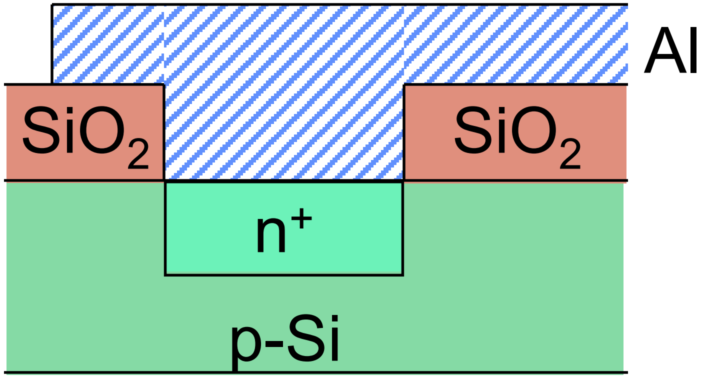
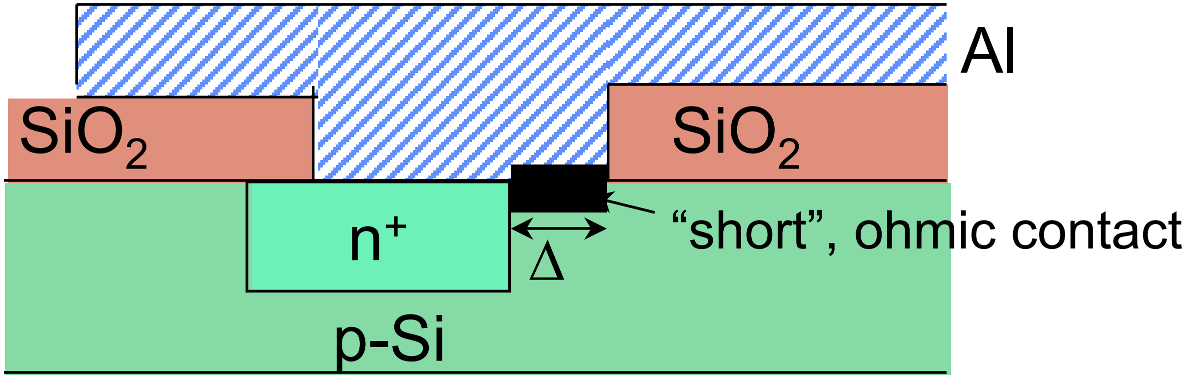
(1) Contact to source/drain of MOSFET.



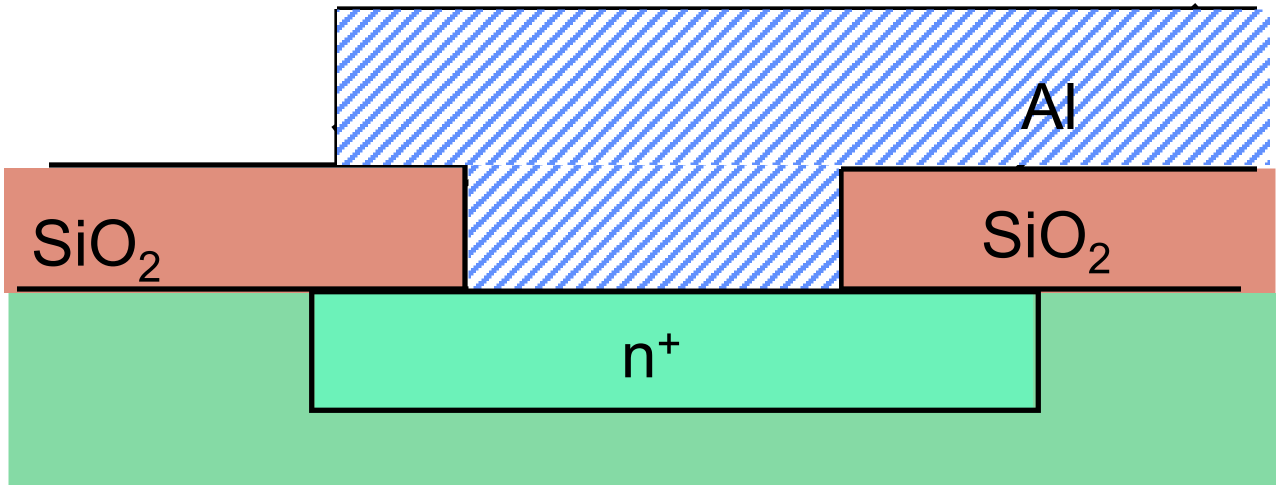
"ideal"

Alignment error



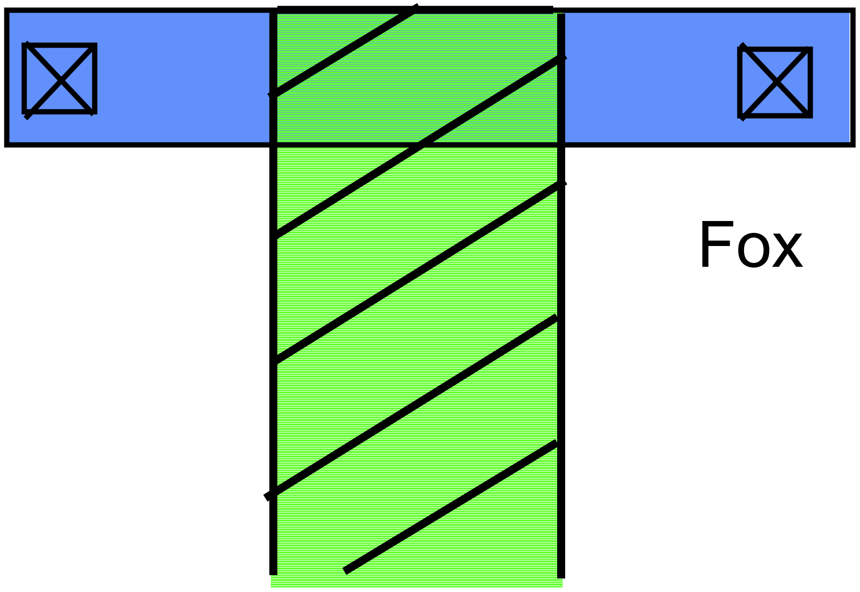
"short", ohmic contact

Solution: Design n+ region larger than contact hole



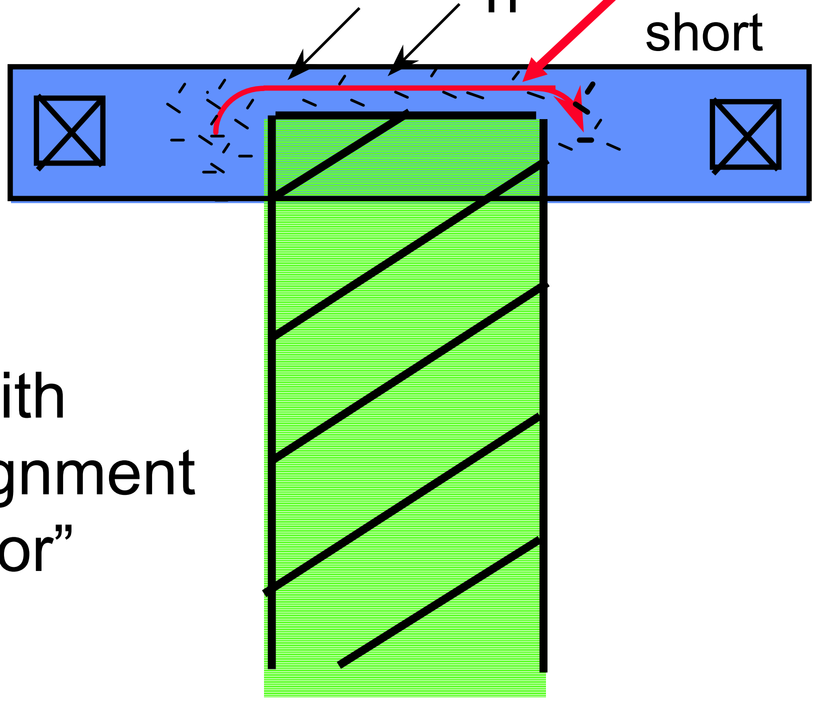
(2) Poly-Gate Overlap over FOX

“Ideal”



Fox

poly-gate



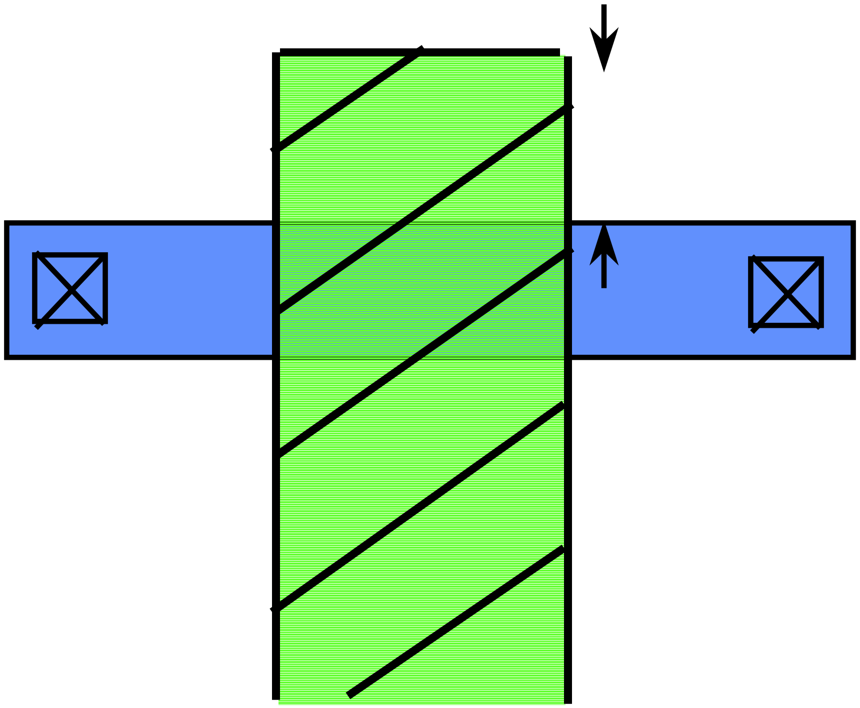
S/D implant

n^+

Electrical short

“With alignment error”

Solution: Make poly gate longer to overlap the FOX



Total Overlay Tolerance

$$\sigma^2{}_{total} = \sum_i \sigma_i^2$$

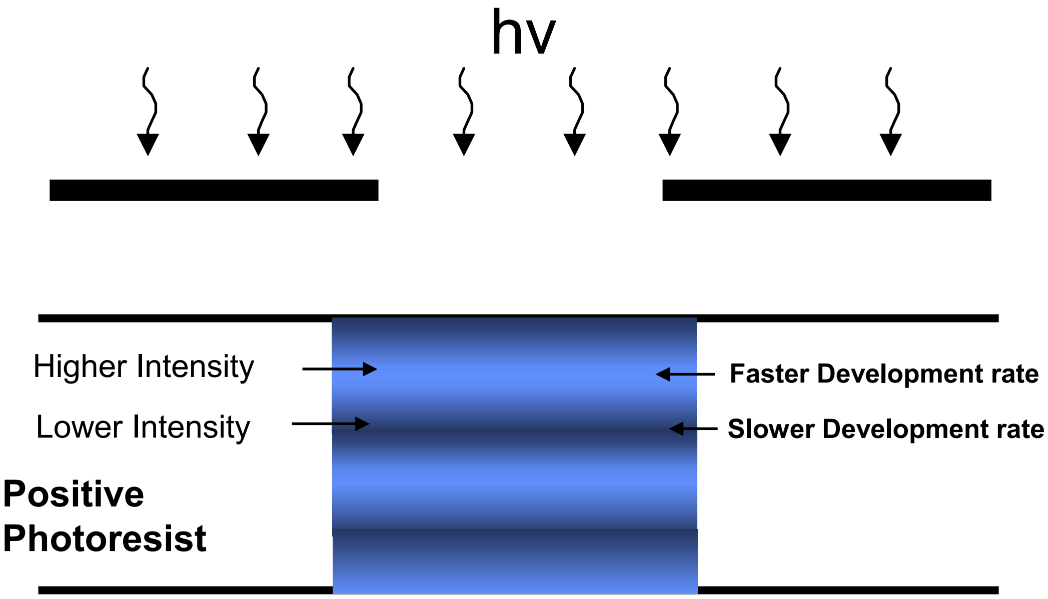
σ_i = std. deviation of overlay error for ith masking step

σ_{total} = std. deviation for total overlay error

Layout design-rule specification should be **>** σ_{total}

Standing Waves

*Photoresist has a finite thickness



hv

Higher Intensity

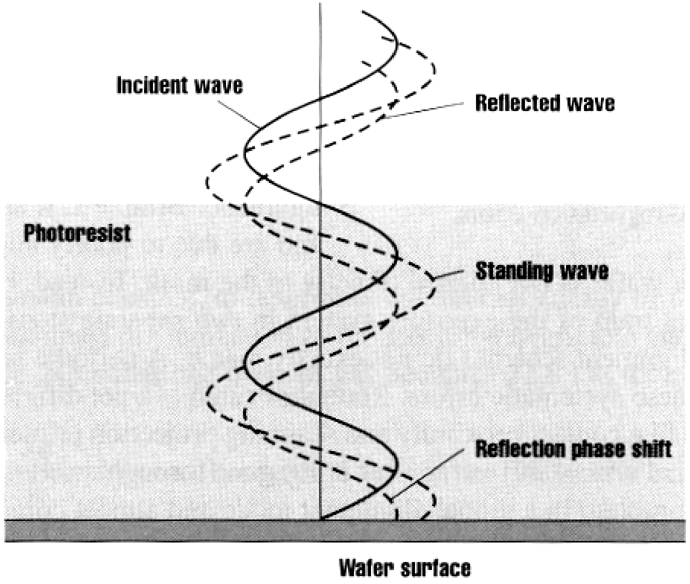
Lower Intensity

Faster Development rate

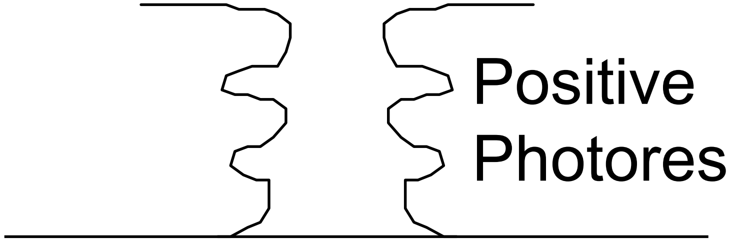
Slower Development rate

Positive Photoresist

substrate



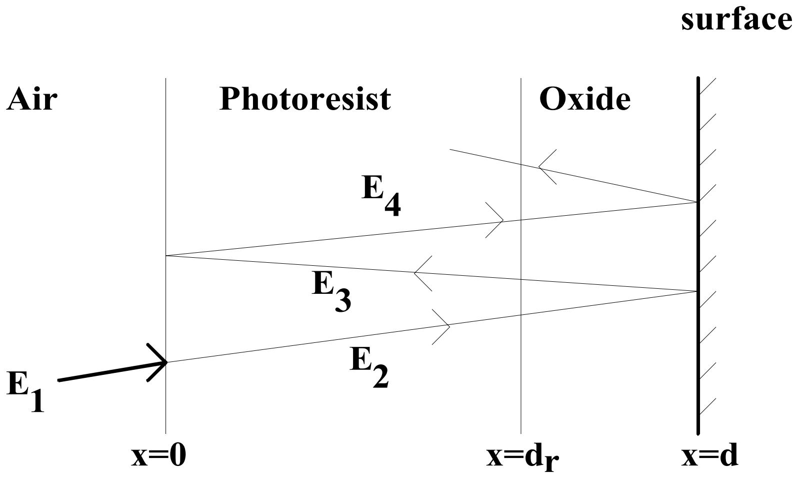
After development



Positive Photoresist.

substrate

Standing wave effect

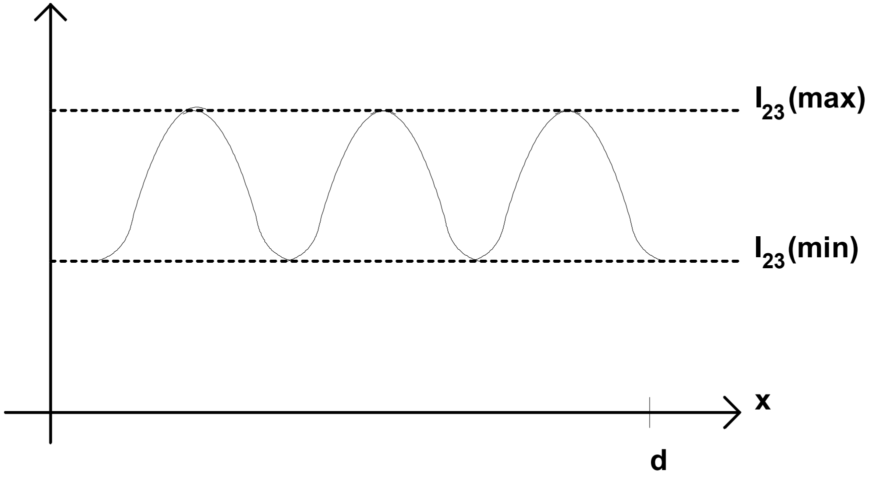


Resist profile and energy deposition depend on oxide thickness underneath (see handout for derivation)

$$I_{23}(x) = \frac{1}{T}\int_0^T (E_2(x)+E_3(x))^2 dt$$

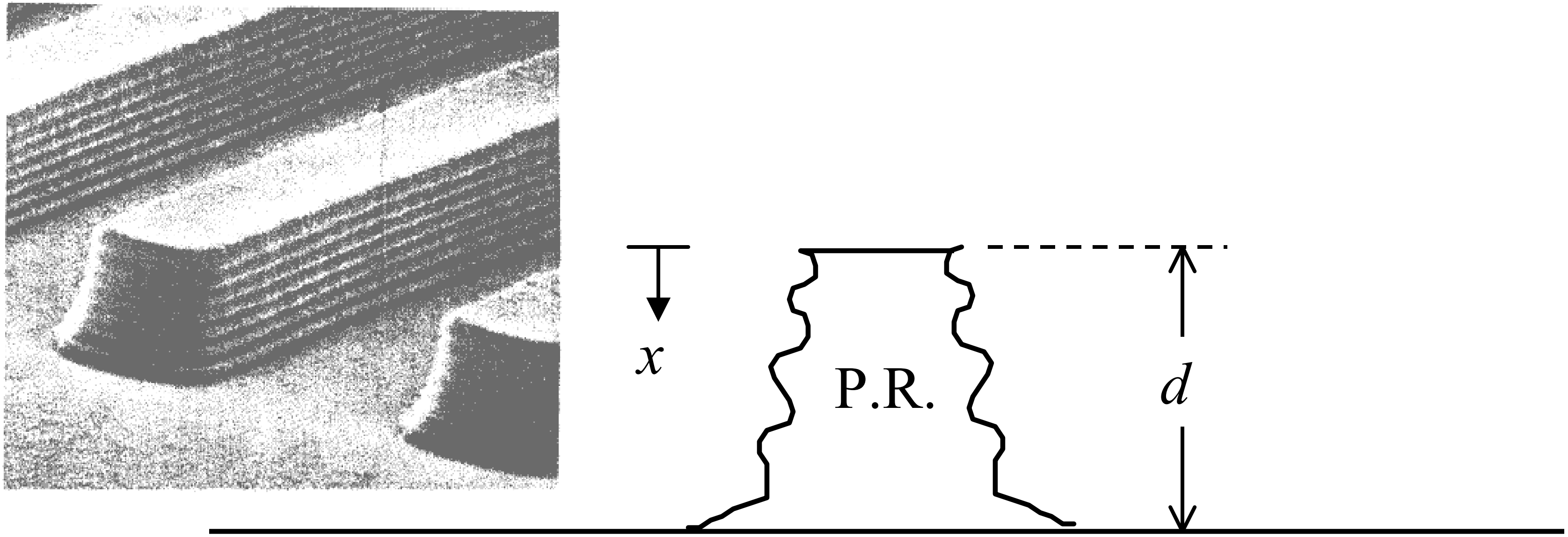
$$= \frac{1}{2}(\mathbf{E_2} - \mathbf{E_3})^2 + 2\mathbf{E_2}\mathbf{E_3}\sin^2[k(d-x)]$$

$$\therefore\ I_{23}(\max) = \frac{1}{2}(\mathbf{E_2} + \mathbf{E_3})^2 \quad ; \quad I_{23}(\min) = \frac{1}{2}(E_2 - E_3)^2$$



Intensity minima occur at : $\frac{2\pi n}{\lambda}(d-x) = 0, \pi, 2\pi, \ldots\ldots$

Intensity maxima occur at : $\frac{2\pi n}{\lambda}(d-x) = \pi/2, 3\pi/2, 5\pi/2, \ldots\ldots$



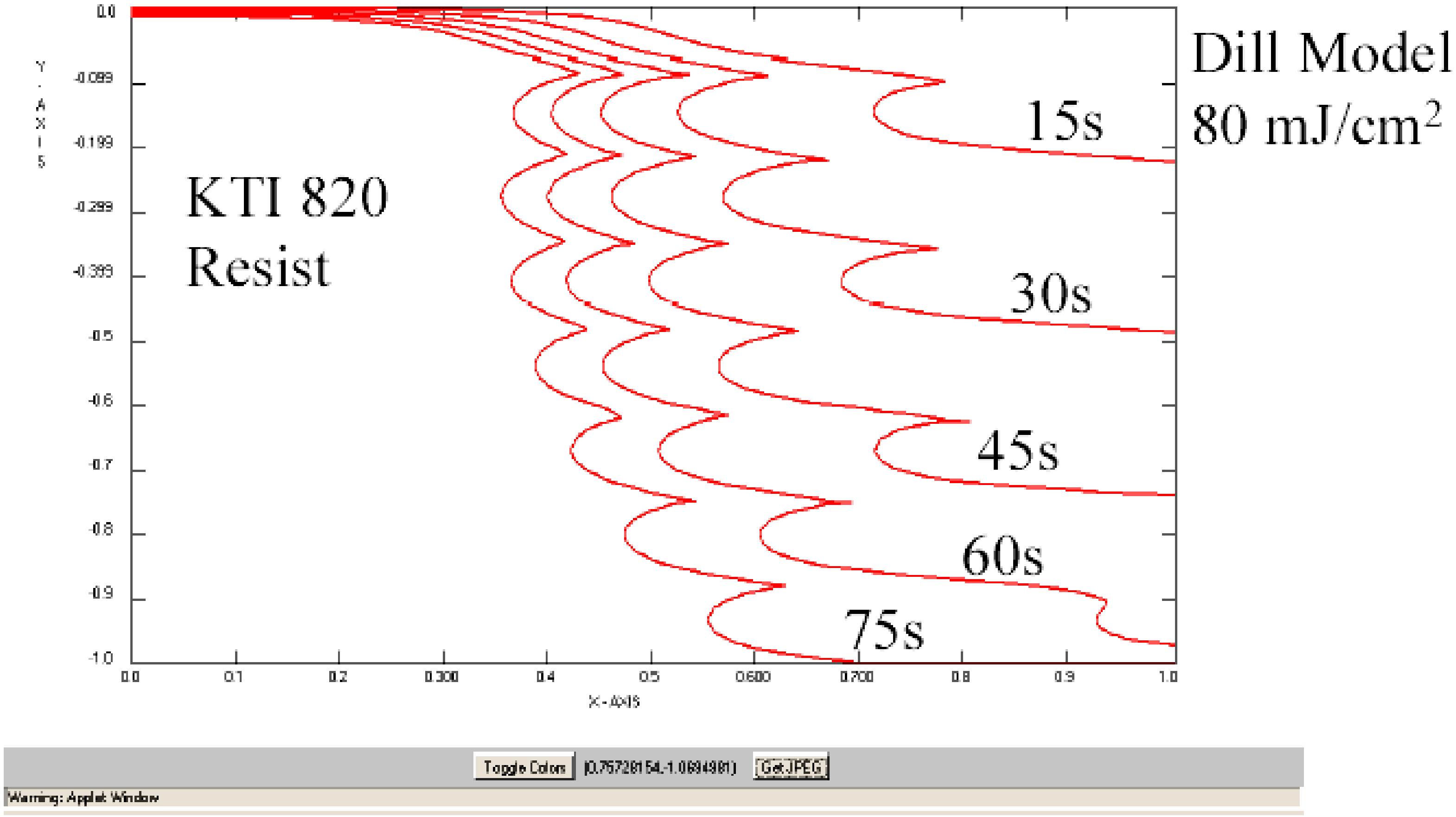
SiO_2/Si substrate

Intensity = minimum when $\boldsymbol{x} = \boldsymbol{d} - \boldsymbol{m}\dfrac{\lambda}{2\boldsymbol{n}}$ **m** = 0, 1, 2,...

Intensity = maximum when $\boldsymbol{x} = \boldsymbol{d} - \boldsymbol{m}\dfrac{\lambda}{4\boldsymbol{n}}$ **m** = 1, 3, 5,...

n = refractive index of *resist*

Simulated Resist Cross-section as function of development time



(0.75728154,-1.0694981)

Warning: Applet Window

Proximity Scattering

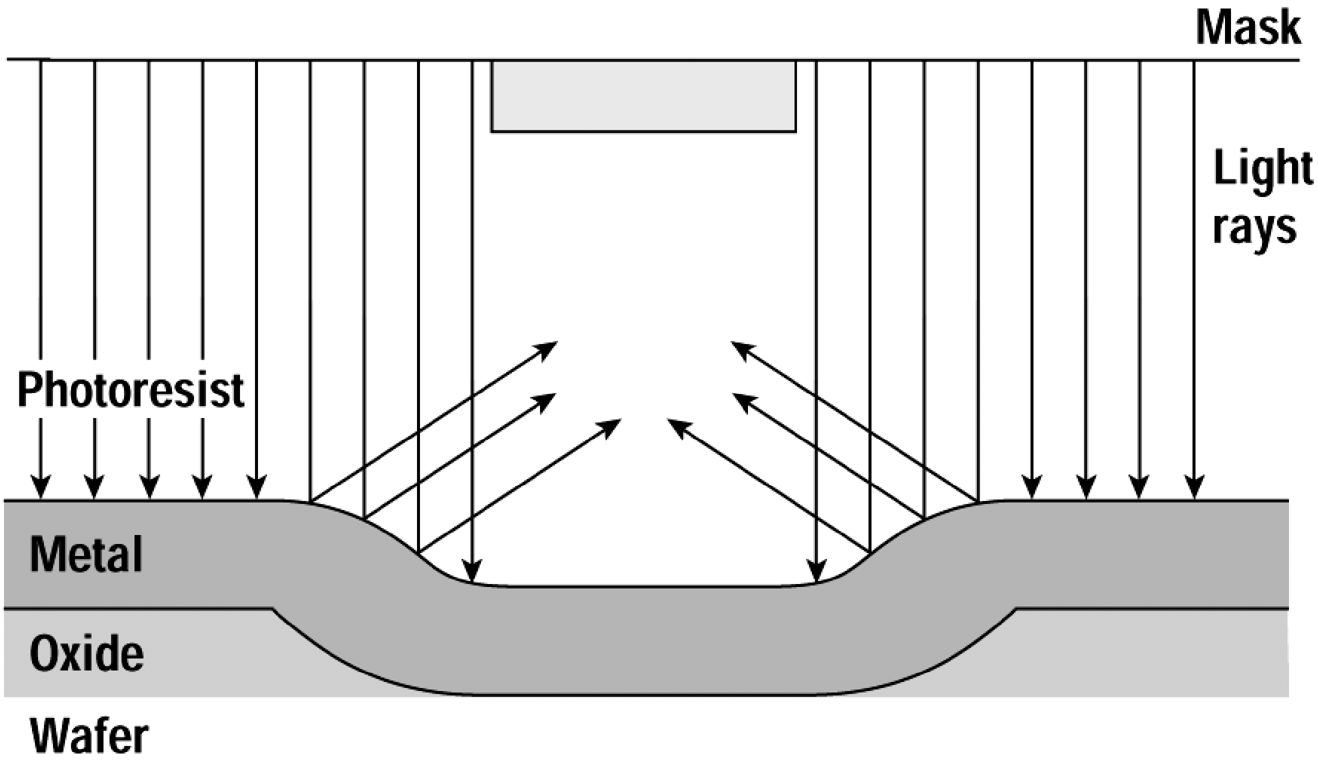
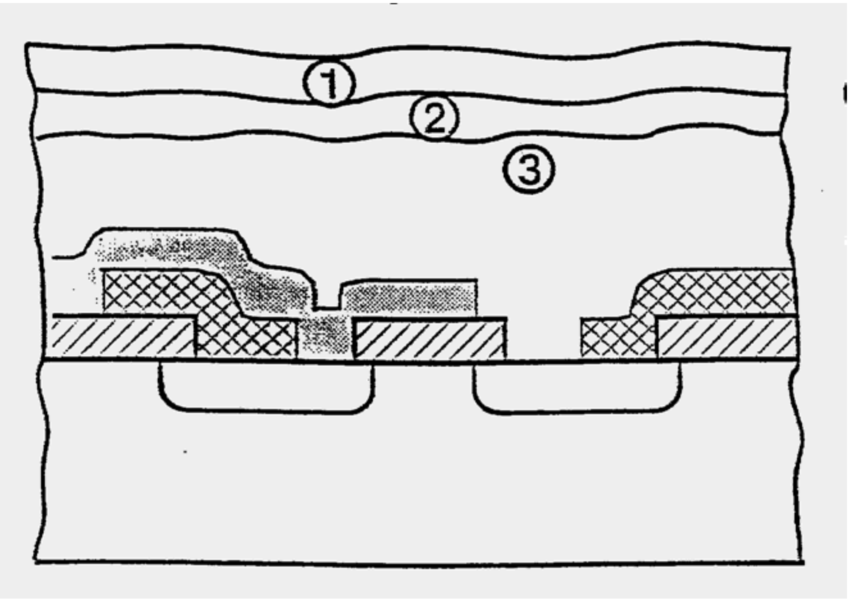


Figure 7.24 Light from the exposed regions can be reflected by wafer topology and be absorbed in the resist in nominally unexposed regions.

Approaches for Reducing Substrate Effects

- Use absorption dyes in photoresist
- Use anti-reflection coating (ARC)
- Use multi-layer resist process
    - 1: thin planar layer for high-resolution imaging (imaging layer)
    - 2: thin develop-stop layer, used for pattern transfer to 3 (etch stop)
    - 3: thick layer of hardened resist (planarization layer)



Electron-Beam Lithography

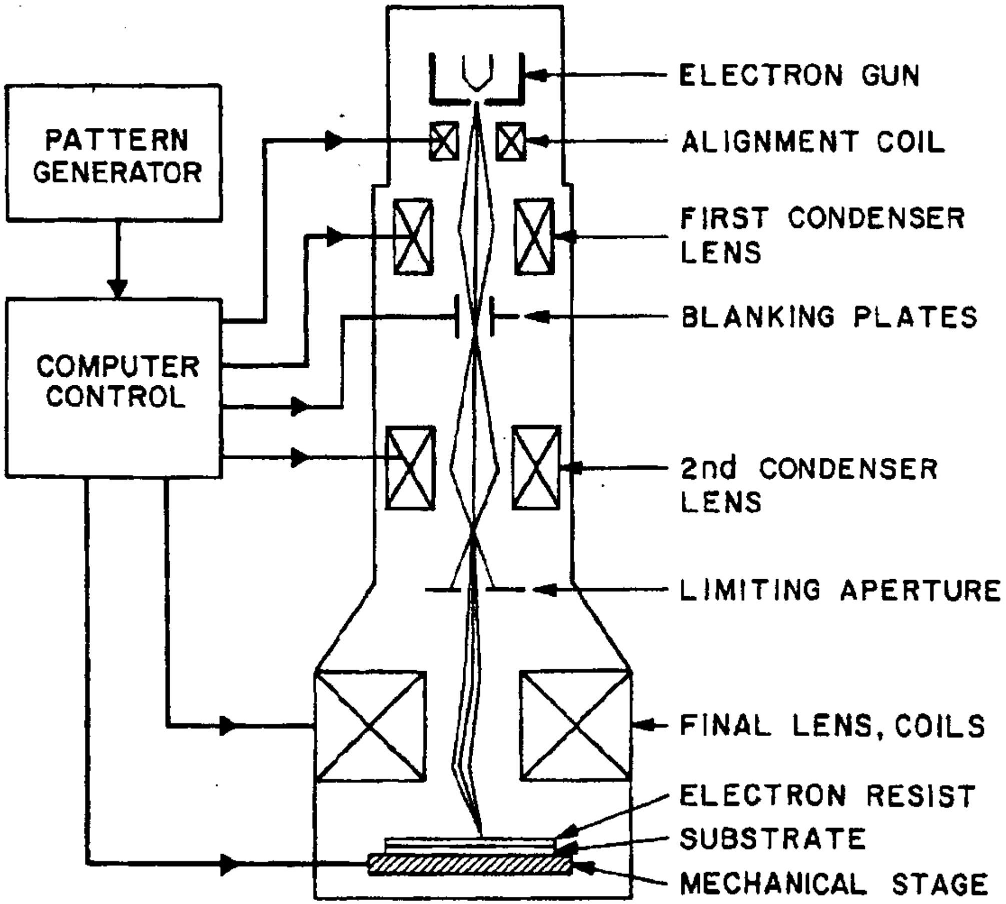


Fig. 13 Schematic of an electron beam machine.[12]

$$\lambda = \frac{12.3}{\sqrt{V}}$$ Angstroms for V in Volts

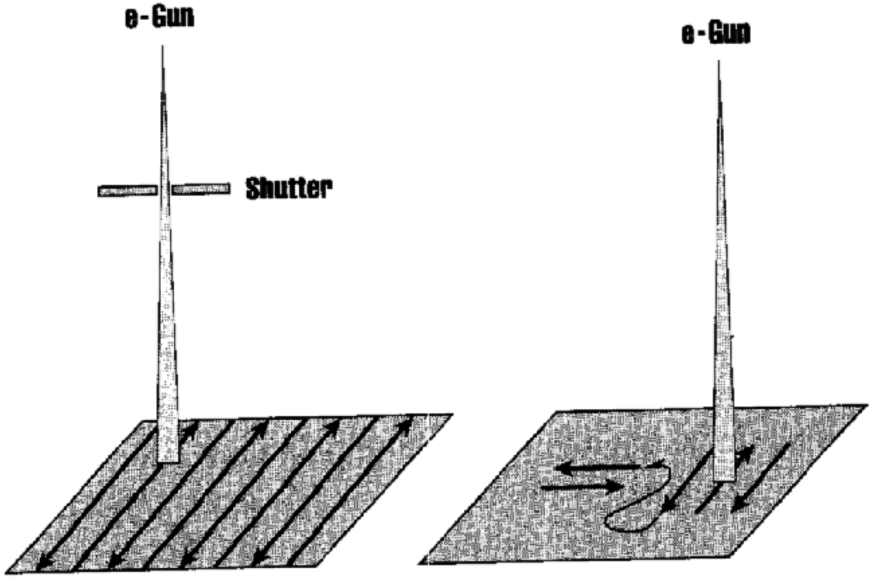
Example: 30 kV e-beam => $\lambda = 0.07$ Angstroms

NA = 0.002 – 0.005

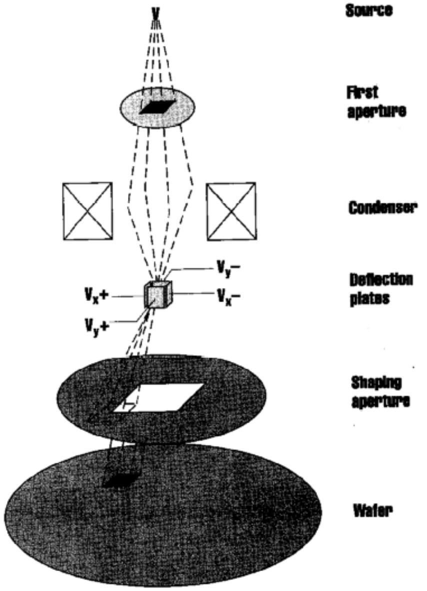
Resolution < 1 nm

But beam current needs to be 10's of mA for a throughput of more than 10 wafers an hour.

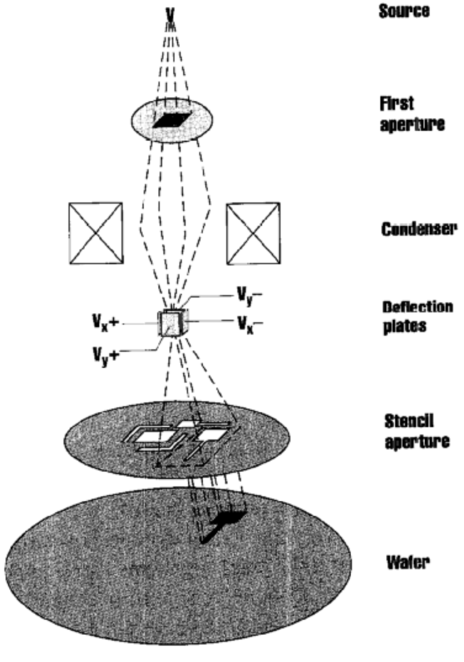
Low Throughput for both raster and vector scanning (Serial Process)



Variable Beam-shape EBL



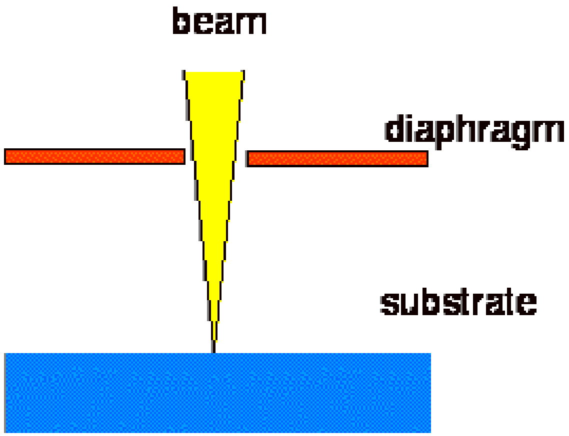
Stencil Mask EBL



e-beam lithography

resolution factors

- beam quality (~1 nm)
- secondary electrons (lateral range: few nm)



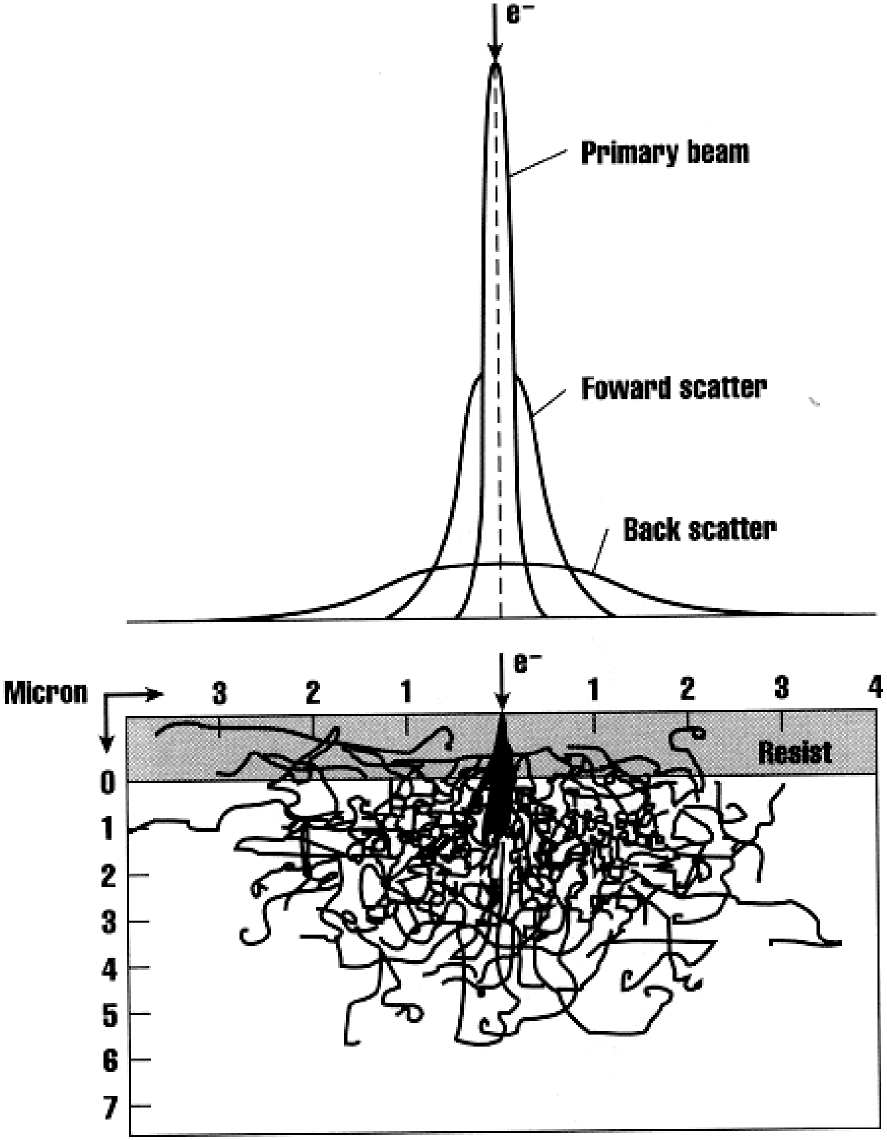
performance records

organic resist PMMA ~ 7 nm

inorganic resist, b.v. AlF_3 ~ 1-2 nm

The Proximity Effect

Monte Carlo simulation of electron trajectories



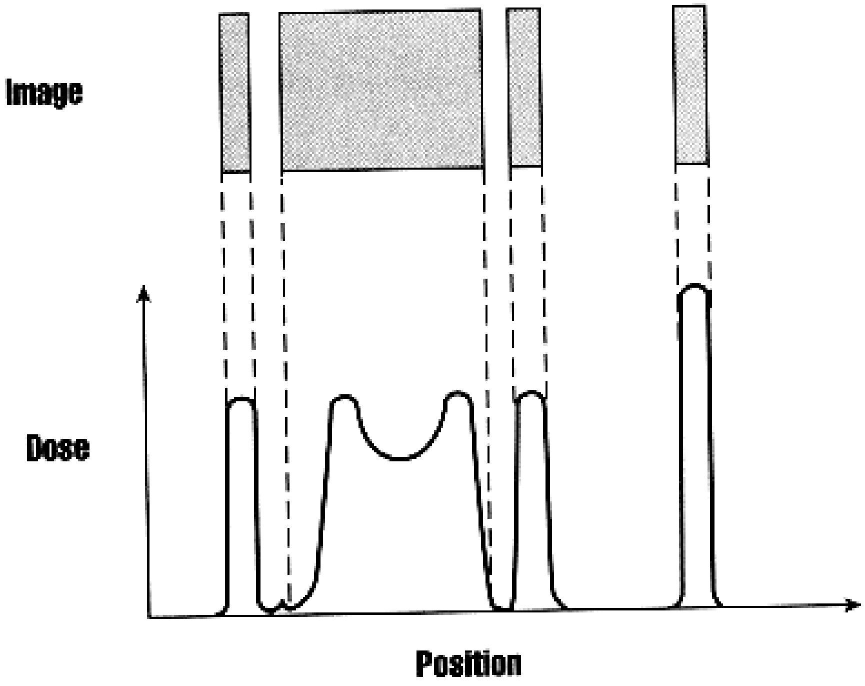


Figure 9-11 Small and large figures to be patterned with EBL requires position dependent dosage to compensate for proximity effects.

X-Ray Source

Synchrotron Radiation

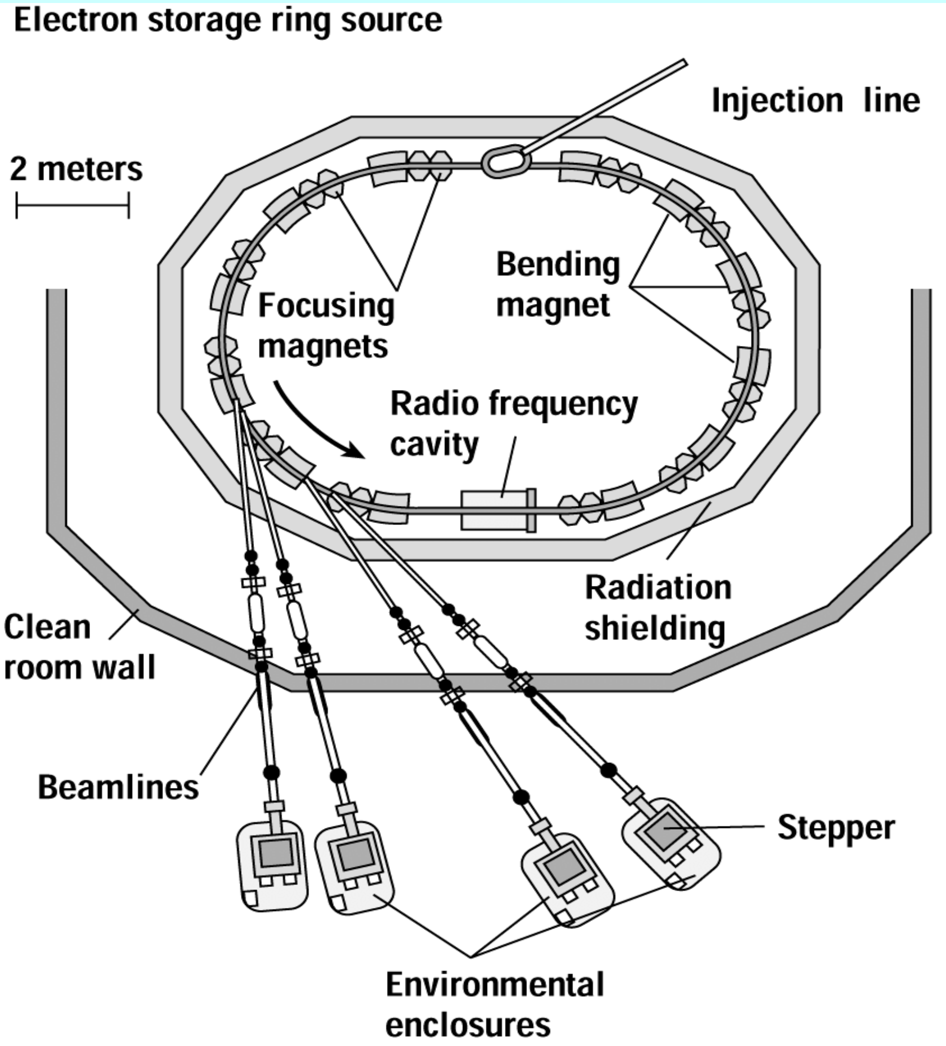
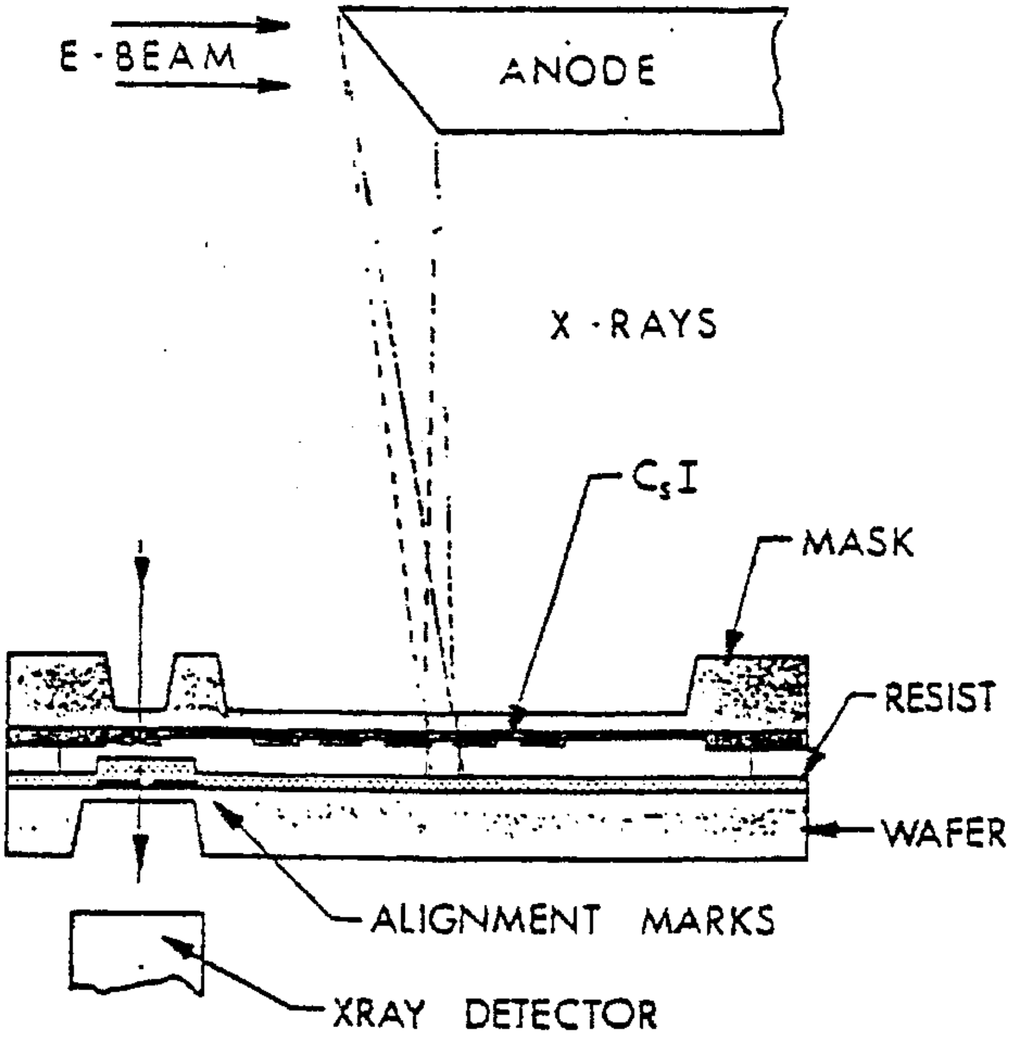


Figure 9.16 Basic schematic of an electron storage ring for XRL. Several exposure stations are indicated (*after Glendenning and Cerrina, reprinted by permission, Noyes Publications*).

X-Ray Proximity Printing



$\lambda \approx 10$ Angstroms

$$l_m \propto \sqrt{\lambda g}$$

X-Ray Projection Lithography

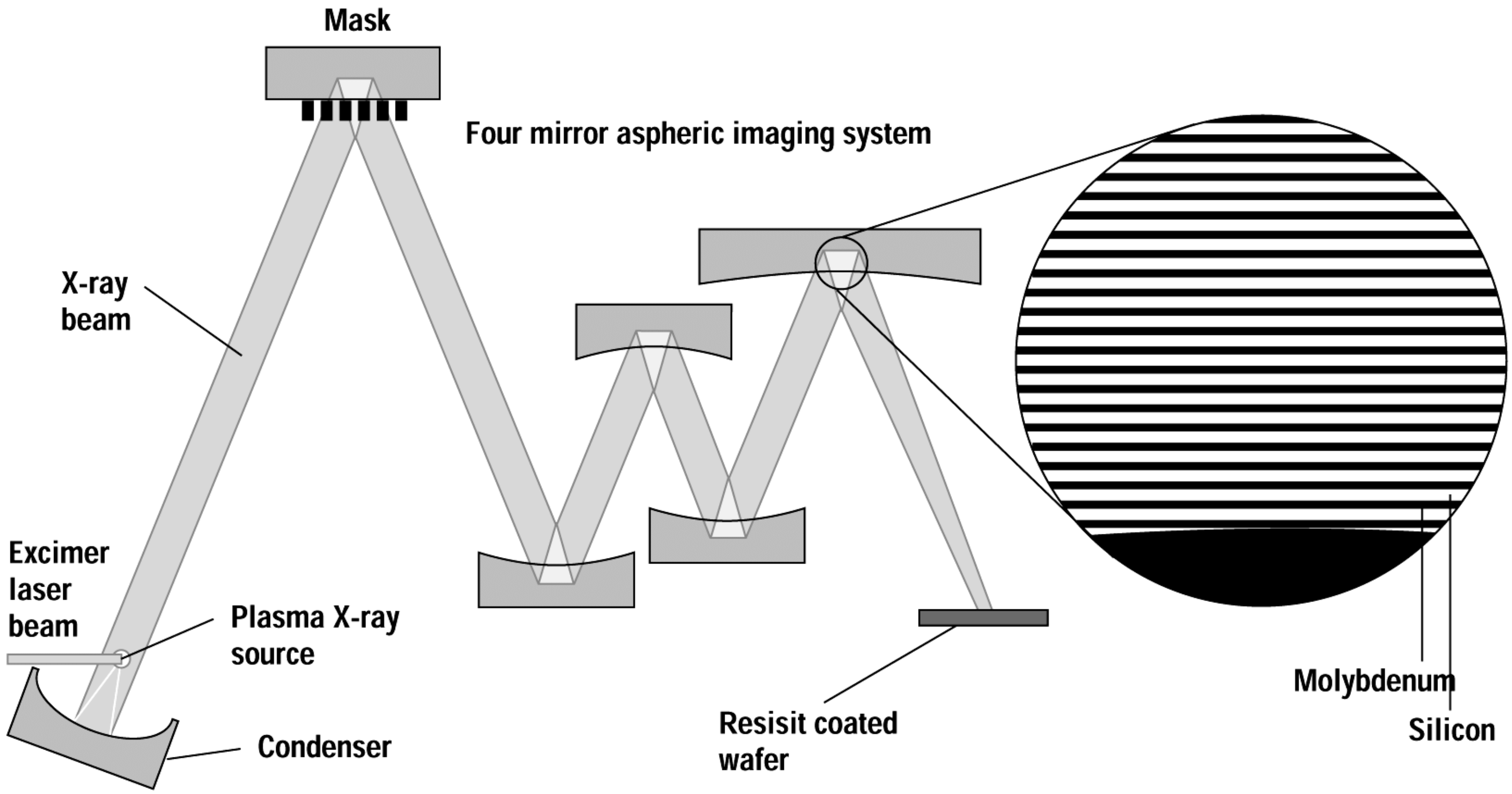
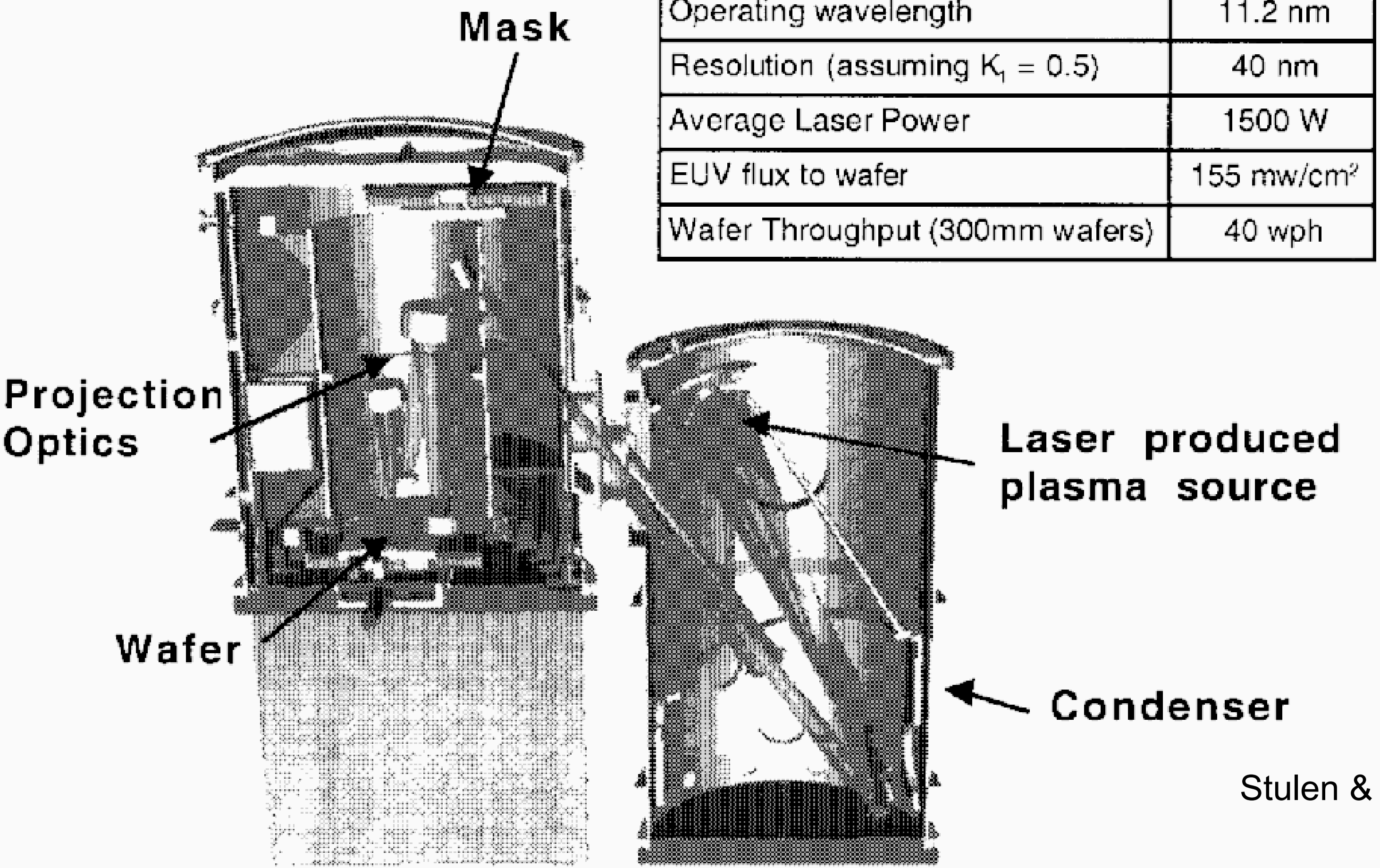


Figure 9.24 An x-ray projection lithography system using x-ray mirrors and a reflective mask *(after Zorpette, reprinted by permission, © 1992 IEEE).*

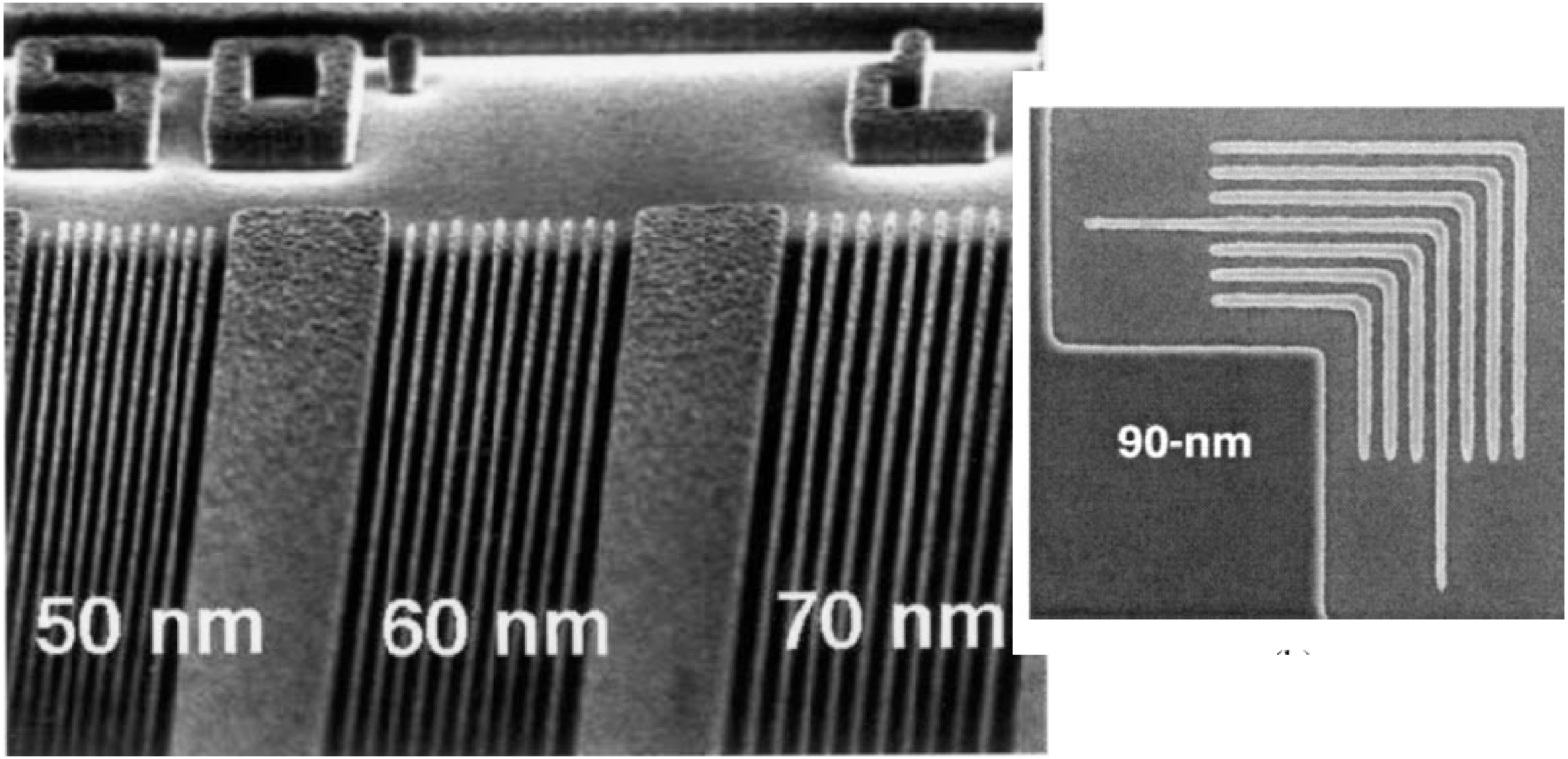
Alpha-Machine for EUV Lithography

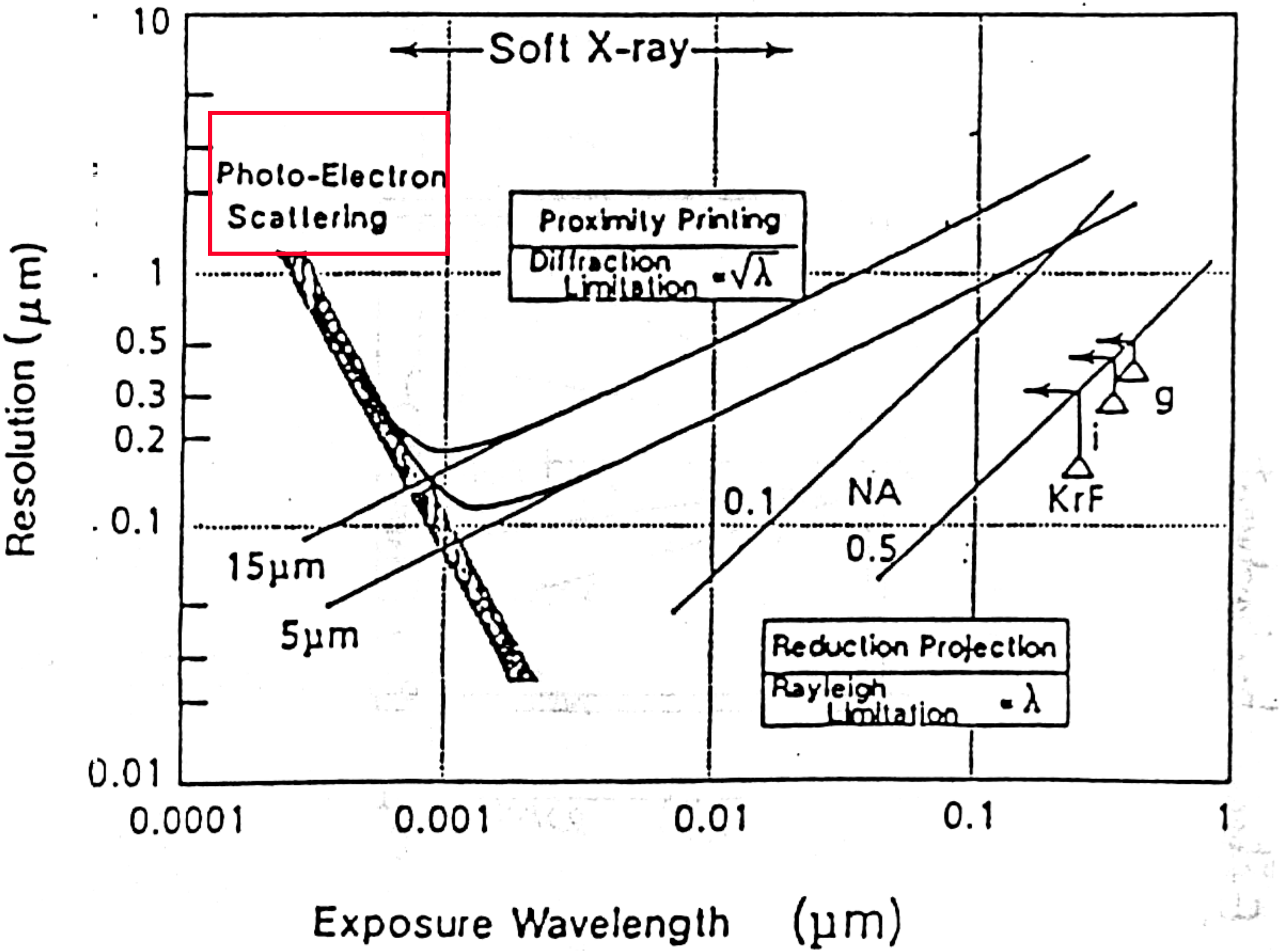
Specification	Beta
Numerical Aperture	0.14
Demagnification Factor	4
Operating wavelength	11.2 nm
Resolution (assuming K_1 = 0.5)	40 nm
Average Laser Power	1500 W
EUV flux to wafer	155 mw/cm^2
Wafer Throughput (300mm wafers)	40 wph



Stulen & Sweeny

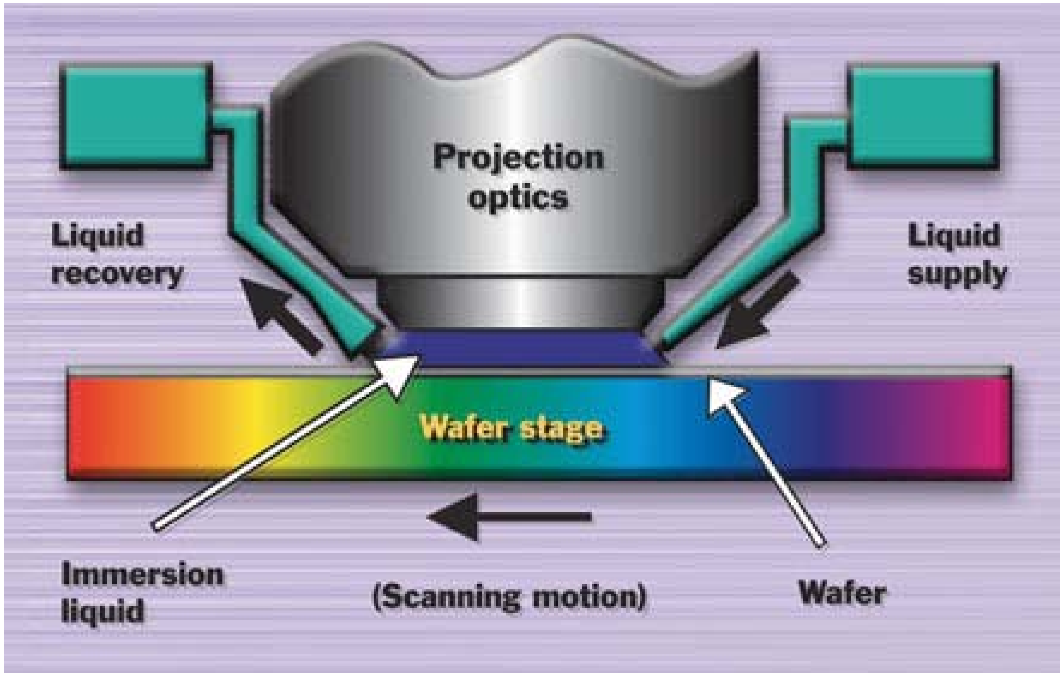
Resist patterned by Extreme UV Lithography




Soft X-ray
Photo-Electron Scattering
Proximity Printing
Diffraction Limitation ∝ √λ
15µm
5µm
0.1
NA
0.5
g
i
KrF
Reduction Projection
Rayleigh Limitation ∝ λ
Resolution (µm)
10
1
0.5
0.3
0.2
0.1
0.01
0.0001
0.001
0.01
0.1
1
Exposure Wavelength (µm)

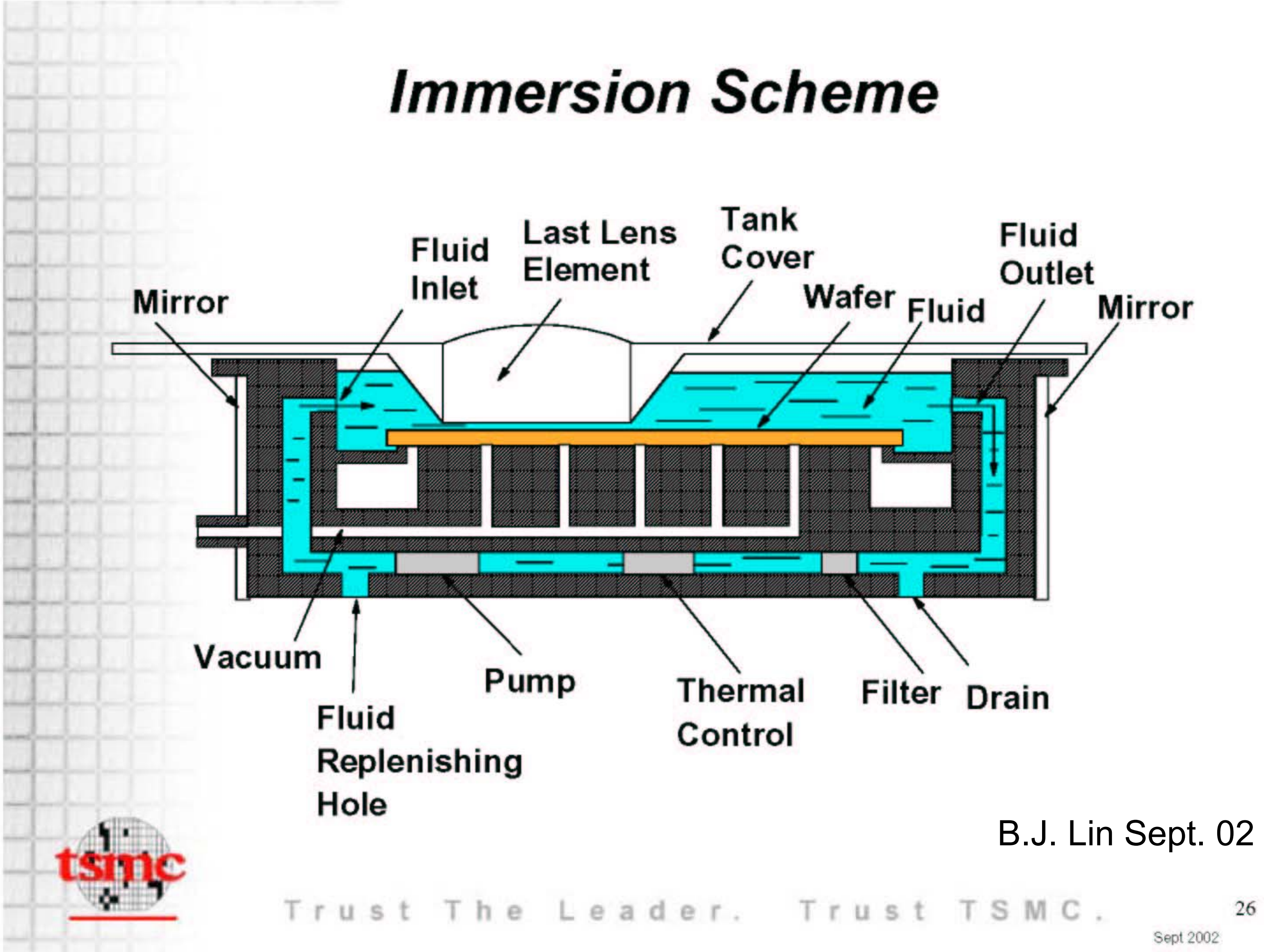
Immersion Lithography

- A liquid with index of refraction *n>1* is introduced between the imaging optics and the wafer.



Advantages

1) Resolution is improved proportionately to *n*. For water, the index of refraction at λ = 193 nm is 1.44, improving the resolution significantly, from 90 to 64 nm.
2) Increased depth of focus at larger features, even those that are printable with dry lithography.



Immersion Scheme

B.J. Lin Sept. 02

Trust The Leader. Trust TSMC.

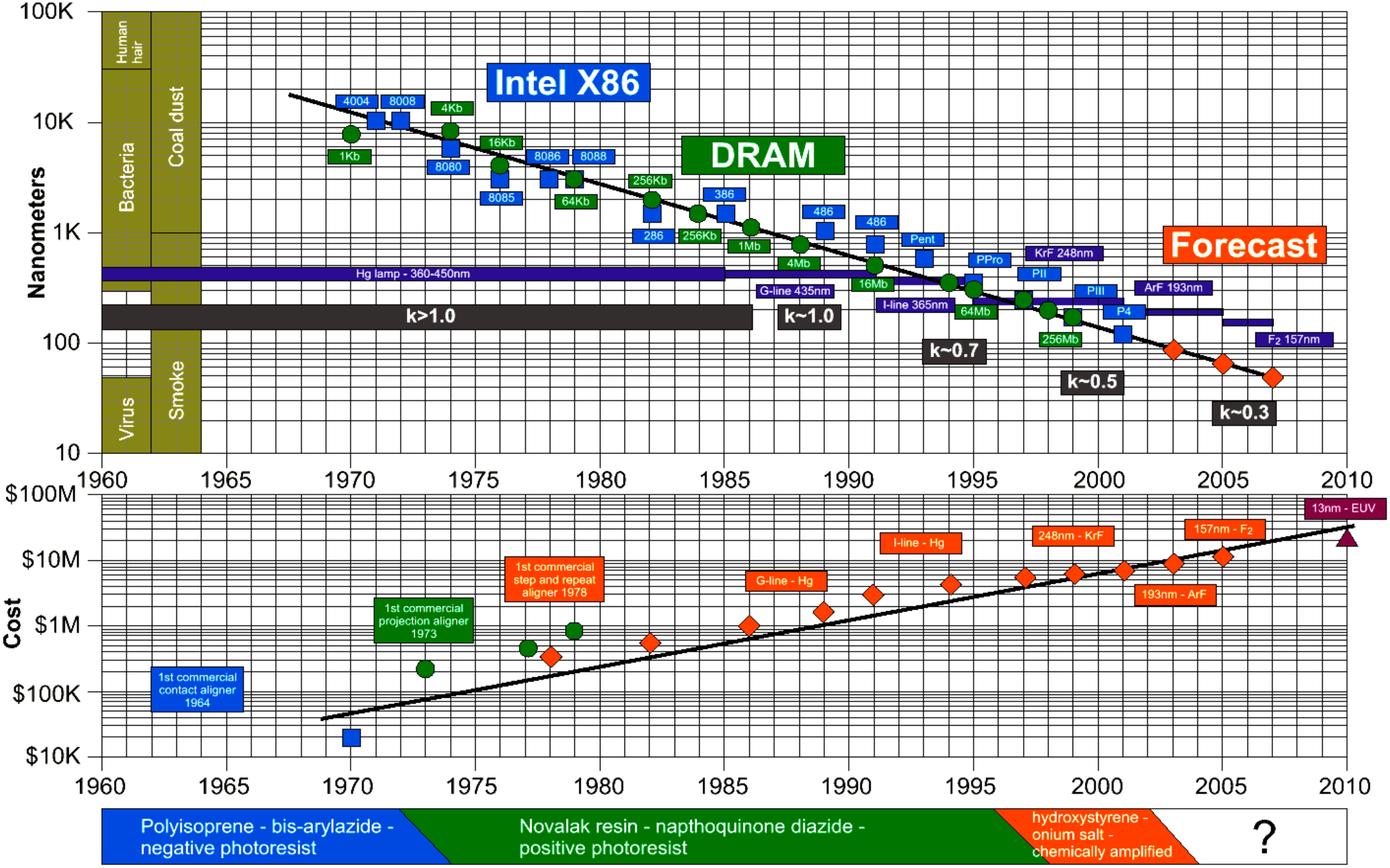
26

Sept 2002

Drag a drop schemes also being considered by UTA.

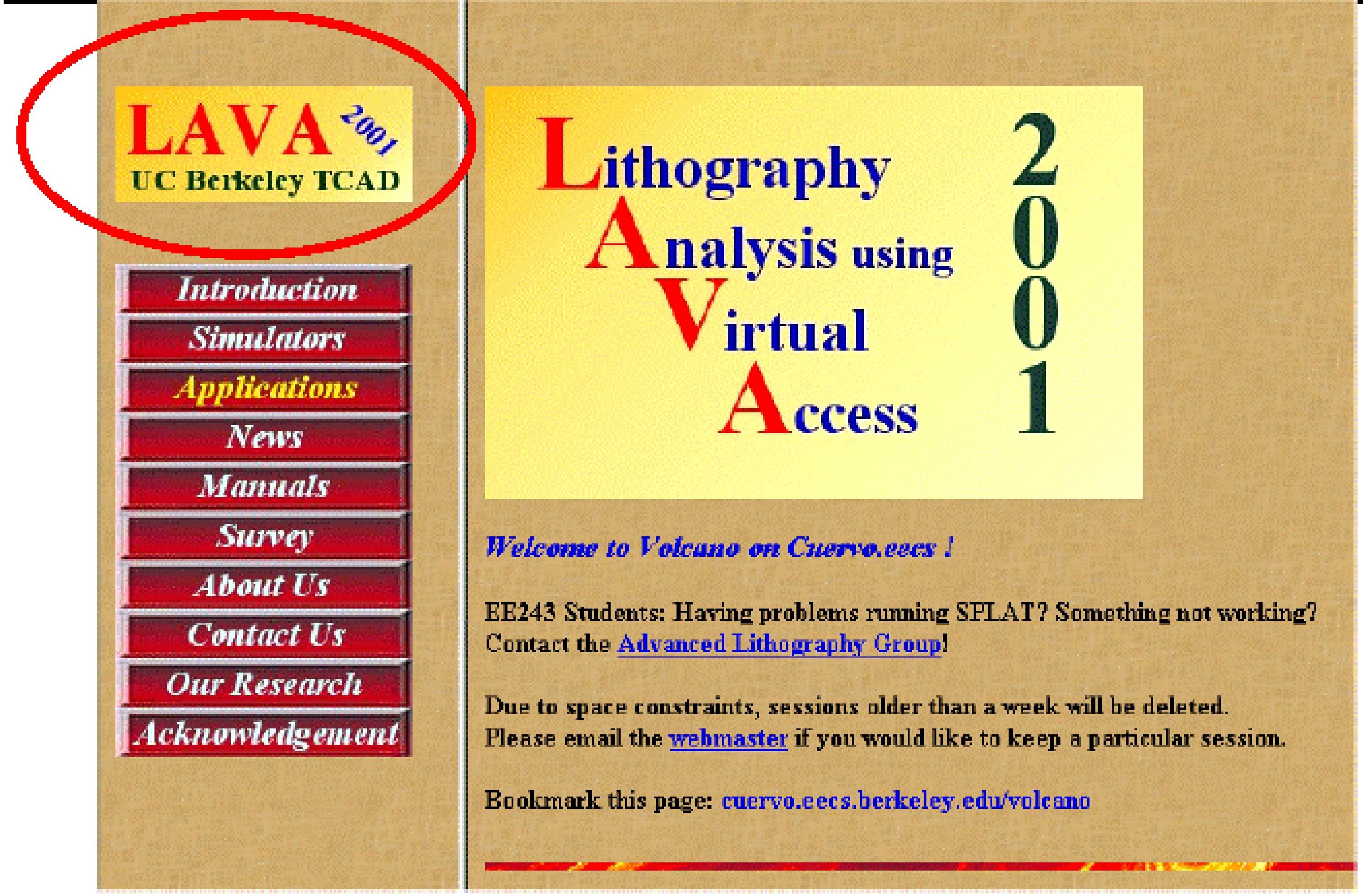
Microlithography Trends

www.icknowledge.com



14019

‘Hands On’ Exploration of Images



Lithography Analysis using Virtual Access 2001

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