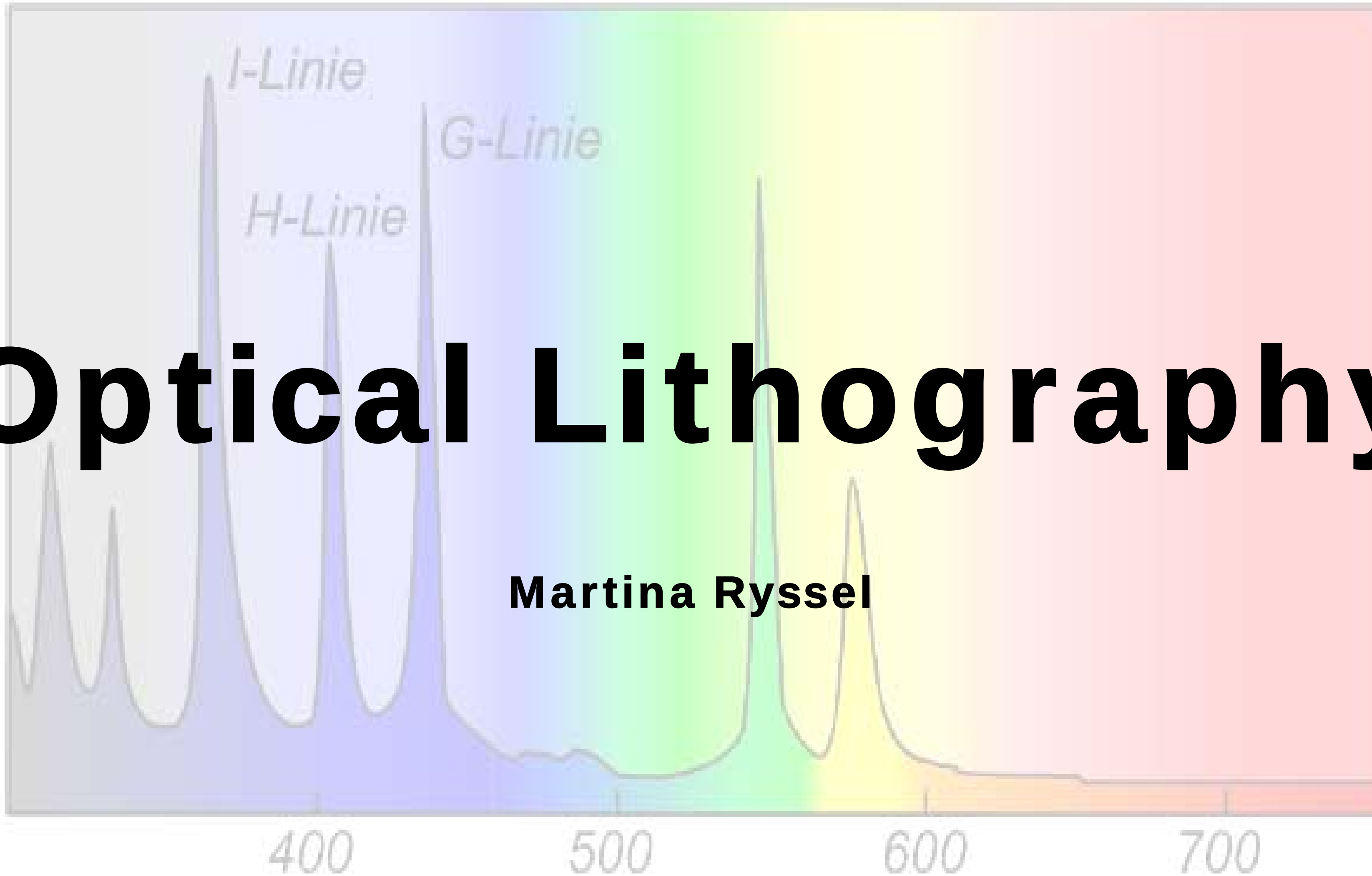


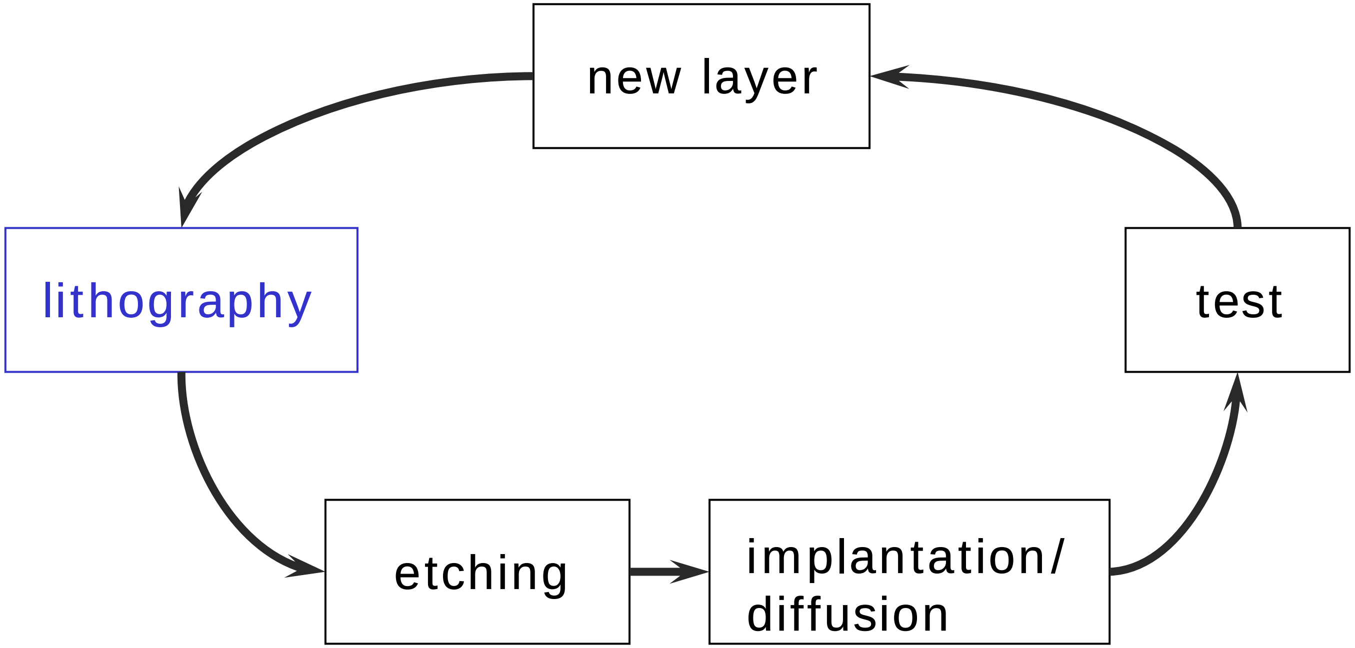
Optical Lithography

Martina Ryssel

Optical Lithography - Outline

1. Introduction
2. Lithography Process
3. Photoresist
4. Mask Technology
5. Beyond the Basics

Lithography in the Integrated Circuit Production Process



1

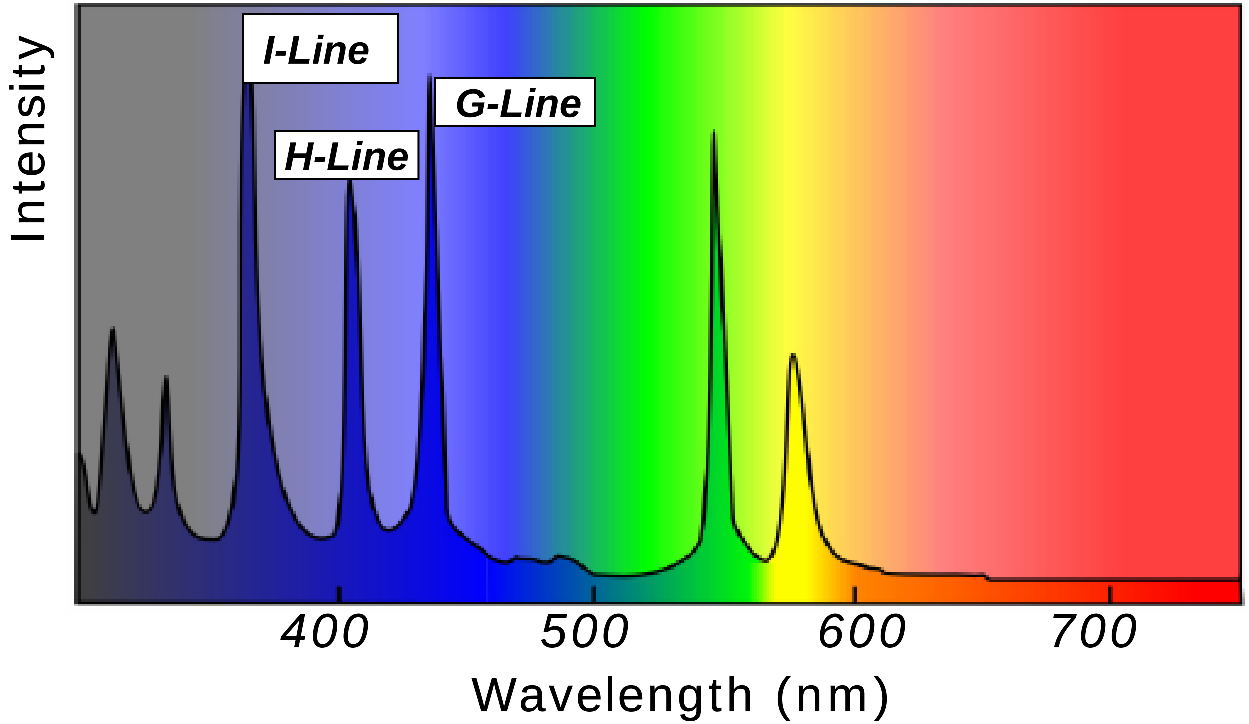
Lithography Classification by Wavelenght

▪ Optical lithography	λ = 100 - 450 nm (EUV: 10 – 15 nm)
▪ X-ray lithography	λ = 0.5 – 2 nm
▪ Electron beam lithography	λ = 0.02 – 0.01 nm
▪ Ion beam lithography	λ << 0.001 nm

Optical Lithography Light Sources (I)

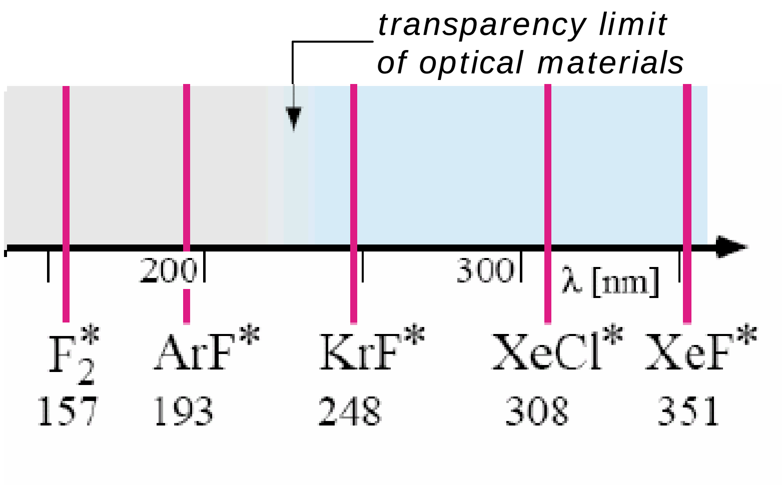
- Mercury arc lamp

Spectrum of an Hg-Lamp



Optical Lithography Light Sources (II)

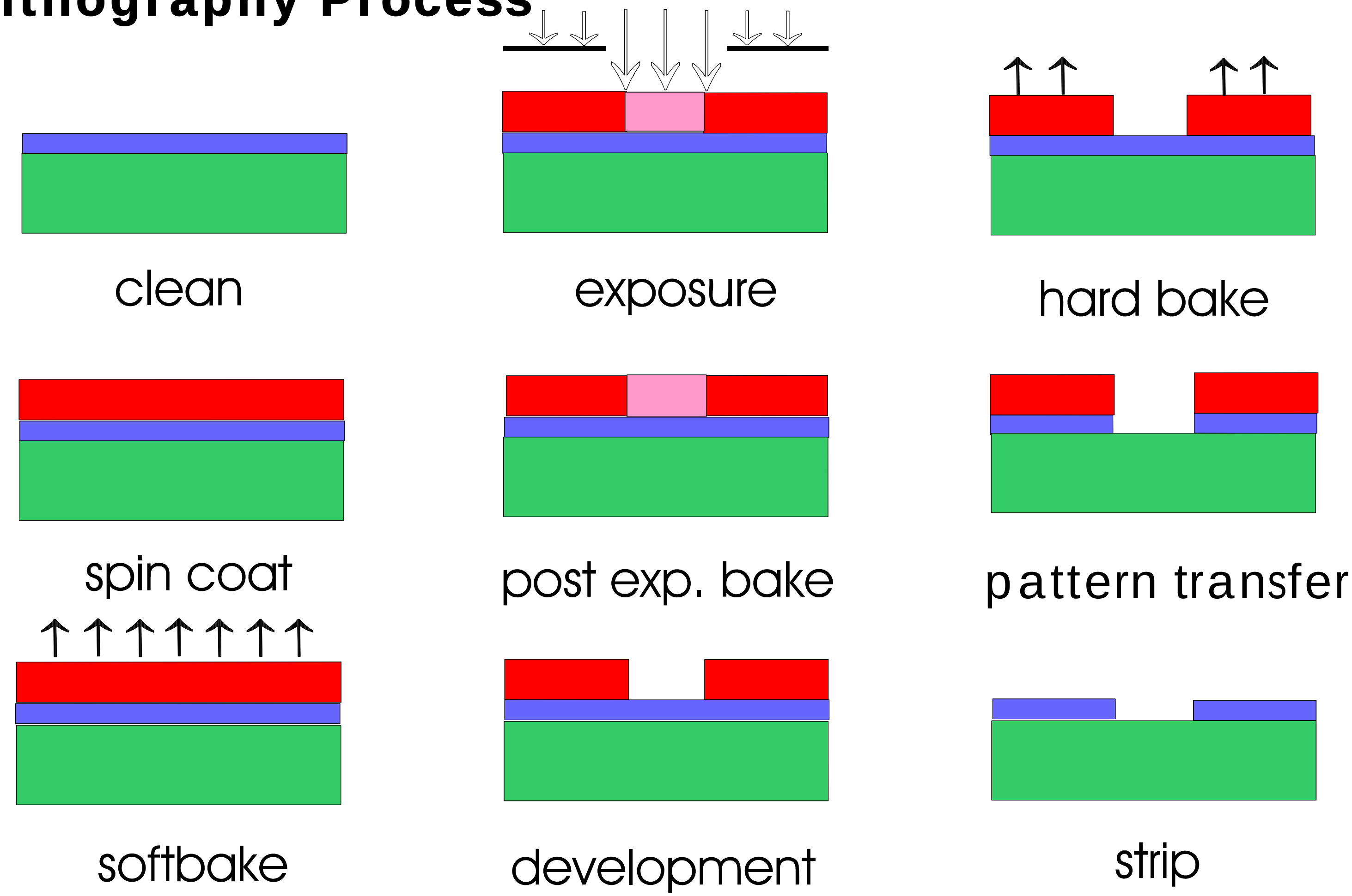
- Excimer laser



Typical gases:	KrF	248 nm
	ArF	193 nm
	F_2	157 nm

2

Lithography Process



2

Substrate Preparation

Cleaning: removes contaminations

Dehydration bake: evaporates any moisture present at the surface of the wafer

Application of primer: promotes adhesion of the photoresist by providing a hydrophobic surface
Most commonly used: Hexamethyldisilizane (HMDS)

Photoresist Application

Spin-on method: used to get resist onto the substrate with the required uniform thickness

The resulting thickness depends on:

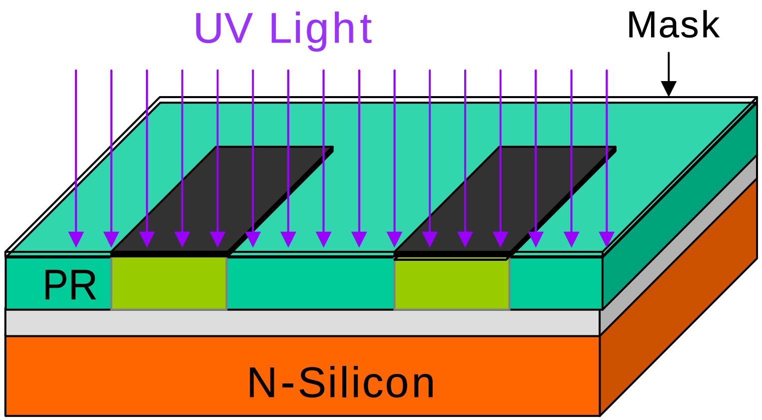
- Spinning speed and time
- Resist viscosity and quantity
- Nature and concentration of solvent
- Humidity
- Substrate material and topography
- ...

Prebake (soft bake)

Prebake is used to drive the solvent from the resist

- film thickness is reduced
- post-exposure bake and development properties are changed
- adhesion is improved
- the film becomes less sticky and thus less susceptible to particulate contamination

Exposure – Contact and Proximity

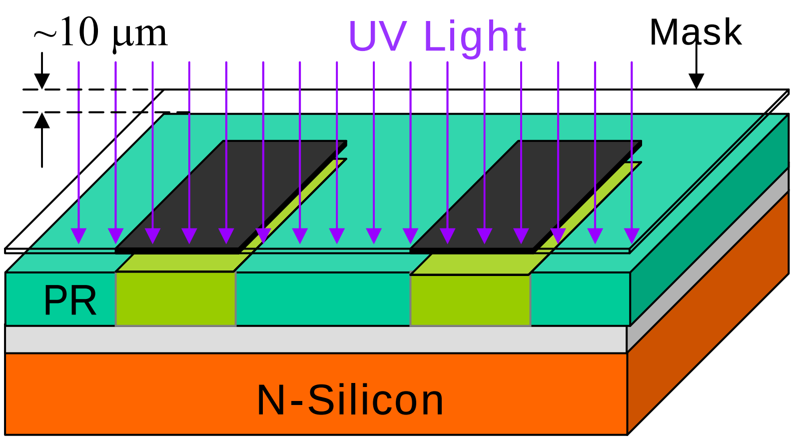


Contact Lithography

- better resolution
- cheaper
- defects
- surface bow and warp can bend mask

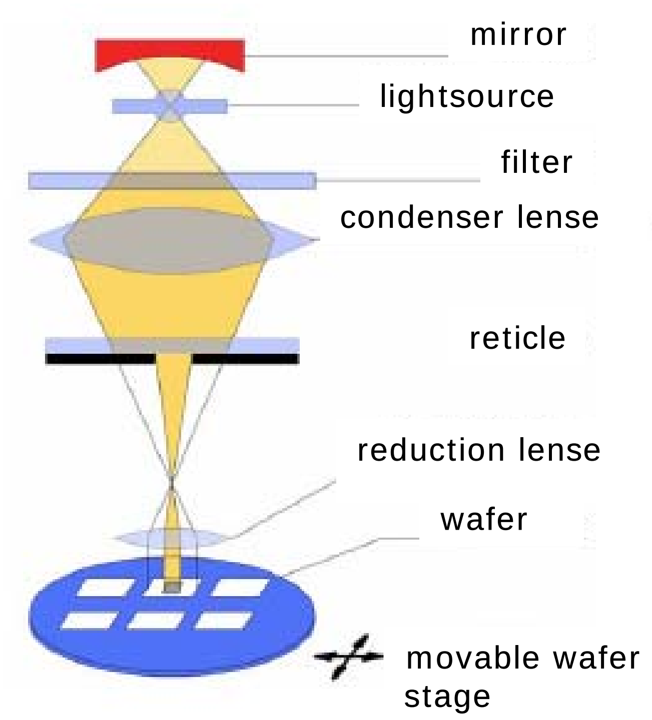
Proximity Lithography

- less problems with defects
- diffraction effects



2

Exposure – Projection



2

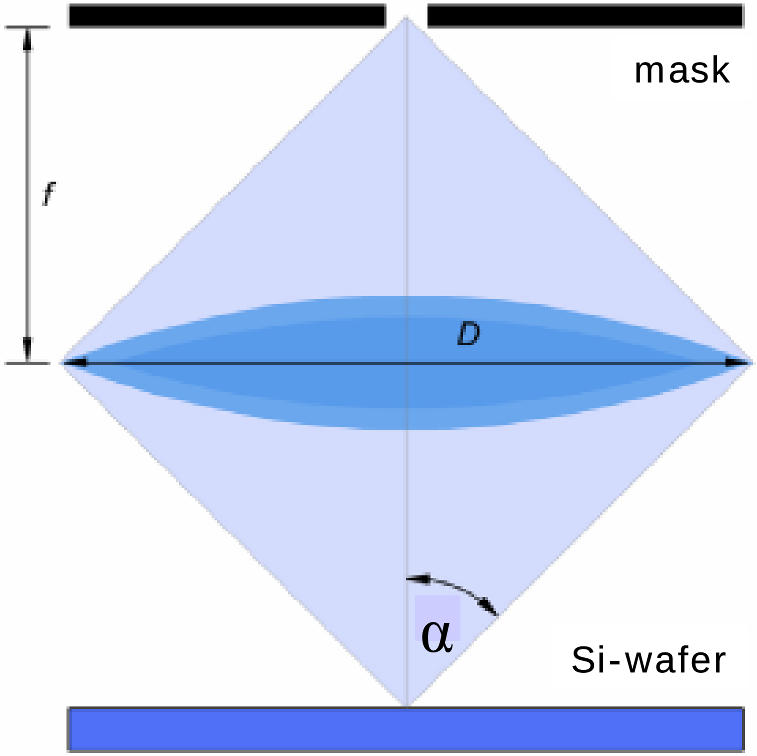
Exposure - Numerical Aperture

$$\boxed{NA = n \cdot \sin\alpha = D/2f}$$

Rayleigh criterion:
(minimum resolvable feature size)

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

k_1 depends on several parameters
(structures, mask, resist, illumination)

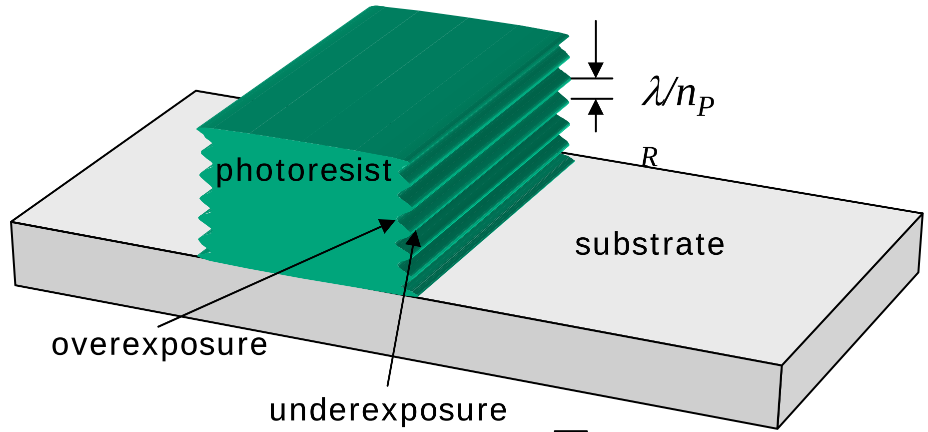


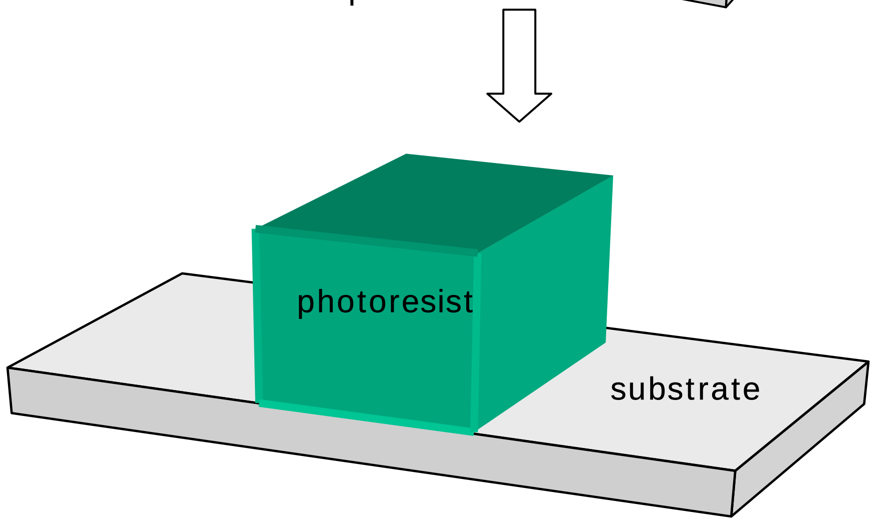
2

Post-Exposure Bake

standard photoresist:

PEB to reduce the standing wave effect



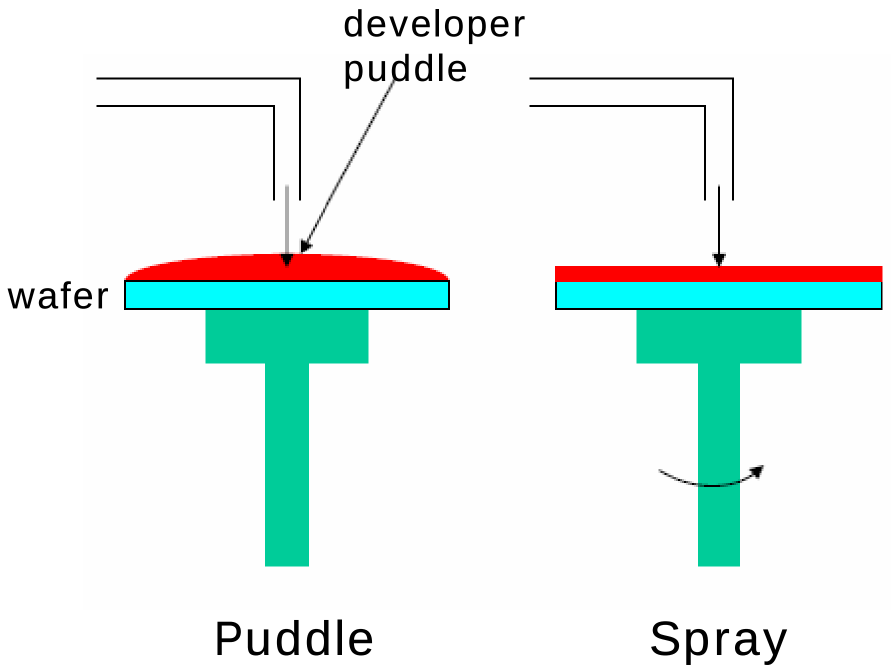


Also: important process step for chemically amplified resists (see there)

2

Development

Developer (for example tetramethyl ammonium hydroxide, TMAH) dissolves the softened part of photoresist

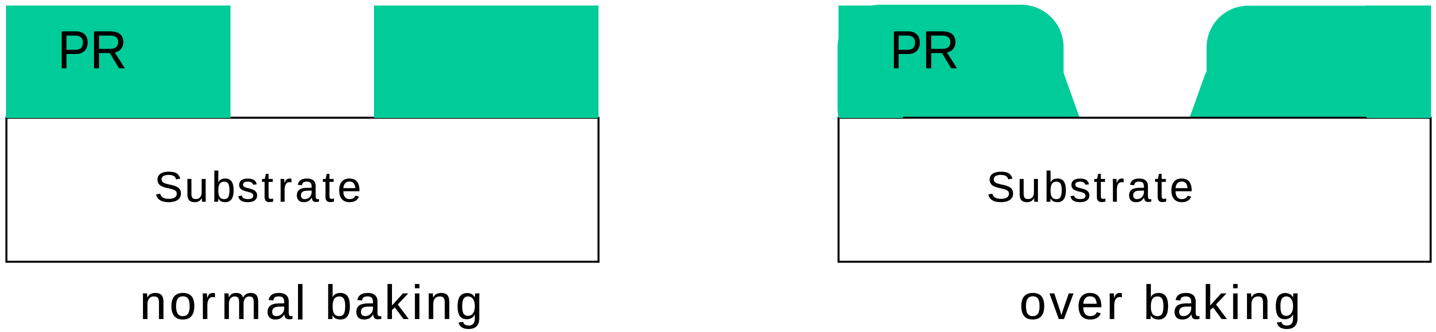


Wafer is spin-rinsed after development

Postbake

- Evaporation of all solvents in PR
- Improvement of etch and implantation resistance
- Improvement of PR adhesion with surface
- Polymerize and stabilize photoresist

But: Overbaking can cause degradation of image by flowing resist

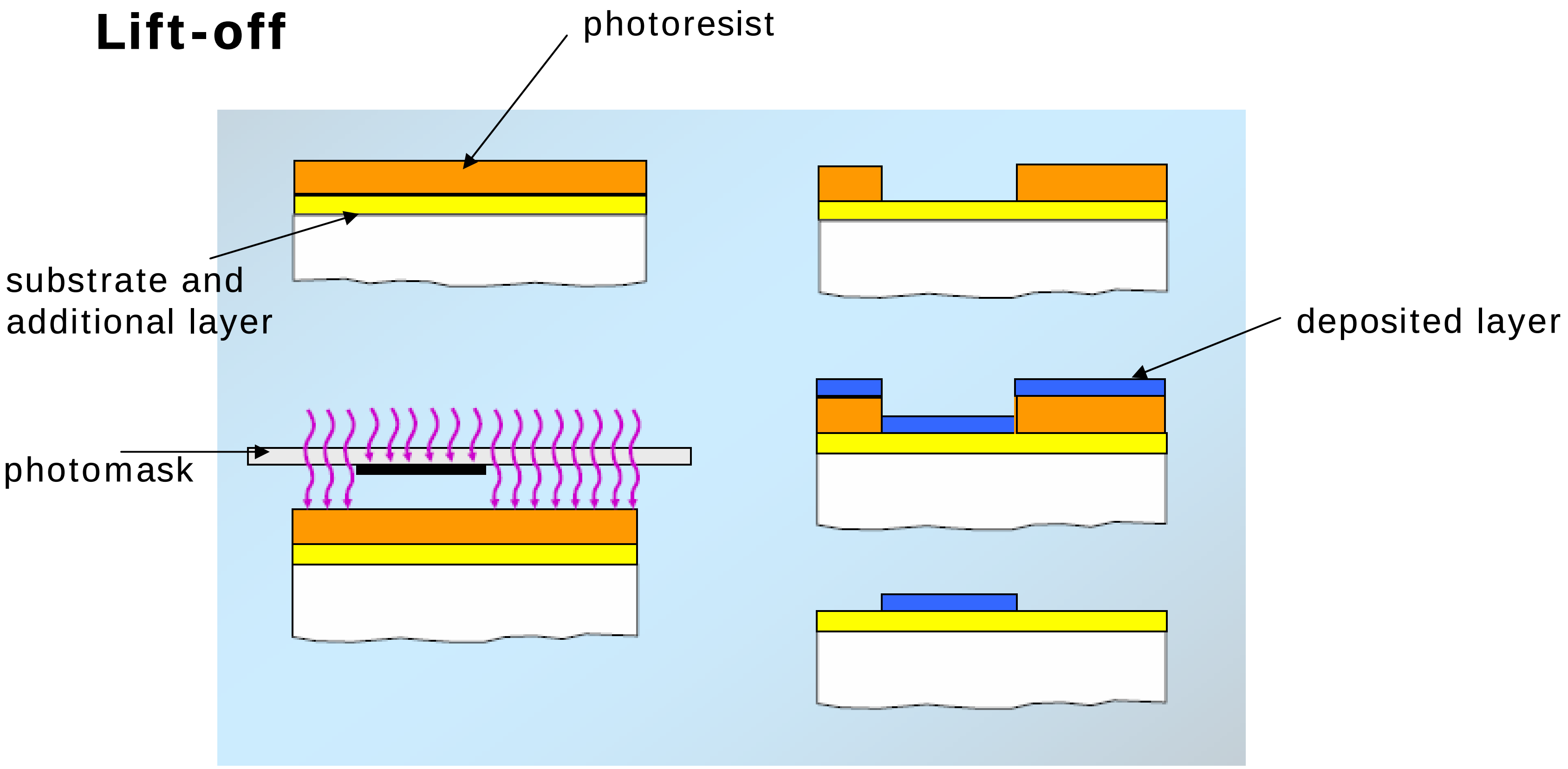


Pattern Transfer

- subtractive transfer (etching)
- additive transfer (selective deposition → lift off)
- and impurity doping (ion implantation)

2

Lift-off



Steep resist flanks are required for this method!

2

Strip

After pattern transfer, the remaining resist has to be removed.

This can be done by

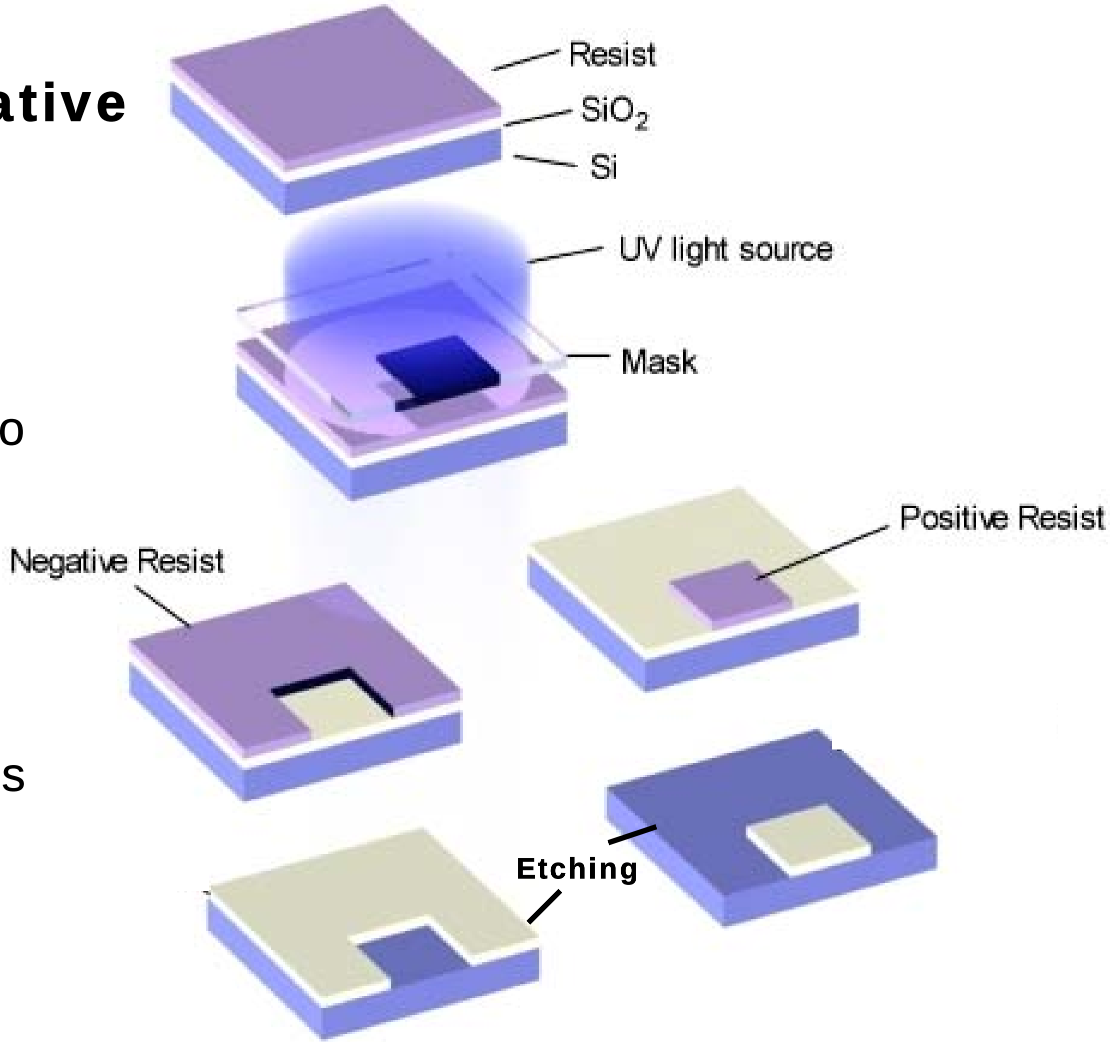
- dissolving in acid (f.e. H_2O_2 and H_2SO_4)
- plasma stripping

3

Positive and Negative Photoresist

Positive resist becomes soluble with exposure to light.

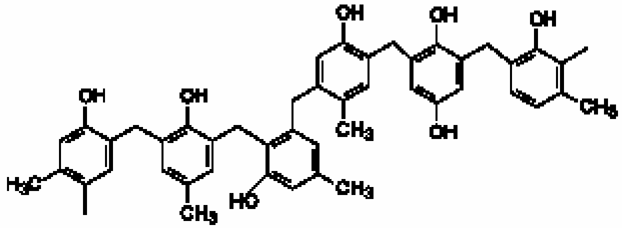
Negative resist becomes insoluble.



3

Chemistry of Standard Resists

- long molecule chains are dissolved by exposure to light
  (positive resist)
  -Example: DNQ (Diazonaphthoquinone) + Novolack

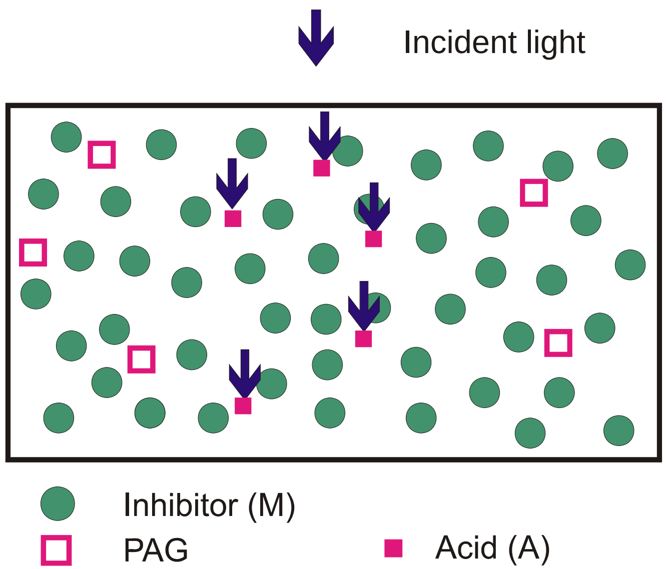


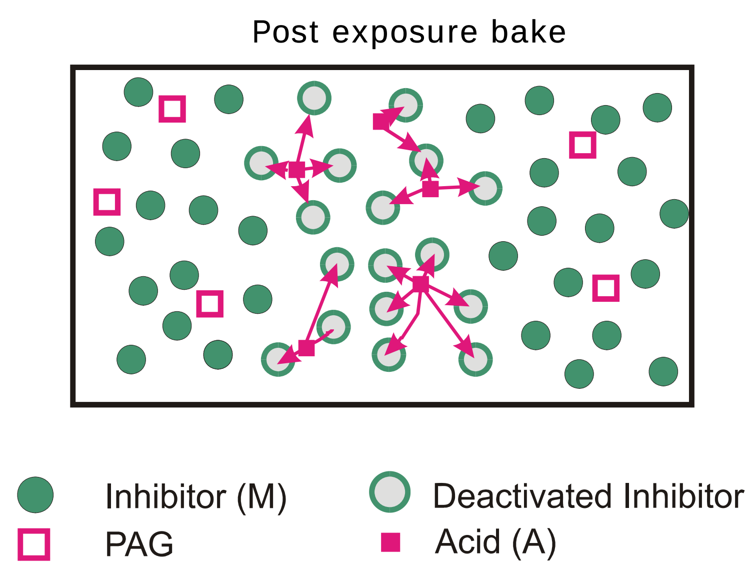
- long molecule chains are produced by exposure to light
  (negative resist)

3

Chemically Amplified Resist

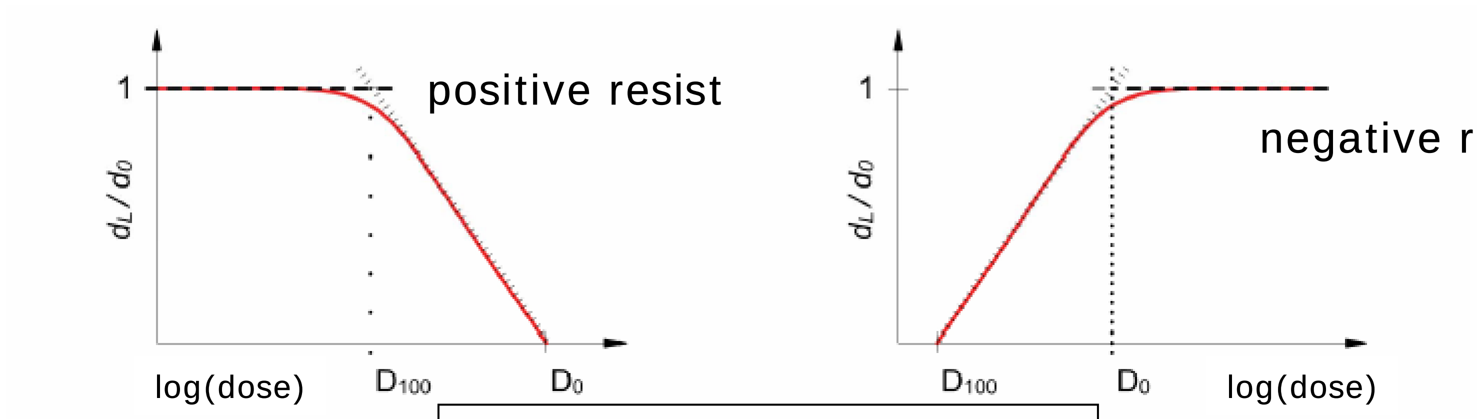
- Resist molecules are photoacid generators (PAG)
- PAGs produce acid when exposed to light
- Acid acts like a catalyst in dissolving the molecule chains





3

Photoresist Characteristics



Film Thickness after Develop

Sensitivity: Exposure dose where resist is totally dissolved (positive)

Contrast:

$$\gamma = \frac{1}{\log \frac{D_0}{D_{100}}}$$

(inverse of curve slope)

Today:

Line edge roughness: molecular structure of resist becomes important

Photoresist Characteristics (secondary)

-Low particle content

-Low ion content

-Good substrate adhesion

-Good thermal stability

-Easy removability

1. Introduction
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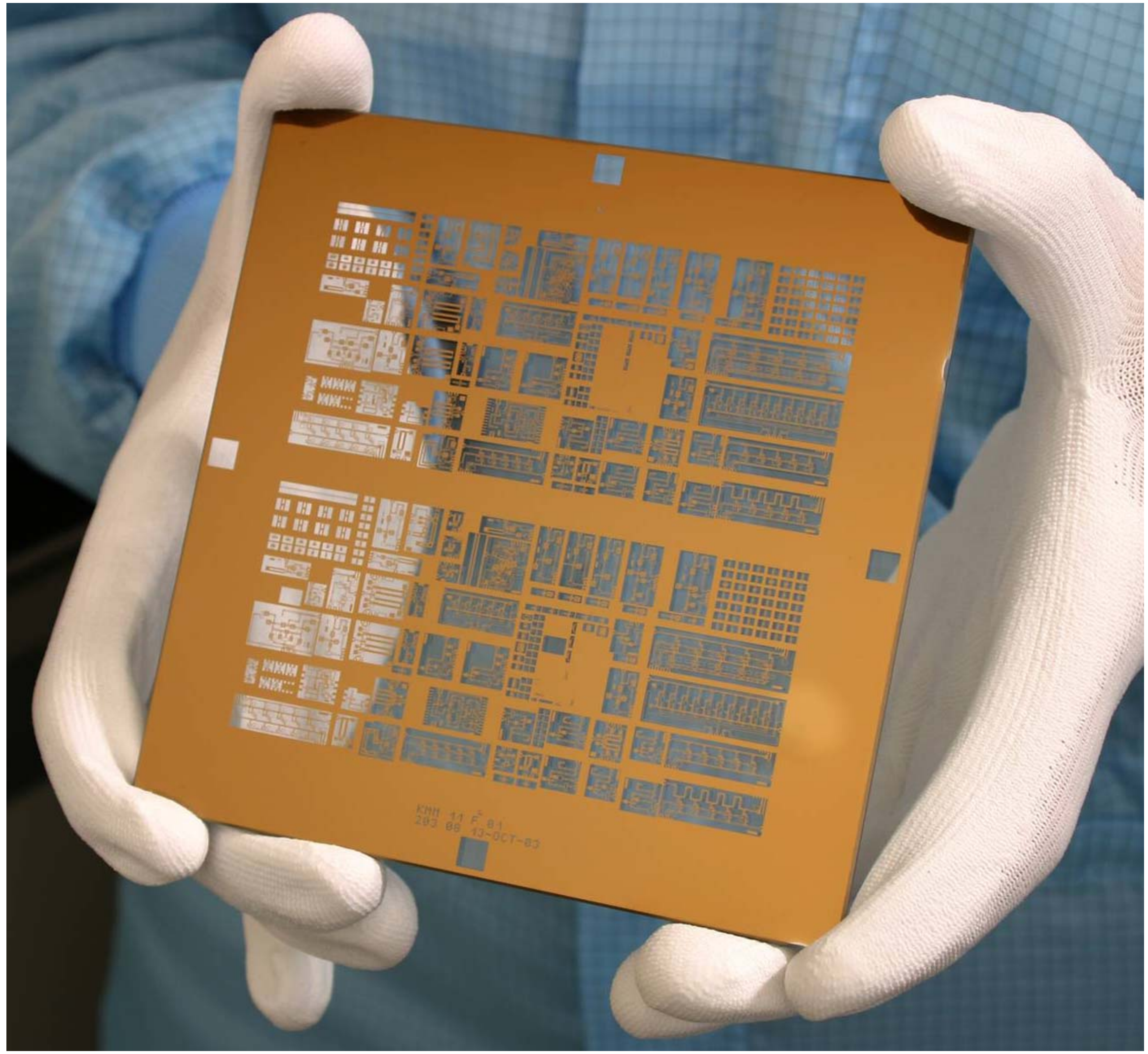
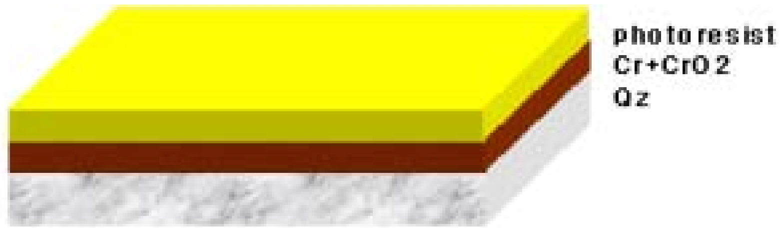
Example

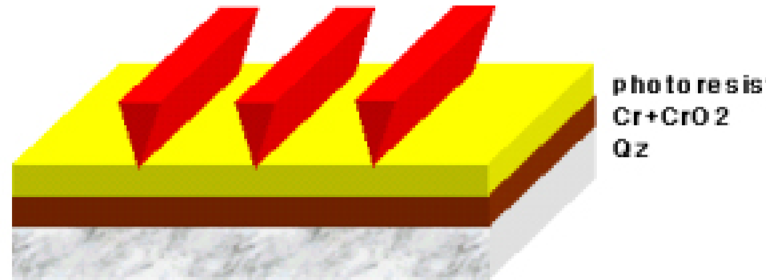


4

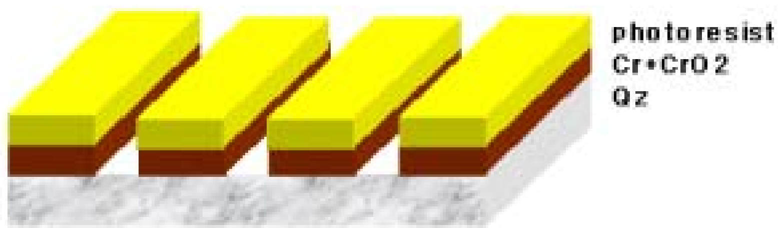
Production



Quartz substrate
Cr/CrO_2 layer (sputtering)
PR coating



Pattern writing by
E-beam lithography



Development and etching

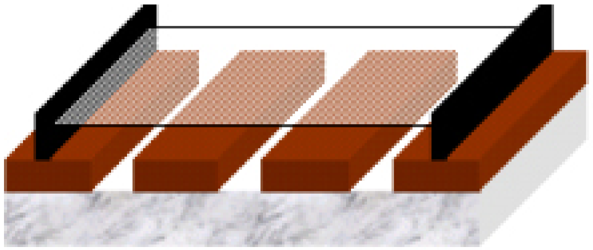
PR removal

Source: PKL

4

Pellicles

Protection for photomasks (projection lithography)

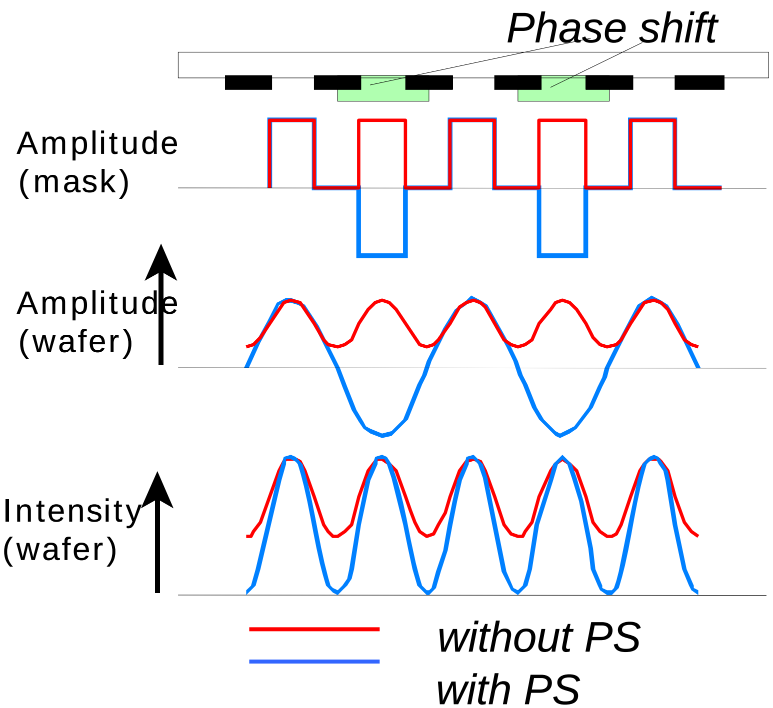


193nm: Organic pellicles

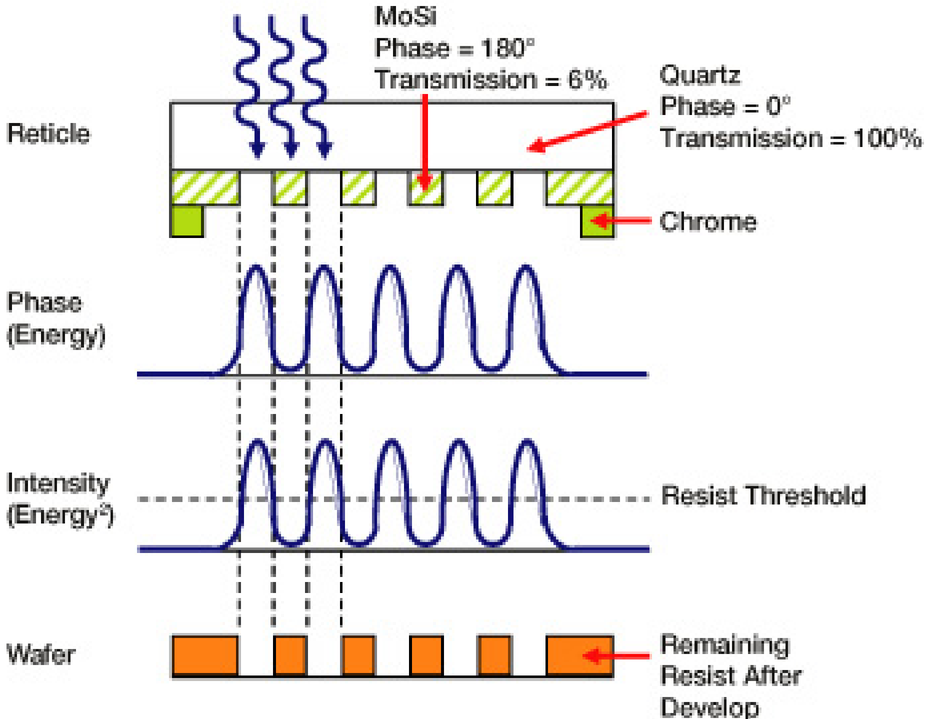
Below 193 nm:Transparency and durability problems

Phase Shift Masks

Alternating PSM



Attenuated PSM

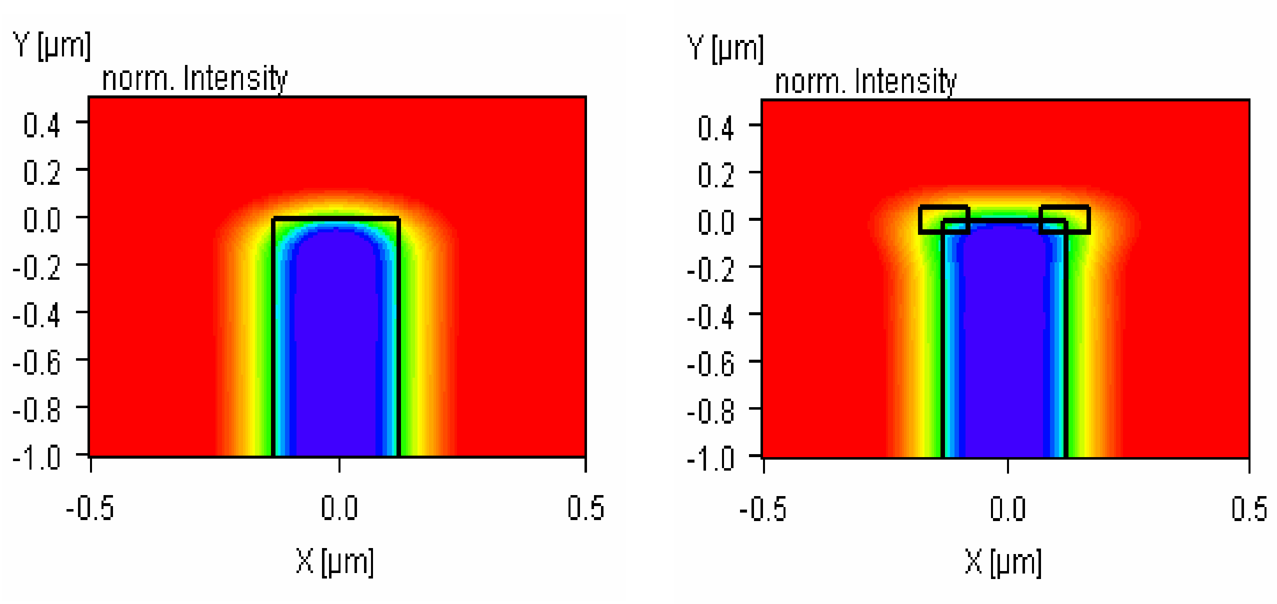


Source: ASML

4

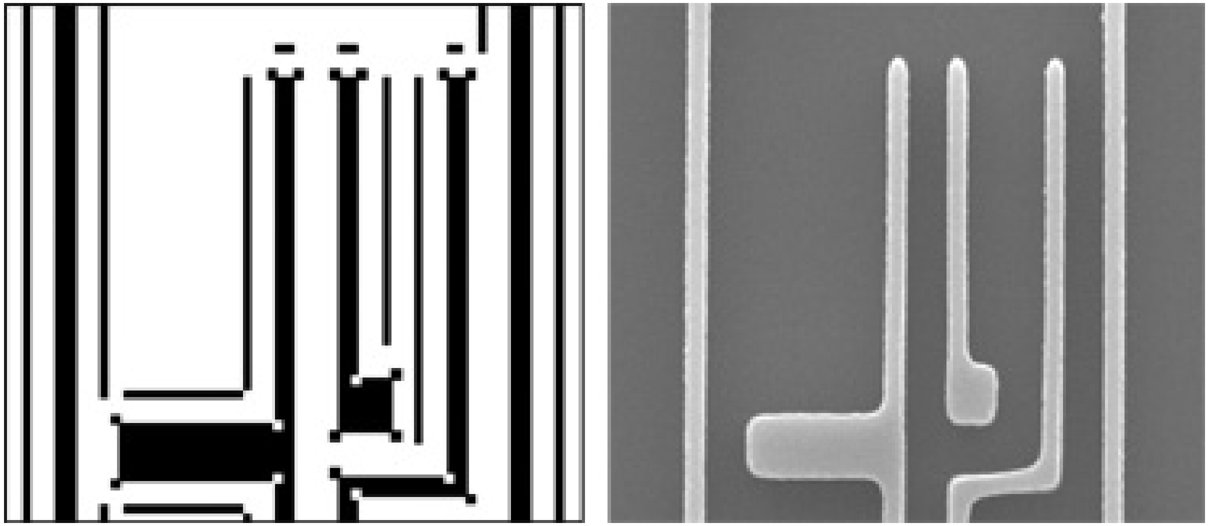
Optical Proximity Correction (OPC)

Mask modifications to reduce image imprecisions



Serifs/Hammerheads → improved precision at corners

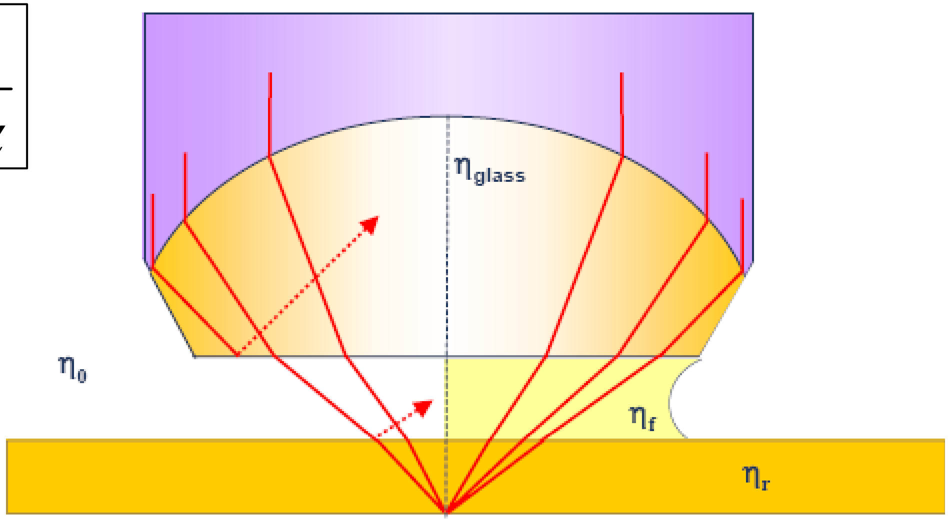
Optical Proximity Correction (II)



Dummy structures below resolution limit
→ improved result due to more homogeneous distribution of etchant

Immersion Lithography

$$\Delta x = k_1 \cdot \frac{\lambda}{NA} = k_1 \cdot \frac{\lambda}{n \cdot \sin\alpha}$$



Advantages:

- Higher numerical aperture can be achieved
- smaller patterns without smaller wavelengths

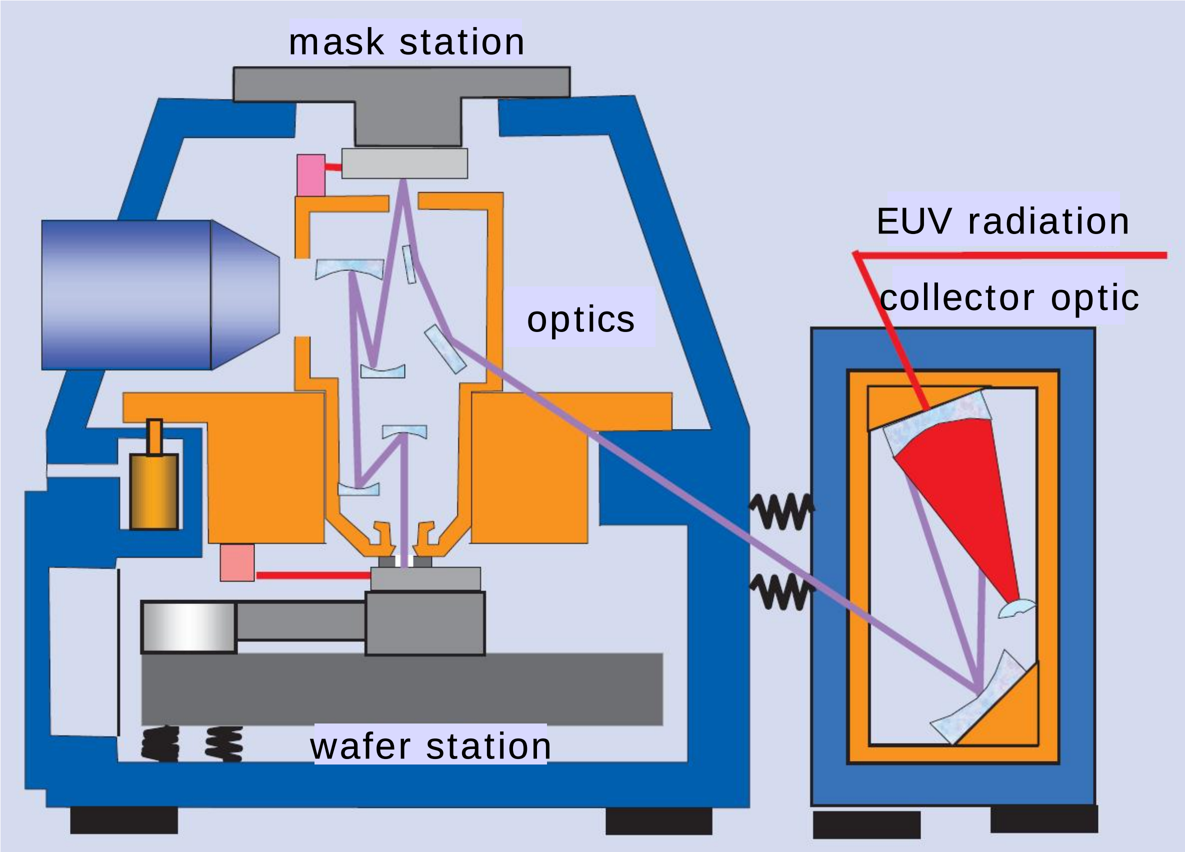
But:
- expensive technique
- defects in the liquid
- complex process

EUV Lithography

high absorption of EUV radiation

→ Optics and masks need to be reflective

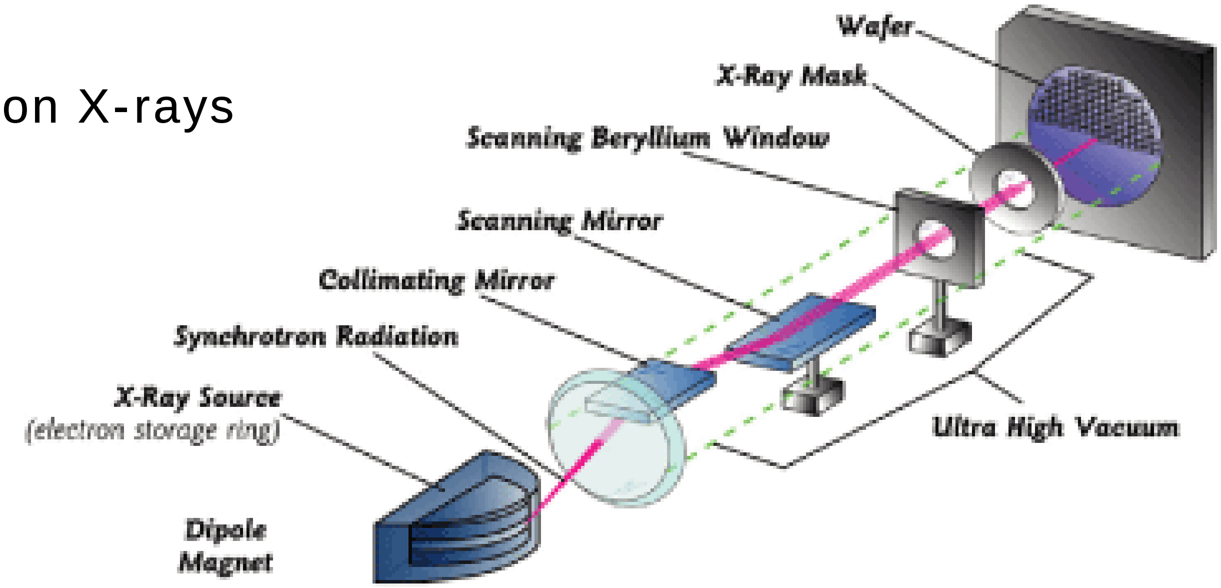
→ Needs vacuum



Source:
Plasma (laser or gas discharge stimulated)

X-ray Lithography

Source: Synchrotron X-rays



Problems: expensive, complex masks required (f.e. gold on SiC, produced by electron beam writing)

Electron Beam Lithography

Scale
resolution of ~20nm

Masks
No physical mask-plates are needed

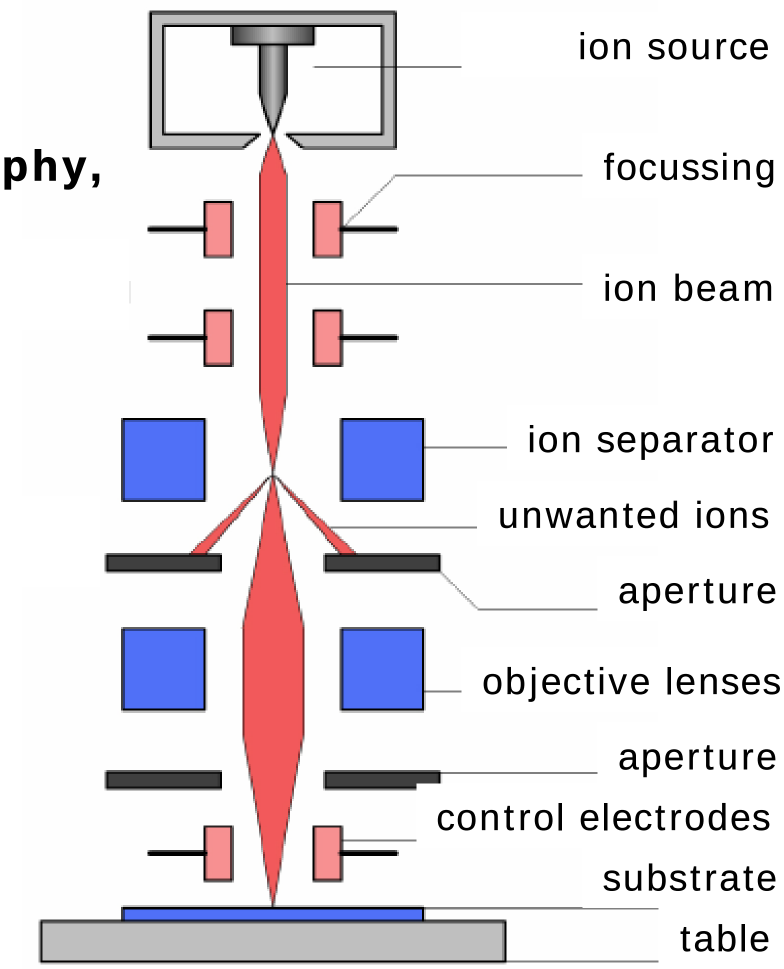
Cost and Maintenance

Time
The electron beam must be scanned across patterned areas pixel by pixel

Fabrication
Conventional fabrication techniques such as metal lift-off and etching can become difficult at sub-micron length scales

Ion Beam Lithography

similar to electron beam lithography, but using a focused ion beam



Scales below 100nm

No masks needed

Ion implantation

Ion/Atom scattering

Optical Lithography - Sources

Görtler, Strowitzki: Kompakte, hochrepetierende Excimerlaser für industrielle Anwendungen, TuiLaser AG

MICROLITHOGRAPHY From Computer Aided Design (CAD) to Patterned Substrate, Cornell Nanofabrication Facility, Microlithography Manual

pi.physik.uni-bonn.de/hertz/bilingual/Vorlesungen/Atomphysik_WS0607/AtomphysikKB2.pdf

http://www.lpm.u-nancy.fr/webperso/nanomag/download/Cours%20Micro-Nano/Techno%20CMOS_Chihiwu/ch06%20rev1.ppt

Thomas Zell: Lithography, 3. Dresdner Sommerschule Mikroelektronik

Prof. Dr. Herberger (FHM), Praktikum Mikroelektronik, WS 06/07

Uwe Stamm, Heinrich Schwoerer und Rainer Lebert, Strahlungsquellen für die EUV-Lithographie

H. Kück, Übersicht über gängige Belichtungsverfahren der Mikrotechnik, izfm, Uni Stuttgart

Vorlesung Nanobiotechnologie, Zentrum für NanoBiotechnologie, Universität für Bodenkultur Wien

Prof. Heiner Ryssel, Vorlesung Technologie Integrierter Schaltungen, Lehrstuhl Elektronische Bauelemente, FAU Erlangen

Andreas Erdmann, Lithography Course, Part 1, Fraunhofer Institut IISB, Erlangen

Prof. Dr. Roland Zengerle, Vorlesung Mikrosystemtechnik 1

Kurt Ronse, Optical Lithography, The Microelectronics Training Center, IMEC

Prof. Heiner Ryssel und Andreas Erdmann, Optik für die Mikro- und Nanoelektronik

Reiser, Huang, The molecular mechanism of novolak–diazonaphthoquinone resists, European Polymer Journal

http://www.lithoguru.com/scientist/lithobasics.html

http://sst.pennnet.com/Articles/Article_Display.cfm?Section=ARCHI&Subsection=Display&ARTICLE_ID=205024&p=28

Andrew Wagner: Resist Sensitivity and Contrast Experiment, Rochester Institute of Technology

Optical Lithography

Thank you for your kind attention!