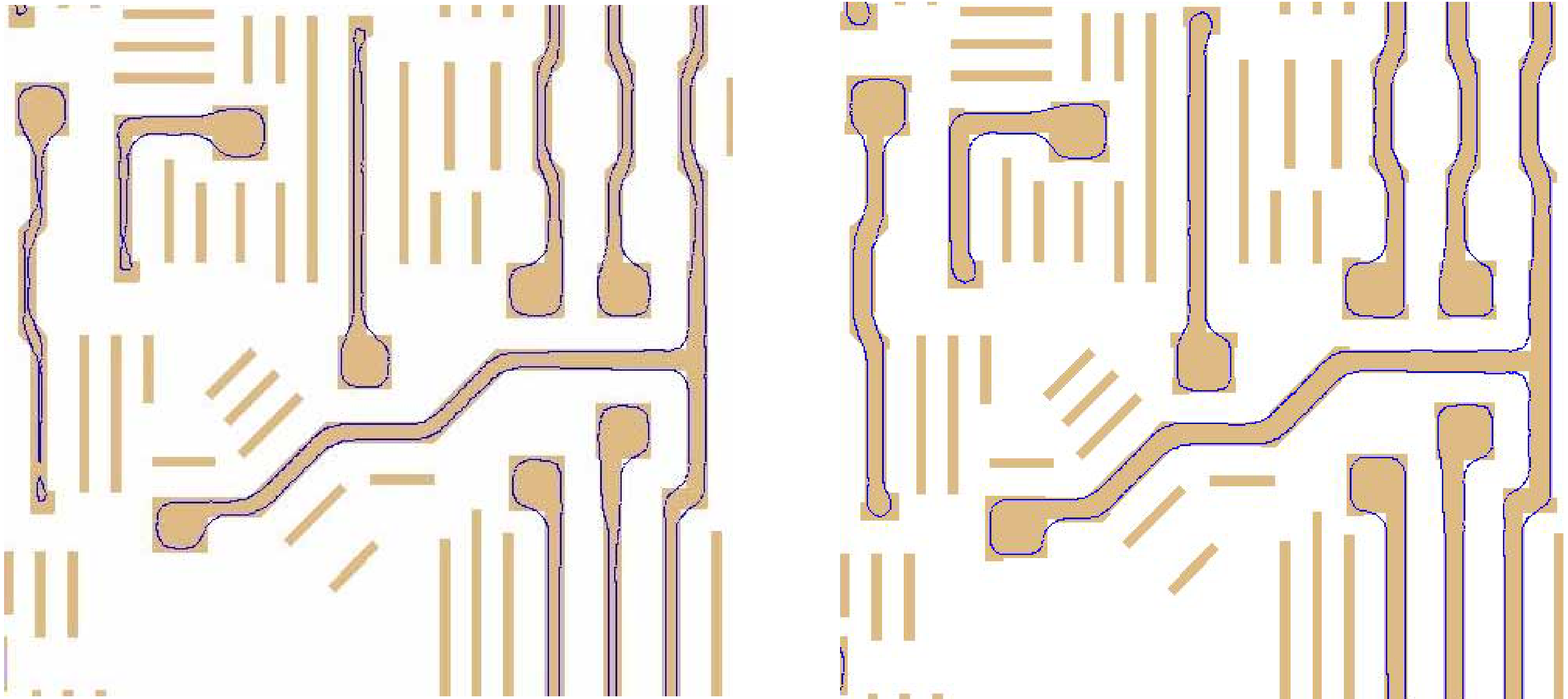


Actual PSM Application



Double Exposure Process

Sub Resolution Assist Features

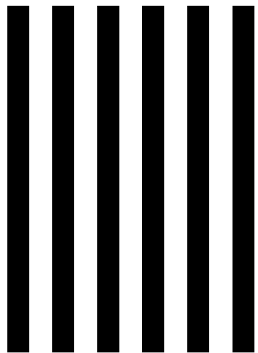


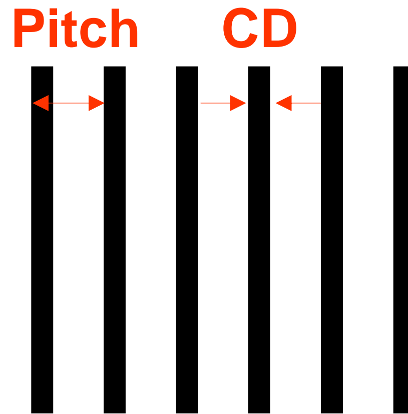
SRAF (OPC) => Process Margin Improvement

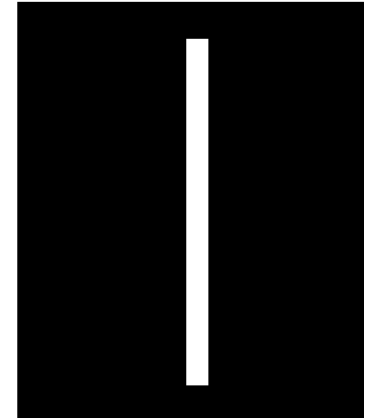
Pattern Type

Line and Space Pattern

(Pitch, Duty Ratio=Line:Space CD)





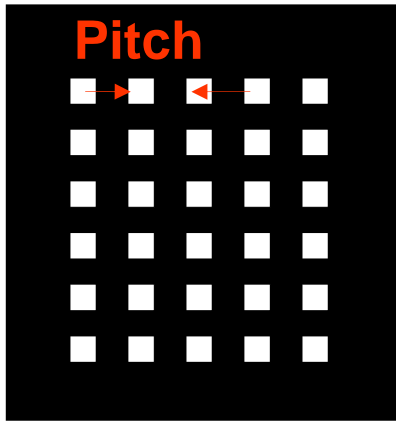


1:1 L/S　　1:2 L/S　　Iso Line　　Iso Space

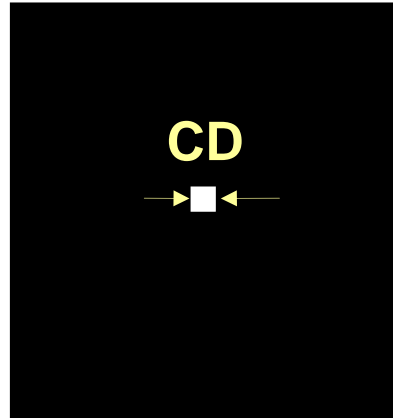
Pattern Type

Contact Hole (Island) Pattern

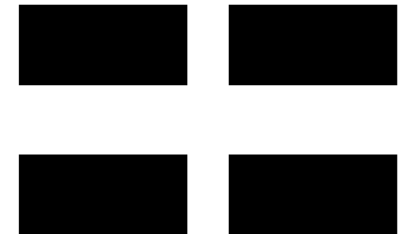
(Pitch, Duty Ratio=Contact CD : Spacing)



1:1 C/H

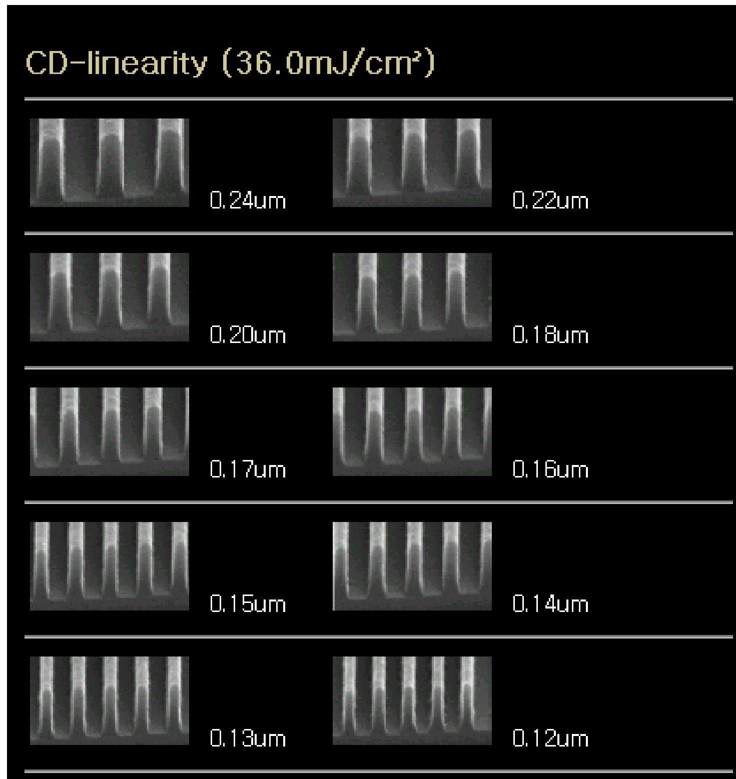


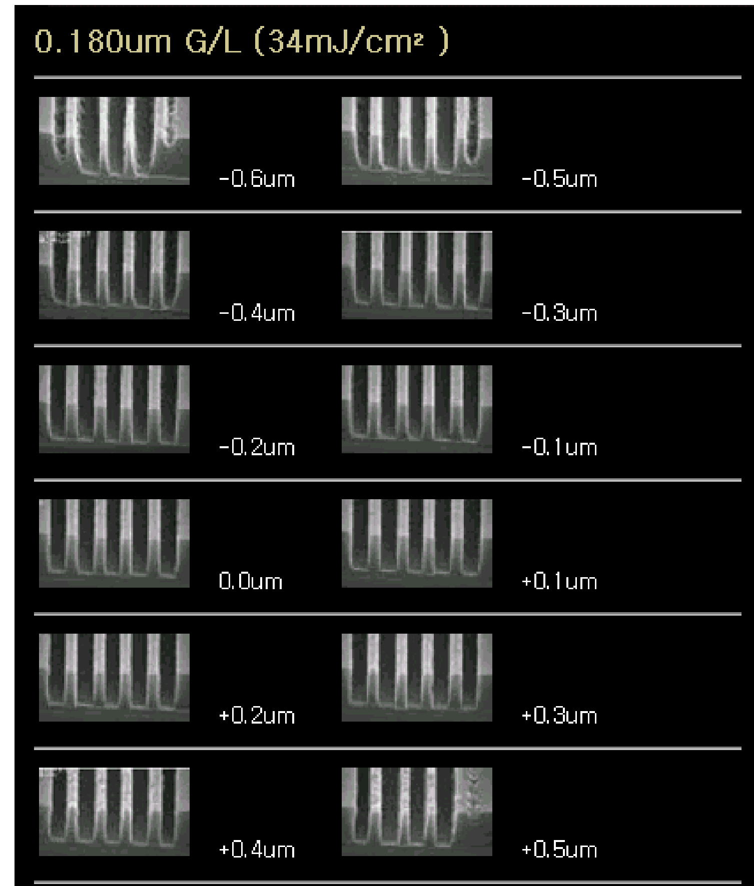
Iso C/H



Island Pattern

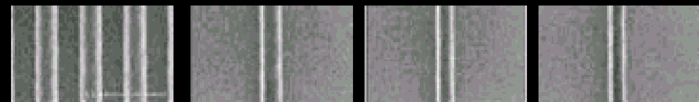
CD Linearity & Focus Margin





Top Down Window

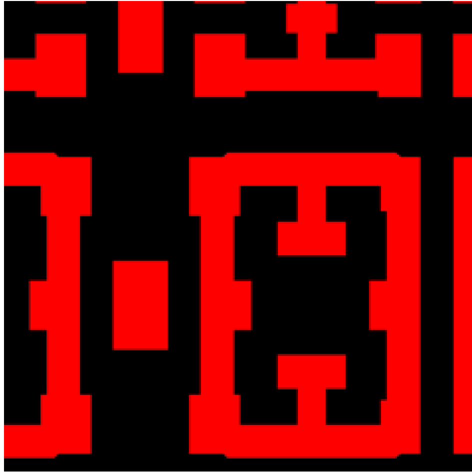
0.180um G/L (34mJ/cm²) 0.180um I/L (29mJ/cm²) 0.160um I/L (29mJ/cm²) 0.140um G/L (29mJ/cm²)



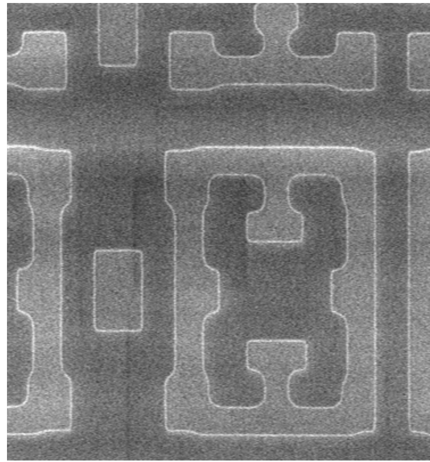
Shin-Etsu Data

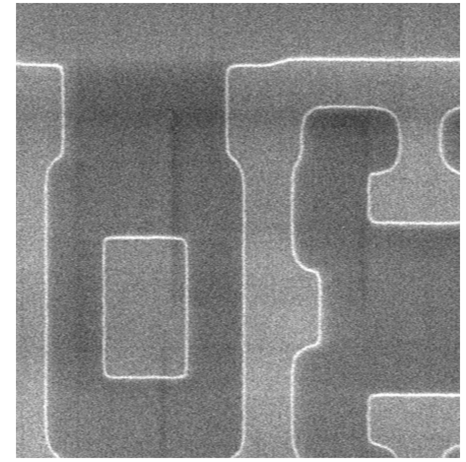
Actual Device Pattern

Moat



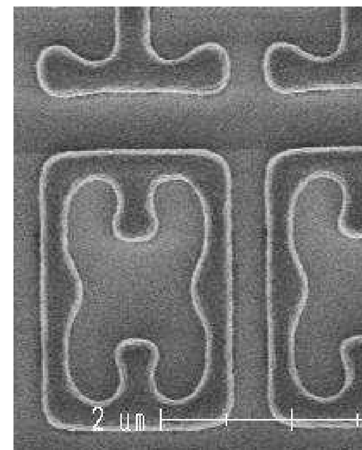
Design





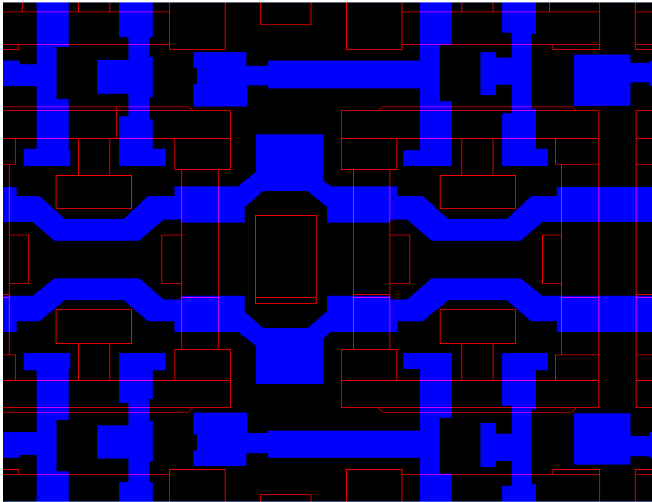
Mask Pattern (Cr / Quartz)

Resist Pattern on Wafer =>

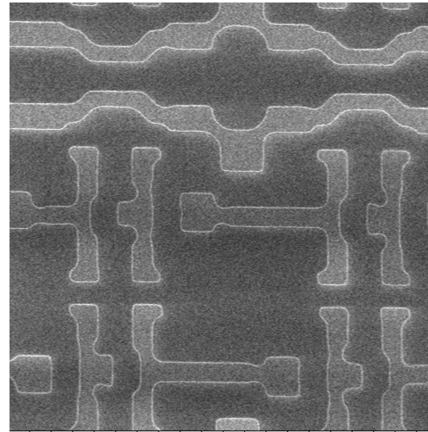


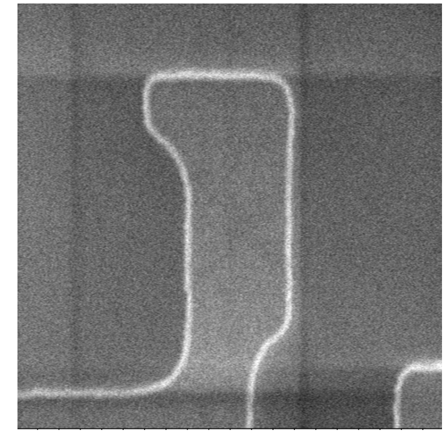
Actual Device Pattern

Gate



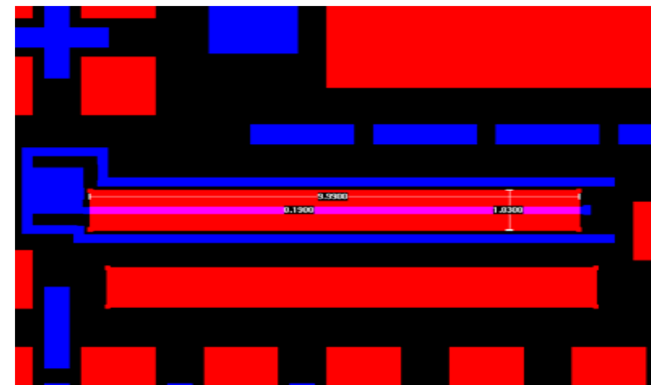
Design





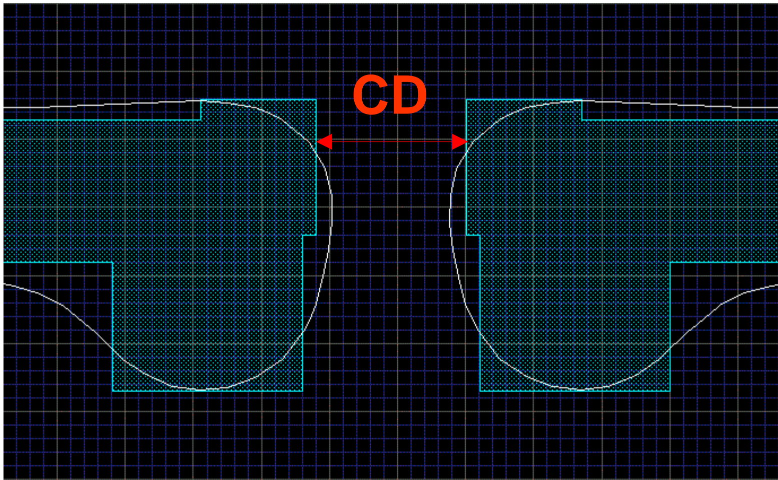
Mask Pattern (Cr / Quartz)

CD Target Pattern =>

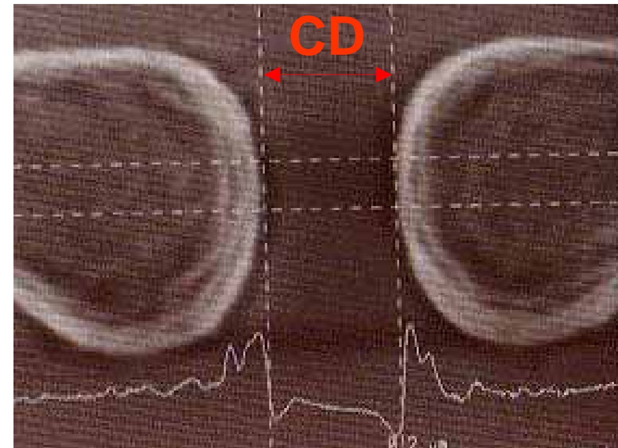


Actual Device Pattern

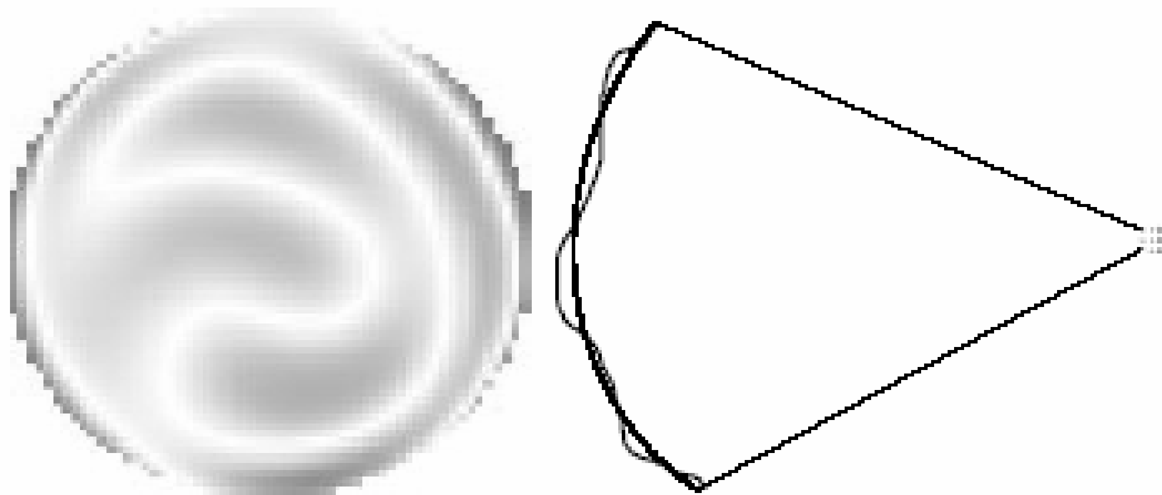
Mask Design / Simulation Data



CD SEM Measurement after Development



Aberration - Wave Front Deviation

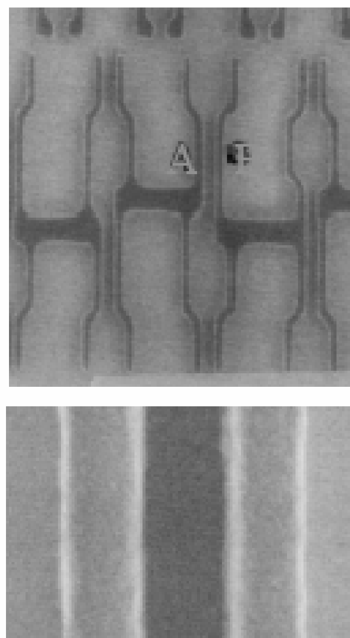


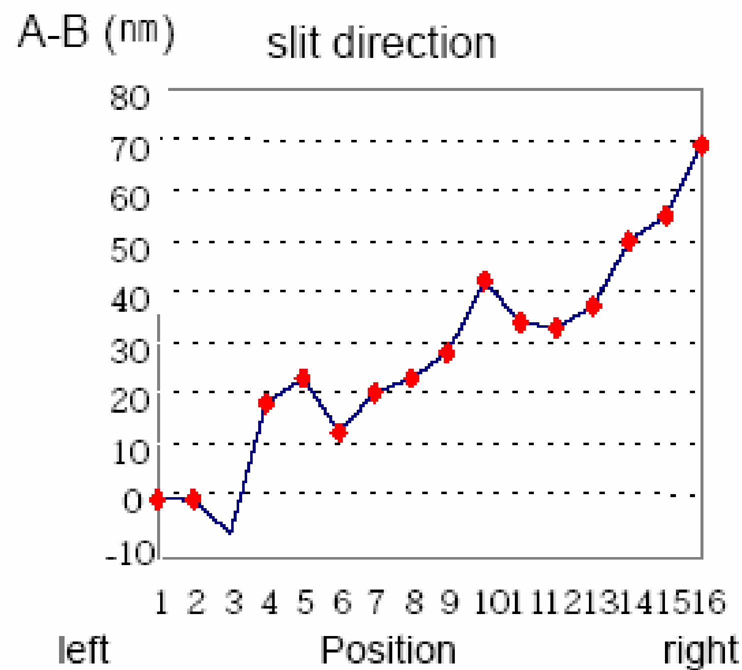
- Lens Design
- Lens Fabrication
- Lens Alignment

Line Pattern CD Asymmetry

☞ double line CD asymmetry due to coma aberration of projection lens

coma → <u>**CD asymmetry**</u> **+ Shift**

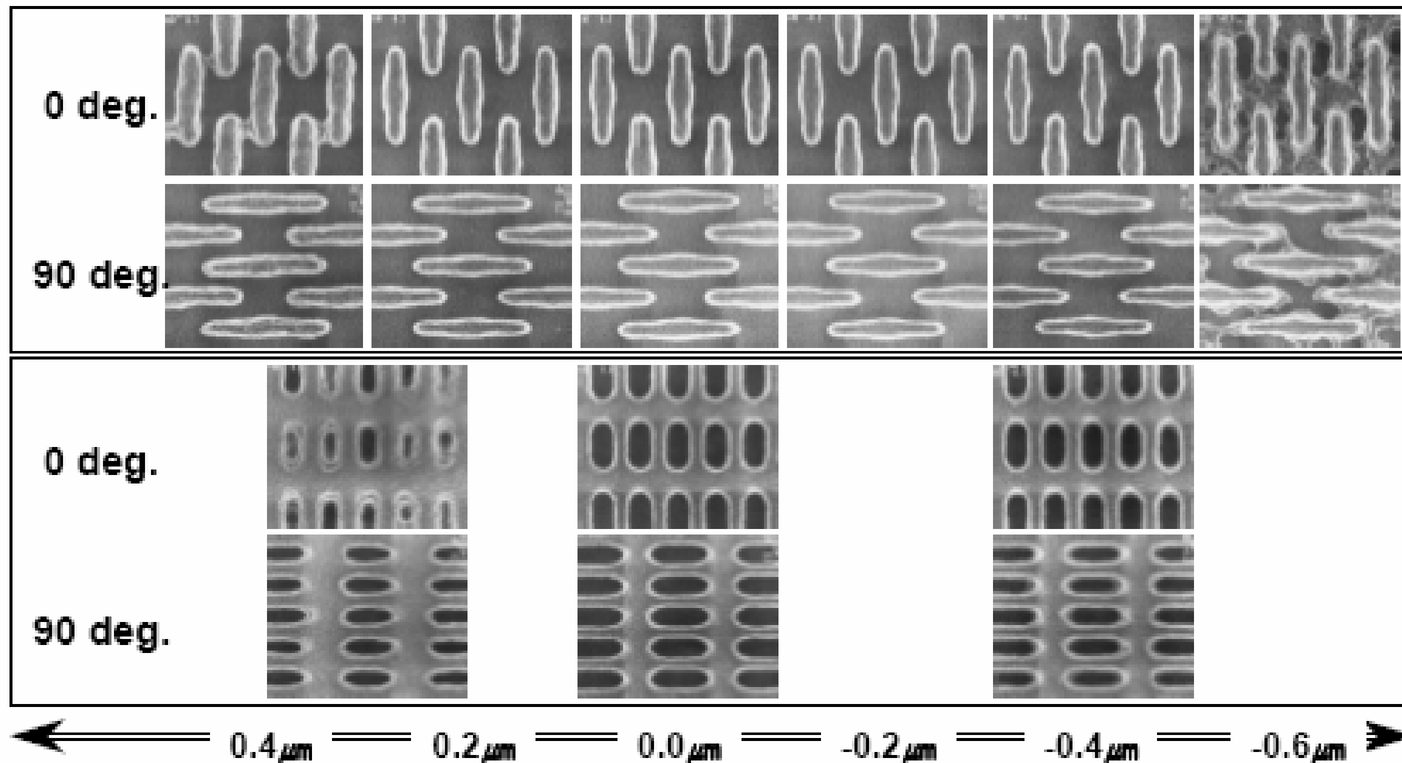




max - min =
ADI 50nm
ACI 69nm

Astigmatism

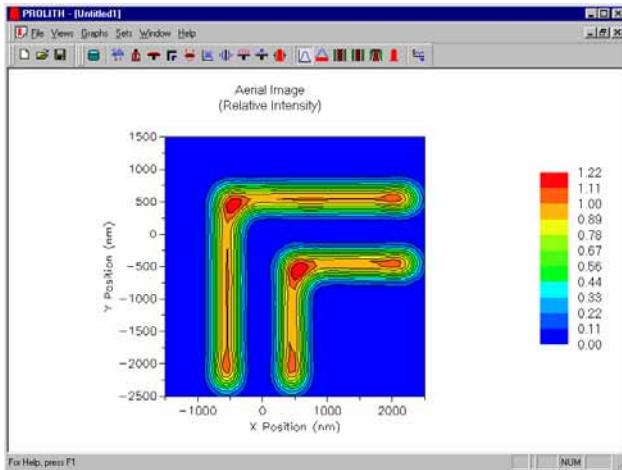
Dependence on Scan Direction



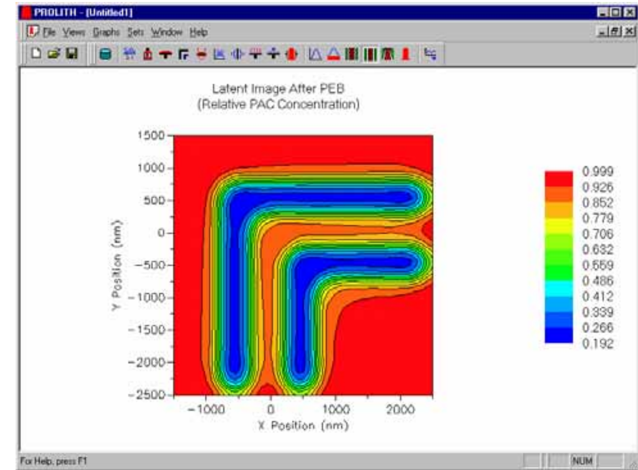
☞ Astigmatism : observed focus shift between H and V pattern (<0.1㎛)

- What is Lithography …
- Resolution Limit and DOF
- Equipment
- Optical Extension
- Simulation in Lithography
- Next Generation of Lithography

Simulation Sequence

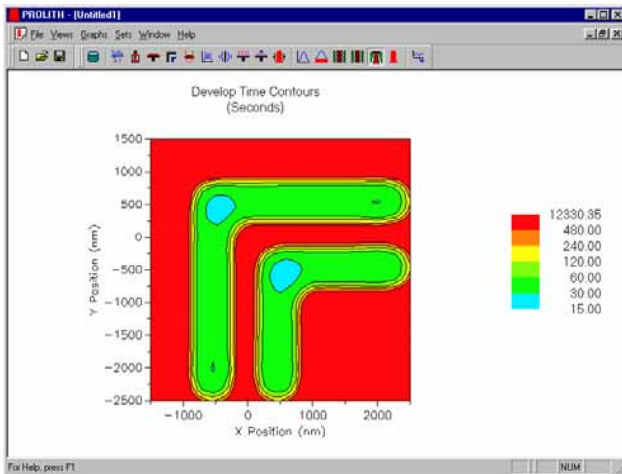


Aerial Image

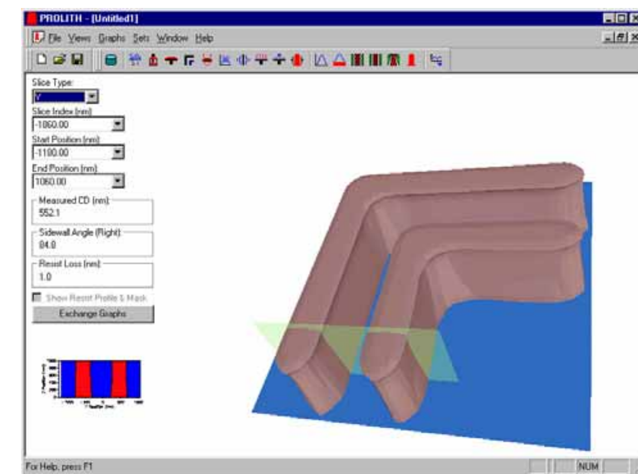


Latent Image

Mask

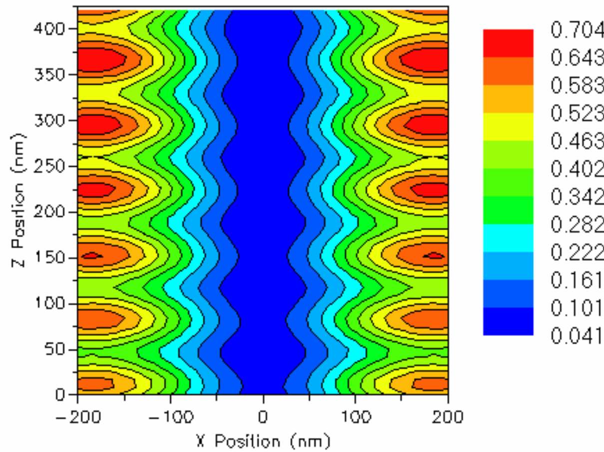


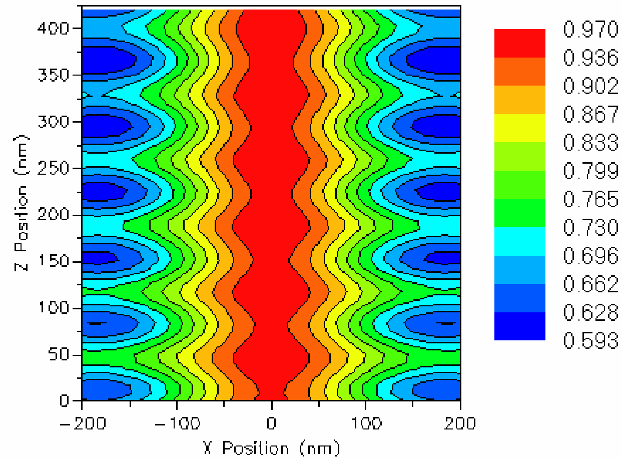
Development Contours

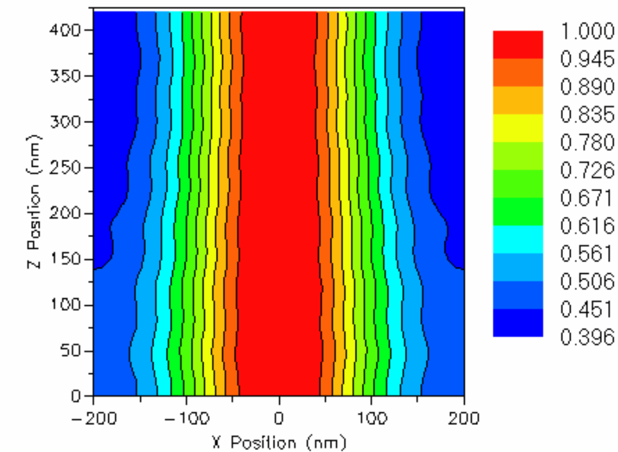


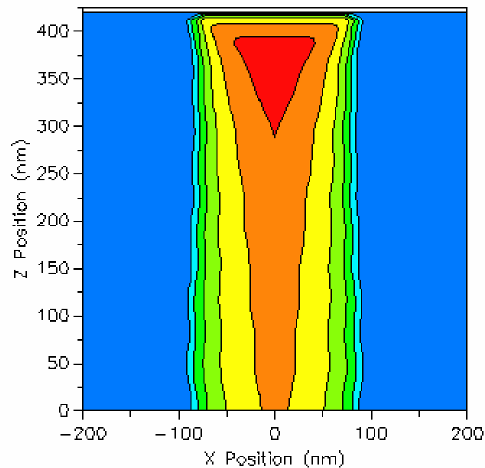
3-D Resist Structure

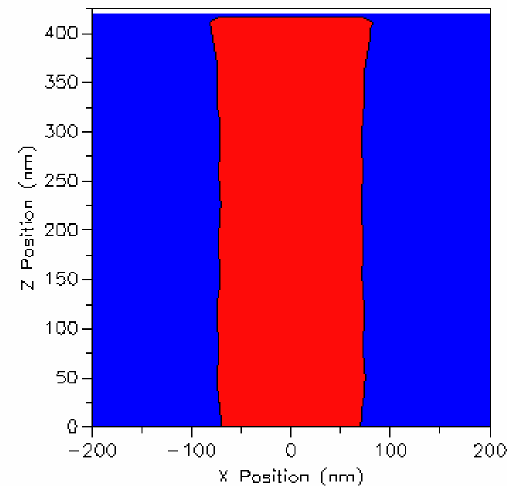
Image Intensity => Resist Pattern







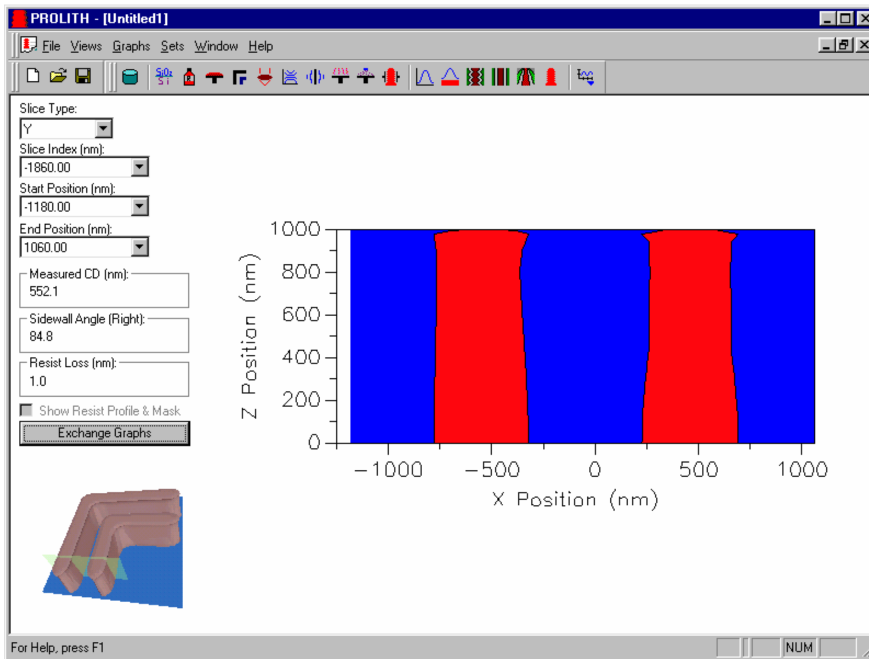




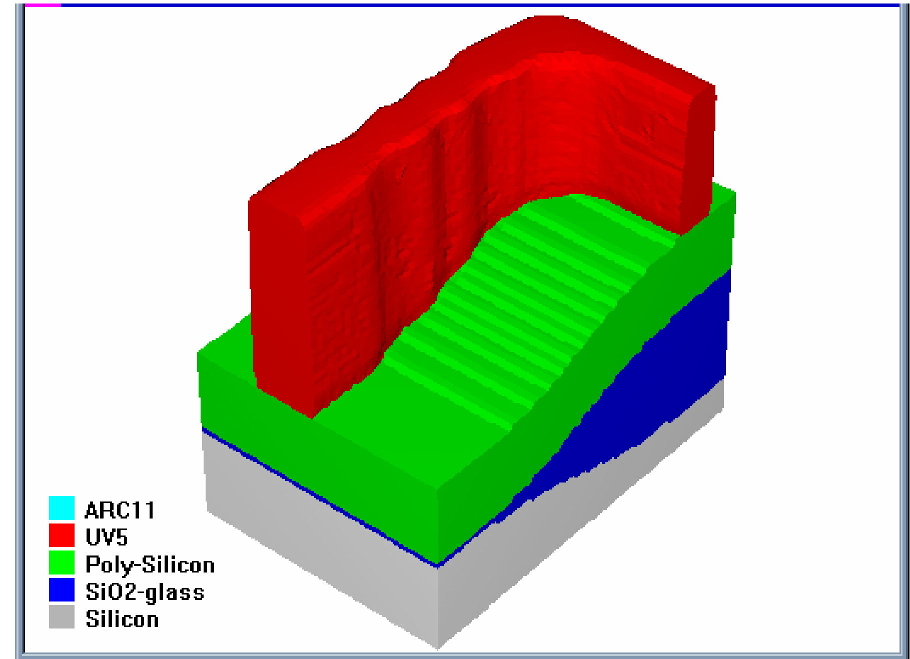
Diffusion

Lithography Sim. Example

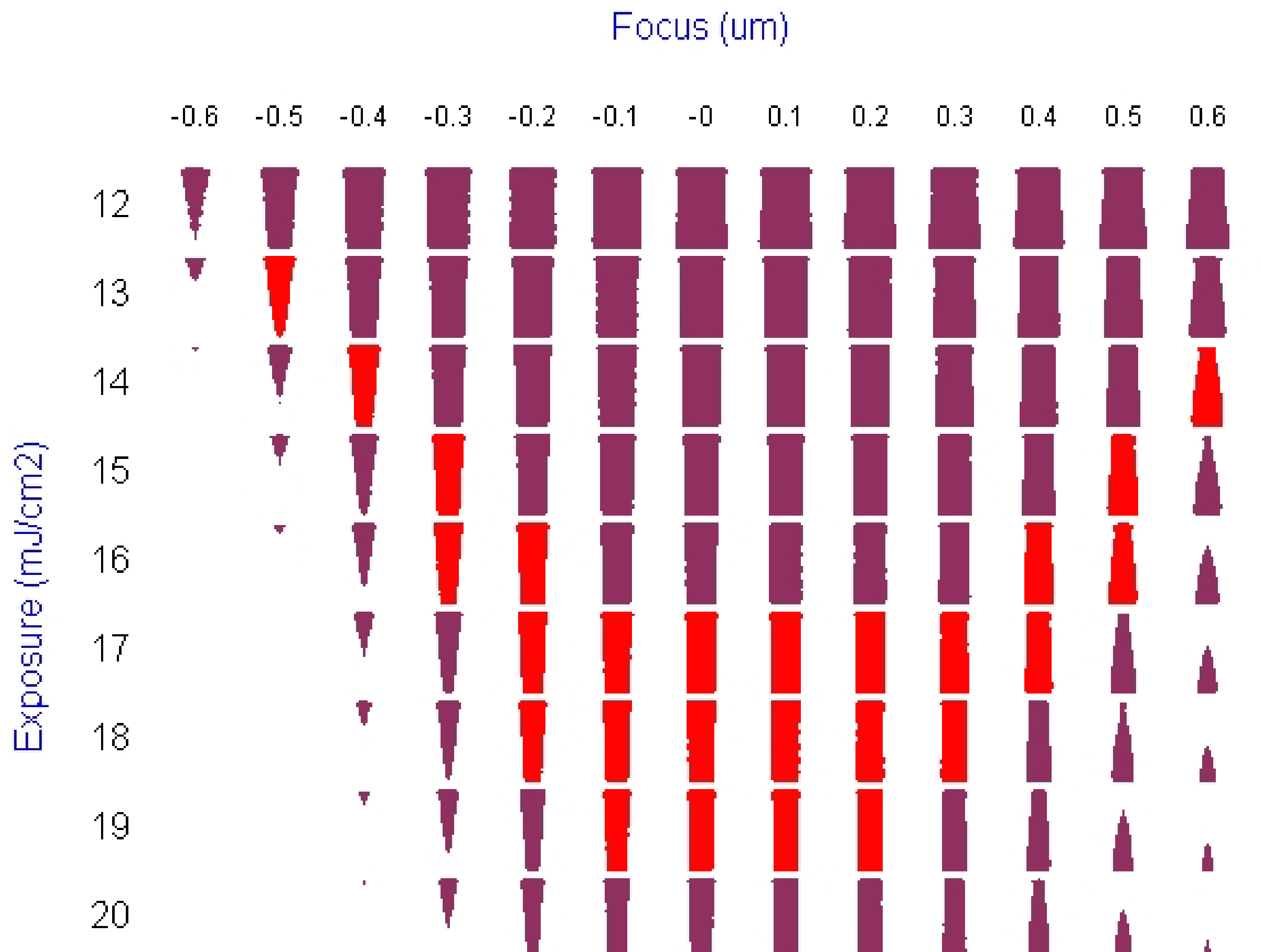
2-D Resist Profile



3-D Resist Profile

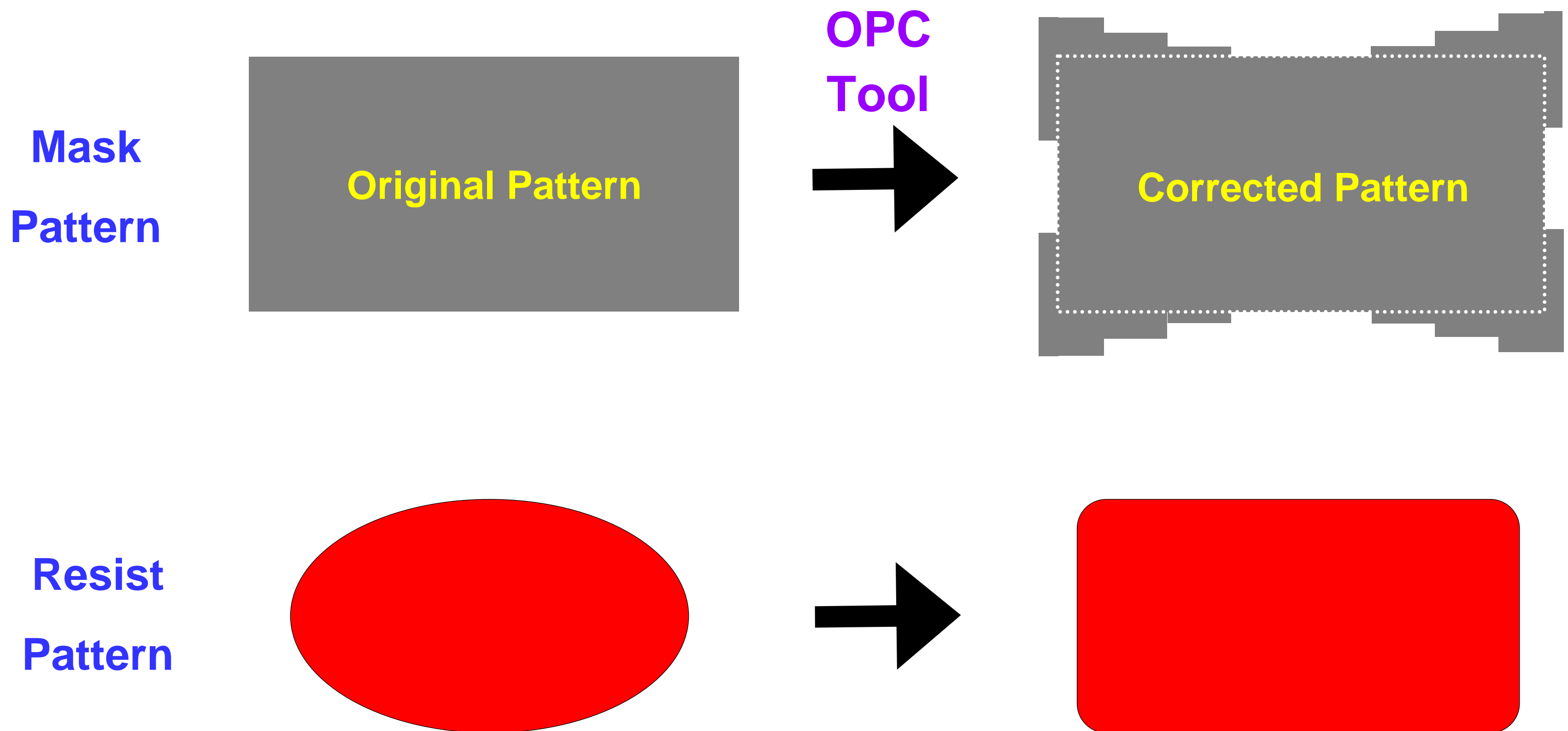


Resist Profile Cross Section

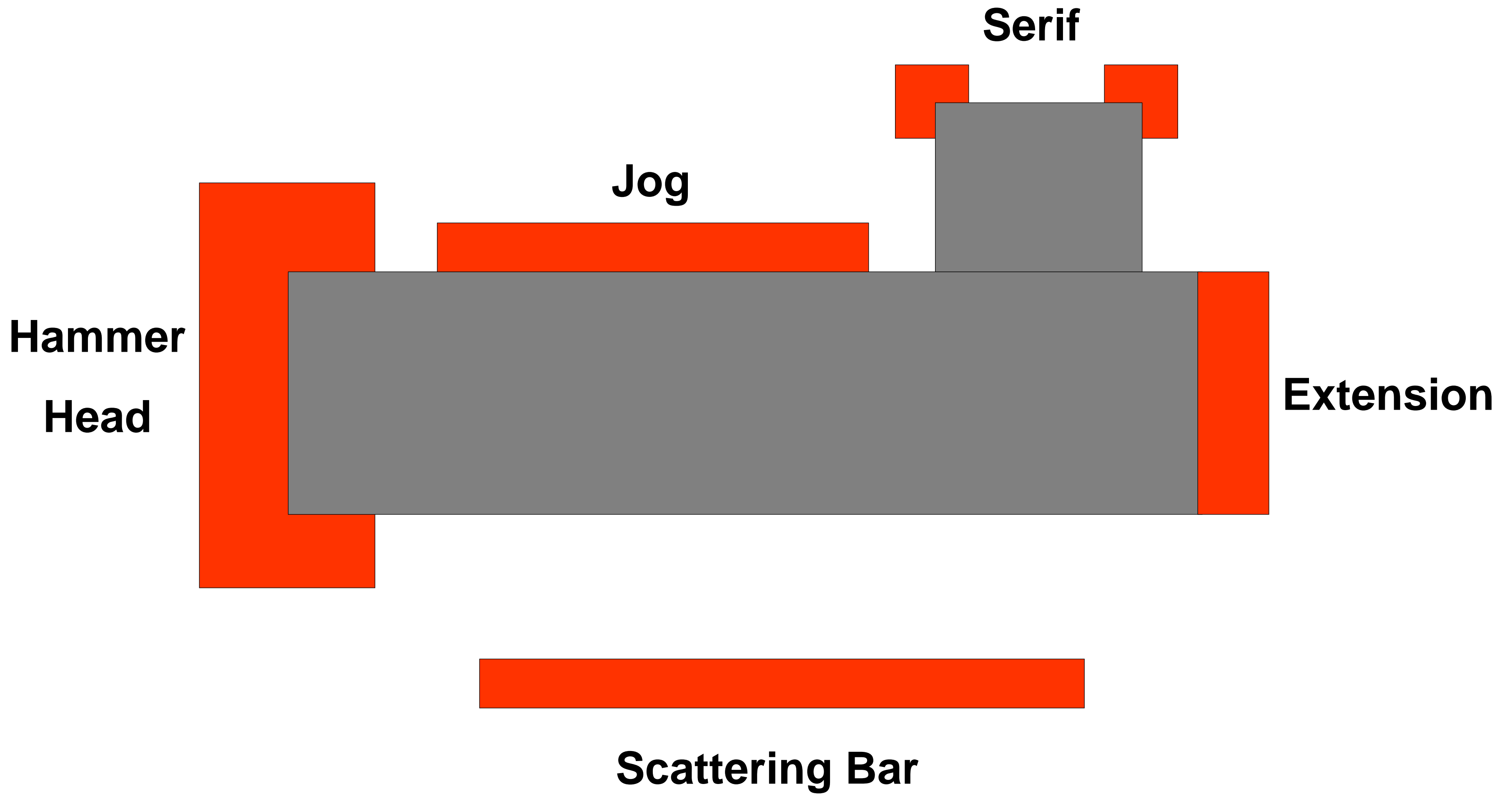


What's OPC?

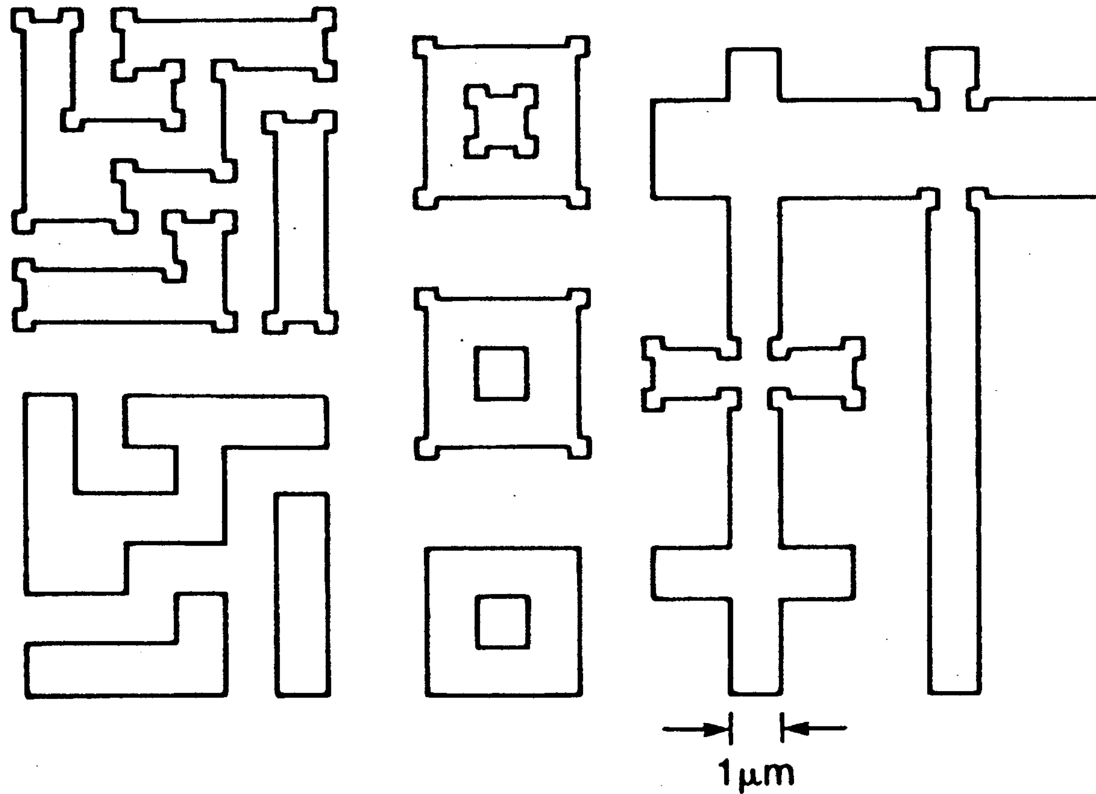
Optical Proximity Effect Correction



OPC Type



OPC at IBM - 1989



(a)

- What is Lithography …
- Resolution Limit and DOF
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- Optical Extension
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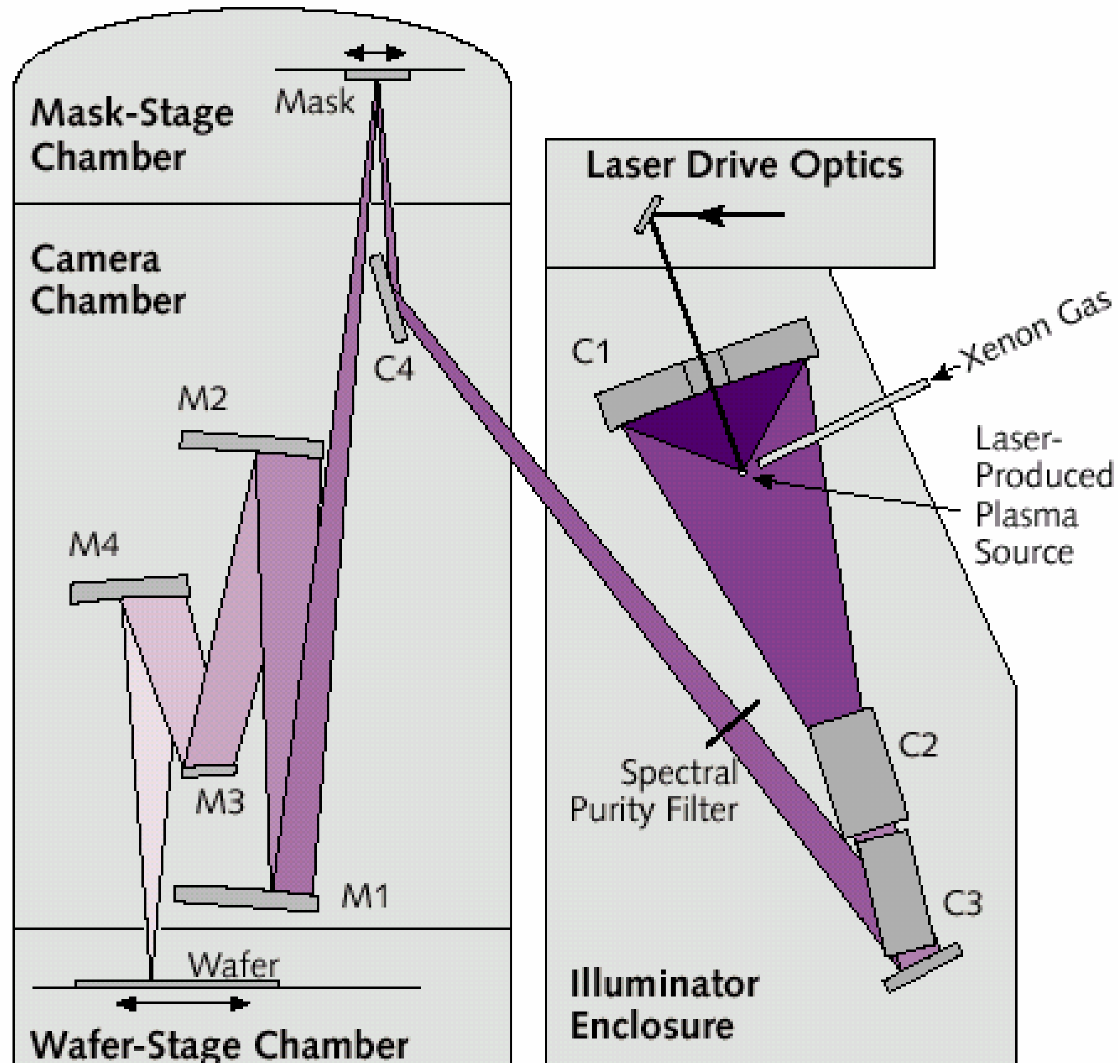
- Next Generation of Lithography

Extension of Optical Lithography

Method / wavelength	NA \ k_1	365nm i-line	248nm KrF	193nm ArF	157nm F_2	13.5nm EUV
		0.65	0.70 → 0.80	0.70 → 0.85?	0.70 → 0.85?	
conventional	0.6	335nm	213 → 185nm			
off axis illumination	0.5	280nm	177 → 155nm	138 → 115nm	110 → 90nm	70-35nm (?)
strong OAI + OPC and/or PSM	0.4		142 → 125nm	110 → 90nm	90 → 75nm	
all the tricks	0.3		106 → 90nm	83 → 70nm	70 → 55nm	

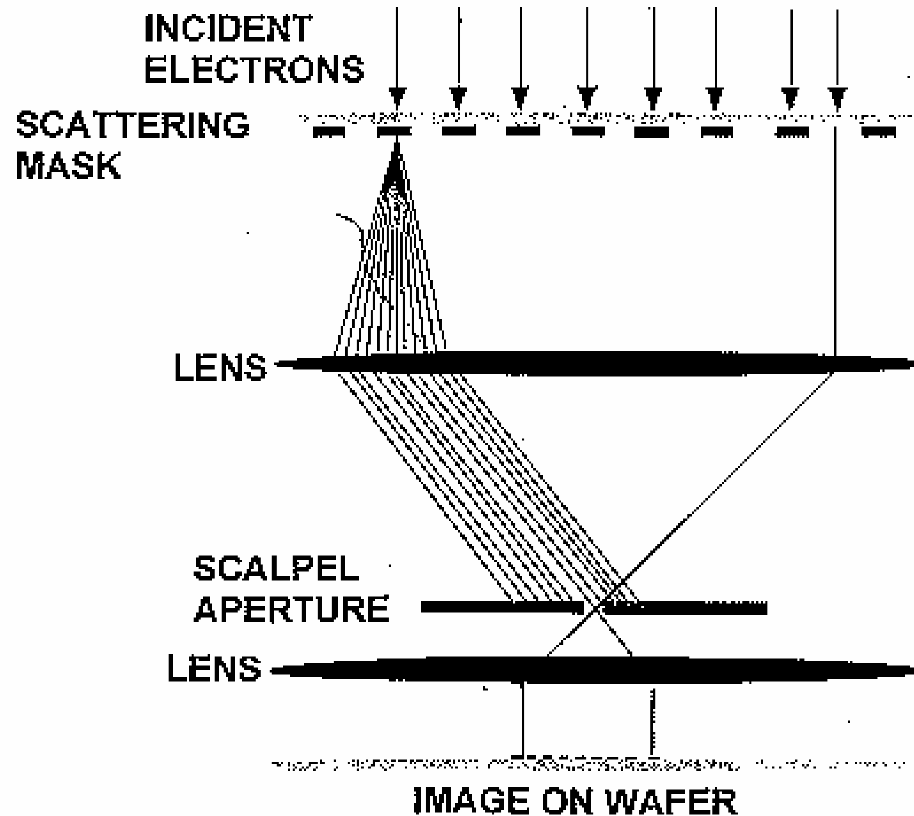
Resolution =
process factor(k_1) / numerical aperture(NA) X wavelength

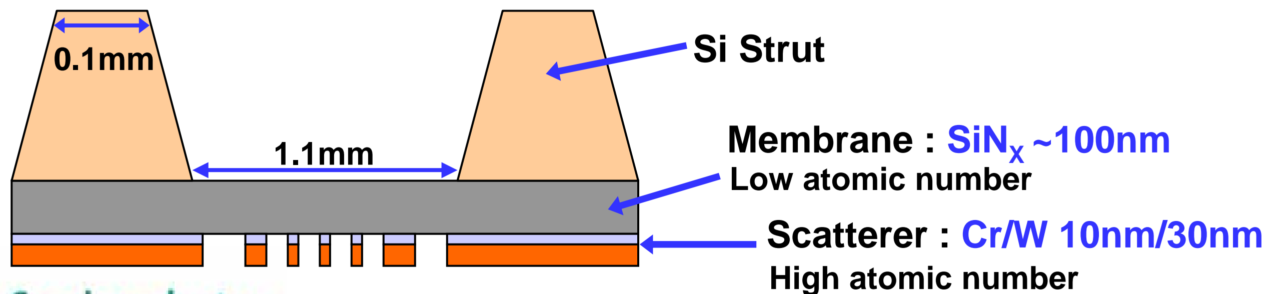
EUV Lithography



Intel

SCALPEL





Electron Projection Lithography

Electron Projection Lithography has significant attractions, represents the other NGL contender with F2.

E-beam stepper will be used for 70-50nm node.