Part III. Functional Polymers for Semiconductor Applications

Outline of Part

Photoresist for Semiconductor Applications

- ❑ Introduction of photolithography
- ❑ Photoresist Materials for Exposure at 193 nm Wavelength
- ❑ Chemically Amplified Resists for F2 Excimer laser Lithography

Motivations

- Creation of integrated circuits, which are a major component in computer technology
- An extension of photolithography processes are used to create standard semiconductor chips
- Play a key role in the production of technically demanding components of advanced microsensors
- Used to make adhesives in electronics

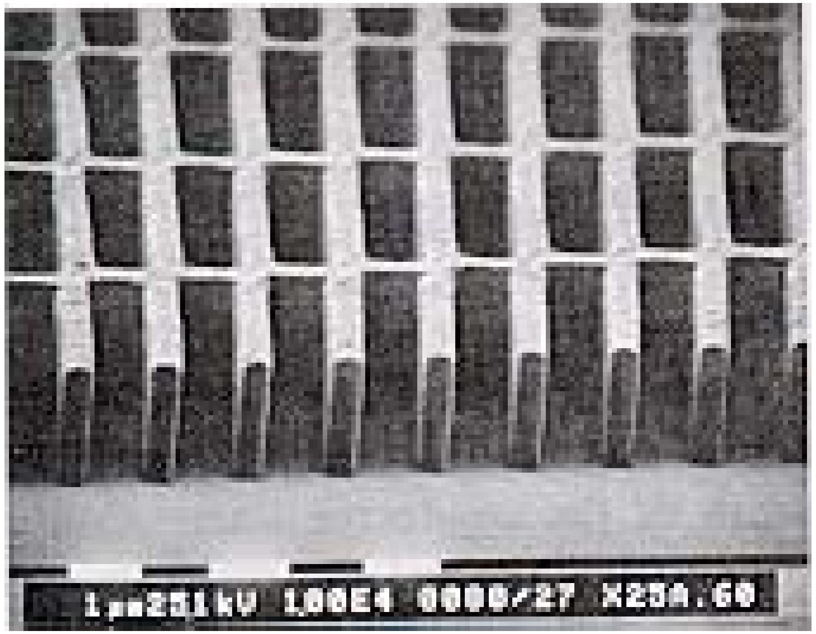
History

- Historically, lithography is a type of printing technology that is based on the chemical repellence of oil and water.
- Photo-litho-graphy: *latin*: light-stone-writing
- In 1826, Joseph Nicephore Niepce, in Chalon, France, takes the first photograph using bitumen of Judea on a pewter plate, developed using oil of lavender and mineral spirits
- In 1935 Louis Minsk of Eastman Kodak developed the first negative photoresist
- In 1940 Otto Suess developed the first positive photoresist.
- In 1954, Louis Plambeck, Jr., of Du Pont, develops the Dycryl polymeric letterpress plate

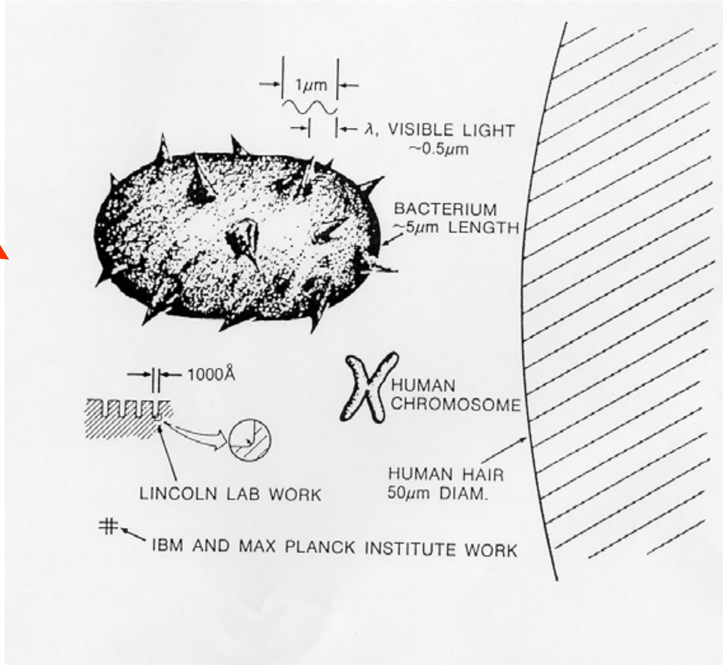
Microlithography

A process that involves transferring an integrated circuit pattern into a polymer film and subsequently replicating that pattern in an underlying thin conductor or dielectric film

How Small Can We Print ?



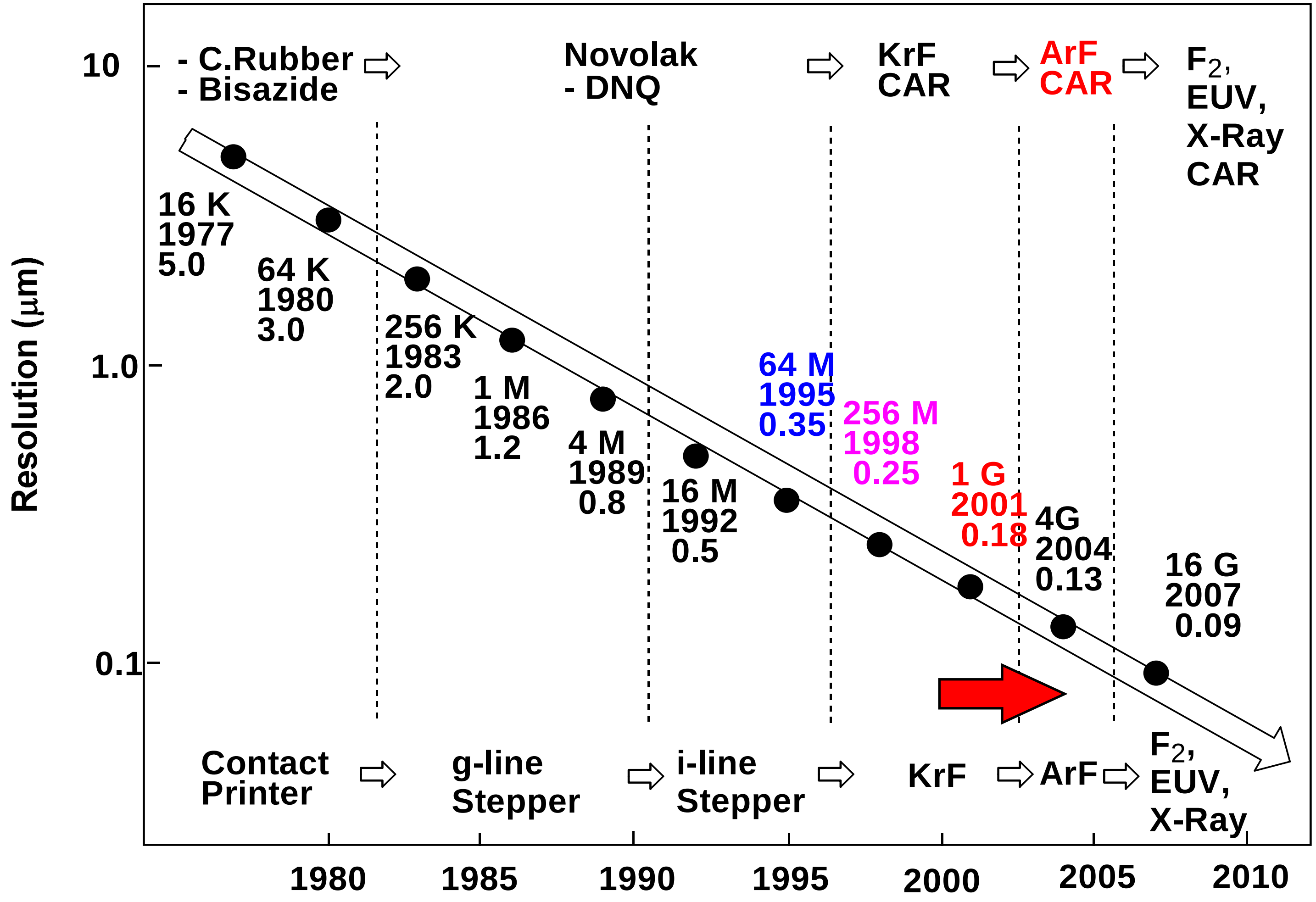
SEM picture of typical lithographic pattern



Comparison of the dimensions of lithographic images and familiar objects

Thompson, L. F.; Willson, C. G.; Bowden, M. J. *Introduction to Microlithography*; 2nd Ed; ACS Professional Reference Book; American Chemical Society; Washington, DC, 1994

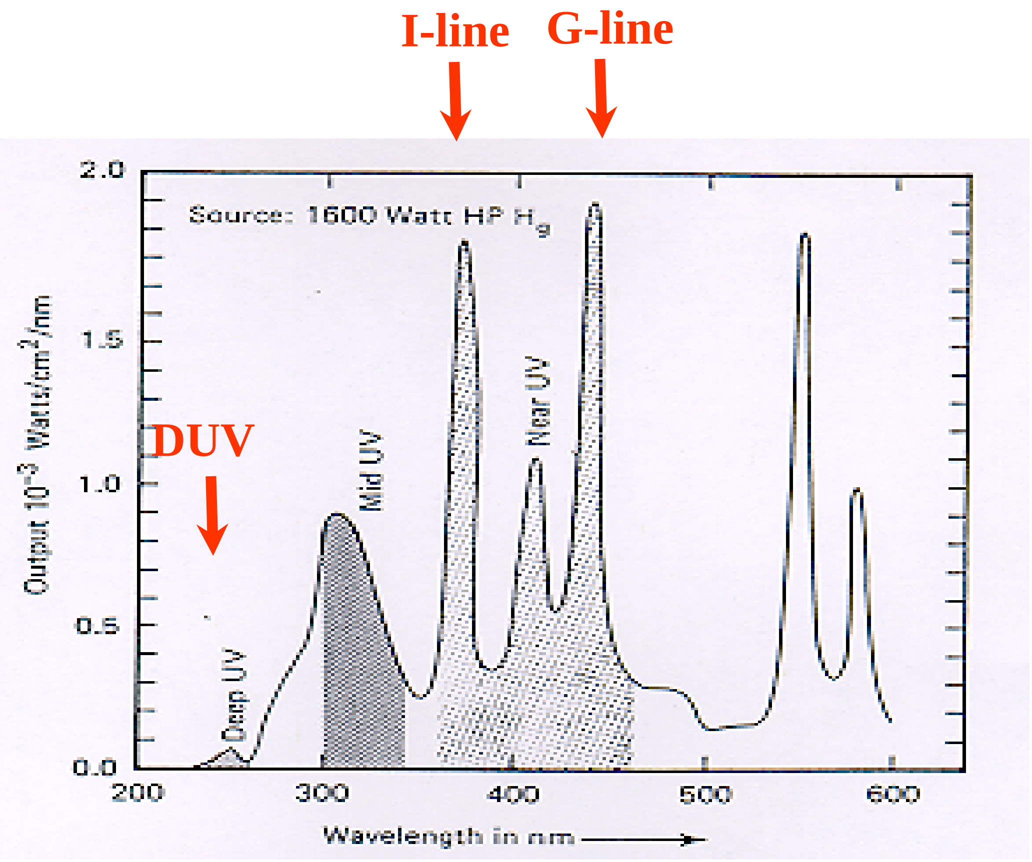
Roadmap of Semiconductor Technology



Resolution

$$R = k\frac{\lambda}{NA}$$

Light intensity(output) of Hg-lamp as a function of wavelength



Thompson, L. F.; Willson, C. G.; Bowden, M. J. *Introduction to Microlithography*; 2nd Ed; ACS Professional Reference Book; American Chemical Society; Washington, DC, 1994

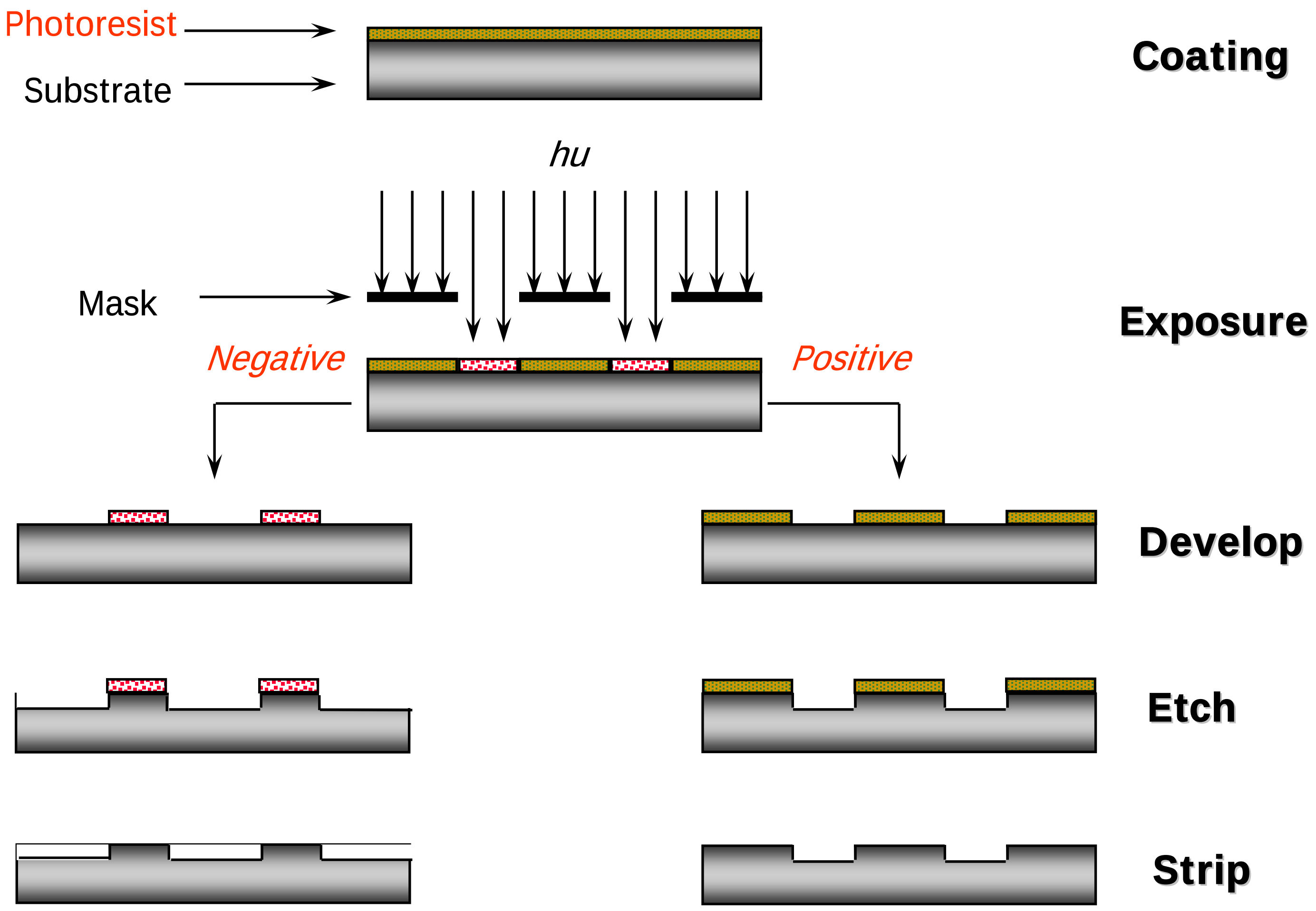
Photolithography

- In photolithography, the pattern is created photographically on a substrate (silicon wafer)
- Photolithography is a binary pattern transfer: there is no gray-scale, color, nor depth to the image
- This pattern can be used as a resist to substrate etchant, or a mold, and other forms of design processes
- The steps involved are wafer cleaning, photoresist application, soft baking, mask alignment, and exposure and development

Photoresist

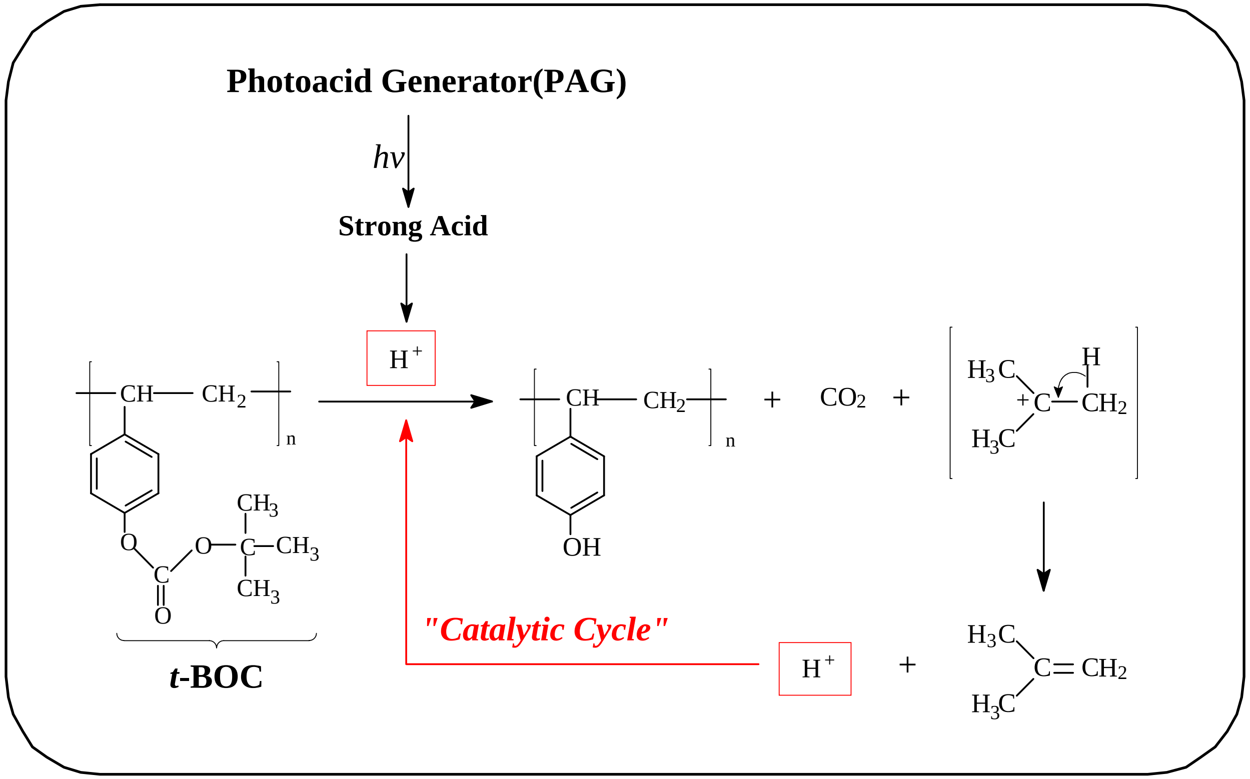
- Photoresist is an organic polymer which changes its chemical structure when exposed to ultraviolet light.
- It contains a light-sensitive substance whose properties allow image transfer onto a printed circuit board.
- There are two types of photoresist: positive and negative

PR Process


Photoresist
Substrate
Coating
hu
Mask
Exposure
Negative
Positive
Develop
Etch
Strip

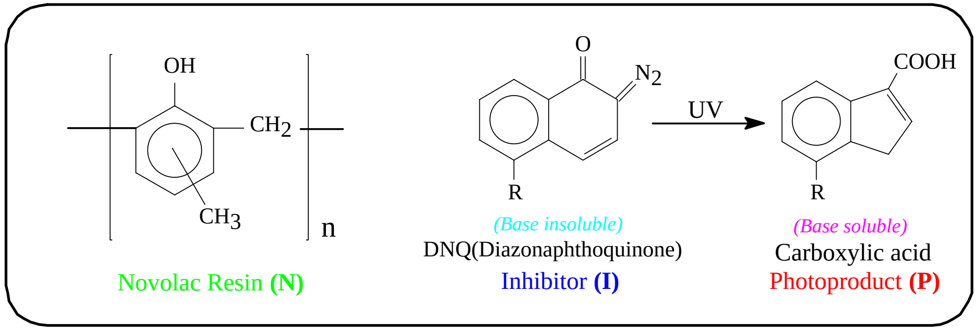
Chemical Amplification

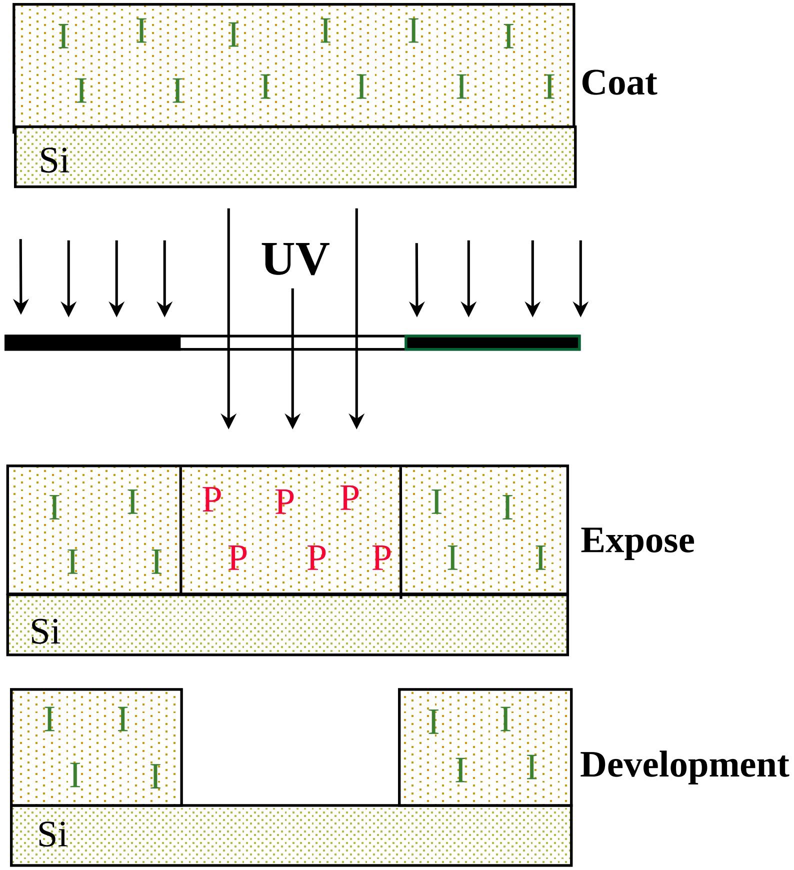
Solution : 1. More sensitive photoresists (Very high efficiency)

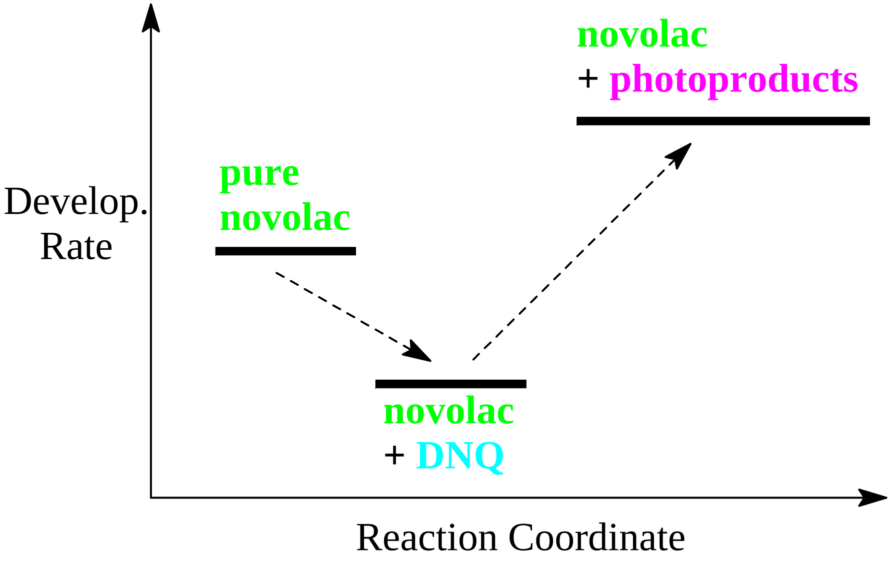


2. Brighter light source
(e.g. KrF laser for 248nm and ArF laser for 193nm)

How Novolac/DNQ Resists Work



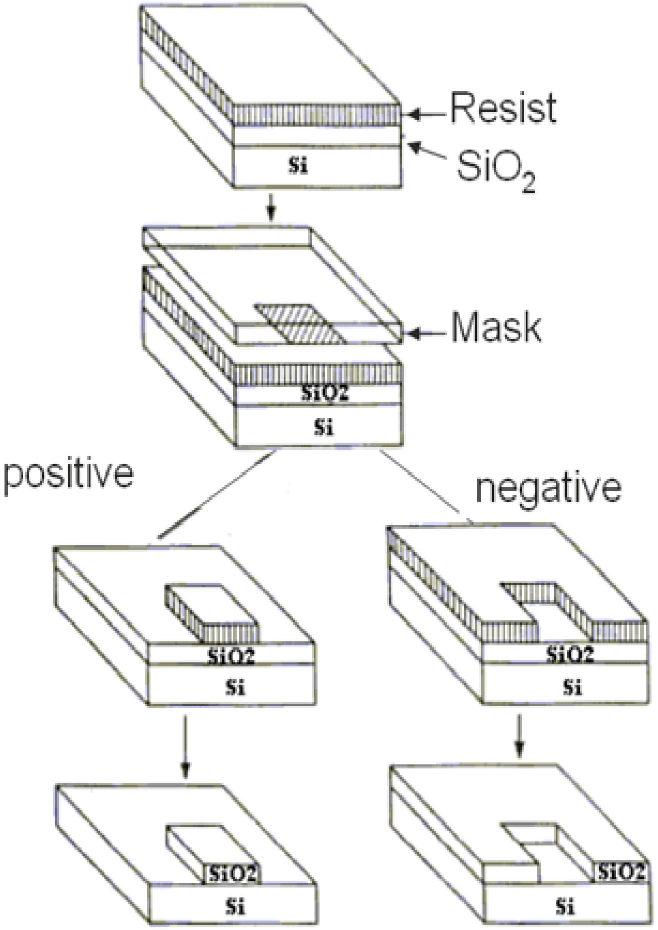




Two Types of Photoresist

Positive Photoresist

- Exposure to UV light makes it more soluble in the developer
- Exposed resist is washed away by developer so that the unexposed substrate remains
- Results in an exact copy of the original design



Negative Photoresist

- Exposure to UV light causes the resist to polymerize, and thus be more difficult to dissolve
- Developer removes the unexposed resist
- This is like a photographic negative of the pattern

Preparation and Priming

- Prepare the substrate (silicon wafer):
  - Wash with appropriate solvent to remove any dirt and other impurities
    - Acetone, MeOH, TCE
  - Dry in Oven at 150°C for 10 min.
  - Place on hotplate and cover with petri dish, let temp. stabilize at 115°C.
- Deposit Primer (optional)
  - Chemical that coats the substrate and allows for better adhesion of the resist

Spin Coating

- Spin-coat the photoresist onto the surface of the wafer
  - RPM: 1000-7000
  - Time: ~30 sec
  - Produces a thin uniform layer of photoresist on the wafer surface.
- Use red/amber safe light at this stage

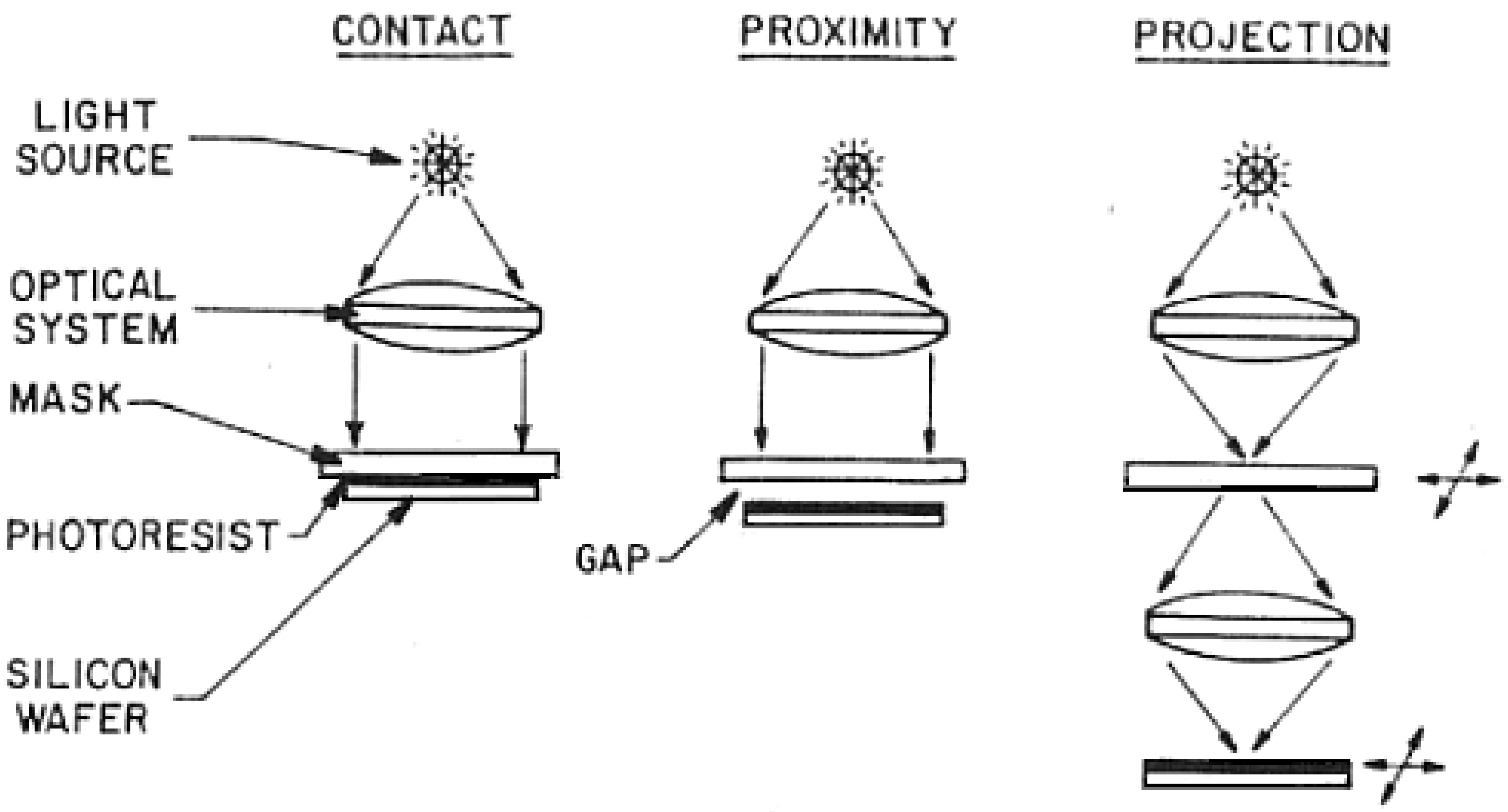
Soft Baking

- Put on hotplate, or in oven
  - Temperature: 65°C-115°C, Time: 1-5 min
- Removes volatile solvents from the coating
- Makes photoresist imageable
- Hardens to amorphous solid
- Be careful not to overbake and destroy the sensitizer

Mask Alignment and Exposure

- Photomask is a square glass plate with a patterned emulsion of metal film on one side
- After alignment, the photoresist is exposed to UV light
- Three primary exposure methods: contact, proximity, and projection

Exposure Methods



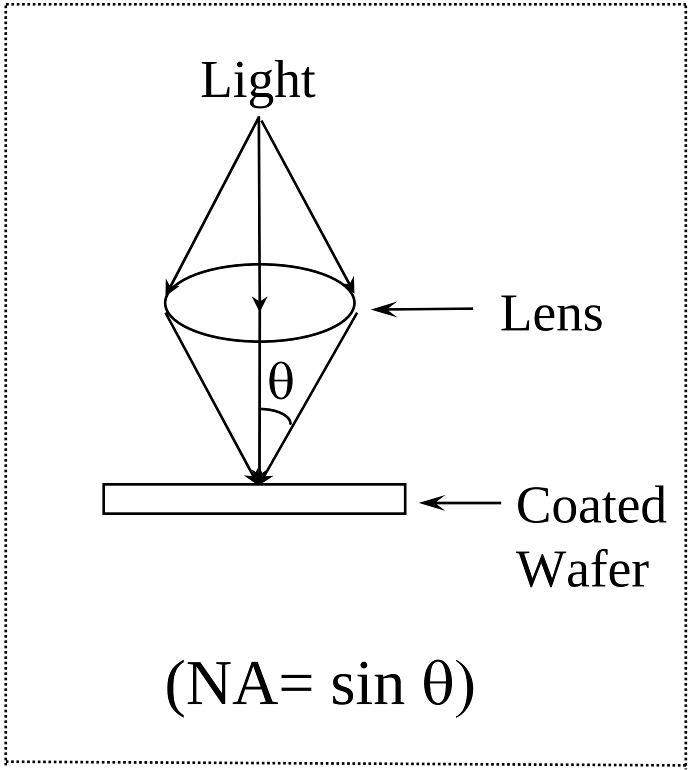
Resolution of Lithographic Process

* Use of shorter wavelength for exposure to get smaller feature size

"Lens Equation"

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

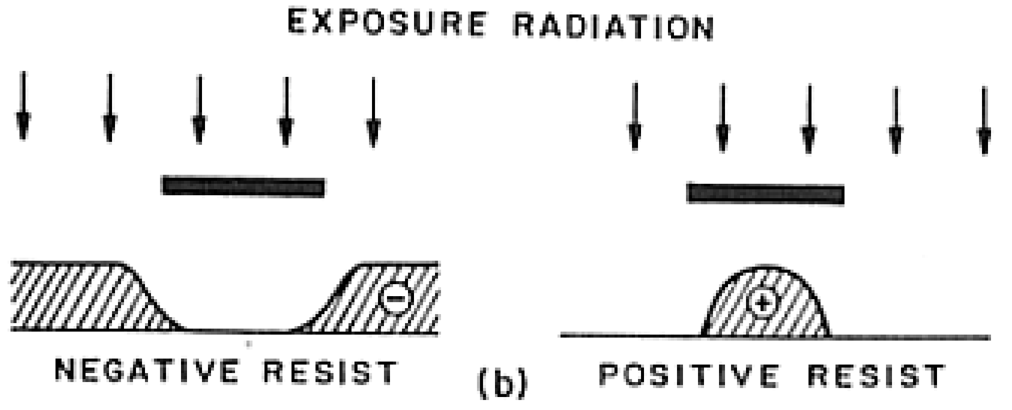
R: Resolution (feature size)
λ:wavelength of light source
k_1:Process factor
NA: Numerical aperture



(NA= sin θ)

Photoresist Developer

- Highly pure buffered alkaline solution
- Removes proper layer of photoresist upon contact or immersion
- Degree of exposure affects the resolution curves of the resist



(a) Resist exposure characteristics. (b) Resist after development.

Hard Baking

- Final step in the photolithographic process
  - Not always necessary; depends on the resist
- Hardens the photoresist
- Improves adhesion of the photoresist to the wafer surface