Course Notes

SPIE Education Services

SC101
Introduction to Microlithography: Theory, Materials, and Processing

Murrae Bowden
EMP Consultants

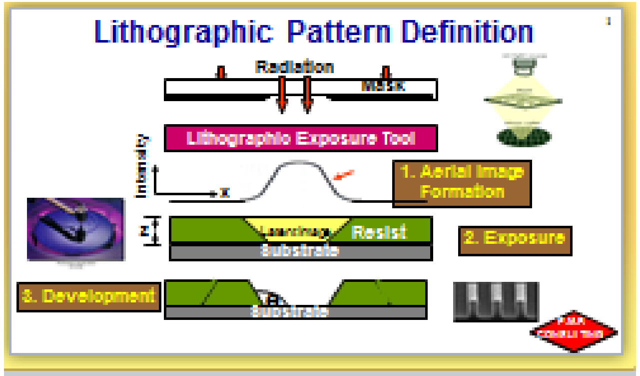
Ralph Dammel
EMD Electronics

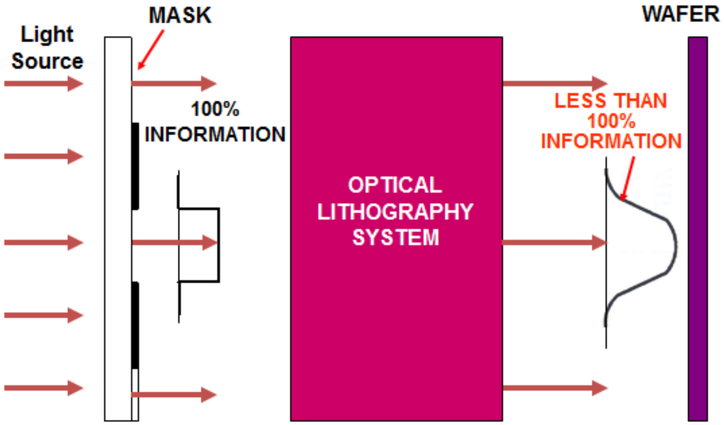
SPIE.
SPIE.org

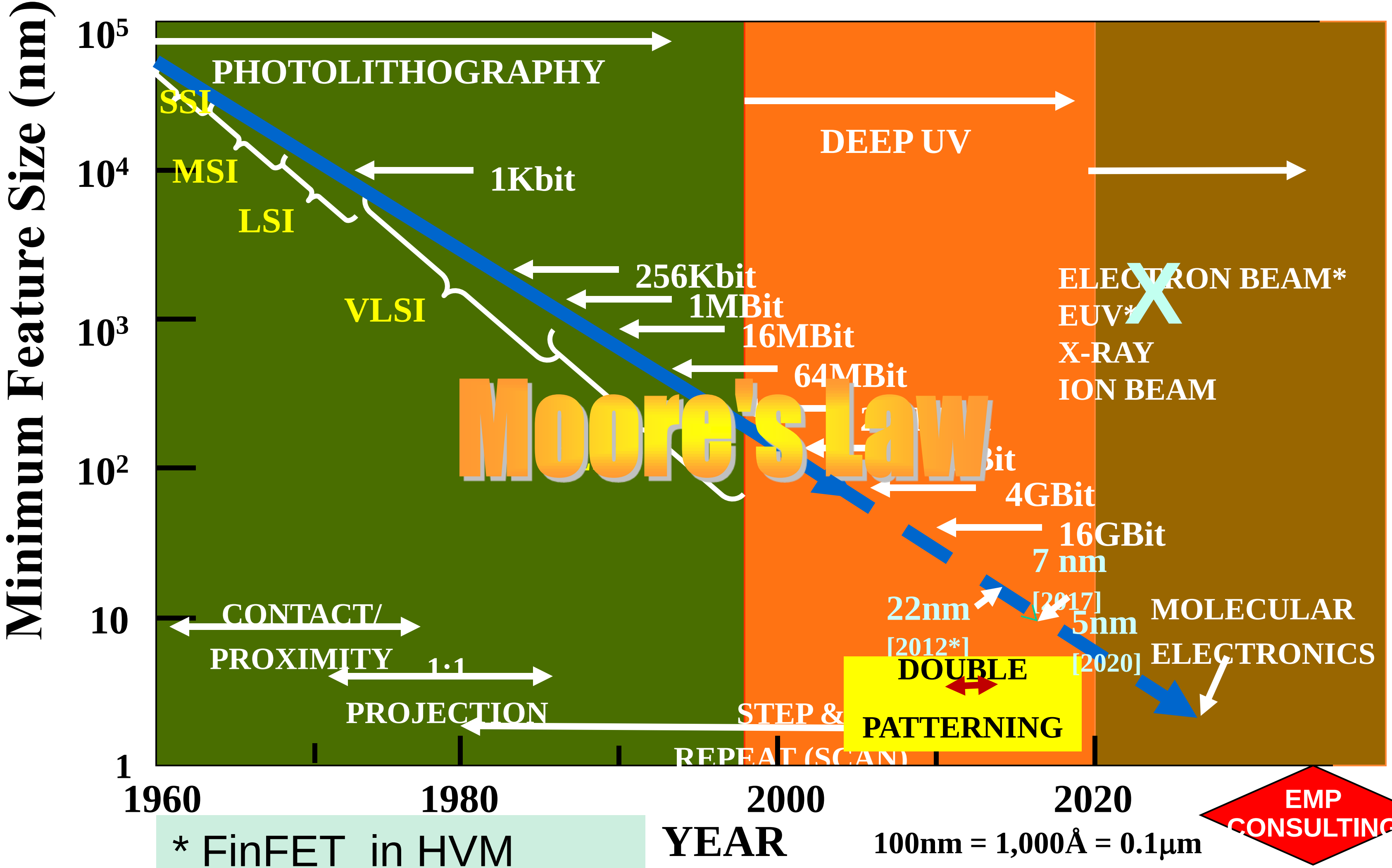
The first part of SC101 deals with the physics of lithographic pattern definition and is targeted at those relatively new to the industry. The course provides students with a broad overview of the different wafer printing technologies with emphasis on optical processing techniques and their evolution over time in response to the demands of Moore’s Law. The problem is that as feature sizes get smaller and smaller in order to accommodate the increasing number of transistors in a given area of silicon that Moore’s Law requires, physical constraints of the different optical exposure technologies result in a loss in the fidelity of the lithographically defined image which negatively impacts resolution.

Part 1 reviews the physical constraints imposed by each printing technology on resolution and covers a broad array of topics including image formation, diffraction, spatial coherence, modulation transfer function, numerical aperture, optical extensions encompassing wave front engineering techniques, among others, giving students an appreciation of the interrelationships between these parameters in optimizing system performance.

The following pages give examples of the kind of information presented.


Lithographic Pattern Definition





* FinFET in HVM

100nm = 1,000Å = 0.1µm

EMP CONSULTING

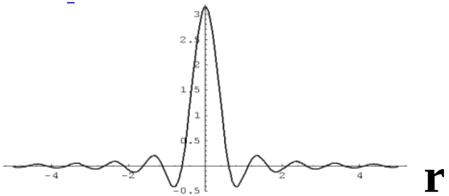
Lithography Resolution and Depth of Focus

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

λ = wavelength of illuminating light

k_1 = process constant

NA = lens numeri

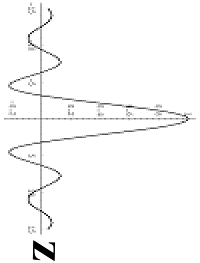


Smaller λ → Light source & Optics

Higher NA → Lens design improvements

Lower k_1 → Process/resist improvements

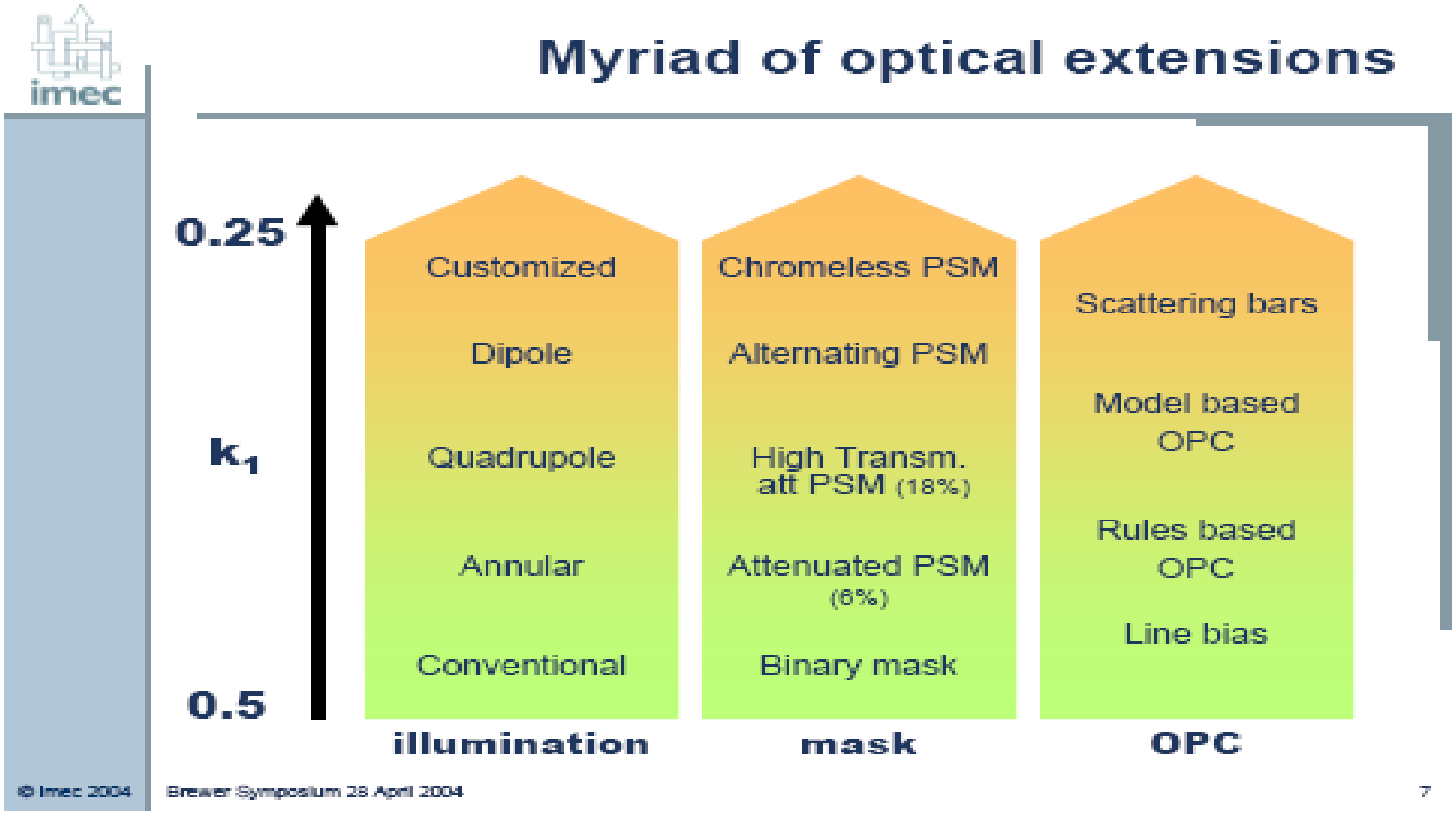
Improved optical schemes



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

k_2: depending on the criteria used to define acceptable imaging and on the type of feature

EMP CONSULTING



imec

Myriad of optical extensions

0.25

k_1

0.5

illumination

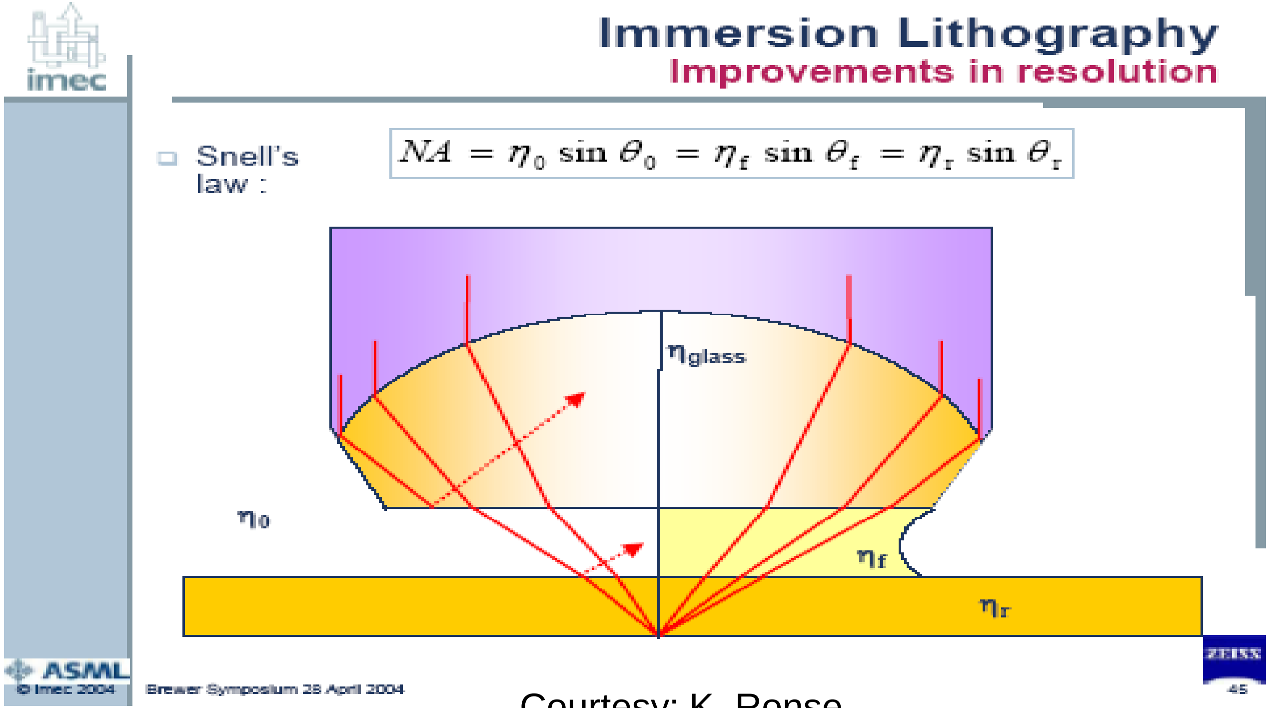
- Customized
- Dipole
- Quadrupole
- Annular
- Conventional

mask

- Chromeless PSM
- Alternating PSM
- High Transm. att PSM (18%)
- Attenuated PSM (6%)
- Binary mask

OPC

- Scattering bars
- Model based OPC
- Rules based OPC
- Line bias



imec

Immersion Lithography

Improvements in resolution

- Snell's law : $NA = \eta_0 \sin\theta_0 = \eta_f \sin\theta_f = \eta_r \sin\theta_r$

ASML
© imec 2004
Brewer Symposium 28 April 2004
ZEISS
45

Courtesy: K. Ronse

$$W = \frac{k_1 \lambda}{n \sin\alpha} = \frac{0.25 \times 193}{1.43 \times 0.93} = 35\ \text{nm}$$

[Practical – 43-45nm]

EMP CONSULTING

Extreme Ultra Violet (EUV) to the Rescue

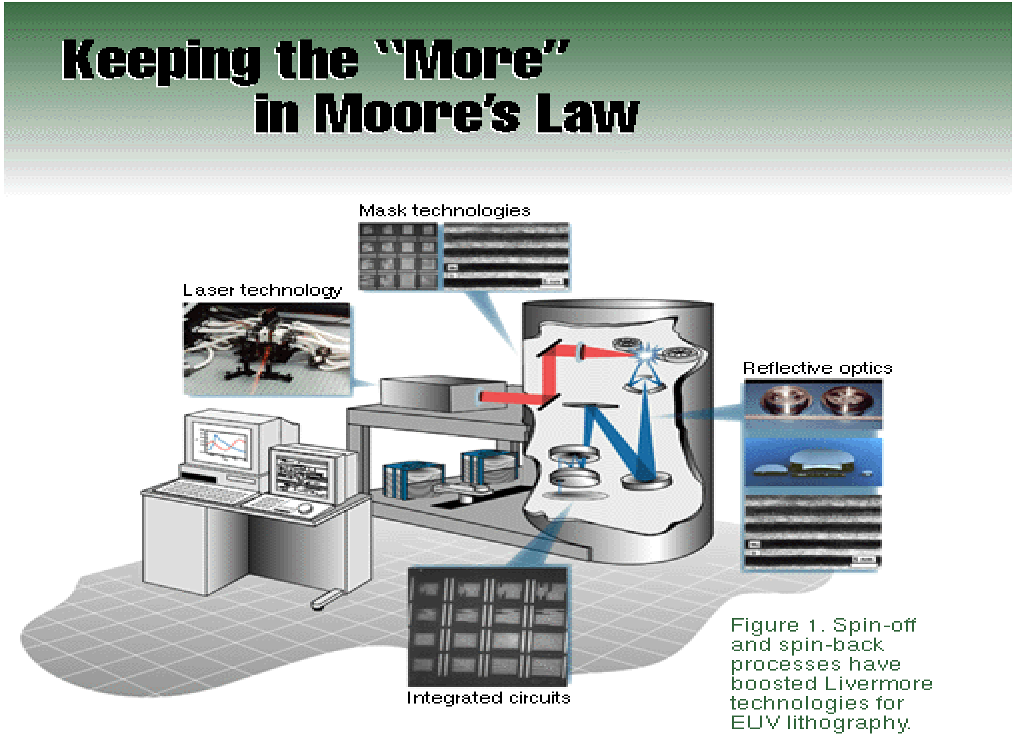

Keeping the "More" in Moore's Law

Figure 1. Spin-off and spin-back processes have boosted Livermore technologies for EUV lithography.

Wavelength: 13.5nm

Issues
- Source
- Mask
- Resist

ASML's Production EUV System

EMP CONSULTING

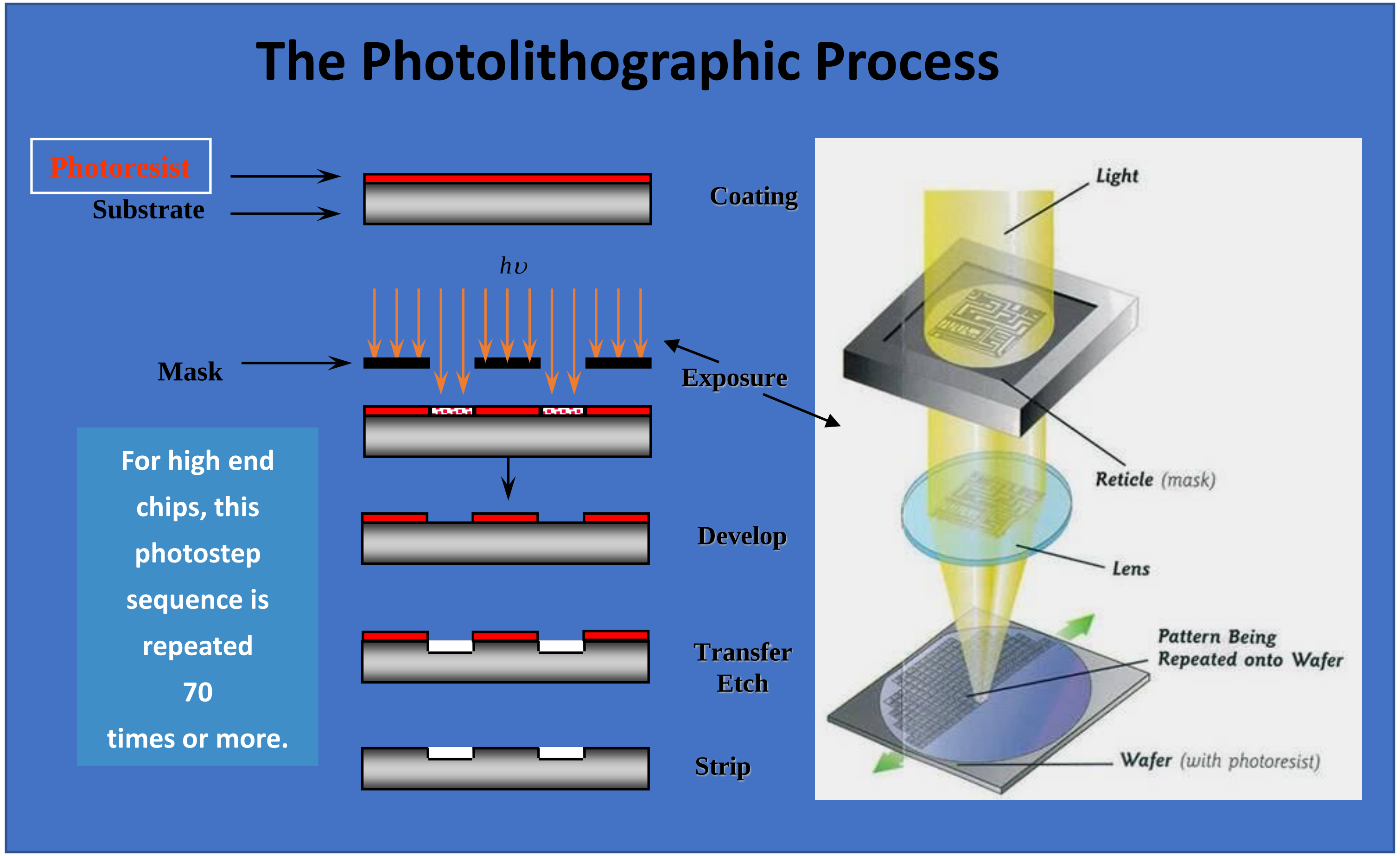
Covered Topics and Learning Outcomes

This second part of SC101 will deal with the underlying chemistry of photoresists and their processing.

The course topics cover the make-up and mechanisms of action of common photoresist materials for the wavelengths used by the industry, from broadband to EUV exposures. Novel patterning techniques such as Directed Self Assembly (DSA) are also presented.

The course concludes with an outlook on the challenges and opportunities of future patterning.

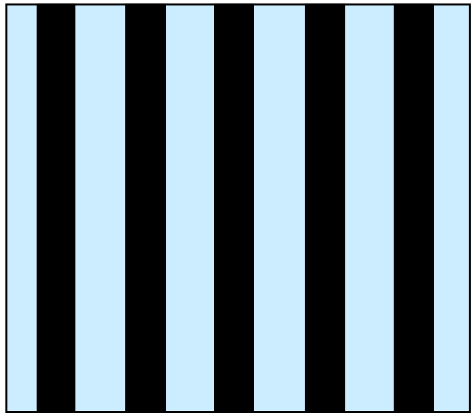
The following pages give examples of the kind of information presented.



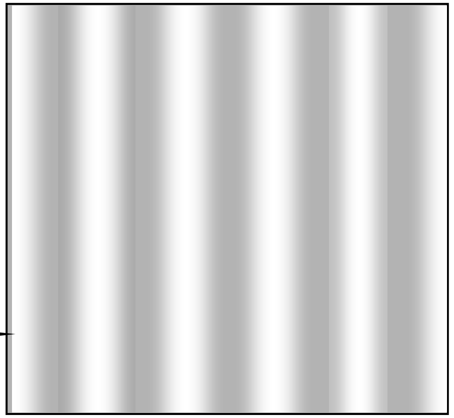
The Photolithographic Process

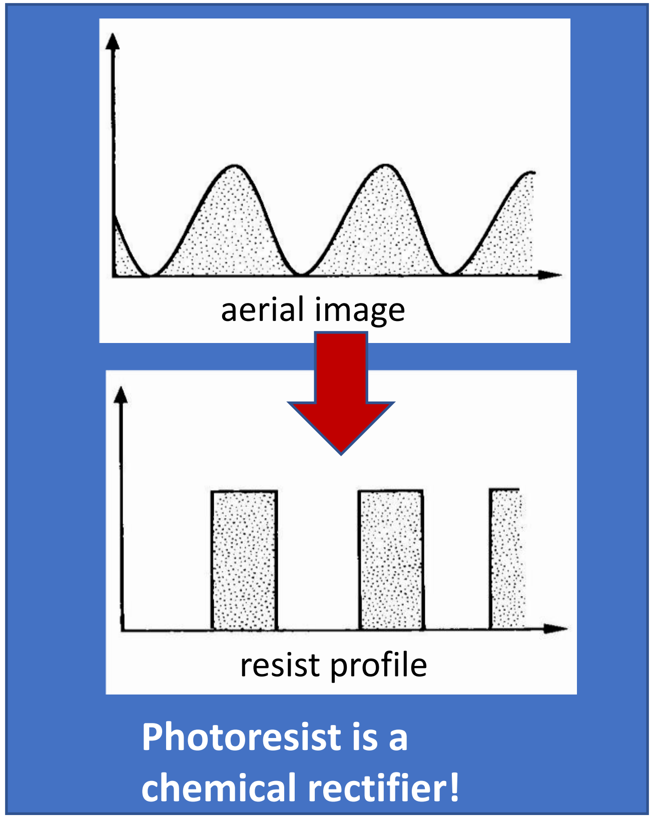
For high end chips, this photostep sequence is repeated 70 times or more.

Well, How do These Things Really Work??

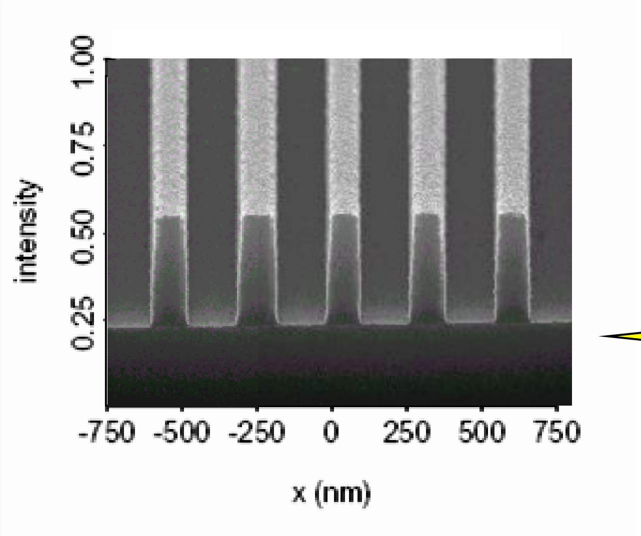


$$$$$$$$$$$$$

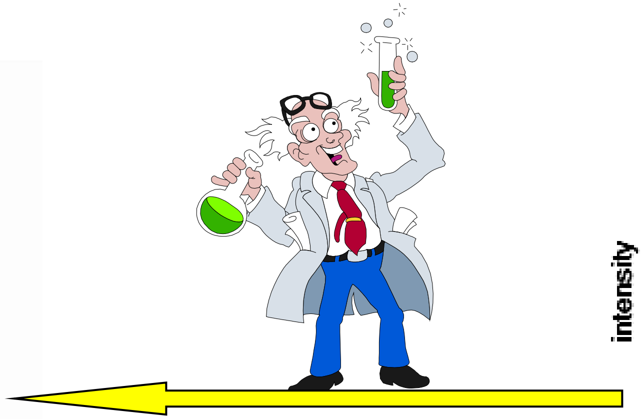




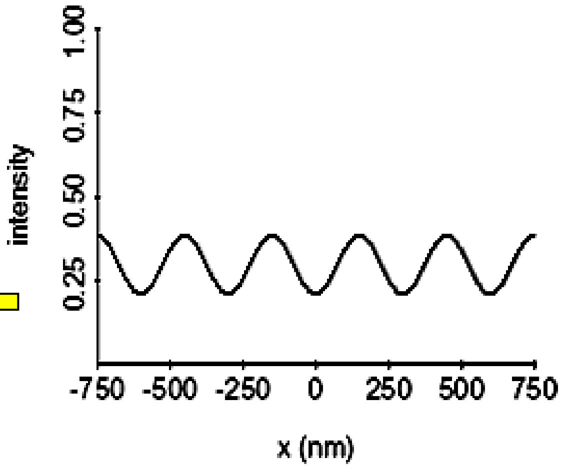
Photoresist is a chemical rectifier!



resist image



¢¢¢¢¢¢!!!

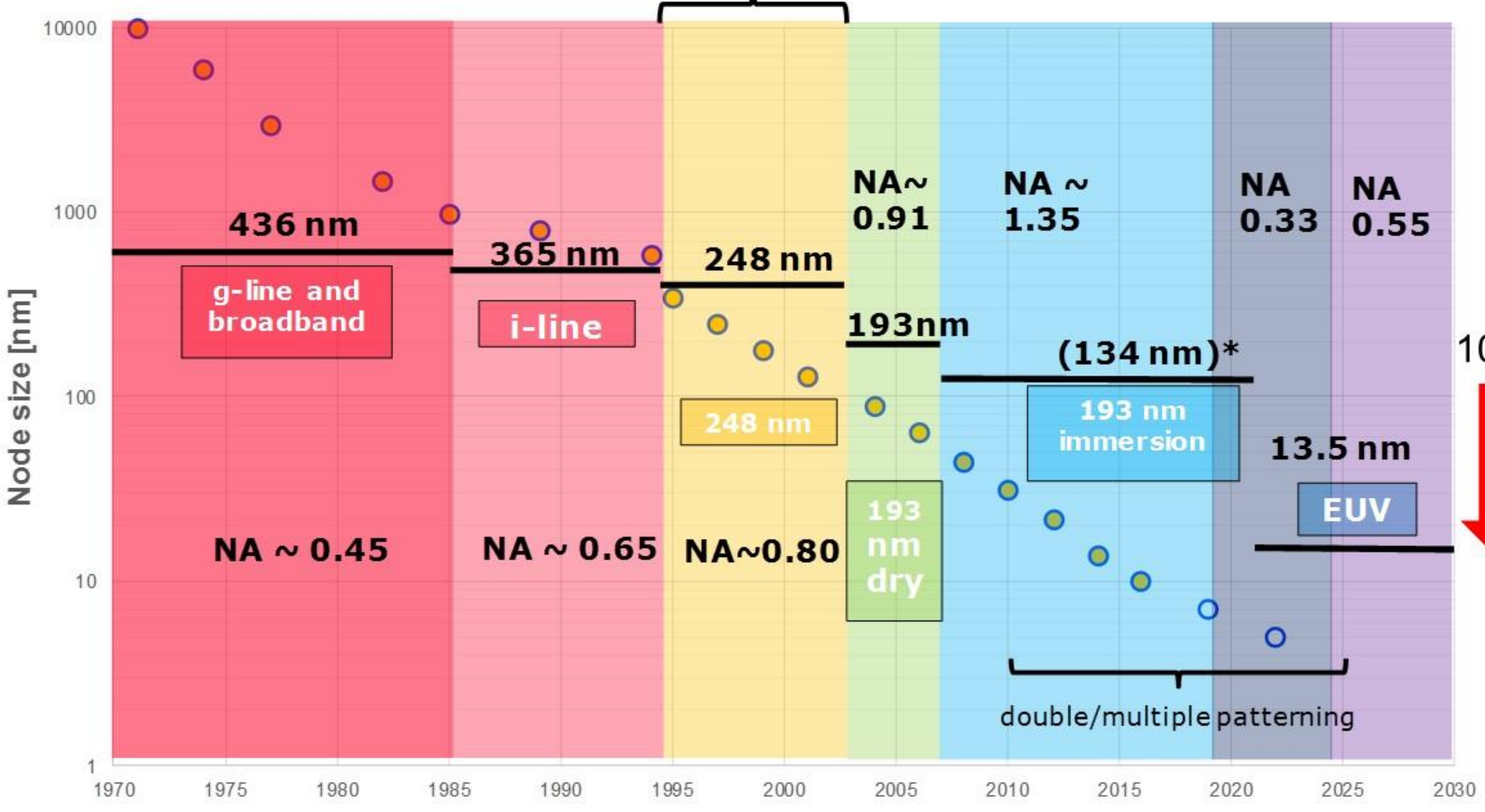


aerial image

Amazing Chemistry!!

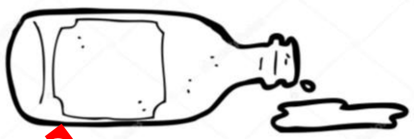
Lithographic Technologies Over Time

DUV resists: ~9 years



10x jump!

The endless supply of Incredible Shrinking Potion…



…is running out!…

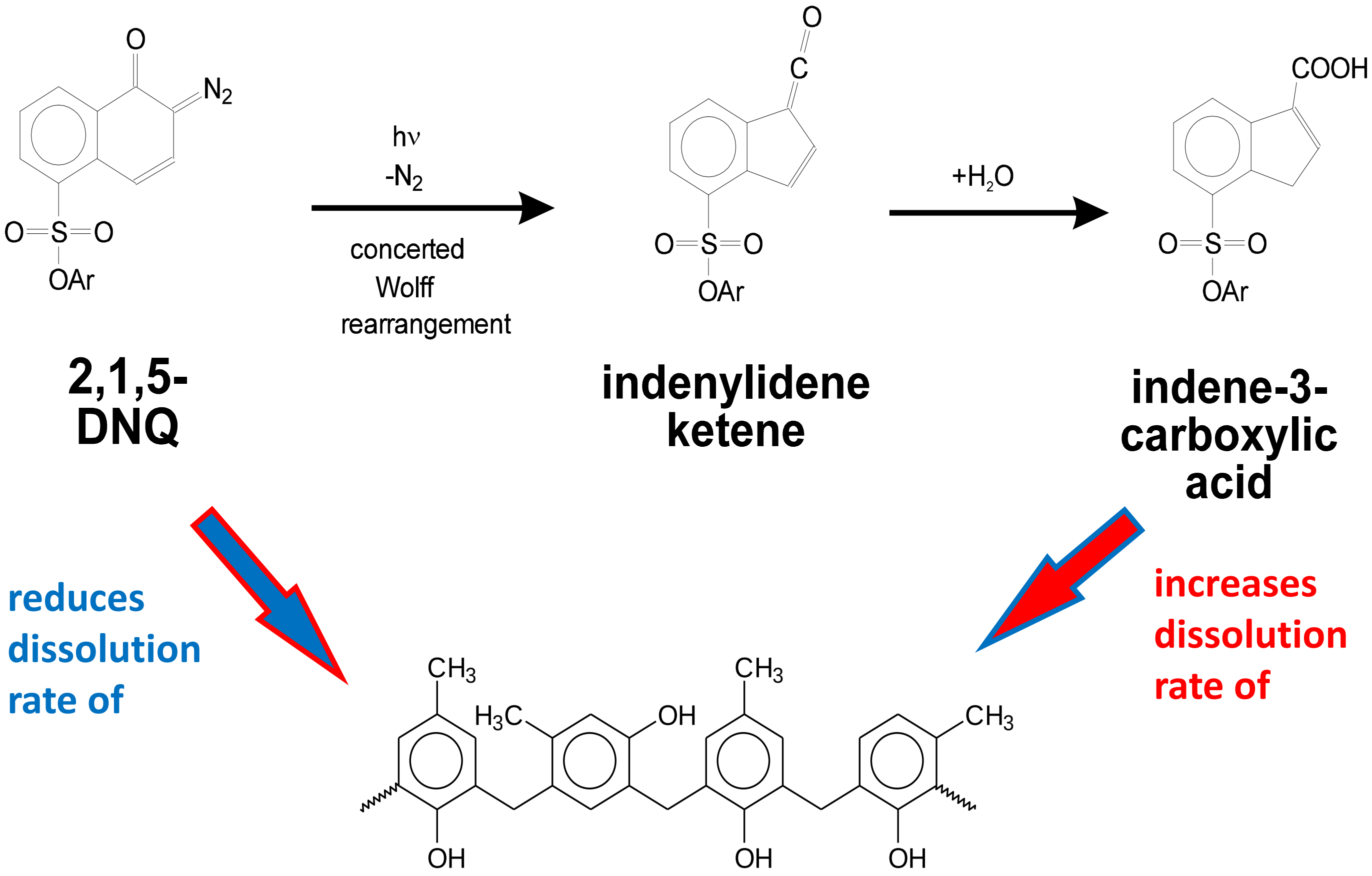
DNQ/novolak resists: 25 years

193 nm resists: 15 years

EUV: ∞

*: in water

Diazonaphthoquinone-Based Resists



2,1,5-DNQ

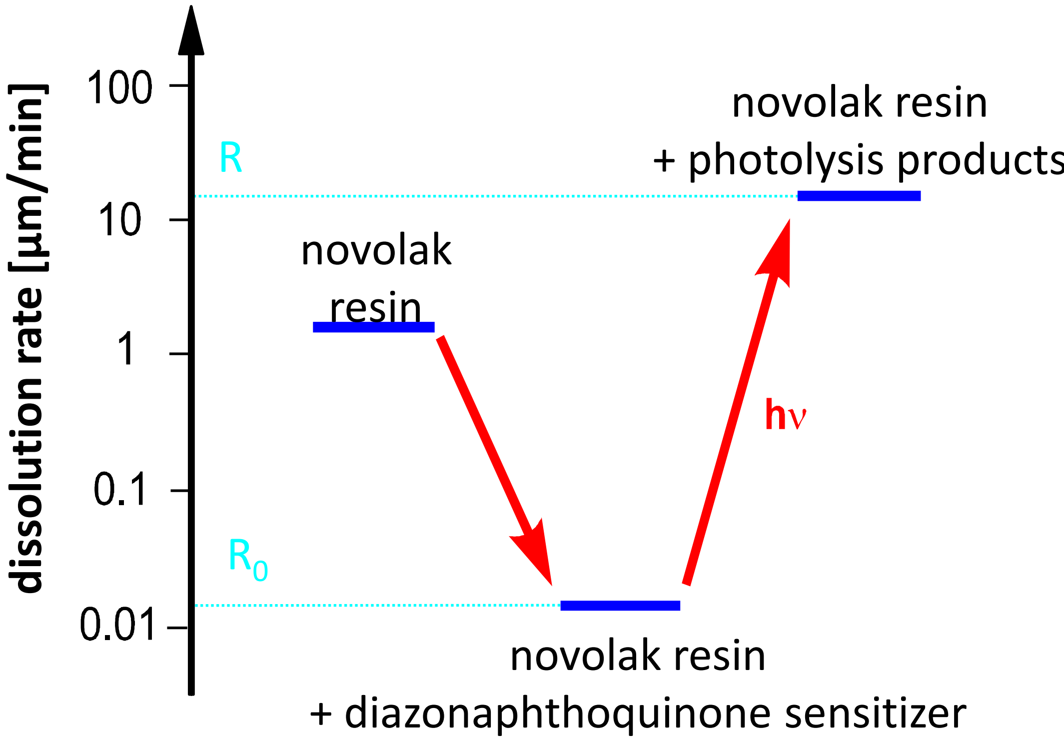
indenylidene ketene

indene-3-carboxylic acid

reduces dissolution rate of

increases dissolution rate of

novolak resin

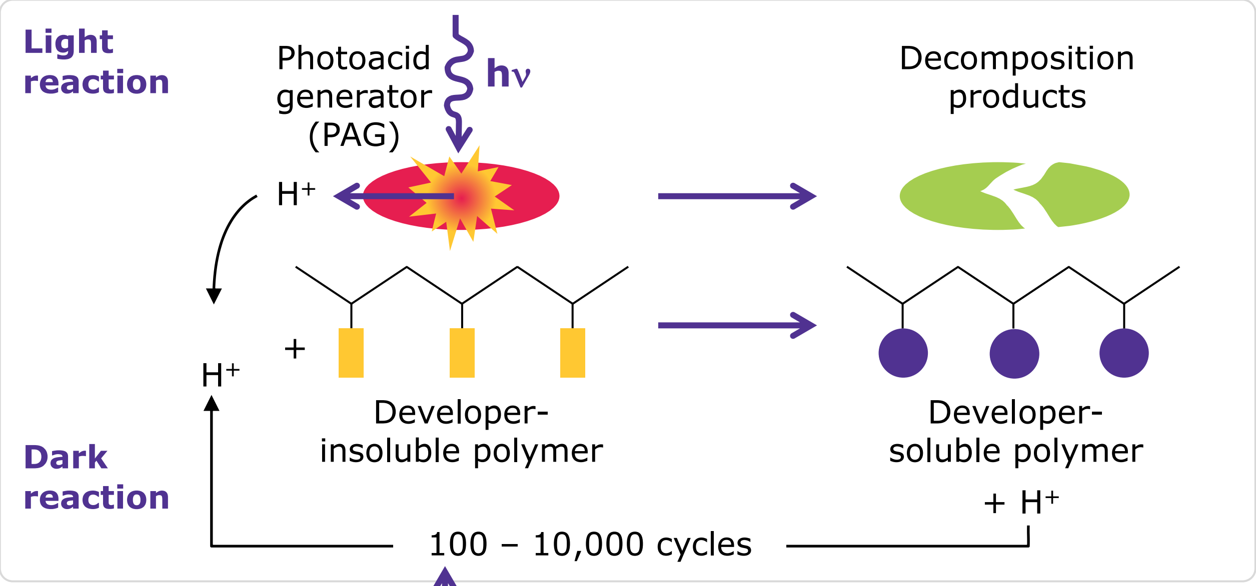


Dissolution inhibition: kinetically insoluble, not thermodynamically.

Materials for New Tech Nodes
Basic EUV Photoresist Types

Chemically Amplified Resists (CARs)

The original photoevent generates a catalyst for solubilization (typically a proton). The photoevent is amplified by the number of cycles each proton catalyzes.



Light reaction

Photoacid generator (PAG)

hν

H^+

Decomposition products

$+$

H^+

Developer-insoluble polymer

Developer-soluble polymer

$+ H^+$

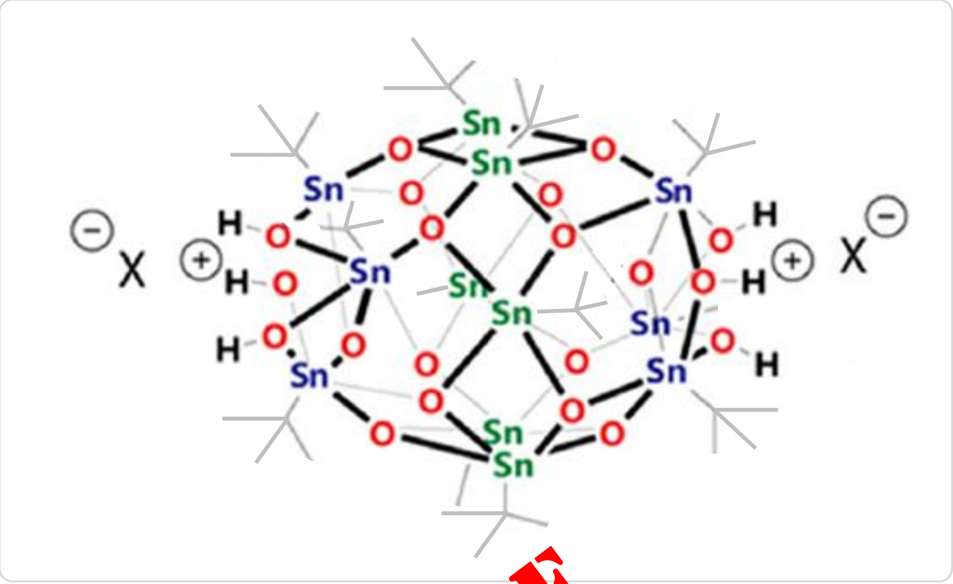
Dark reaction

100 – 10,000 cycles

Light Reaction is amplified by this amount

Metal Organic Resists (MORs)

Tin cluster provides high absorption but there is no chemical amplification:
1 exposure event = 1 chemical reaction.



Dodeca-tin oxo cluster (Sn_{12} cluster)

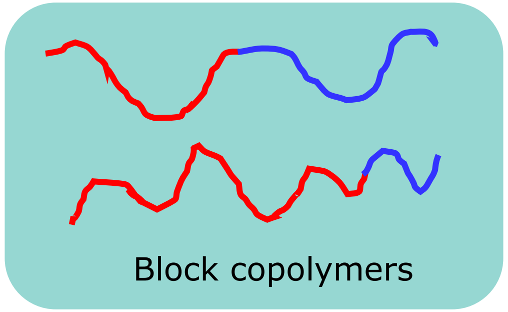
Block Copolymer Self-Assembly

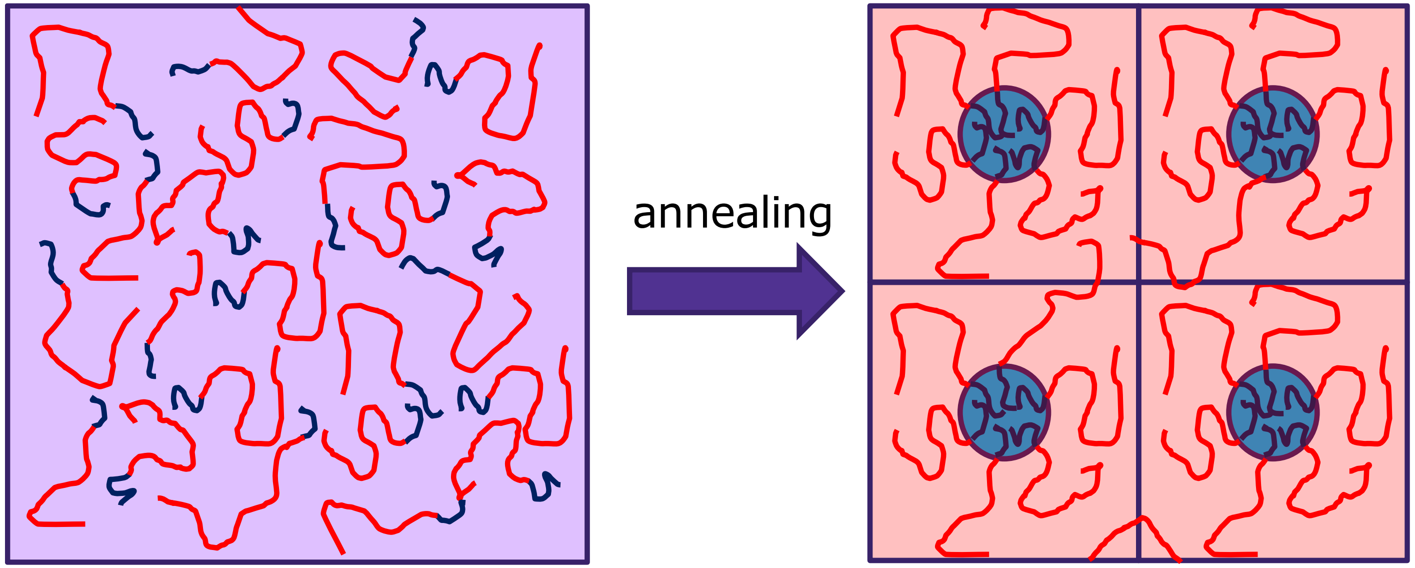
Random Copolymer:

n A + m B → -A-A-B-A-B-B-A-A-B-B-A-B-A-B-

Block Copolymers:

n A + m B → -A-A-A-A-A-A-A-B-B-B-B-B-B-B-





Blocks “like” each other less than themselves.

With BCPs, minimization of surface interaction leads to the formation of distinct phases.