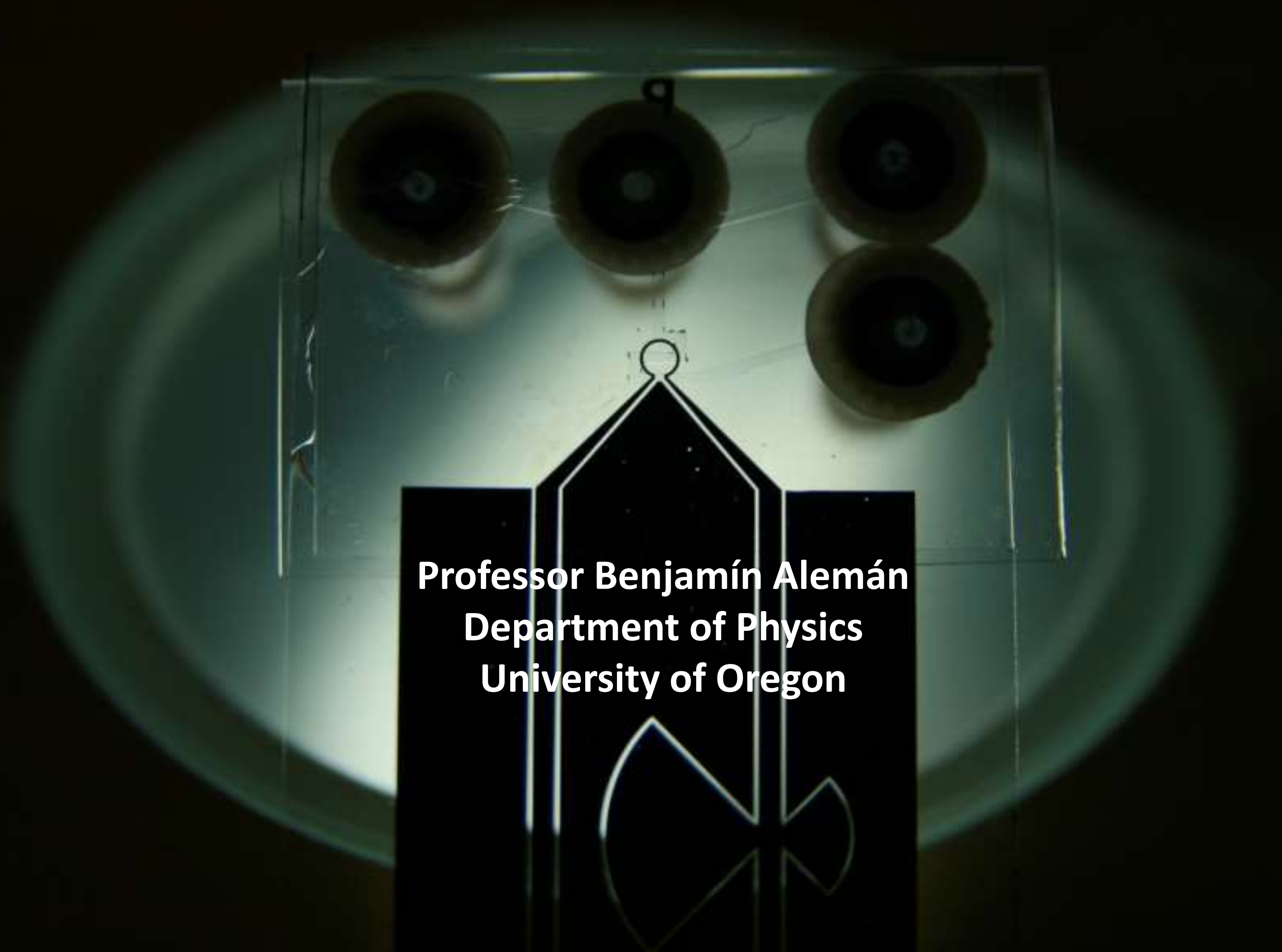
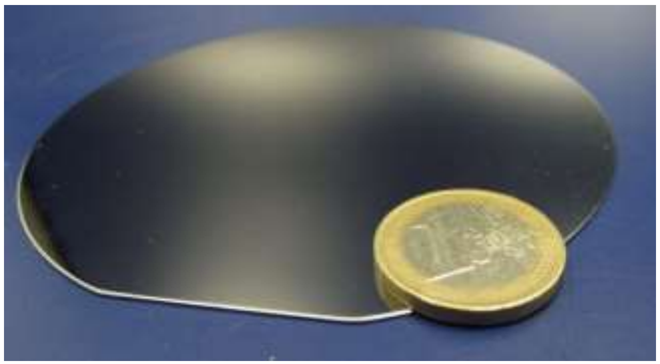
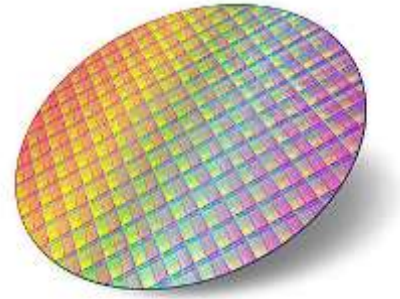
Semiconductor Processing: Lithography Part I

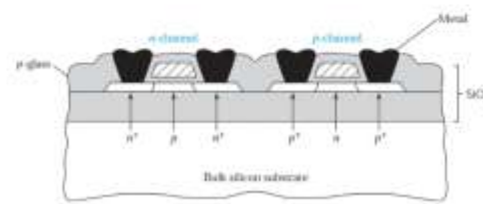


Professor Benjamín Alemán
Department of Physics
University of Oregon

Planar Processing with Semiconductors (Silicon): Course Map





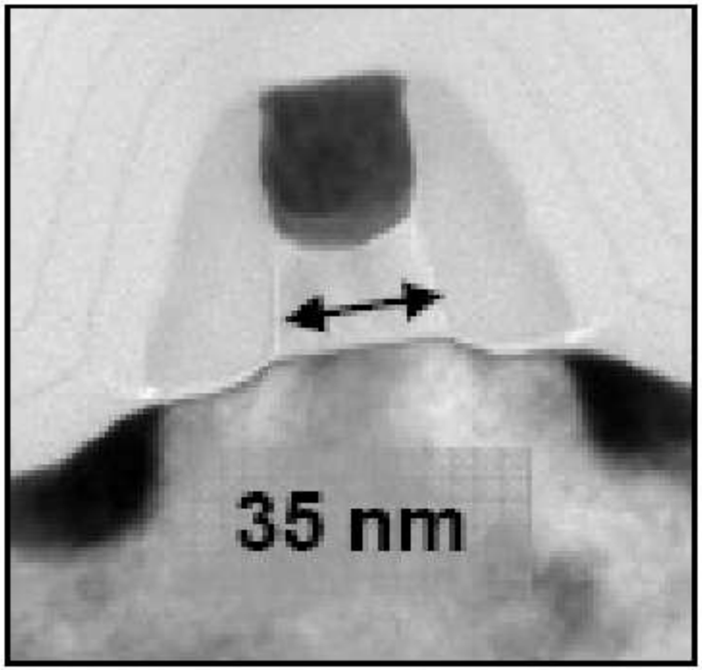


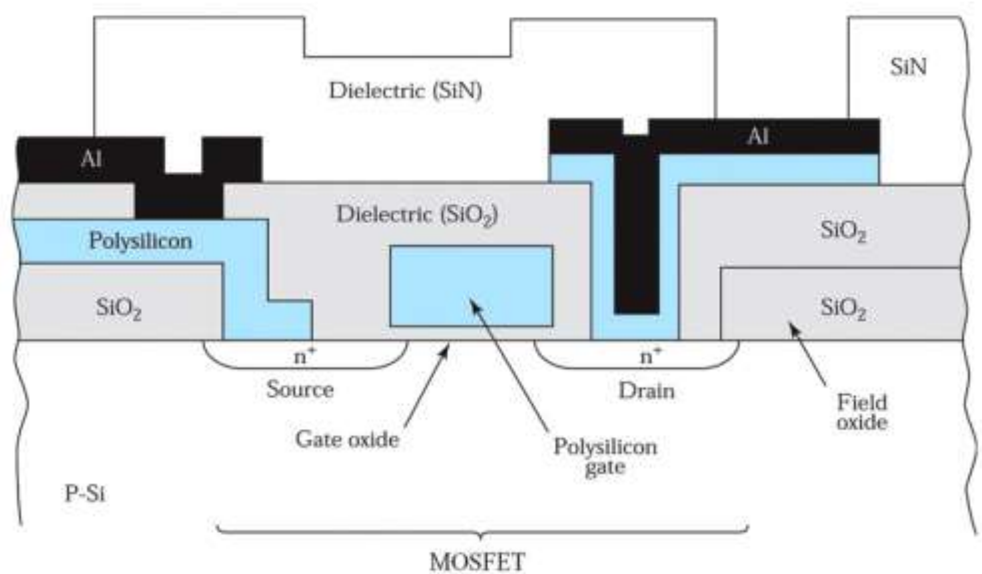
- Crystal growth (semiconductors)
- Wafer doping (*in situ*)
- Wafer characteristics
- SiO_2 growth*
- Defects and impurities

- SiO_2 growth*
- **LITHOGRAPHY**
- Masked diffusion doping
- Vacuum Systems
- Thin Films: CVD, MBE, PVD, ALD
- Implantation
- Wet and Dry Etching
- Integration

Lithography

How do we make the n doped regions in channel?





(Gatan, 2003)

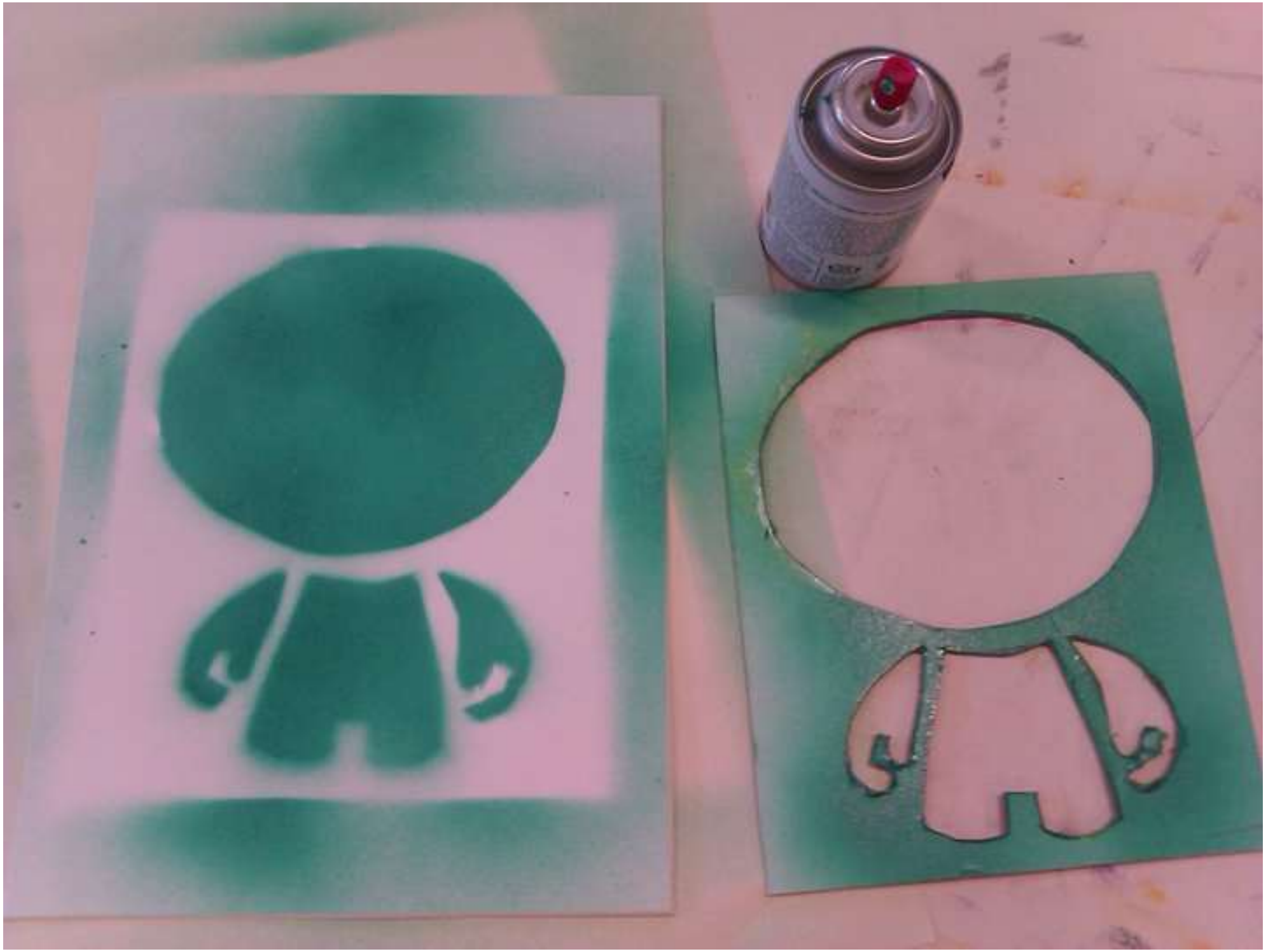
How do we generate masked areas and doping windows for diffusion doping?

How do we generate patterned oxides, wires, contact pads, waveguides, mechanical resonators, microfluidic channels of a micro- or nanodevice?

Transfer pattern using a stencil or a mask

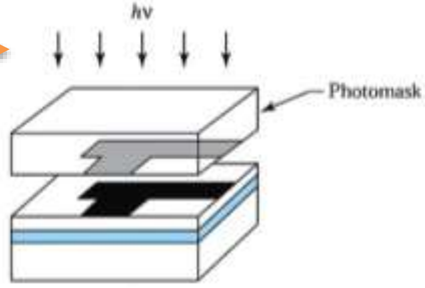
(Banksy, West Bank)

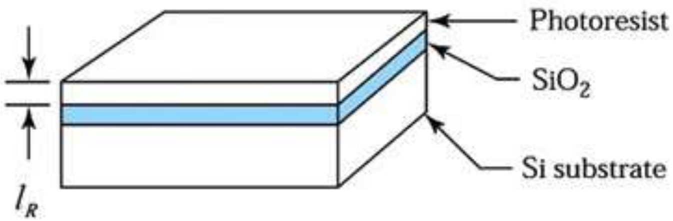
Transfer pattern using a stencil or a mask



Use light and patterned semitransparent mask to transfer patterns to radiation sensitive material

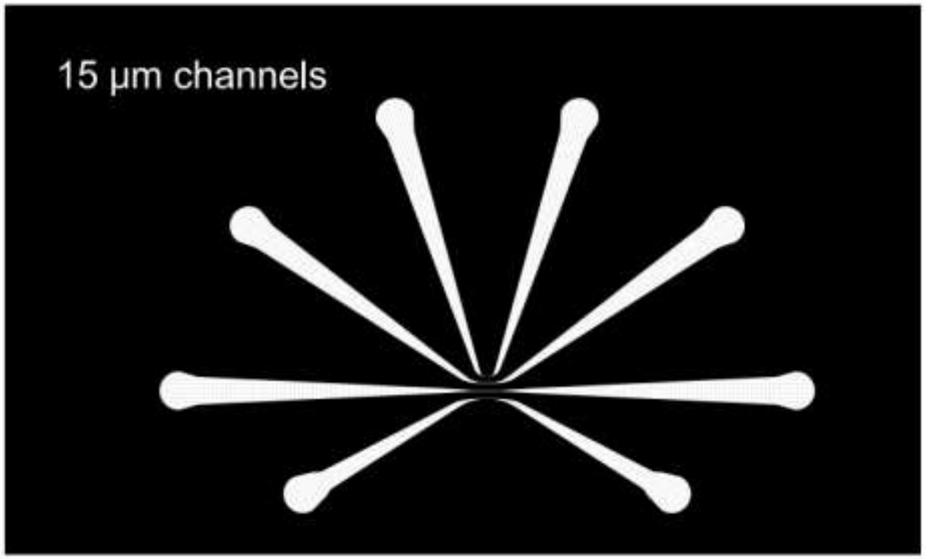
UV light or other radiation

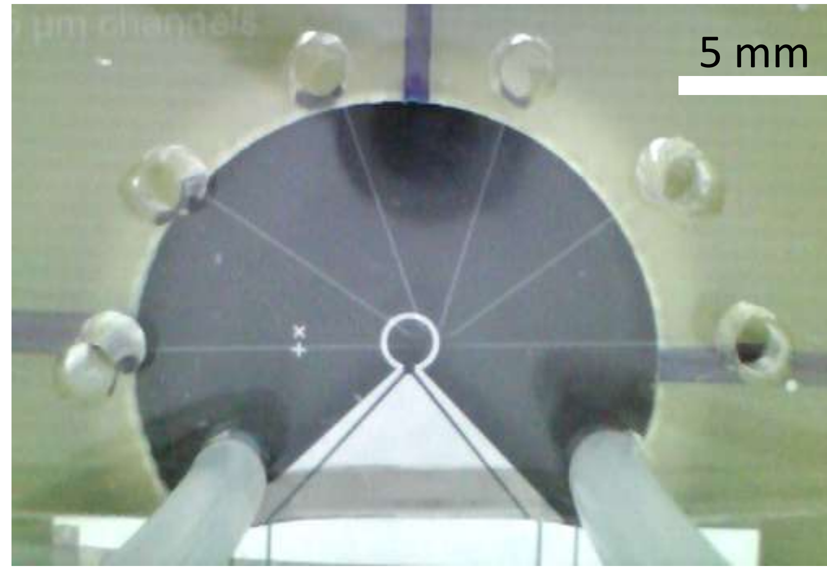


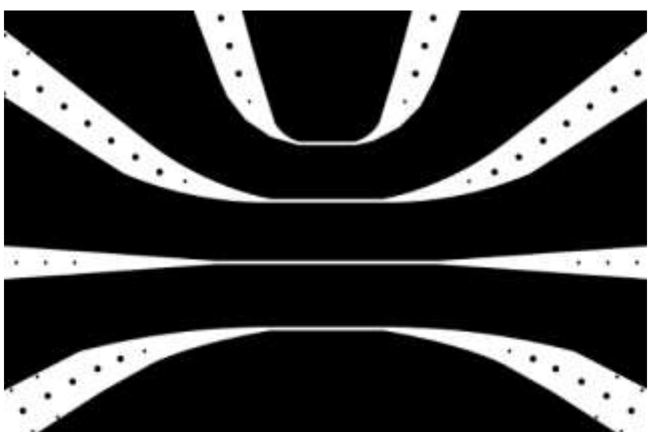


An example that uses negative and positive resists

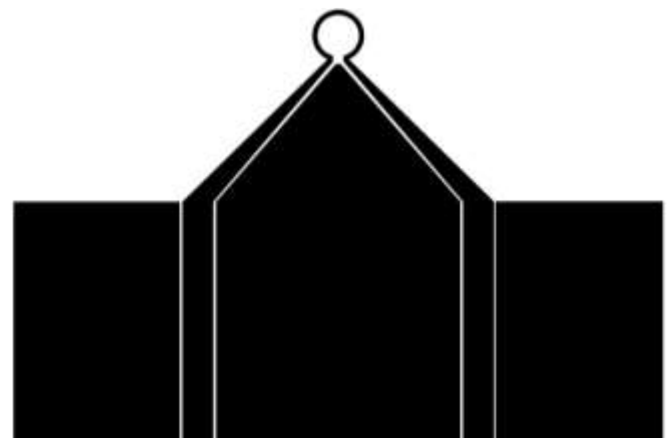
Negative



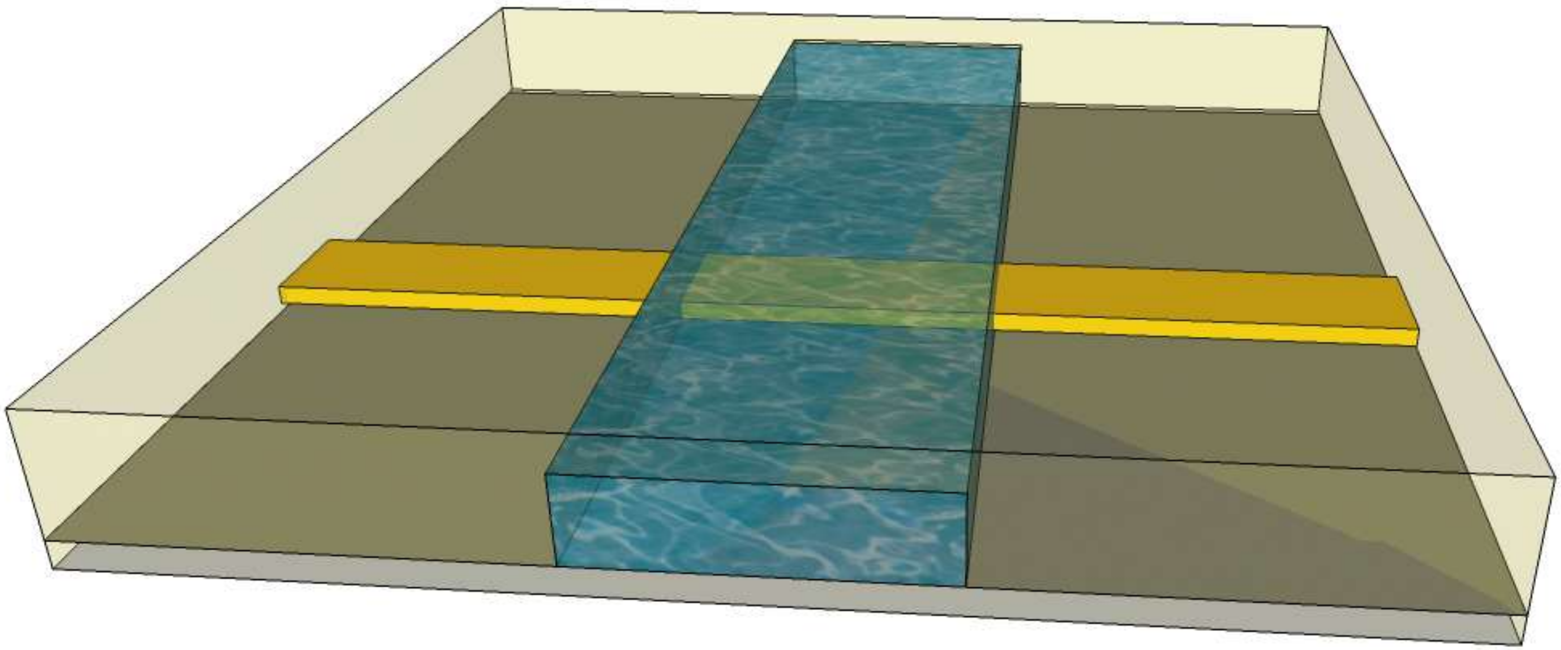




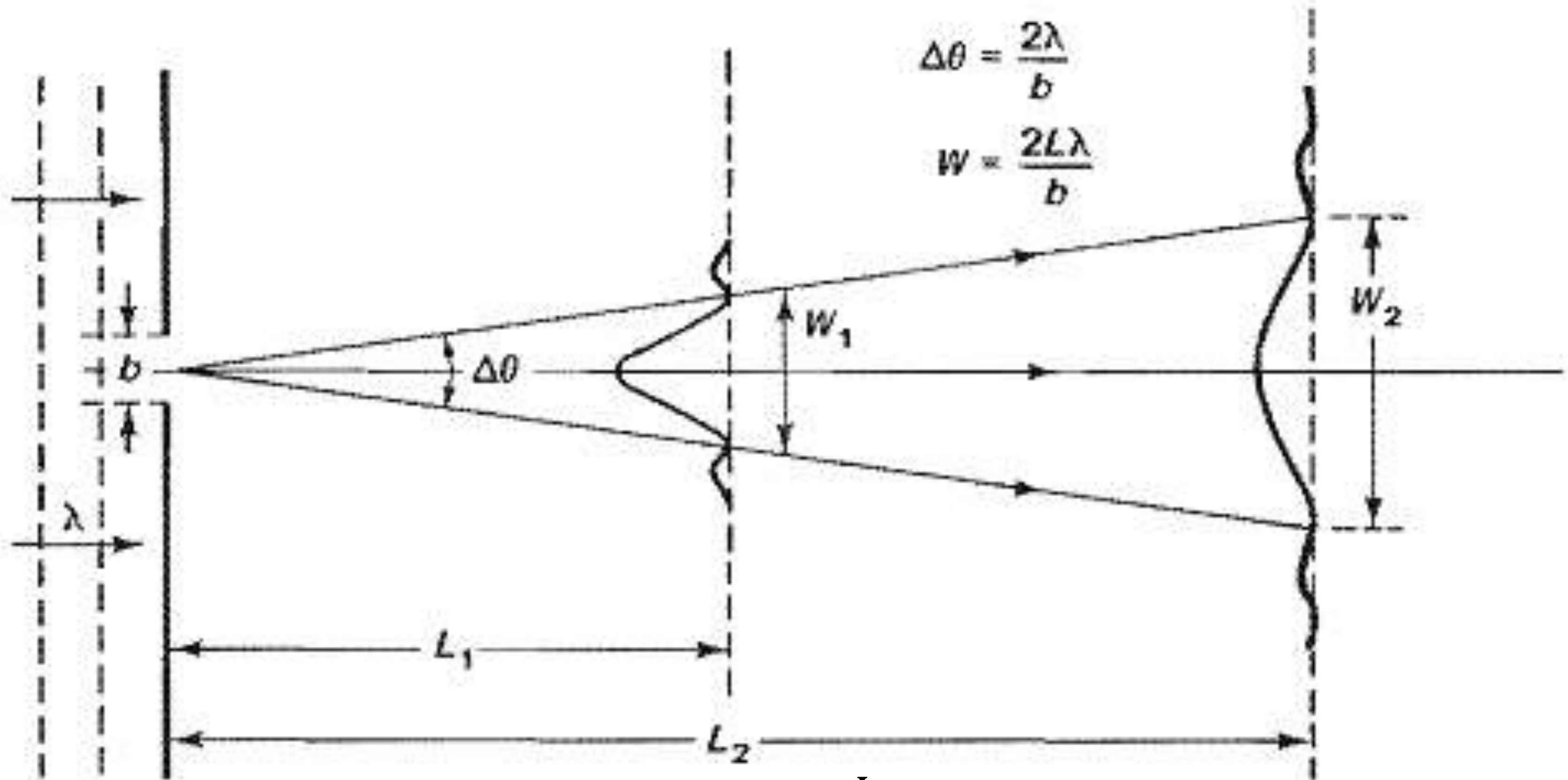
Positive



An example that uses negative and positive resists



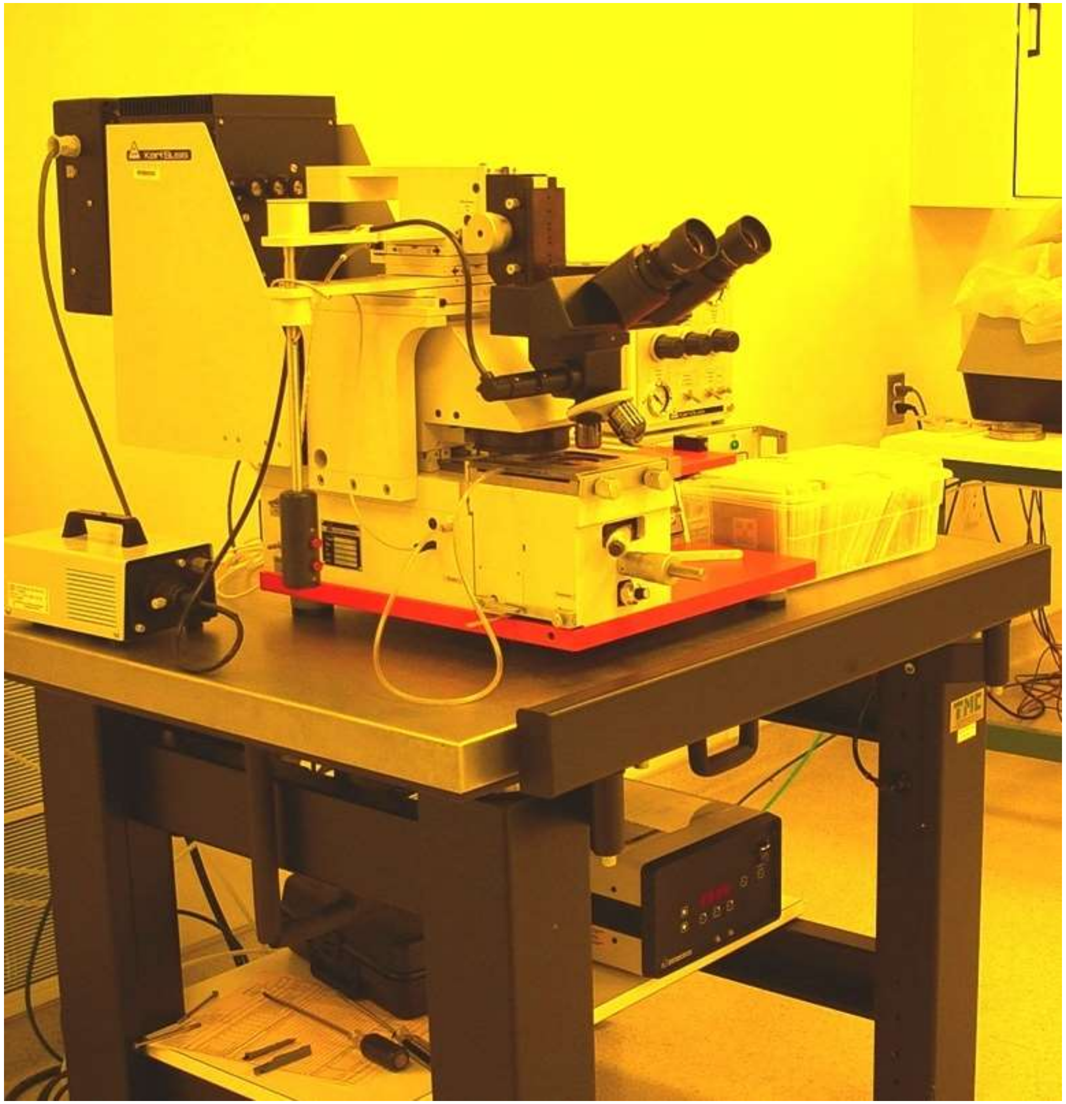
Shadow Printing:
Diffraction through a single slit



$$W \approx \sqrt{L\lambda}$$

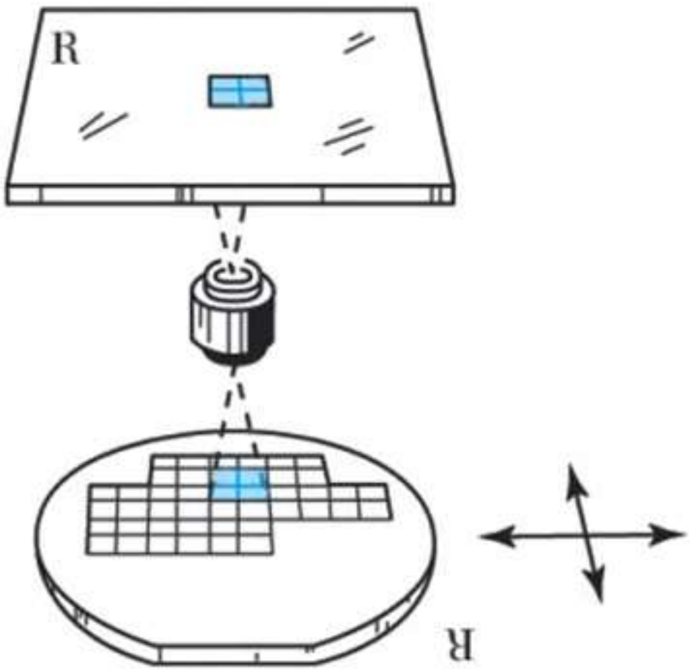
Shadow printing resolution determined by gap L and wavelength λ

Mask Aligner



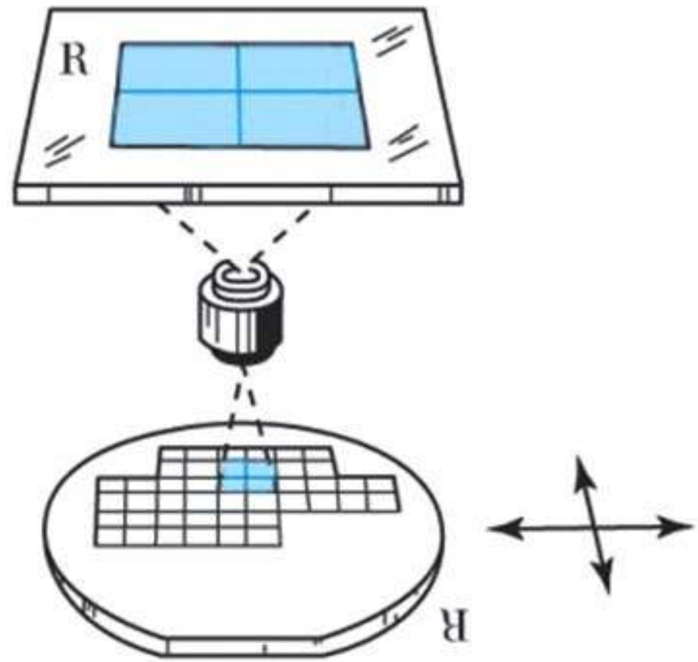
Projecting Steppers

Non-reducing



Reducing (5:1-10:1)

$10\ \mu m \rightarrow 1\mu m$



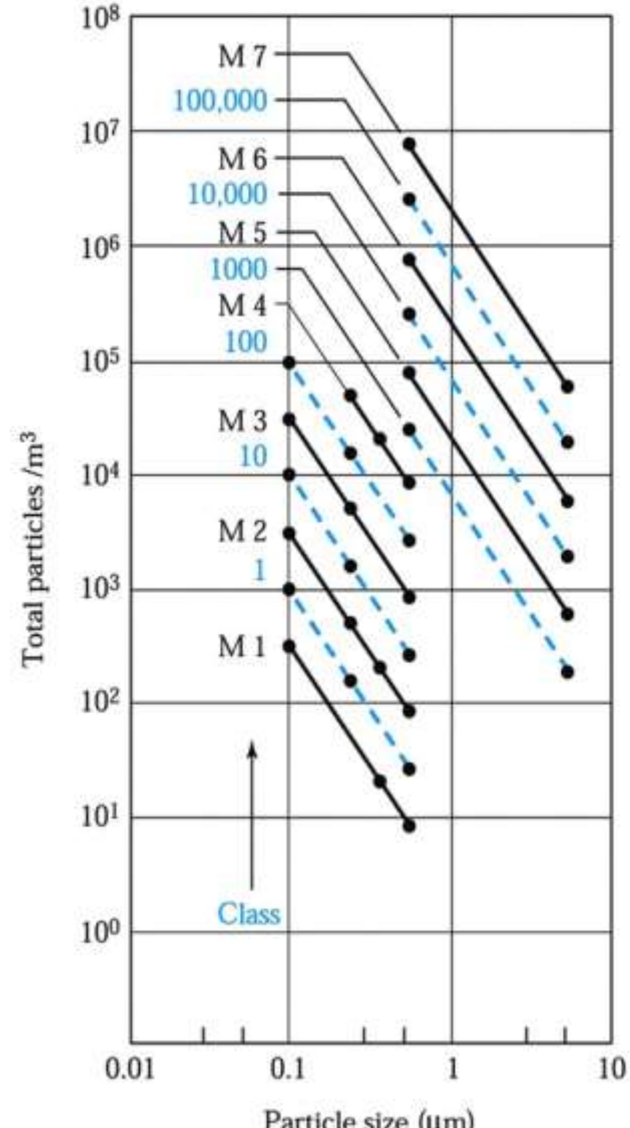
Single Wafer Stepper

(UCSB)

Cassette Stepper

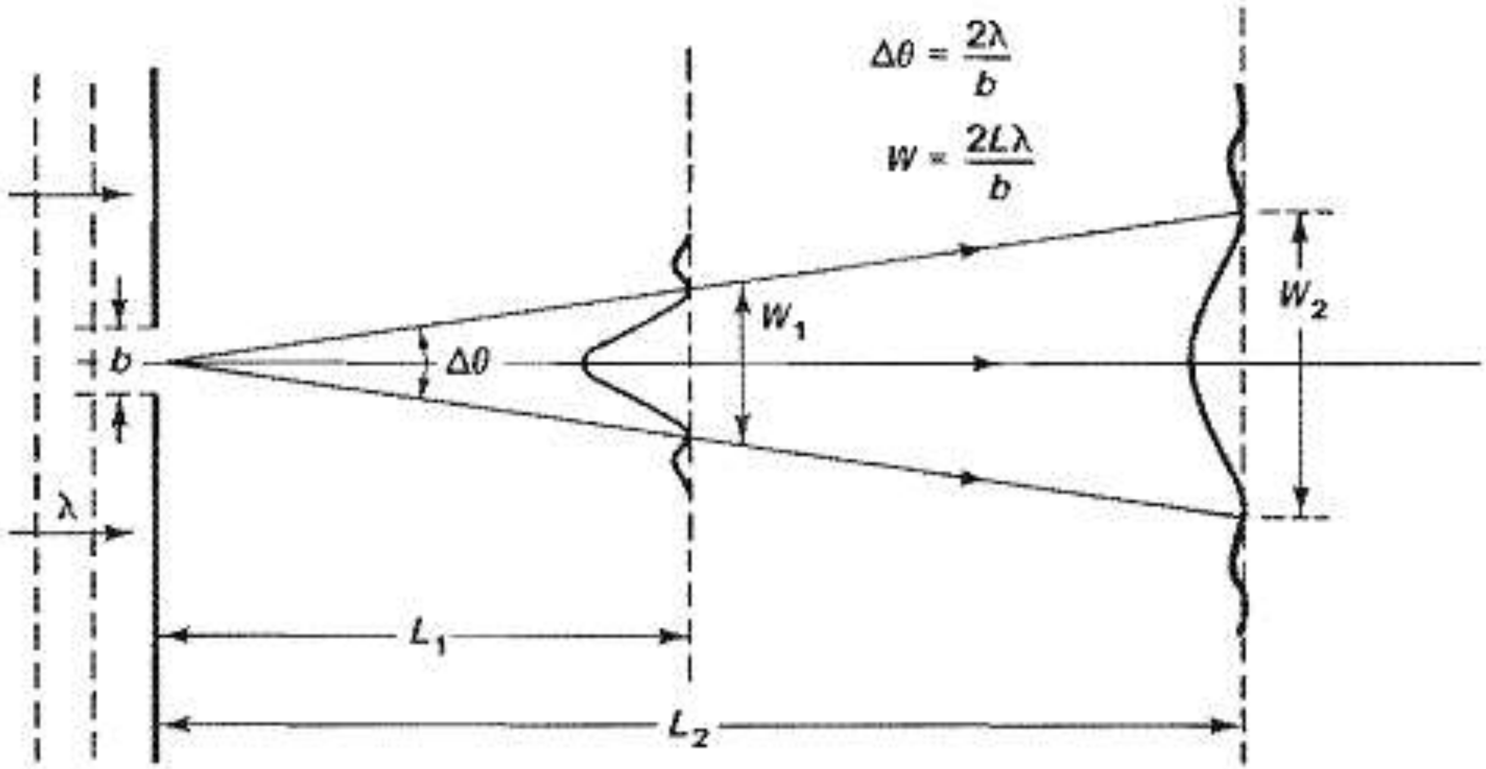
(UCSB)

Cleanrooms are important for lithography



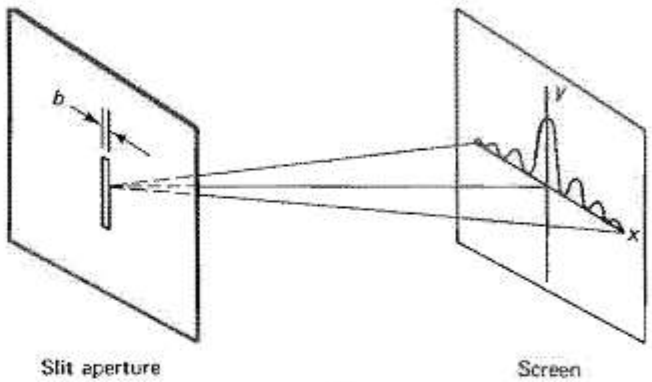
Diffraction affects pattern transfer

Diffraction through a single slit

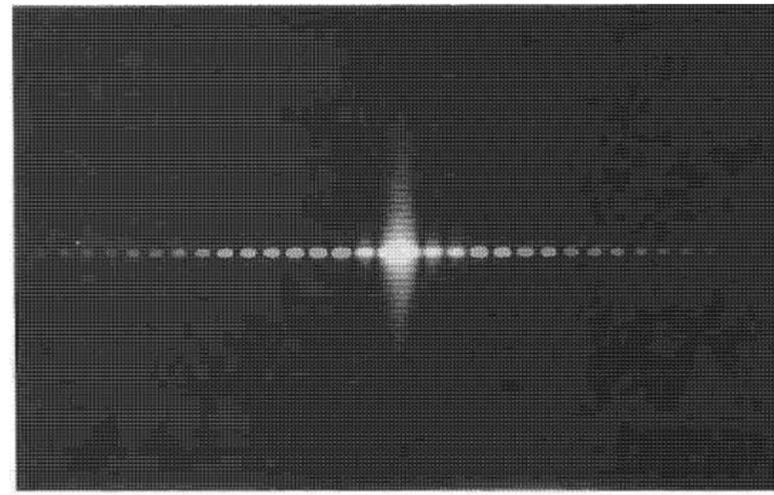


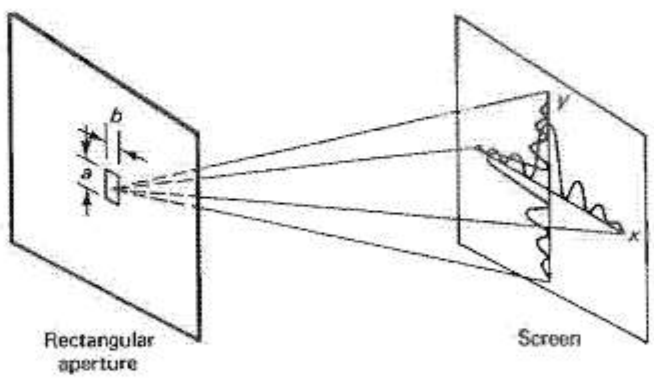
$$W = \frac{2L\lambda}{b}$$

Diffraction through a rectangular slit

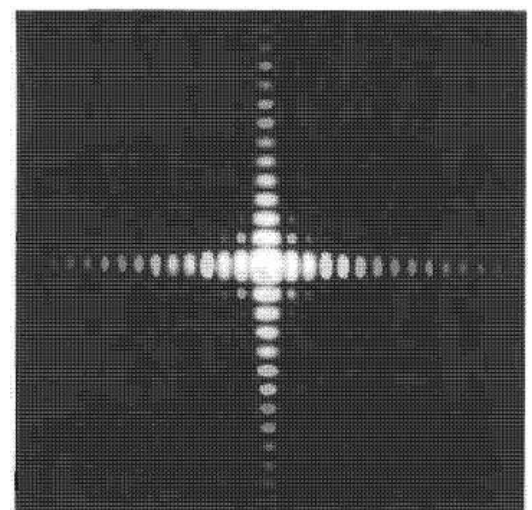


(a)

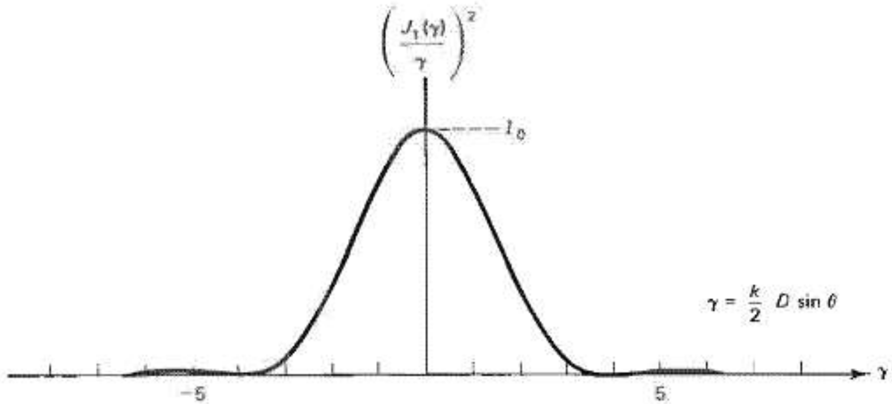


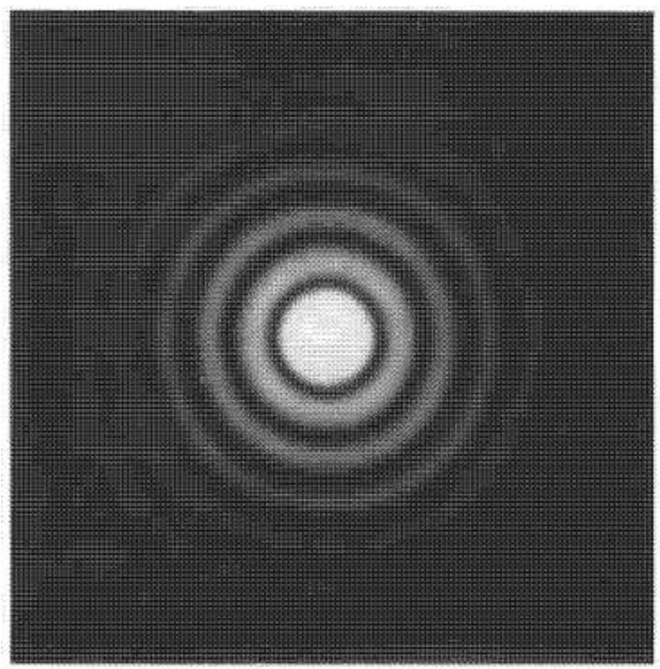


(b)

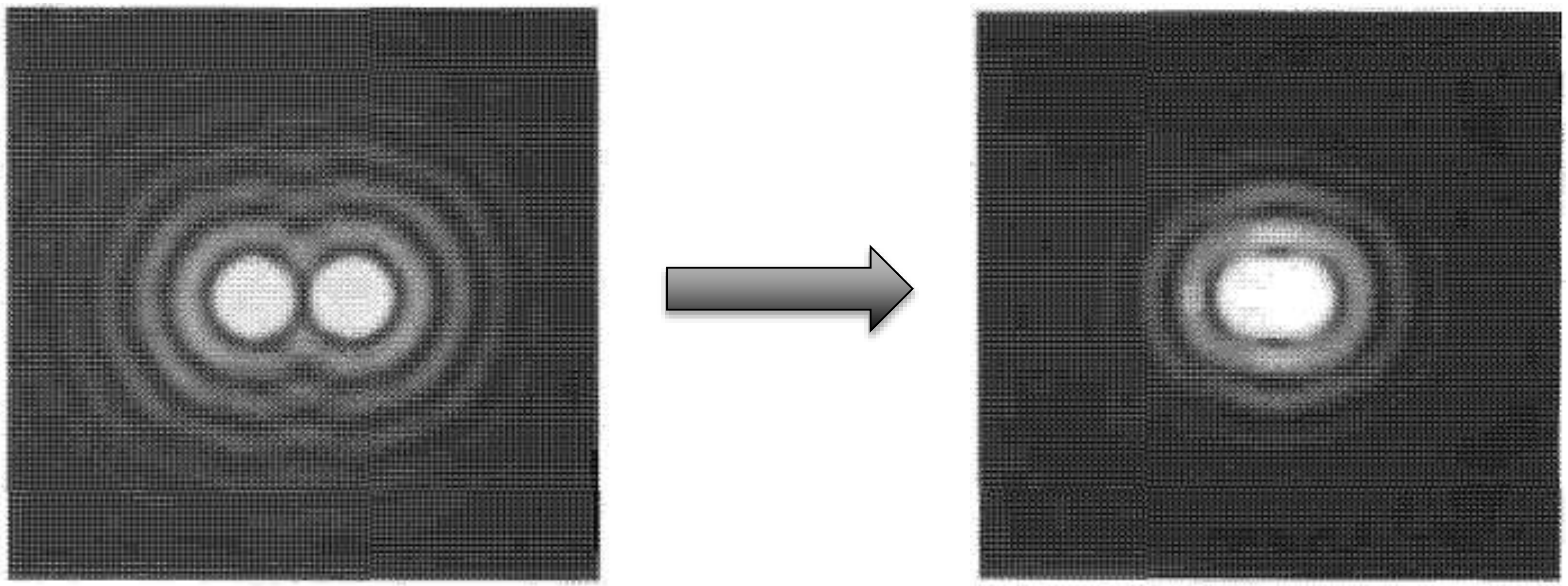


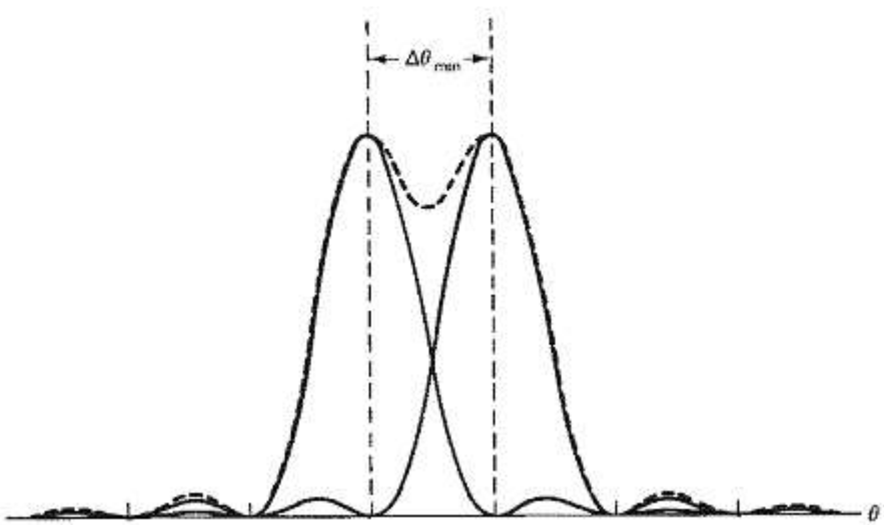
Diffraction through a circular slit (Airy Disk)





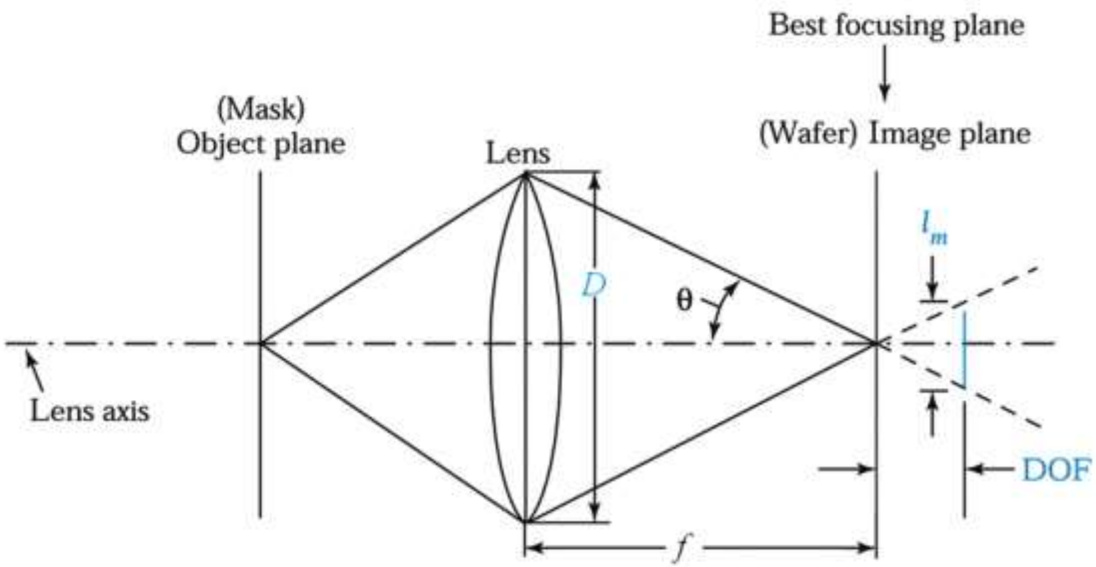
Rayleigh's Criterion





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

Resolution and Depth-of-focus of an optical system



Resolution

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

Depth of field

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

Numerical aperture

$$NA \equiv \frac{D}{f} \equiv n \sin\theta$$

DOF is a measure of distance over which image formed by lens will remain in focus

Sources of light:
Spectrum of Tungsten-Halogen Lamp

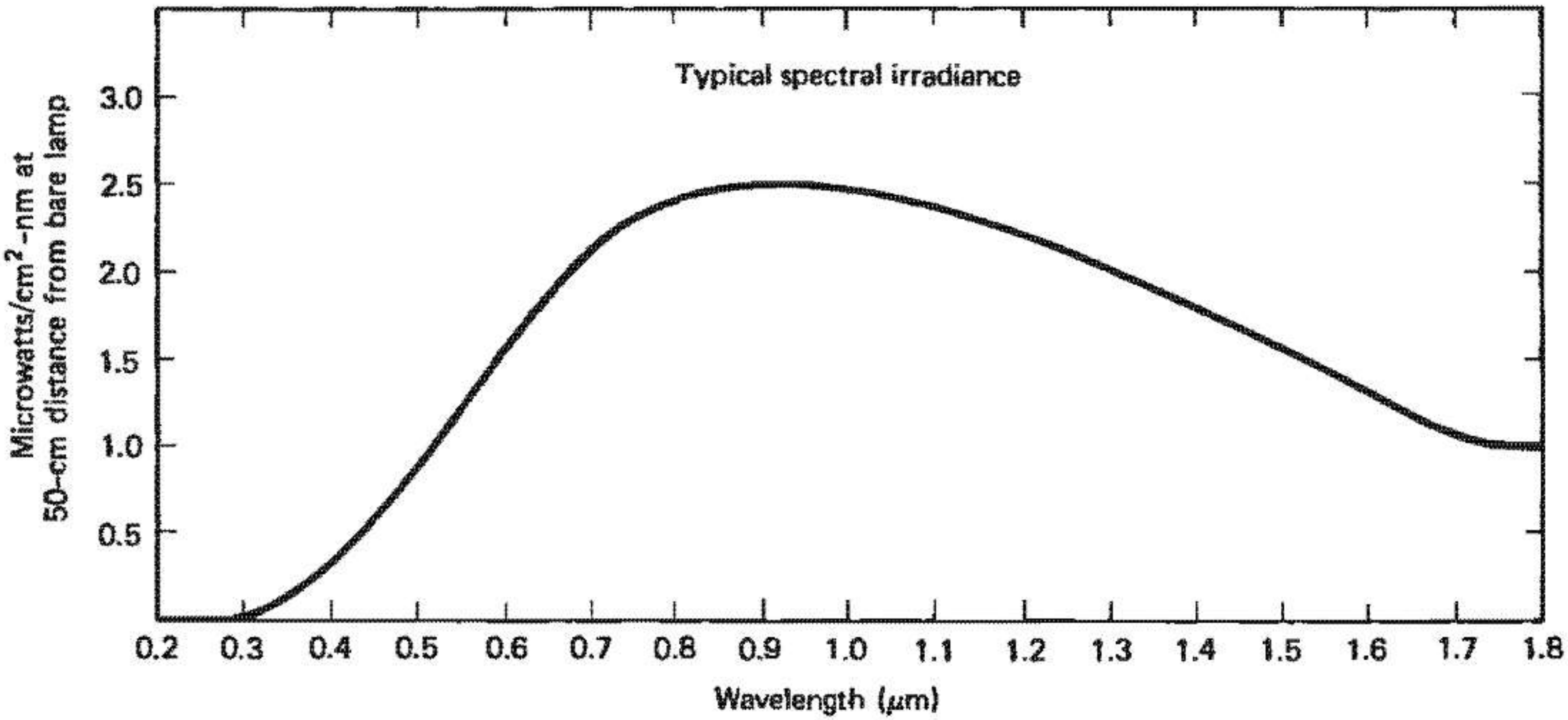


Figure 2-11 Spectral irradiance from a 100-W quartz halogen lamp, providing continuous radiation from 0.3 to 2.5 μm. (Oriel Corp., General Catalogue, Stratford, Conn.)

Sources of light: Spectrum of Mercury-Xenon Lamp

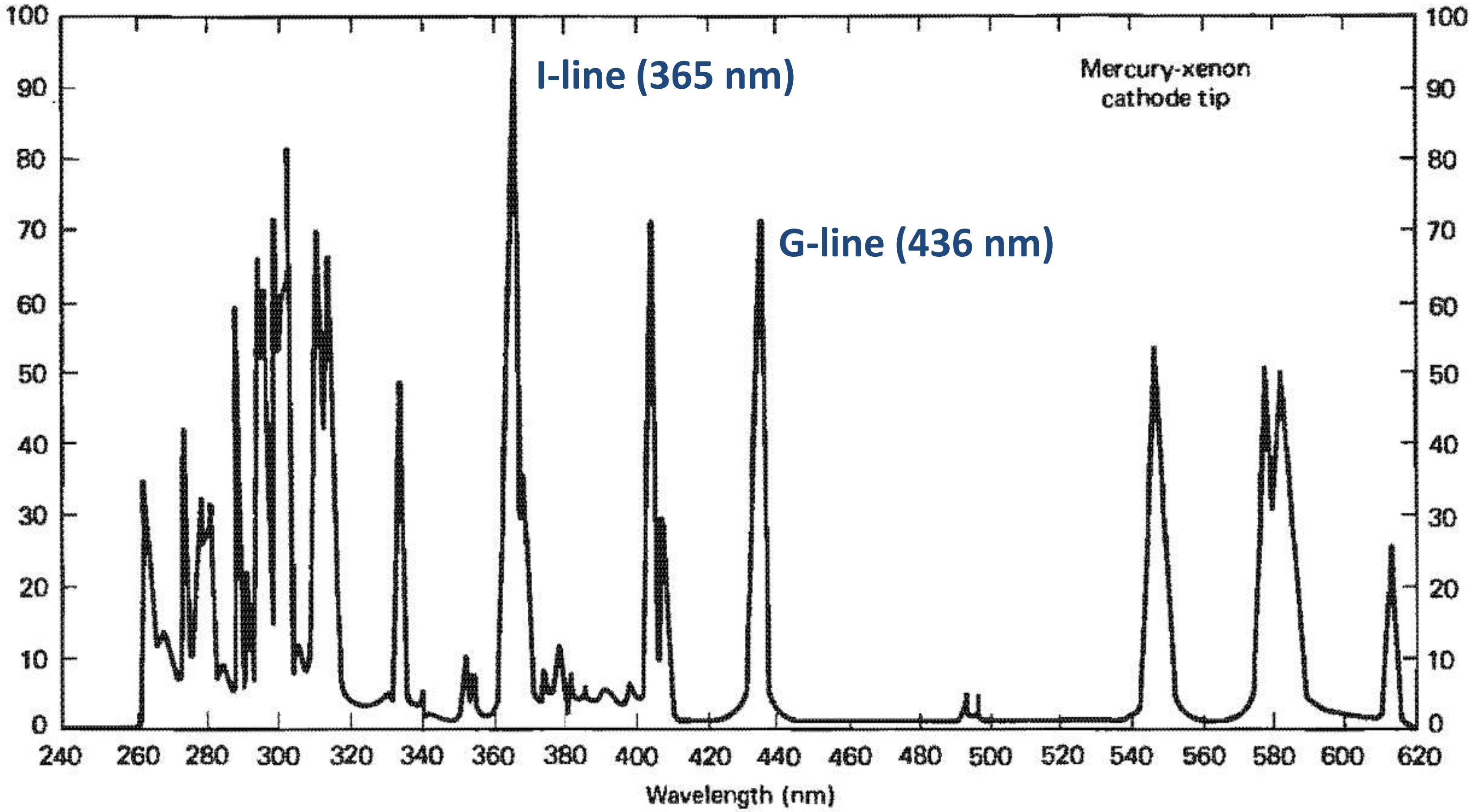
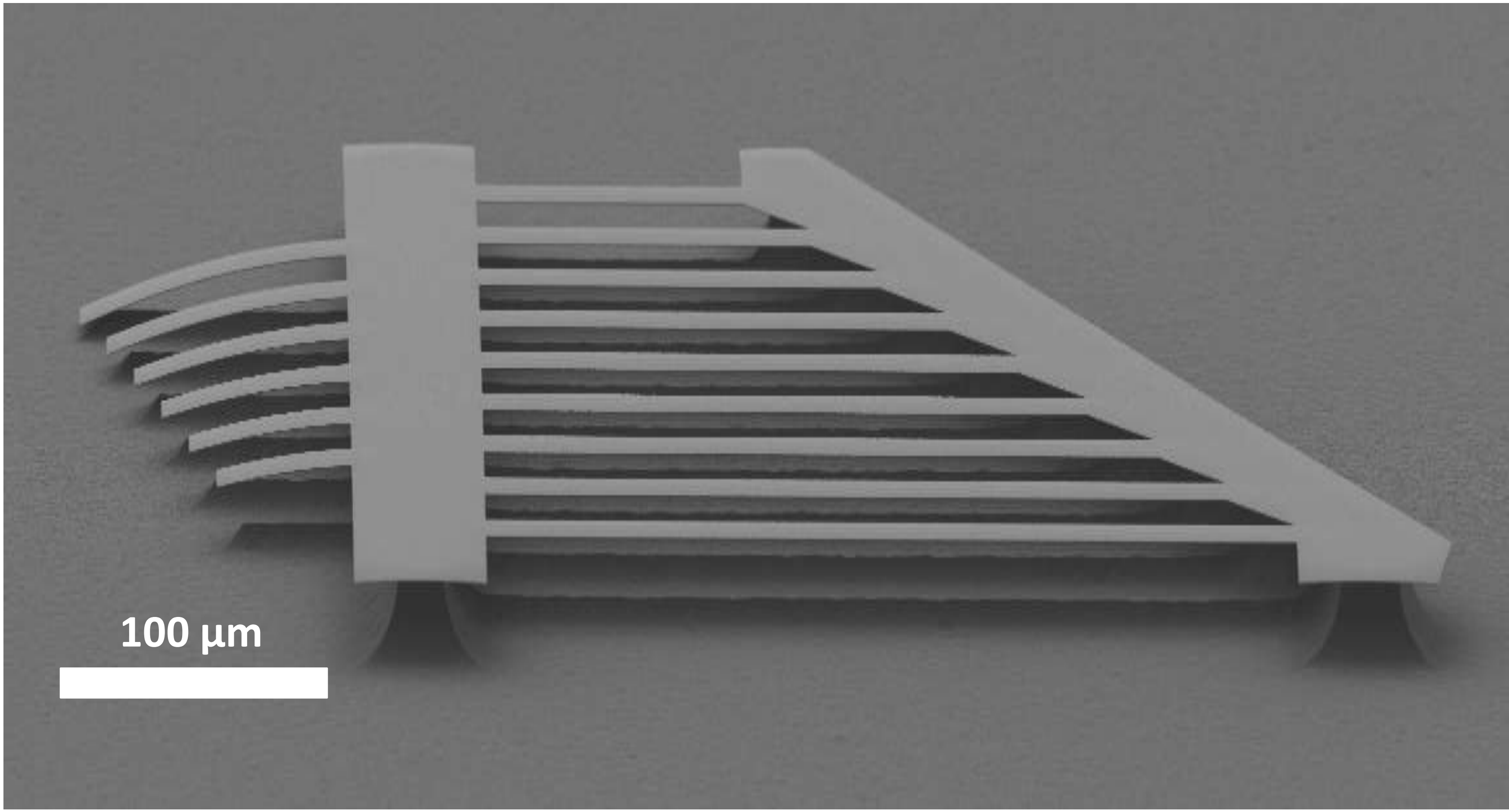


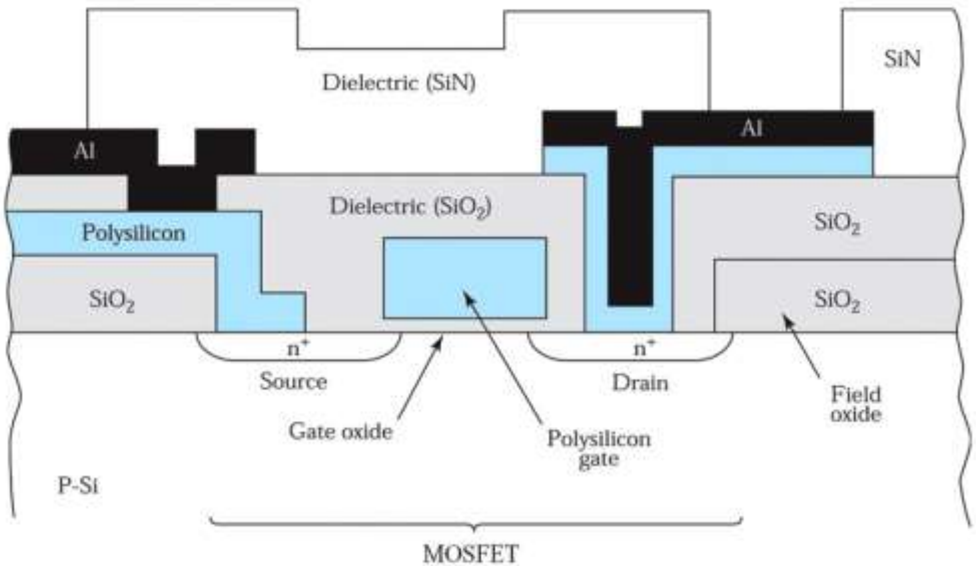
Figure 2-14 Spectral emission for Hg-Xe arc lamp. (Canrad-Hanovia, Inc.)

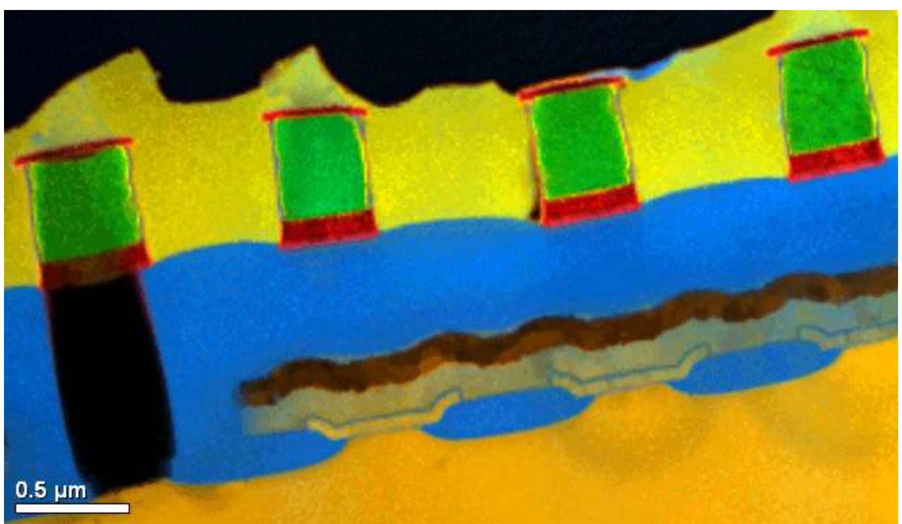
SEMs have μm DOF and nm resolution

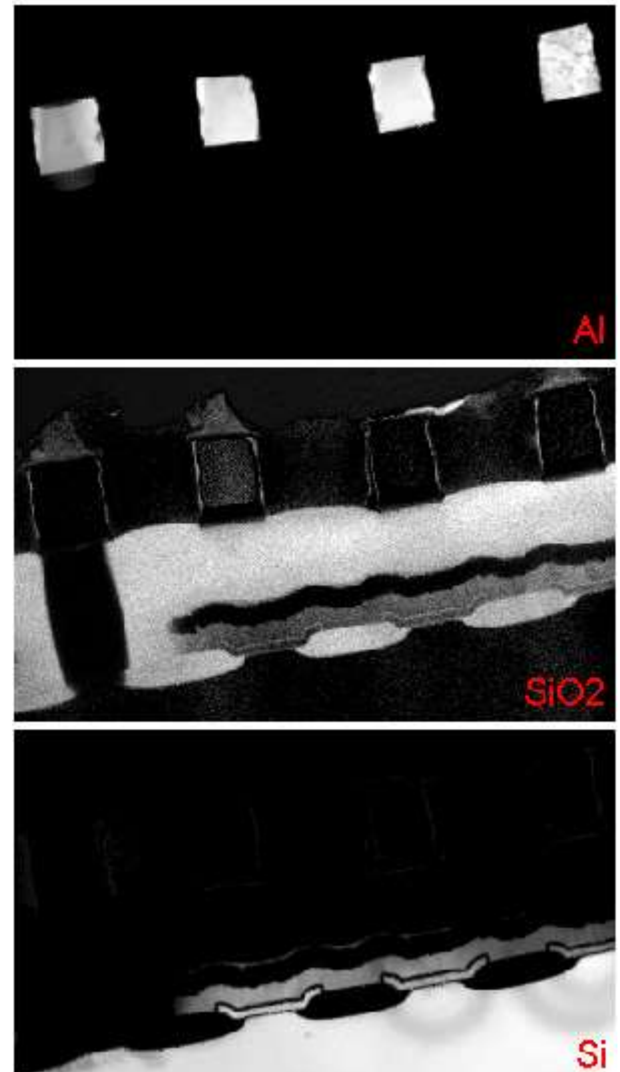


Large part of image in focus. Large DOF and small l_m

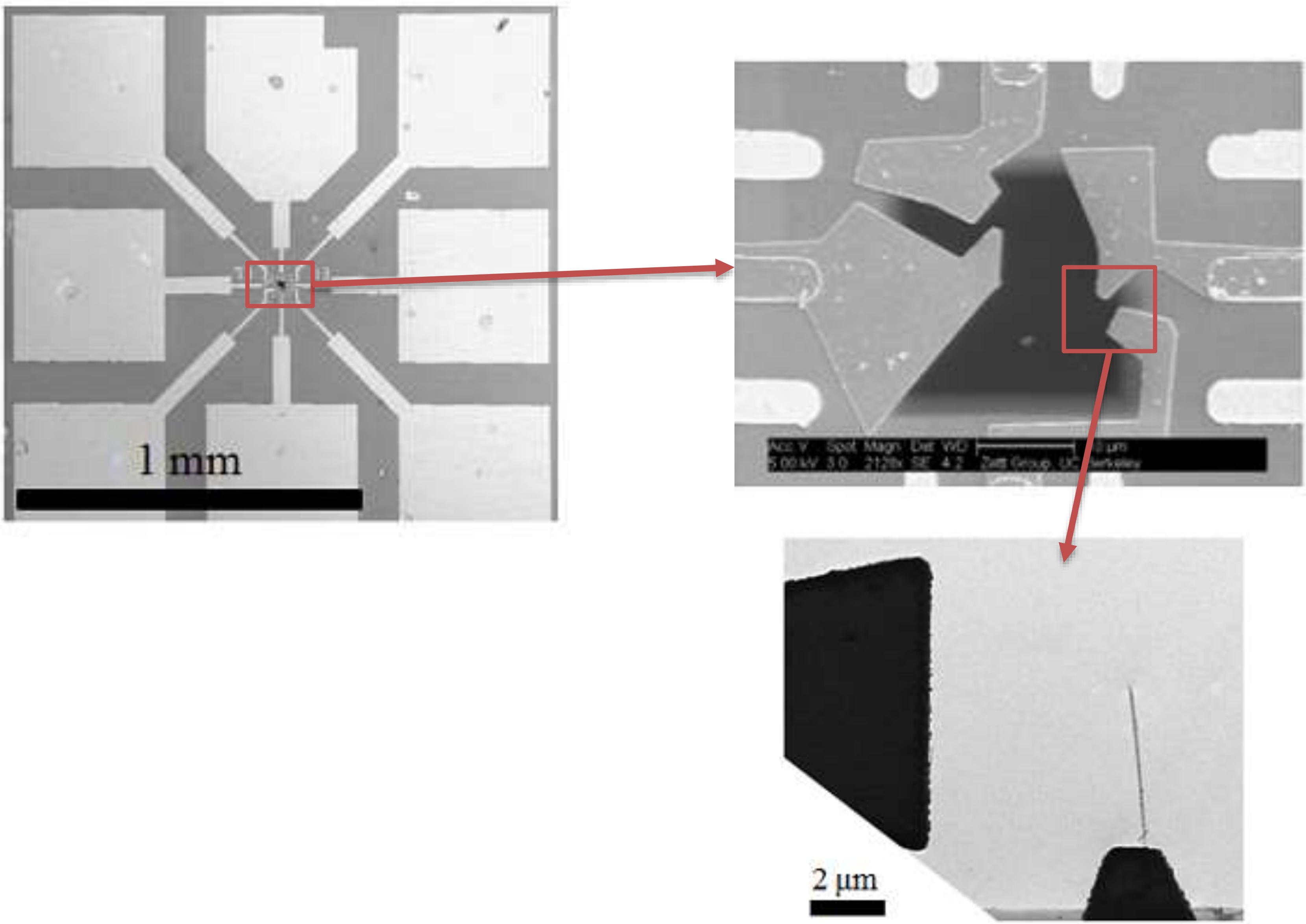
The challenges of registration illustrated by the 7 nm transistor



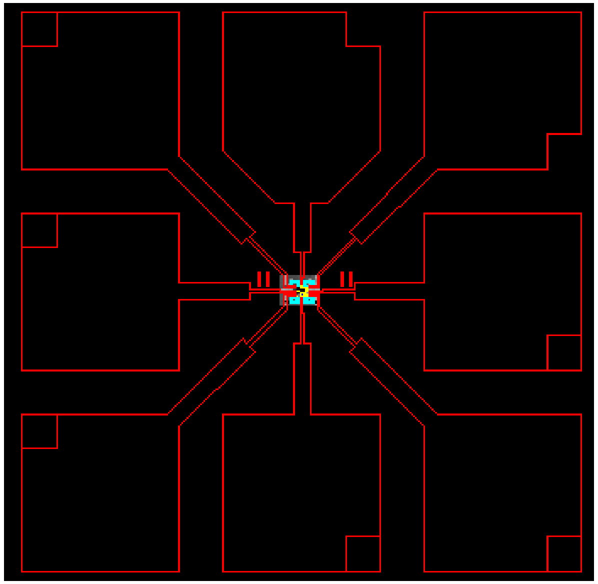


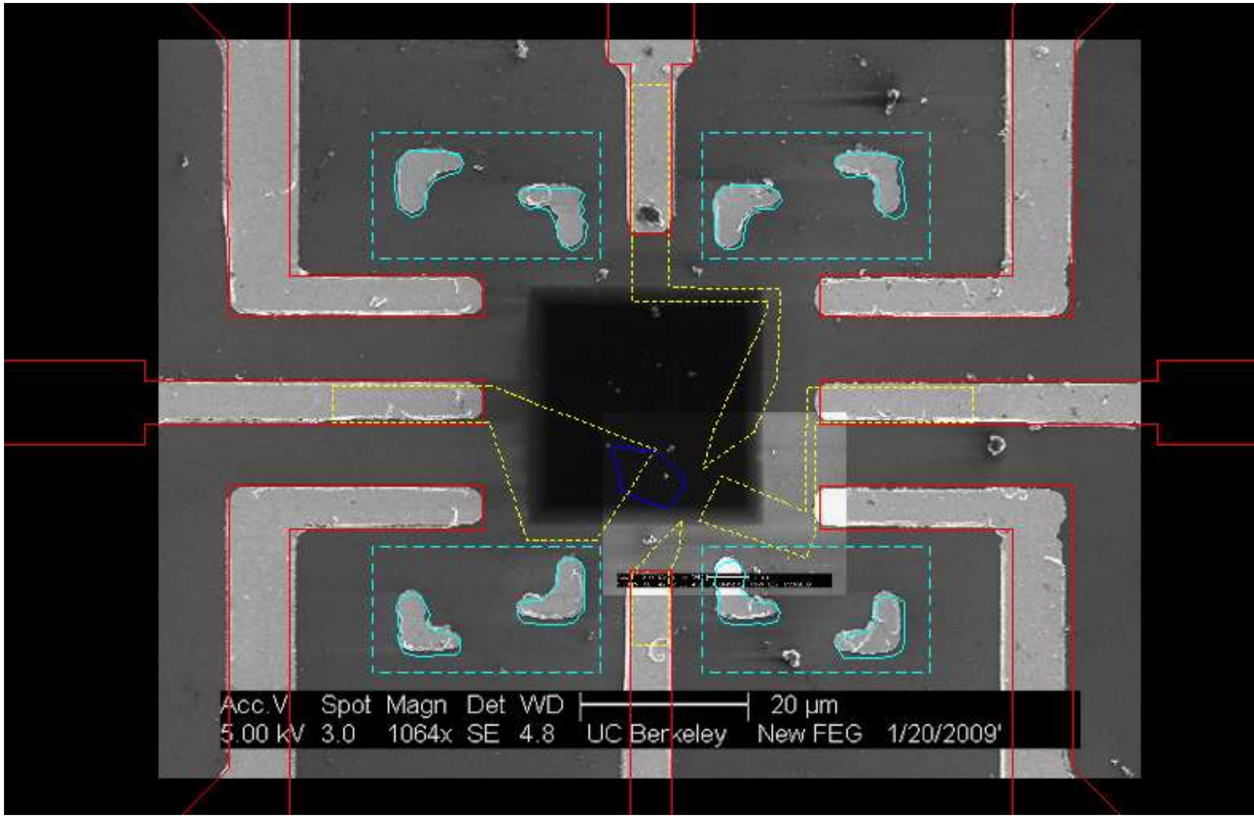


An example of registration in e-beam lithography

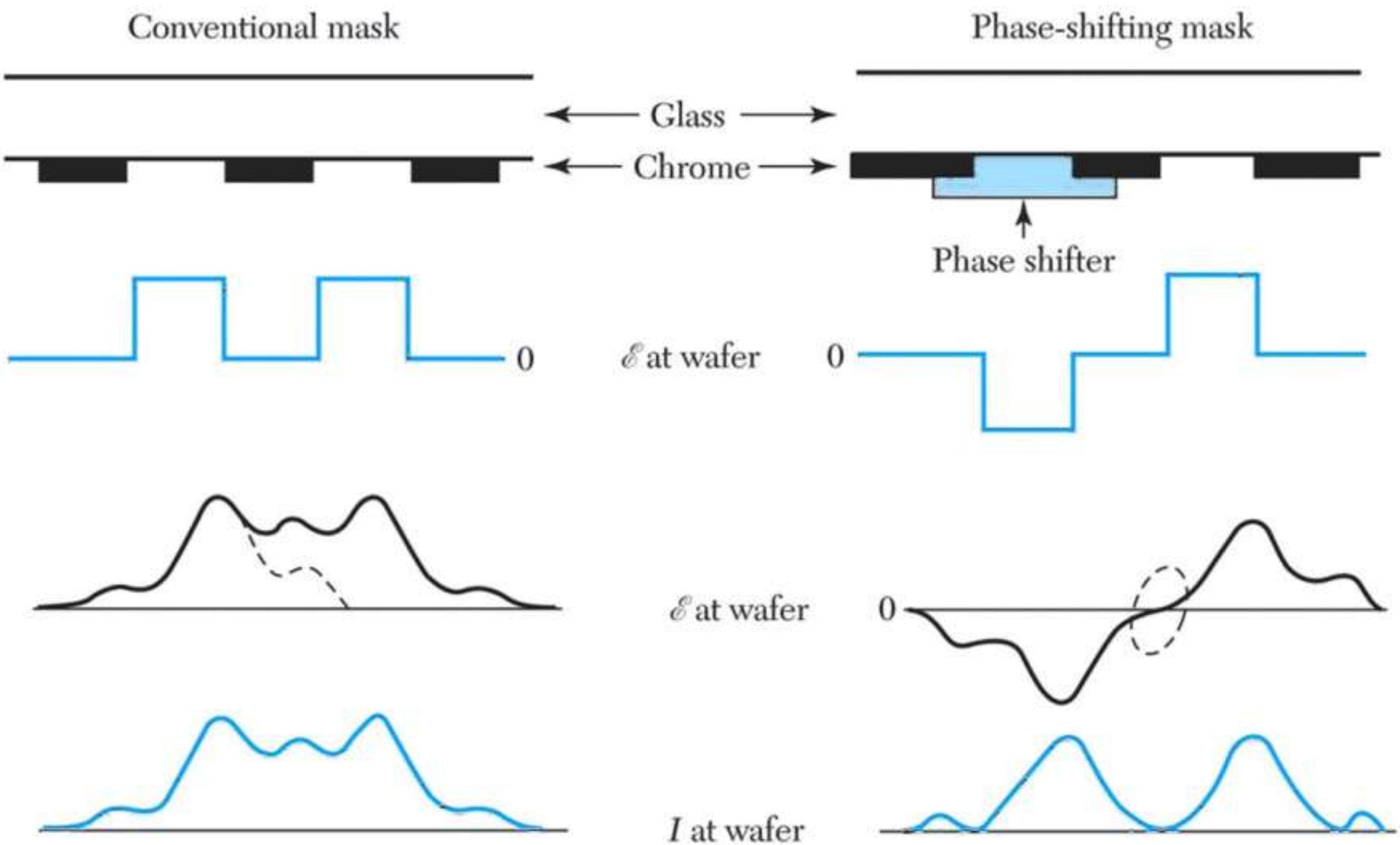


An example of registration in e-beam lithography



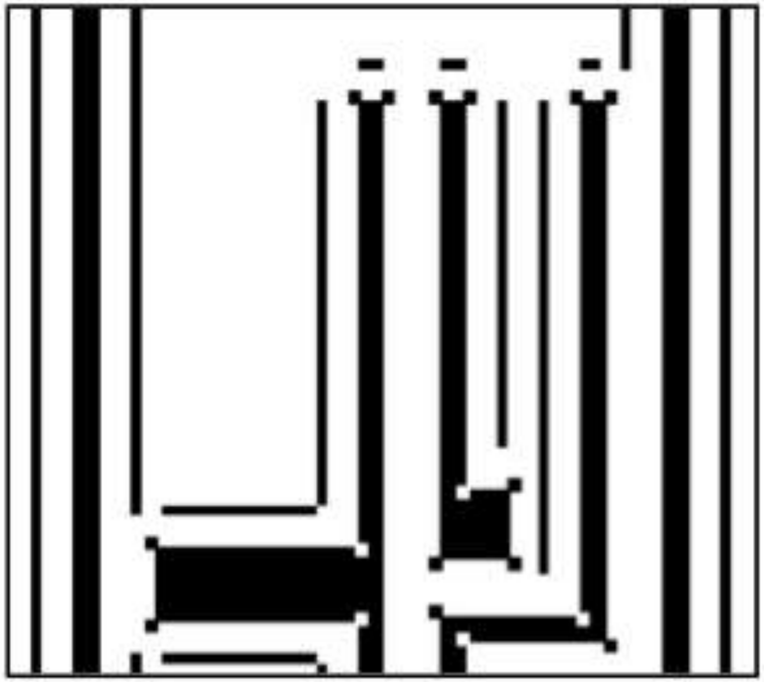


Phase Shifting

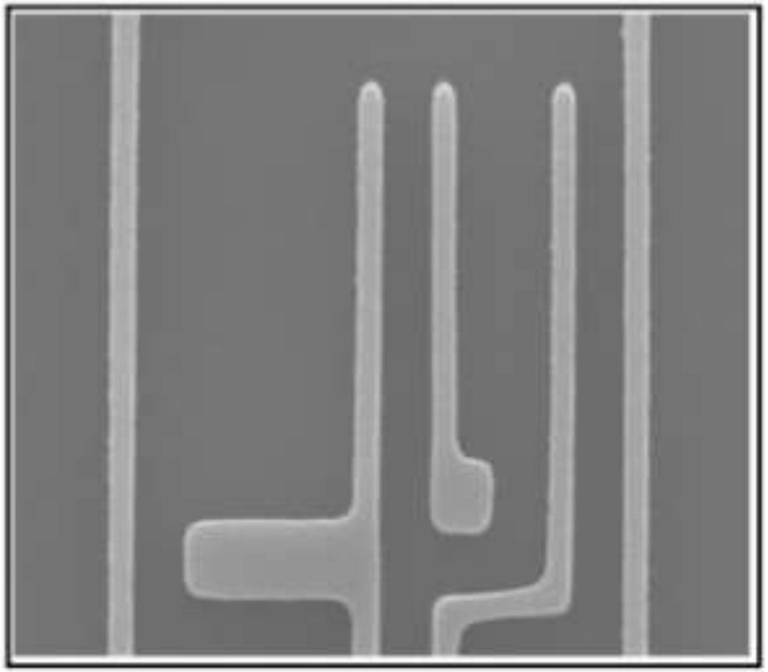


Optical Proximity Correction (OPC)

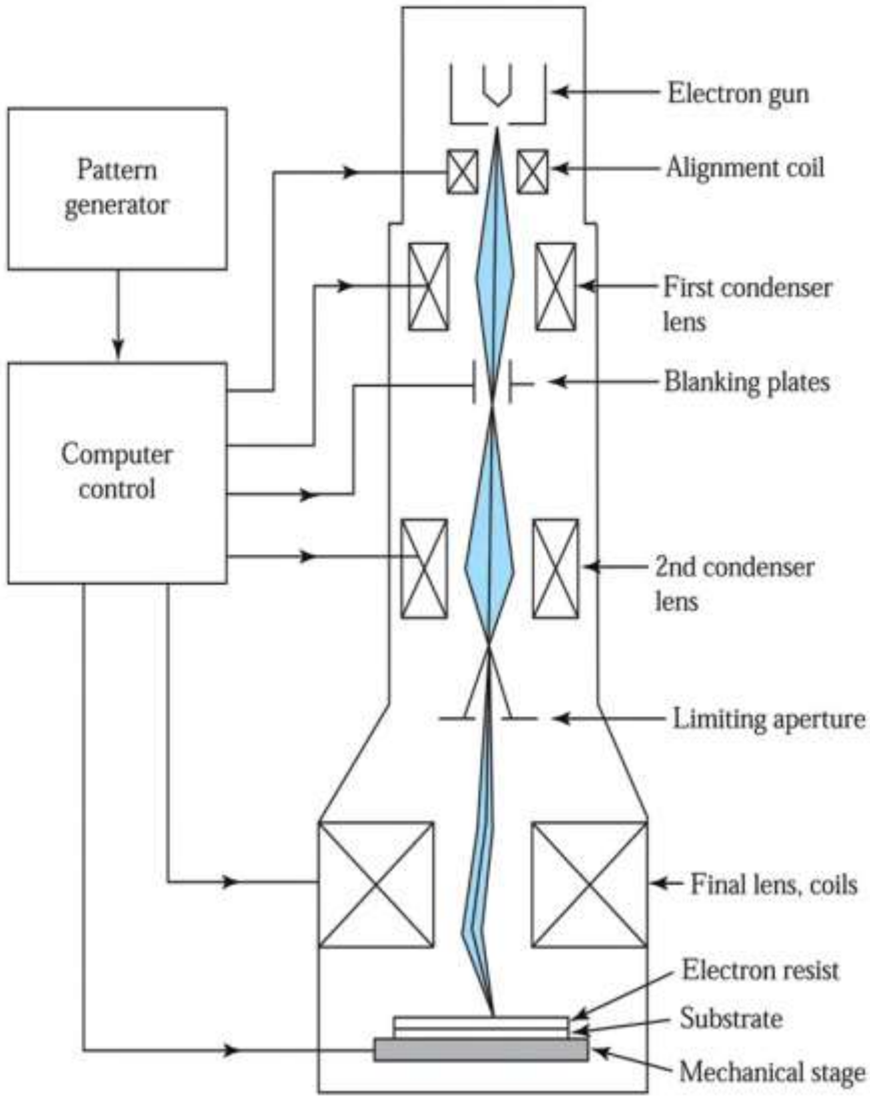
Mask



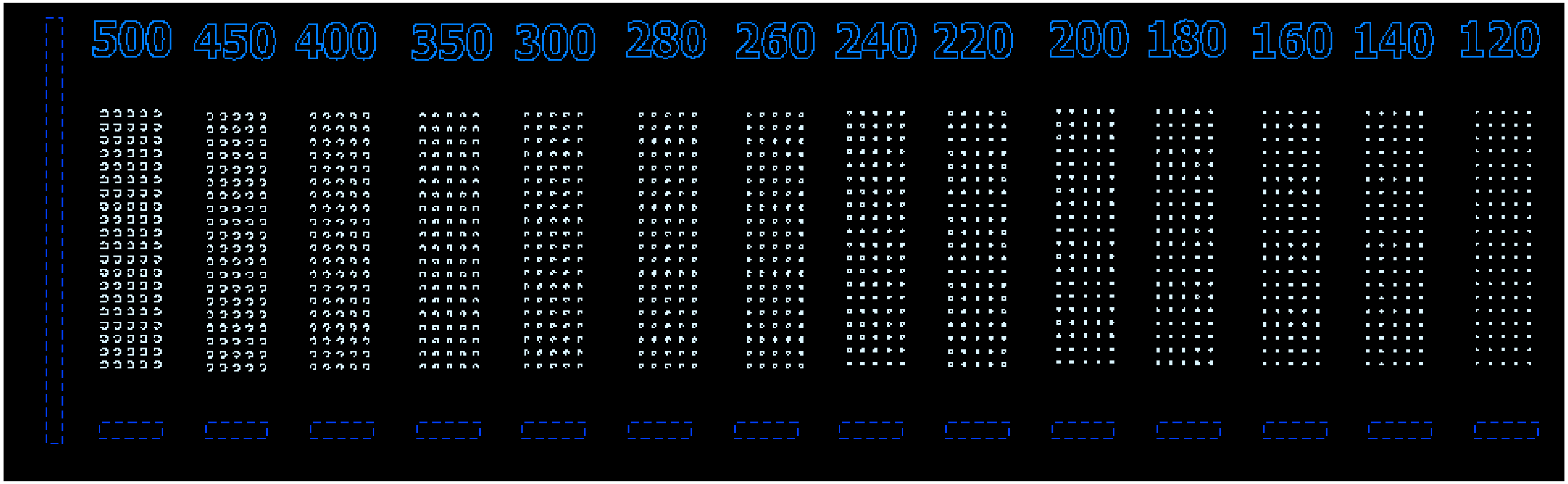
Wafer

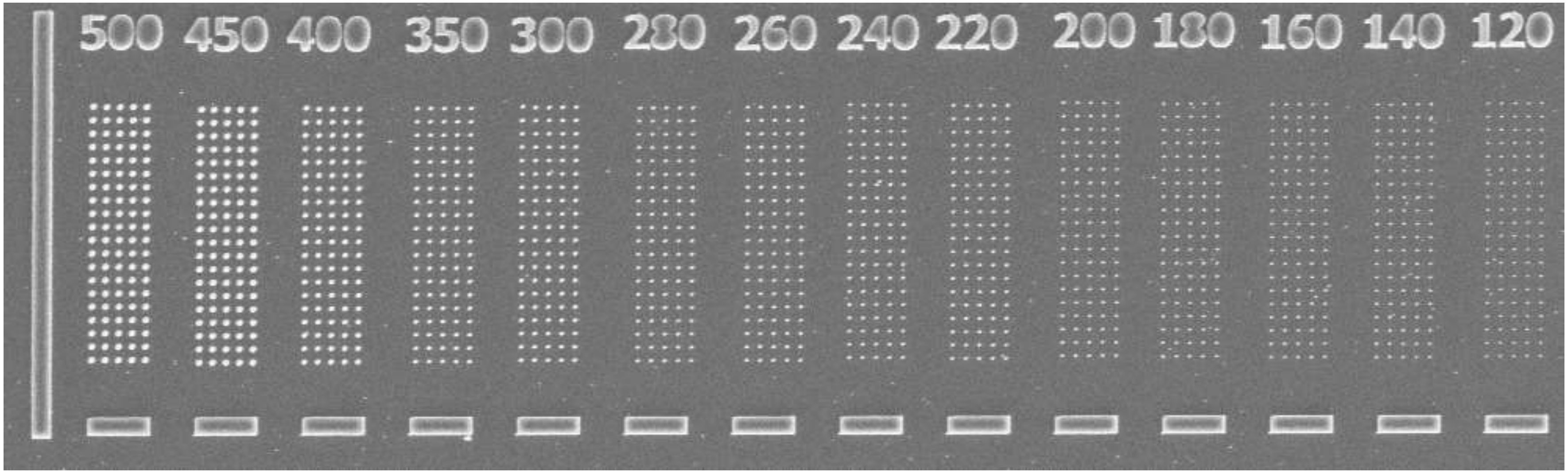


Electron-beam lithography



An example of electron-beam lithography



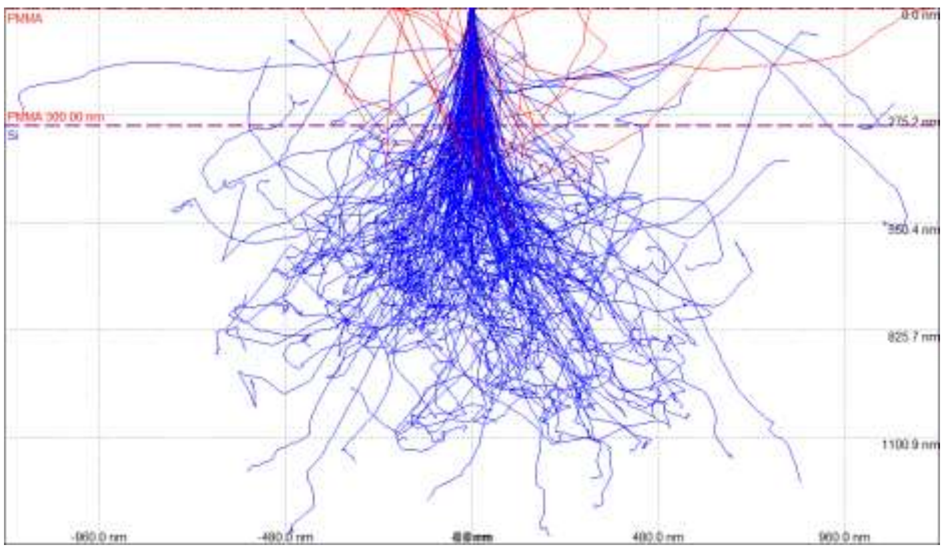


Simulating proximity effect with CASINO

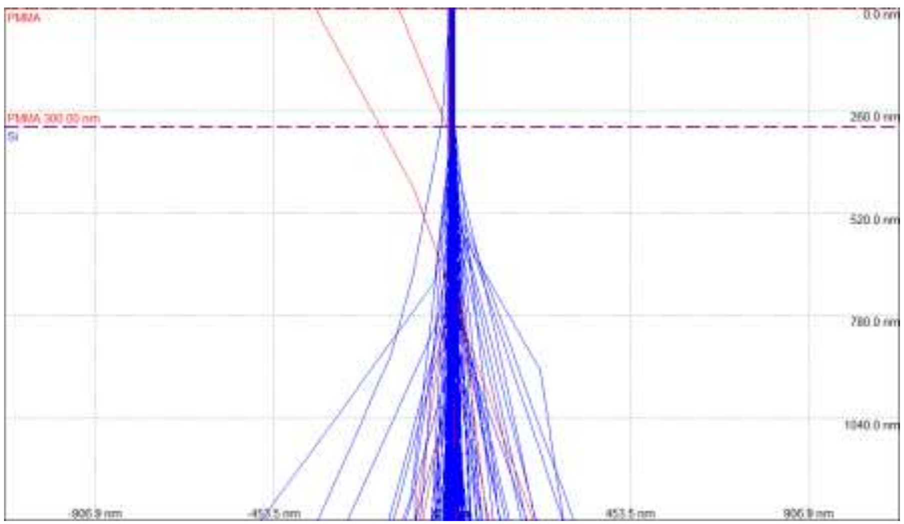
monte CArlo SImulation of electroN trajectory in sOlids

300 nm PMMA, Si Substrate
10 nm beam diameter

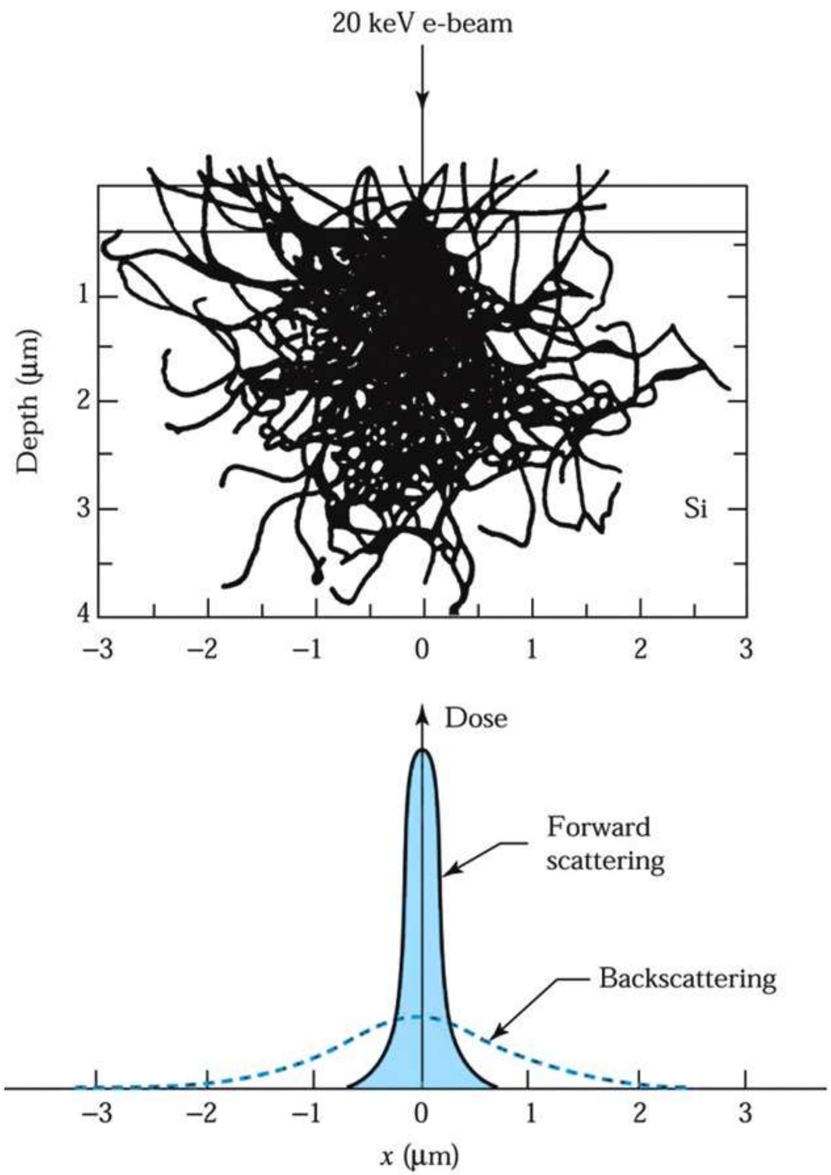
10 keV



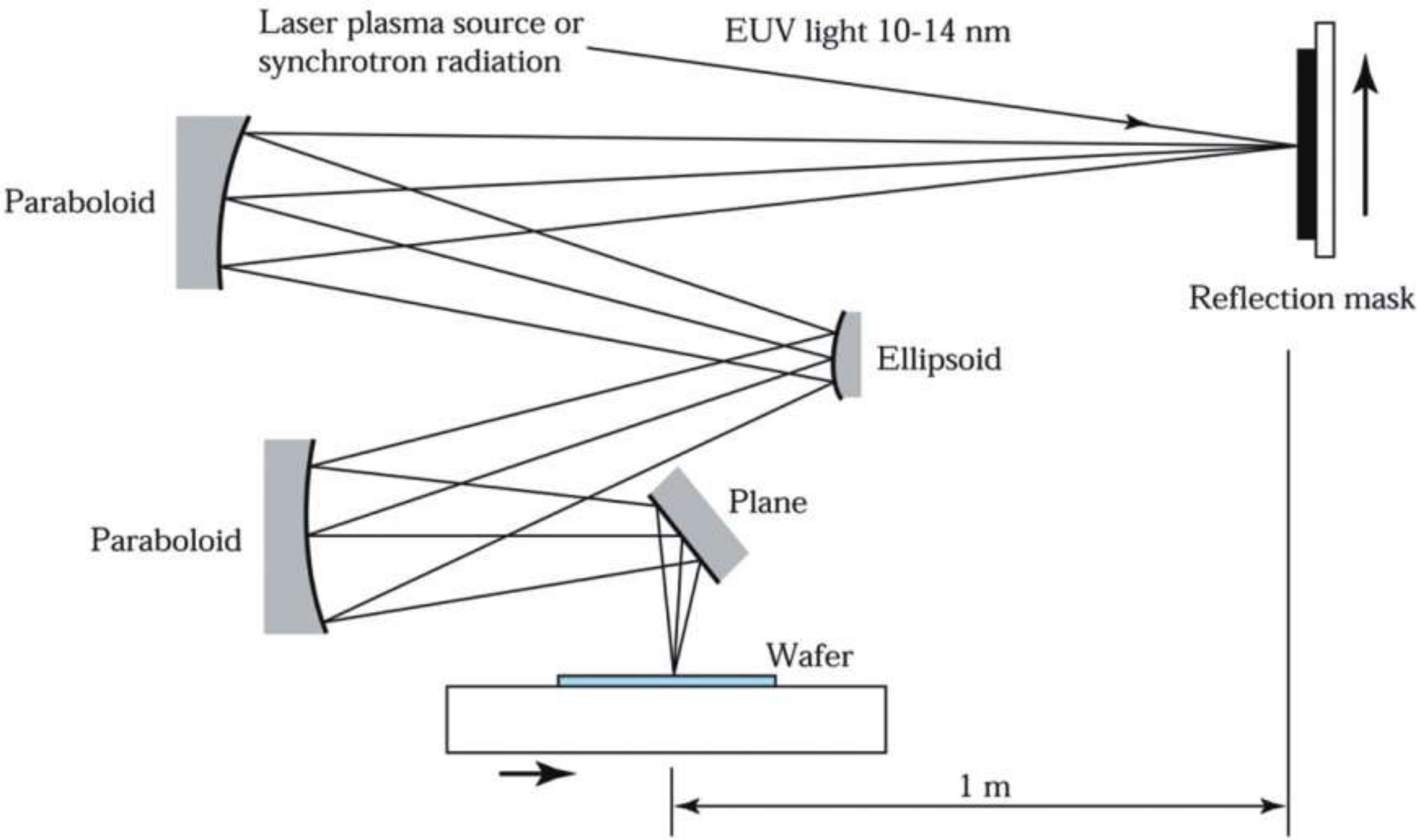
100 keV



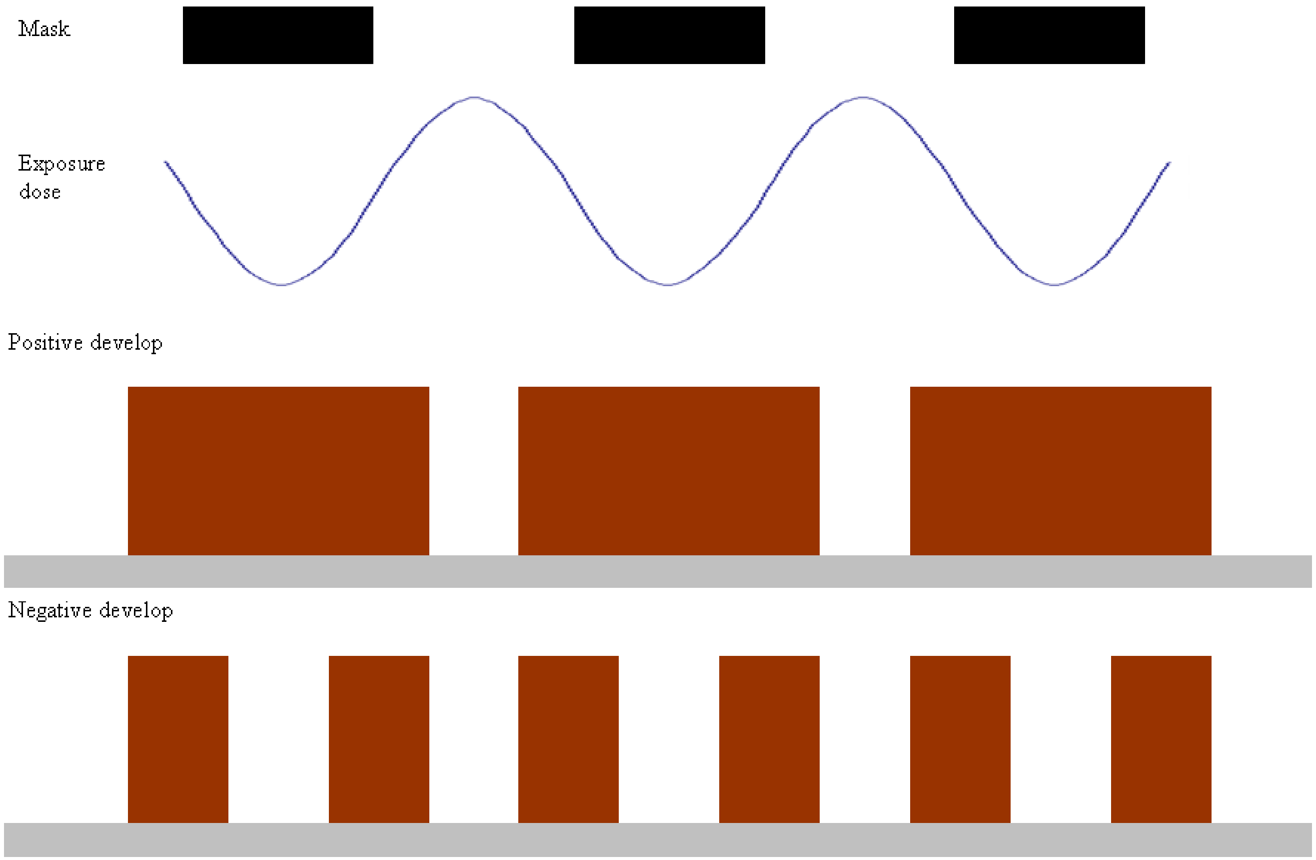
The proximity effect limits e-beam resolution



Extrem UV (100 eV) lithography



Double Patterning



Roadmap

Node	180 nm	130 nm	90 nm	65 nm	45 nm	32 nm	22 nm	15 nm
Leading chipmaker	KrF + OPC	KrF + OPC + RET	ArF + OPC + RET	ArF + immersion + OPC + RET	ArF + immersion + OPC + strong RET	45 nm + DP	45 nm + DP + restricted layout	45 nm + MP
Lagging chipmaker	KrF + OPC	KrF + OPC + RET	Increasing cost barrier					

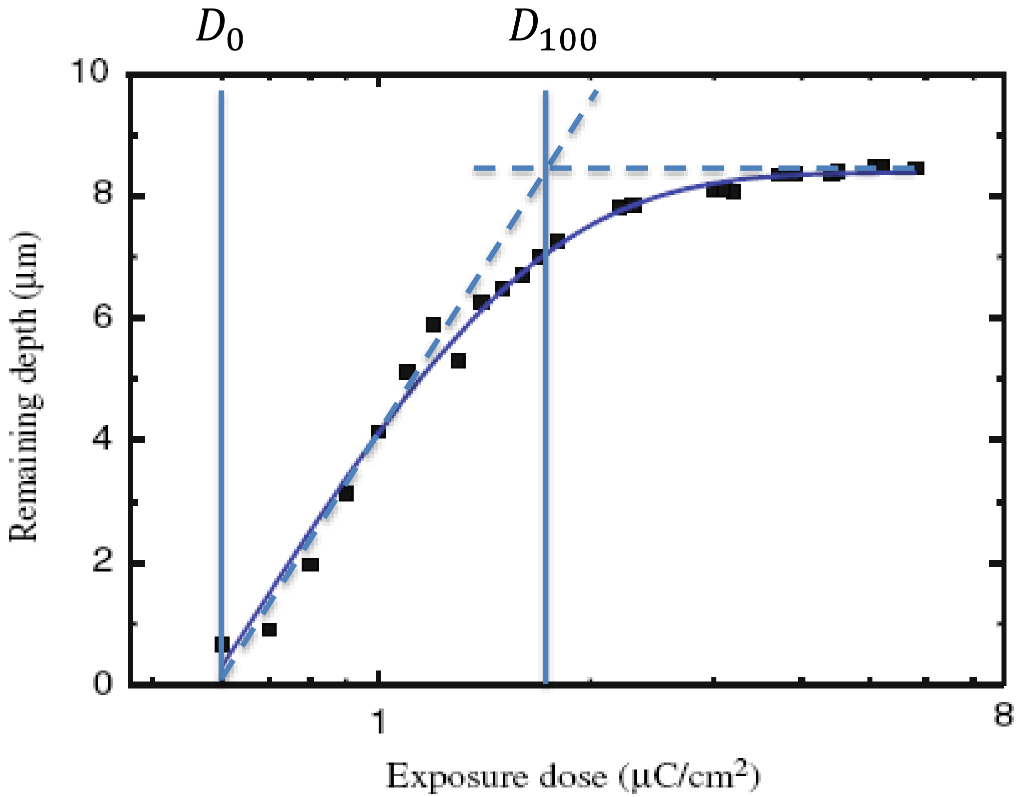
wikipedia

Photoresist Materials

Exposure-Response Curves of Photoresist

$$Sensitivity \propto \frac{1}{D_0} \qquad \gamma = \frac{1}{\log \frac{D_{100}}{D_0}} \quad (Contrast)$$

An example of calculating γ



$$D_0 = 0.6$$
$$D_{100} = 1.8$$

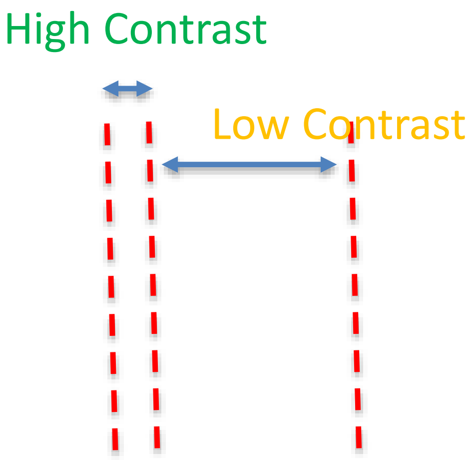
$$\gamma = 1/\log\frac{1.8}{0.6}$$
$$= 2.1$$

Exposure-Response Curves of Photoresist: Sensitivity and Contrast

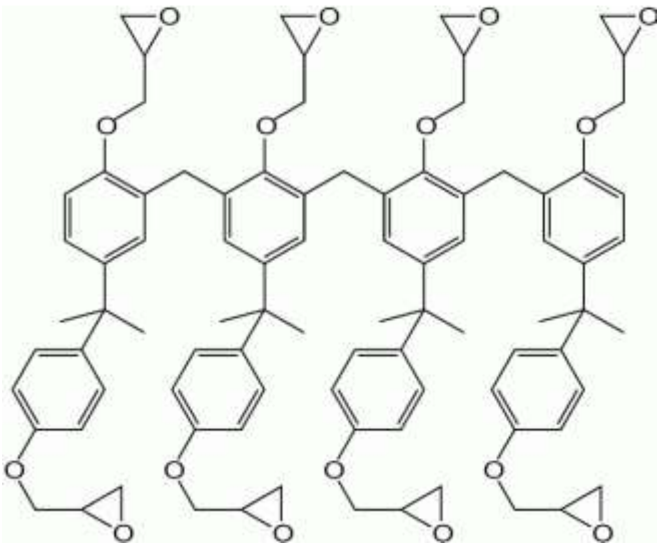
Sensitivity

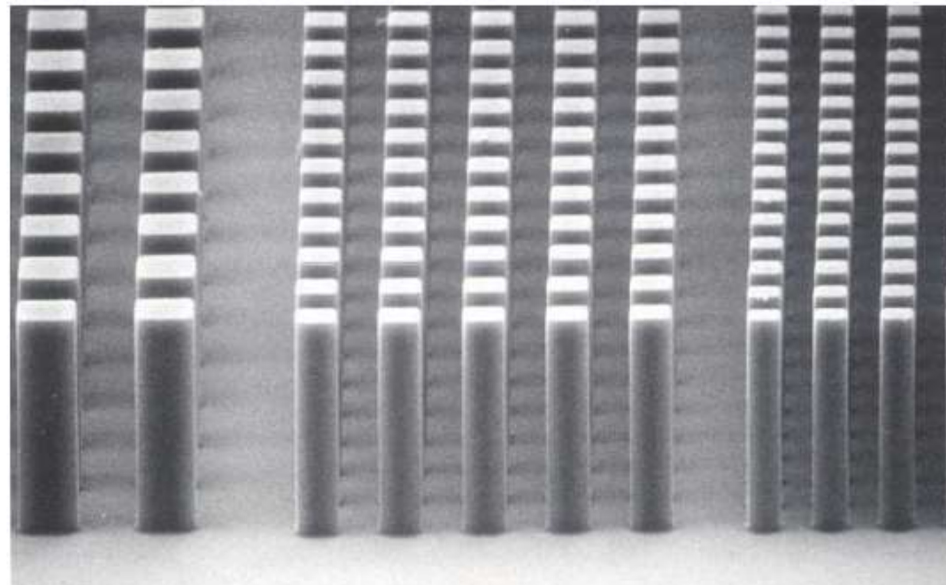
Contrast

Resist contrast determines resolution, sidewall angle and line width (minimum feature size)



SU-8 is a negative tone resist with high contrast





10 um features, 50 um SU-8 2000 coating

Microchem

Critical resist Modulation Transfer Function (CMTF) and the Modulation Transfer Function (MTF)

$$CMTF = \frac{D_{100} - D_0}{D_{100} + D_0} = \frac{10^{1/\gamma} - 1}{10^{1/\gamma} + 1}$$

$$MTF = \frac{M_{image}}{M_{mask}} \quad \rightarrow \quad M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

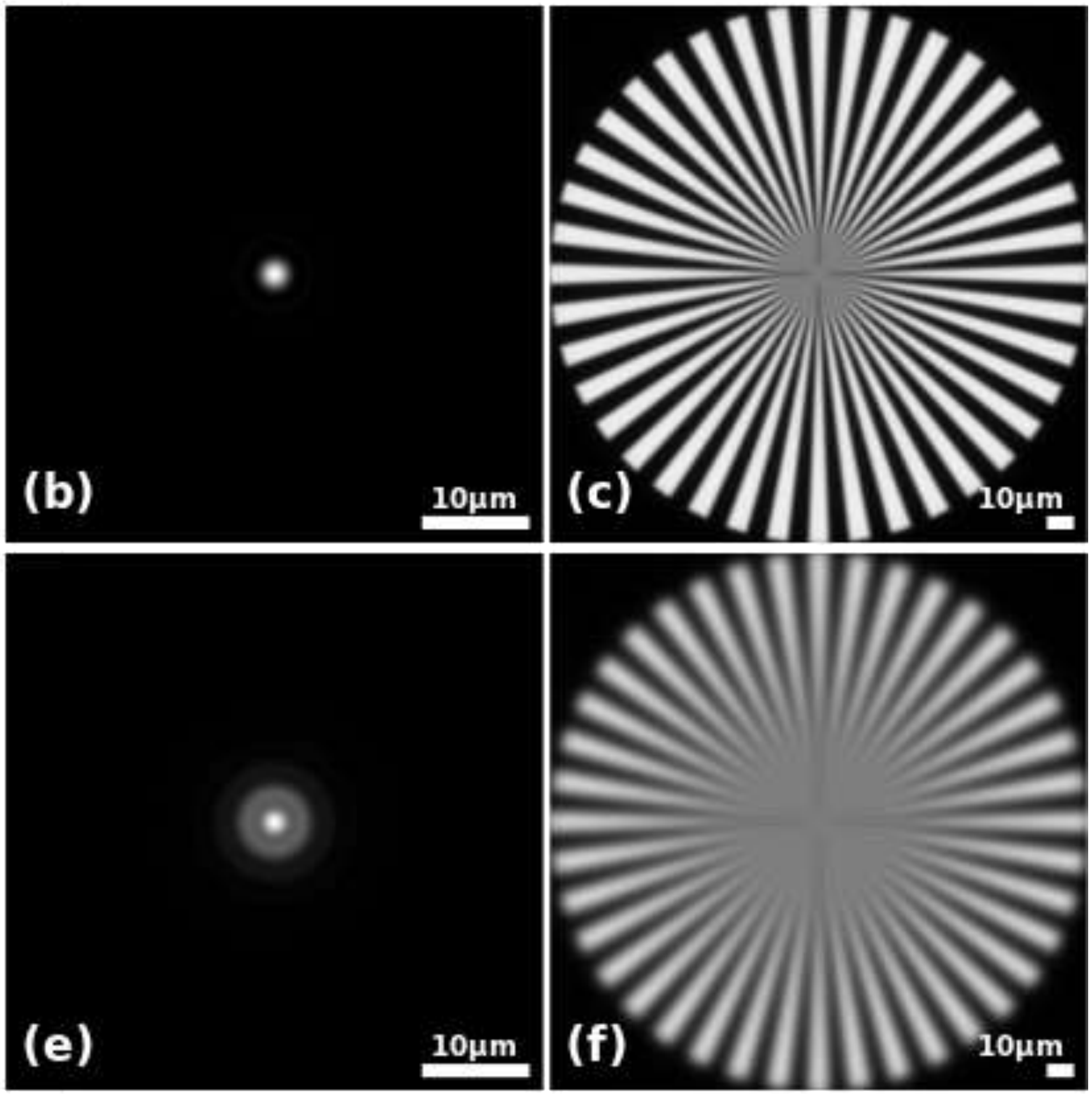
$$MTF = M_{image} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

No image is formed if $CMTF > MTF$.

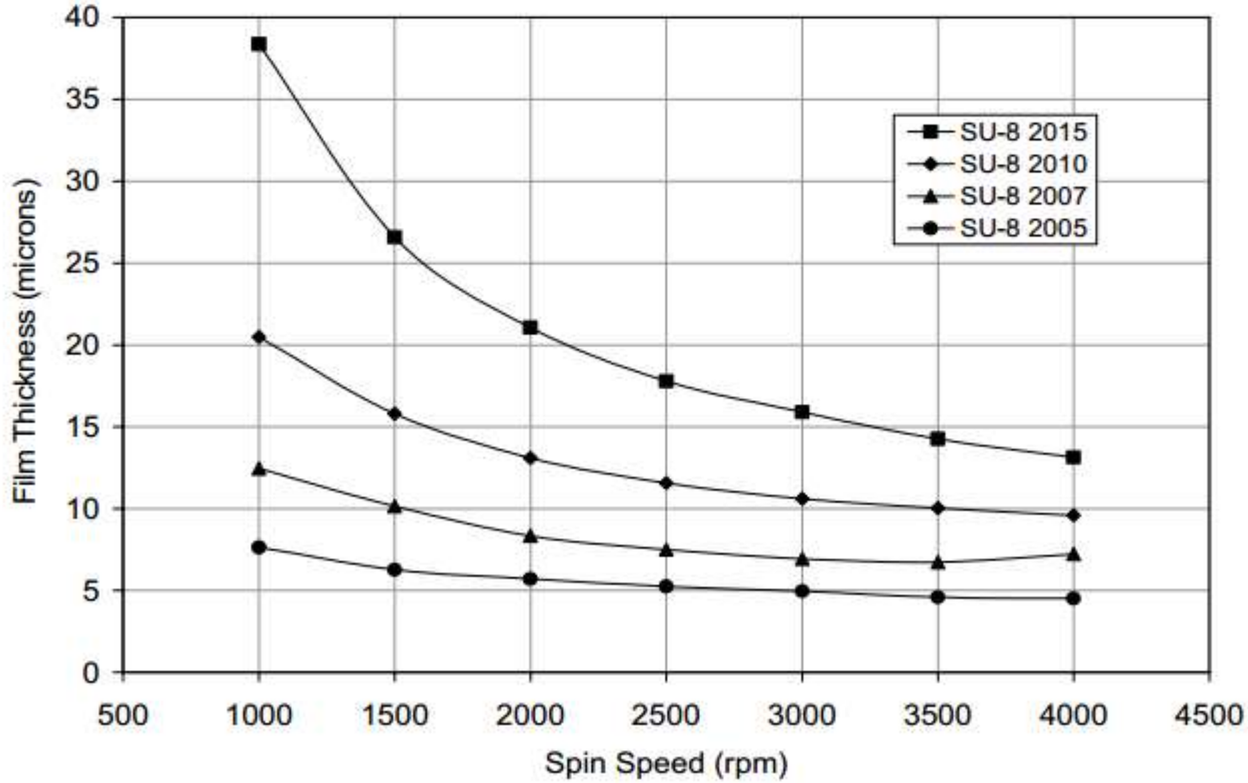
Modulation Transfer Function

Mask

Image



SU-8 Thickness vs. spin-speed curve



Microchem