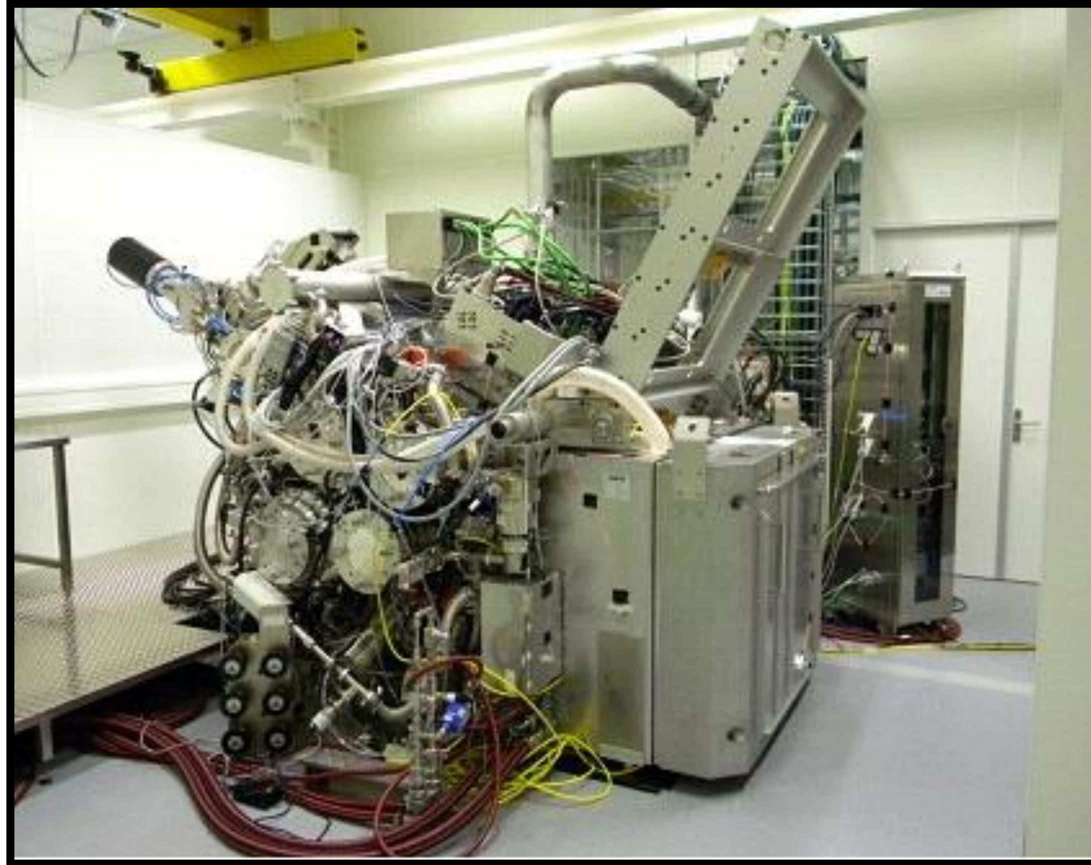
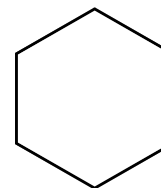
Lecture 6

Chemical Engineering for Micro/Nano Fabrication



Let there be light

Cyclohexane



Absorbance (cm^{-1})

2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

190 200 210 220 230 240 250 260 270 280 290 300

Wavelength (nm)

- 99+% Purity
- 1 – Sulfuric Acid Wash
- 2 – Sulfuric Acid Wash, Silica Gel Chromatography
- 3 – Sulfuric Acid Wash, Silica Gel Chromatography, Distillation
- 4 – Sulfuric Acid Wash, Silica Gel Chromatography, Distillation, De-oxygenation

Absorbance Edge

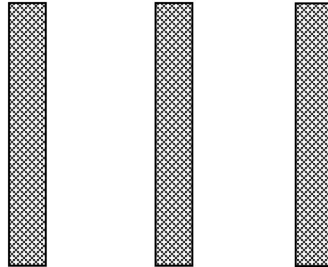
Absorbance (/cm)

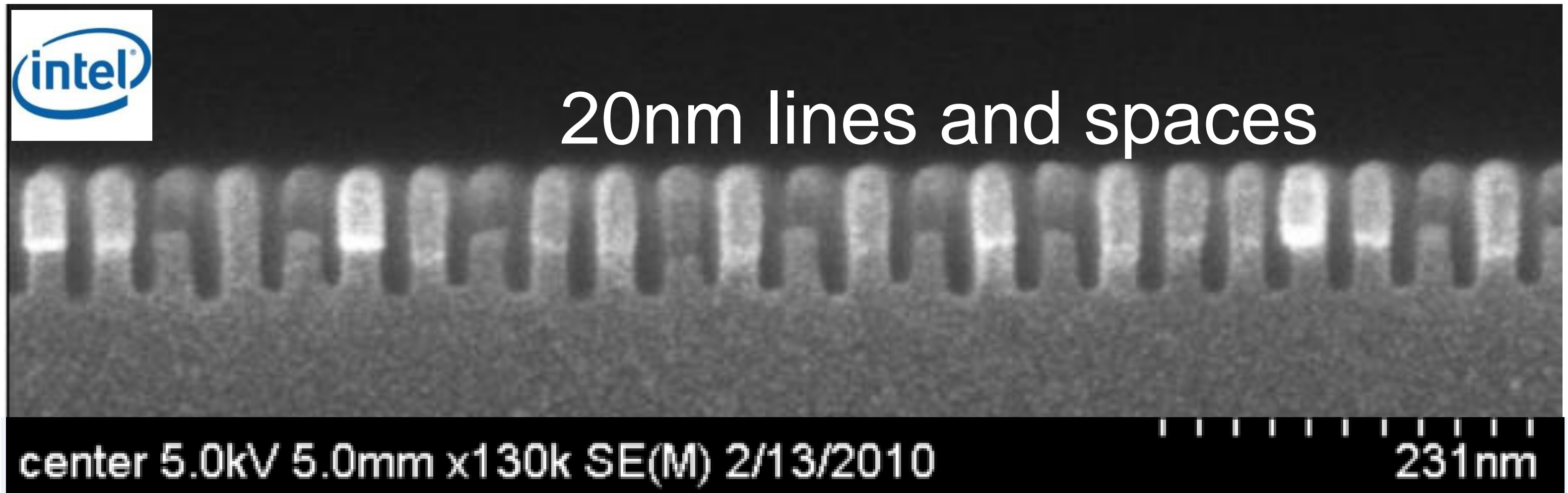
18
16
14
12
10
8
6
4
2
0

165 170 175 180 185 190 195 200

Wavelength (nm)

Only option is double exposure?





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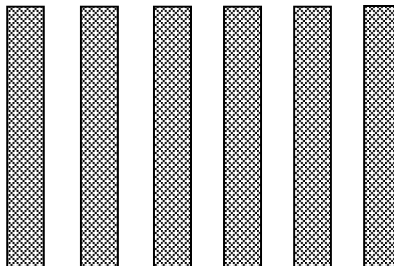
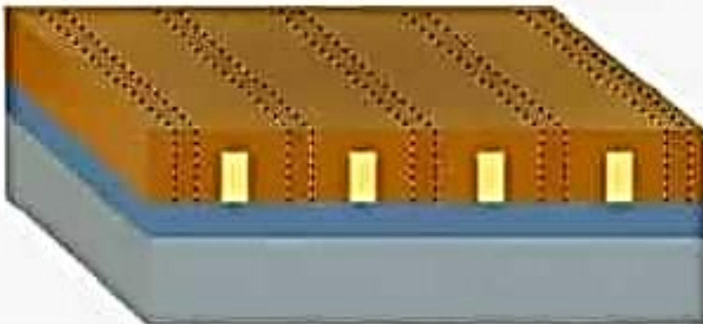


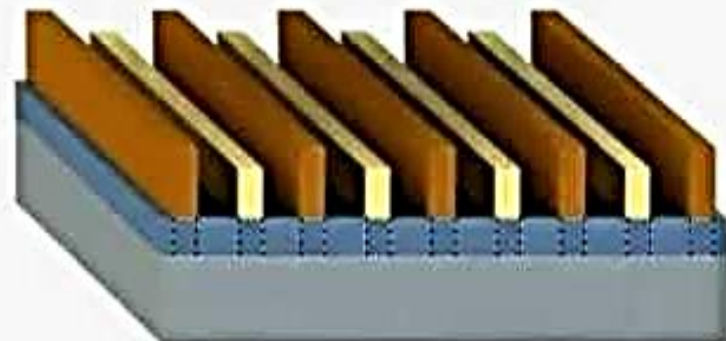
Litho Freeze Litho Etch - LFLE

1 **Litho 1.** The first pattern [yellow] is exposed onto silicon [blue].

2 **Freeze, coat with new resist.** The already developed layer [yellow] is chemically frozen and coated with a second layer of resist [brown].



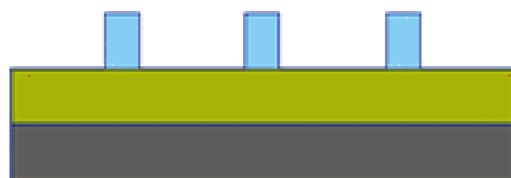
3 **Litho 2.** A second pattern [brown] is exposed, doubling pattern density.



4 **Etch.** The unprotected silicon is engraved with the final, double-density pattern in a single etching operation.

Litho-Freeze-Litho-Etch LELE

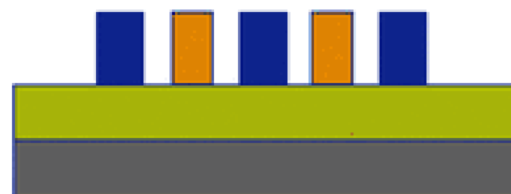
Litho1
Standard resist



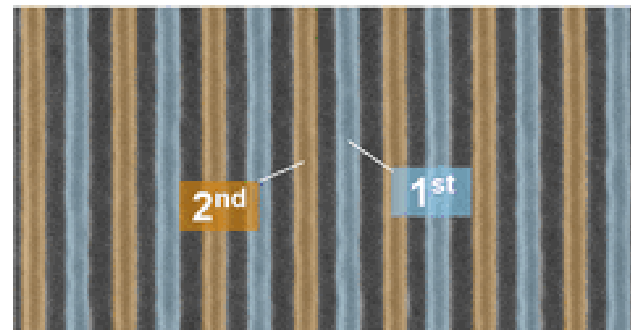
"Freezing" process first developed image:

1) Coat first developed (shown)
2) Thermal treatment
3) Pos/Neg resist
4) Other post development treatment

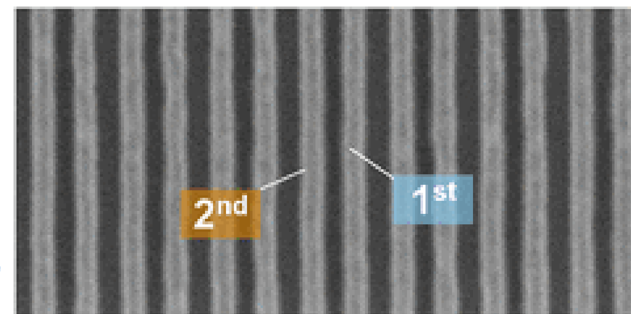
Litho 2
Coat, expose, develop 2nd pattern



Litho1 + Litho2



After etch into 60nm poly



32 nm

Litho-Etch-Litho-Etch LELE

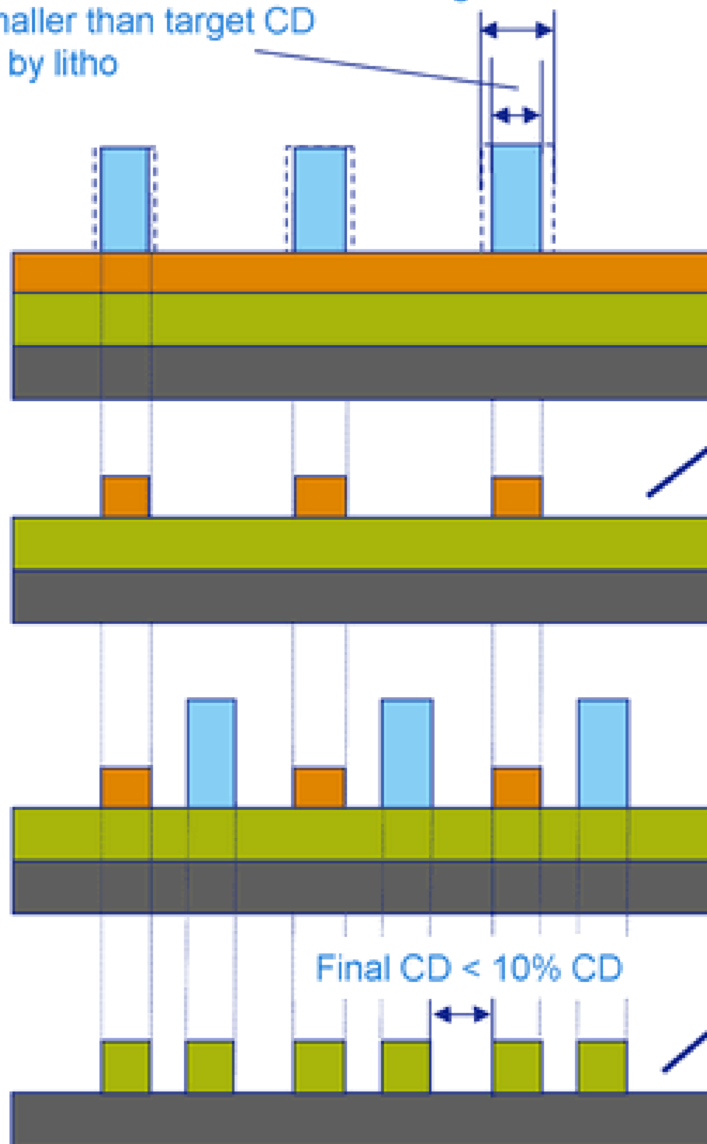
Real CD litho is smaller than target CD litho. Error caused by litho

1st Photo CD errors during litho will result in smaller/larger lines

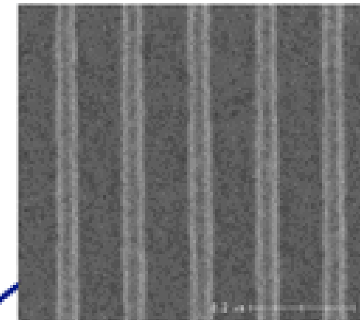
1st Etch+CD trim Extra CD errors could take place

2nd Photo Overlay error translates into CD error between lines

2nd etch+CD trim 2nd pattern with CD errors from 2nd etch/trim and overlay

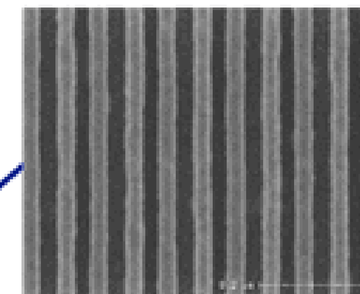


32 nm lines/96 nm spaces



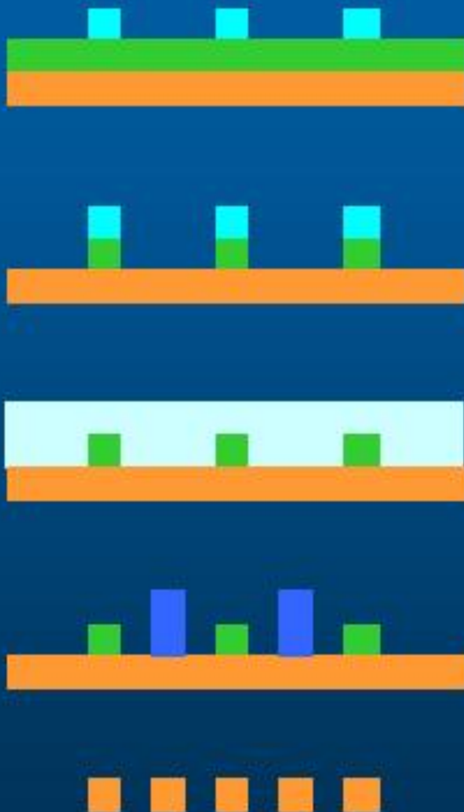
CD determined by 8 error components; 2 x litho, 2 x etch and overlay:

ΔCDlitho < 3.5% of CD
Overlay < 7% of CD



32 nm lines/32 nm spaces

Double Patterning for L/S - LELE



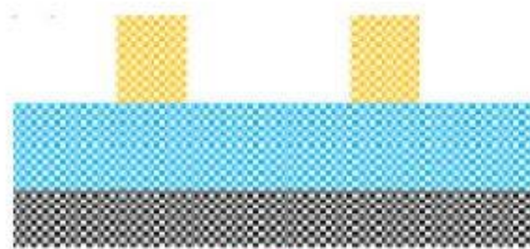
57.8 nm pitch

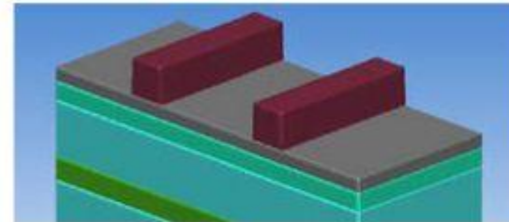
57.8nm

S-5200 1.5kV x200k SE

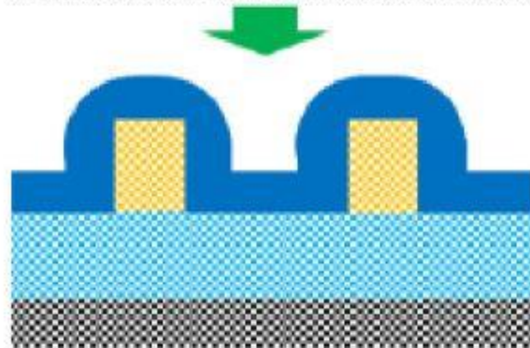
200nm

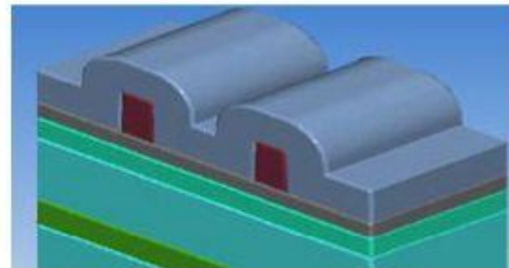
SADP Process



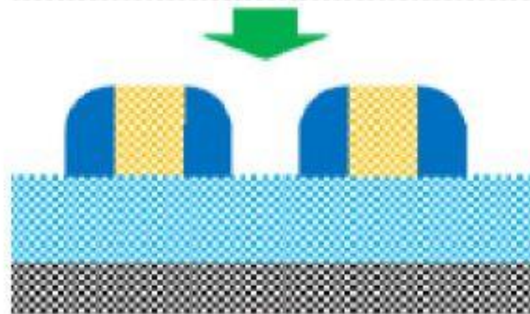


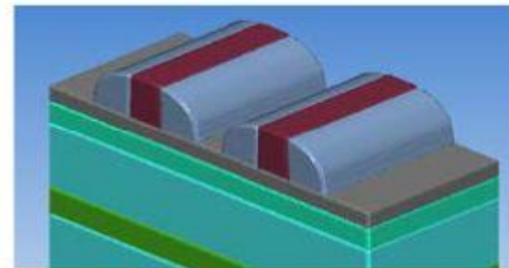
Mandrel Definition



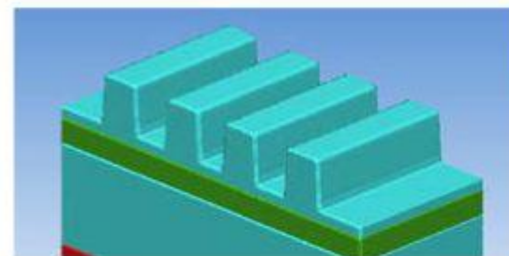


Spacer Deposition



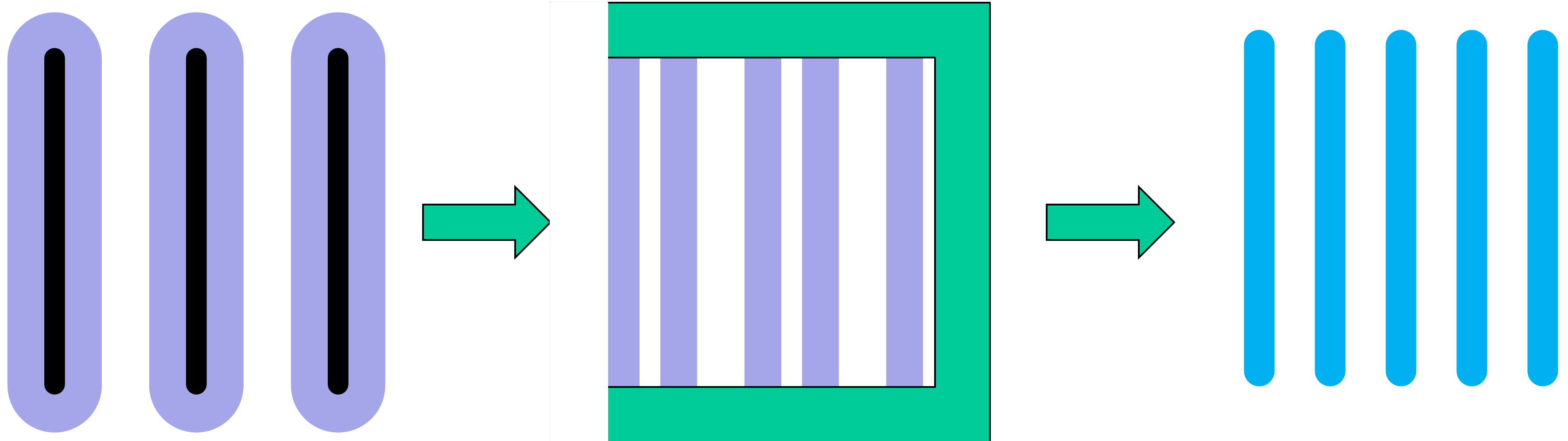


Spacer Etch



Hard Mask Etch

Some Issues…



X-ray Proximity Printing

Beryllium

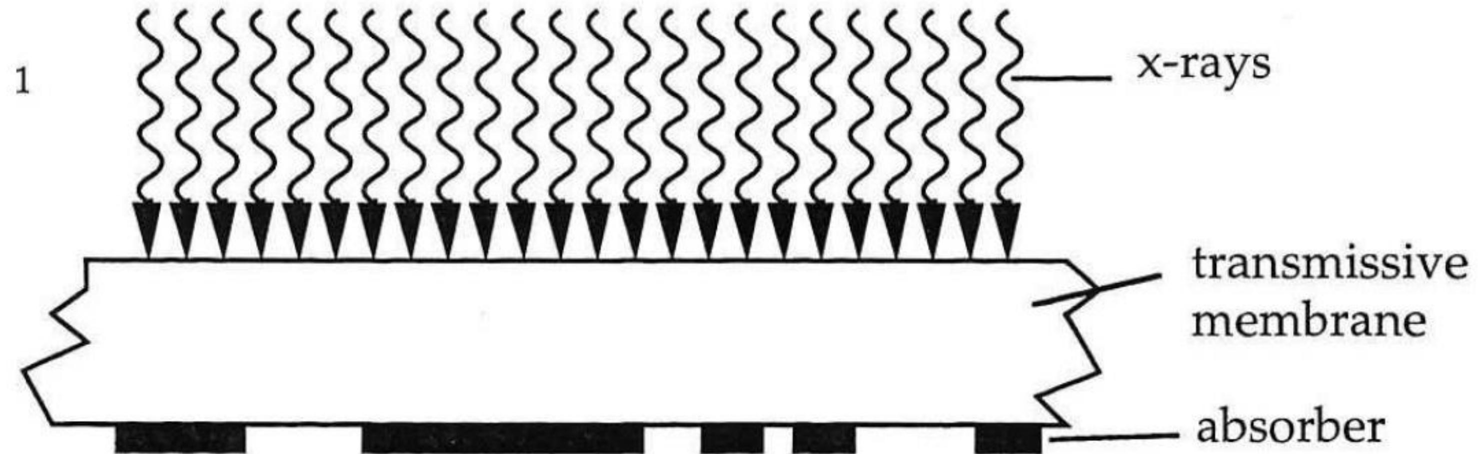
X-ray

Gold

Photoresist

Substrate

X-ray shadow mask



- Soft X-Rays: Wavelength Range 0.4–15 nm
- Diffraction Reduced by a Factor of 100–1000 Compared to Photolithography
- Shadow Printing Method (Proximity Printing)

Basic X-Ray Lithography Setup

d

2γ

X-Rays

D

Penumbra

$\delta = G(d/D)$

G

Mask

Substrate

RUN OUT ERROR

a
X-RAY SOURCE
L
X-RAY MASK
PYREX RING
Si
BN
POLYIMIDE
Au
g
X-RAY RESIST
r
d
Si WAFER
δ

Penumbral blur

$$\delta = ag / L$$

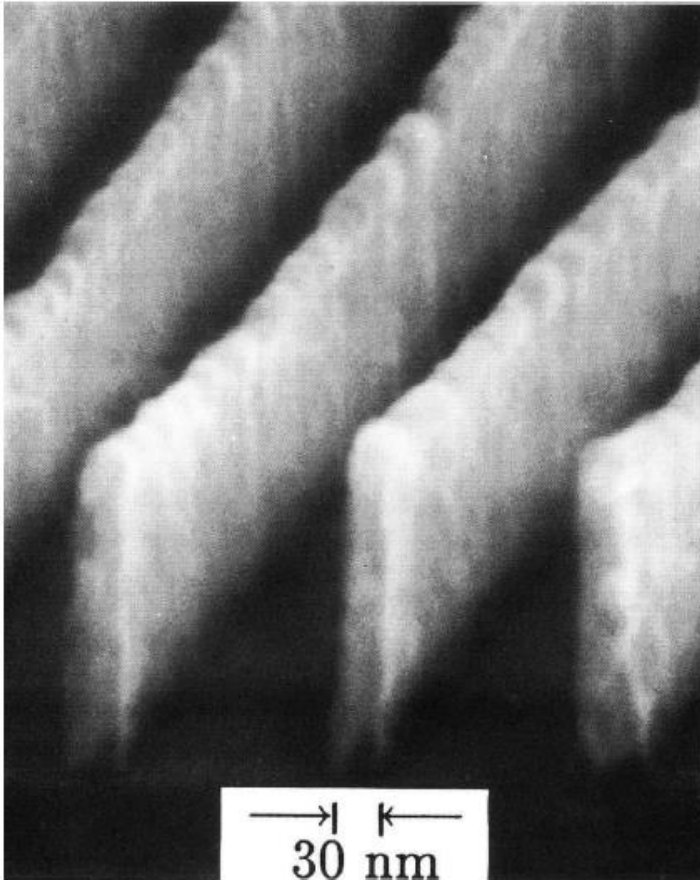
Run out mag err

$$d = rg / L$$

Source needs to be very far away!

but intensity proportional to $1/L^2$

Resolution of X-Ray Lithography



- PMMA Resist
- Conformable Mask
- $\lambda = 4.5\,\text{nm}$, C_K-line

H.I. Smith, M. Schattenburg
IBM J. Res. Develop., vol 37, no. 3, pp. 319–329, May 1993

Basic Elements of an Electron Storage Ring

Linac

Injection kicker

Injection septum magnet

rf cavity

Direction of magnetic field B

Direction of electric field E

Emitted fan of X-rays

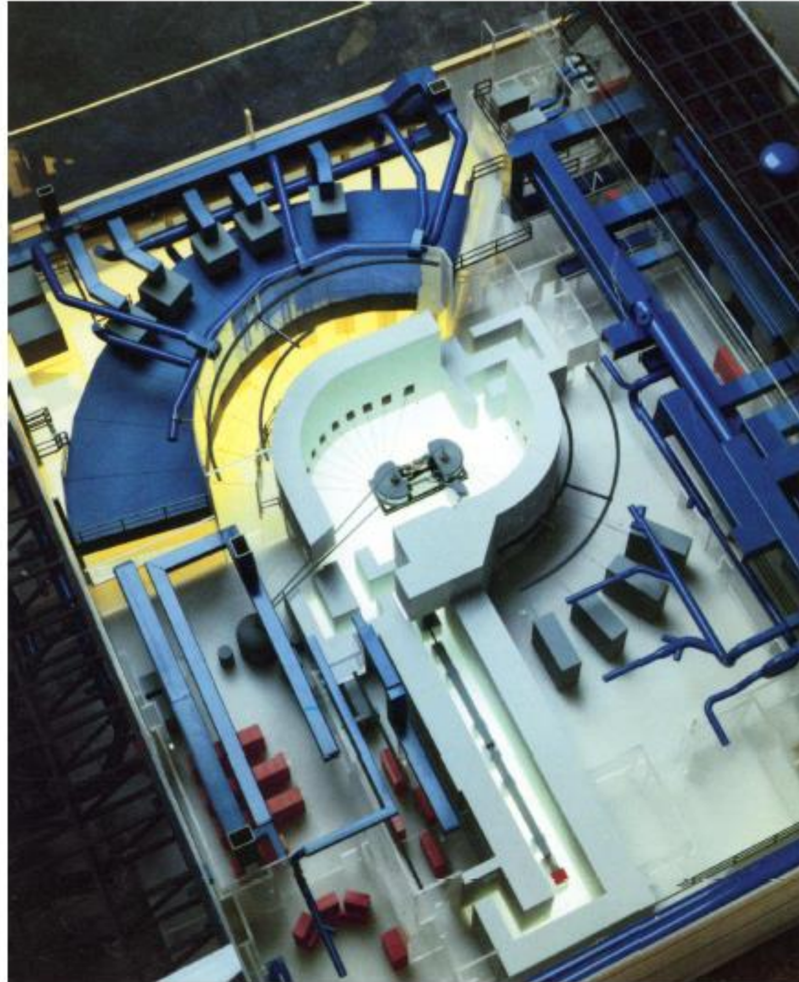
Focusing quadrupole

Dipole magnet

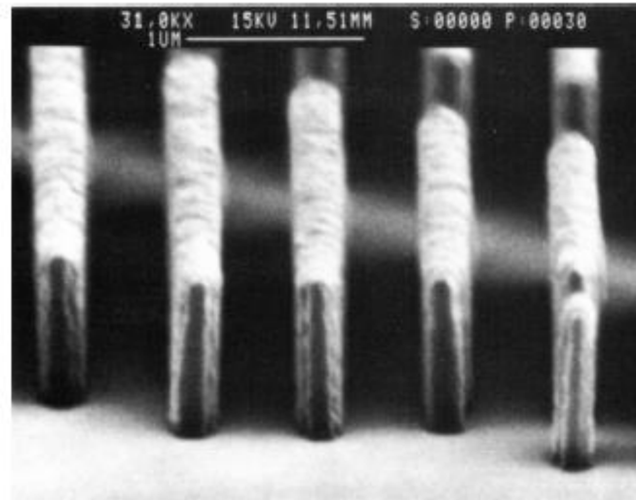
The IBM–Oxford Compact Storage Ring

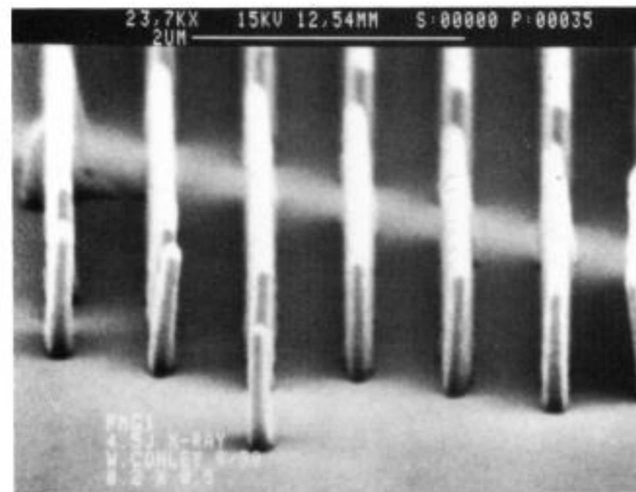
Photograph of the Compact Storage Ring

IBM Advanced Technology Center, East Fishkill



Resist Profiles Obtained with the Compact Ring





LIGA Process

Cast PMMA on metal
1

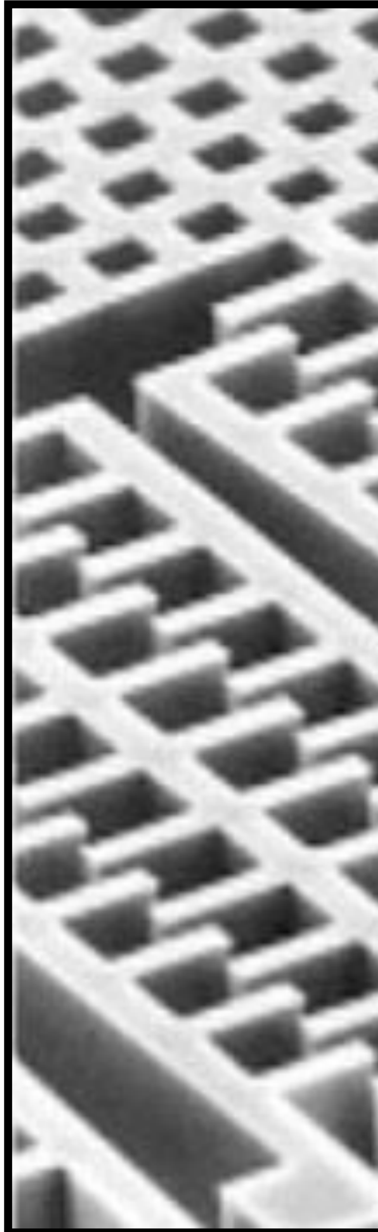
X-ray Radiation
2

Develop PMMA
3

Electroplate through PMMA
4

Separate metal from PMMA
5

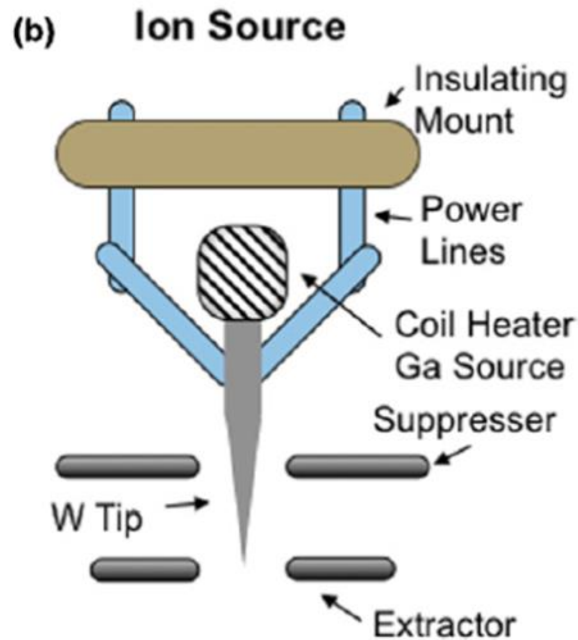
The LIGA Process



In the end….

- **Over lay and mask issues killed the x-ray program**
  - Distortion due to patterning
  - Heating
  - Optical transparency issues
- **Optics caught up and was cheaper, faster and safer.**
  - I-line steppers could out perform the x-ray system
- **LIGA led to MEMS which is alive and well**

Focused ion beam lithography



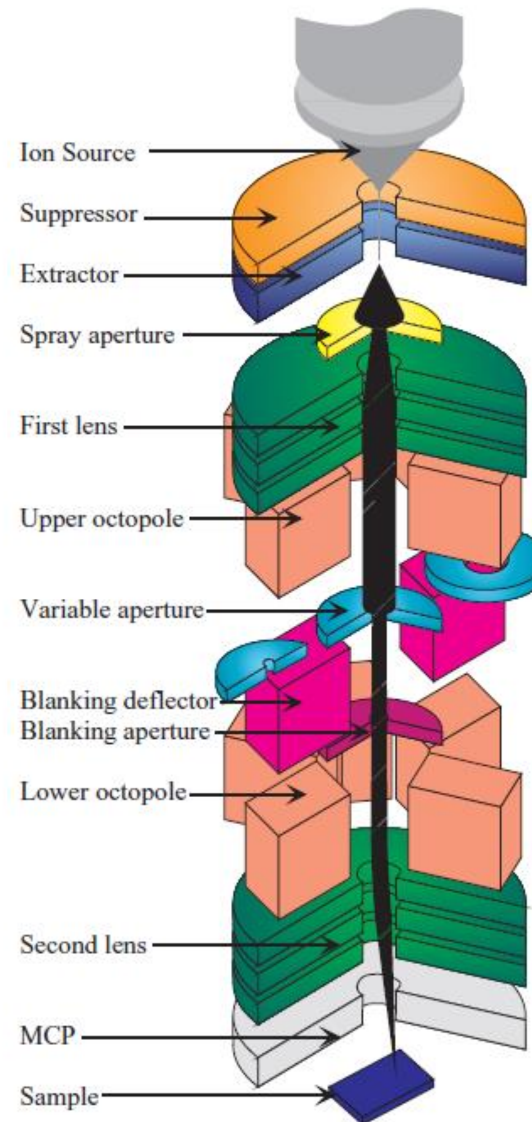


Figure 2. Schematic diagram of a FIB ion column.

Focused Ion Beam (FIB) Lithography

- Ions scatter much less than electrons
- Sources:
  - Liquid metal ions (Ga; Au-Si-Be alloys)
  - Long lifetime, high stability
- Resolution
  - sub-µm dimensions (~250 nm)
  - High resist exposure sensitivity
  - Negligible ion scattering in resist
  - Low back scattering from substrate
- Extensive substrate damage
- Also used for etching, deposition, and doping