Lecture 2

Microscale Manufacturing Practices

Review

Mass transfer in micromixers acts on a length scale of a few microns within milliseconds or less.

Fast reactions require short and small channels and a sufficiently high number of channels, problems for slow reactions.

Combined reactions with slower side-reactions or unstable intermediates will show a higher selectivity and higher yield in micro-structured devices.

Reactions with high energy demand or release are suitable for micro-devices.

In the case of chemical reactions in microchannels, the mixing patterns can be controlled very effectively.

Hence mass transfer limited reactions are well-suited.

The characteristic dimensions of microreactors are in the range from 50 to 500 µm, which produces a high specific surface and allows effective heat and mass transfer.

For continuously operating microstructured reactors, heat transfer, temperature control, mixing and residence time characteristics, are optimal for a channel diameter of approx. 200 µm.

Two Approaches in Micro/Nano Manufacturing

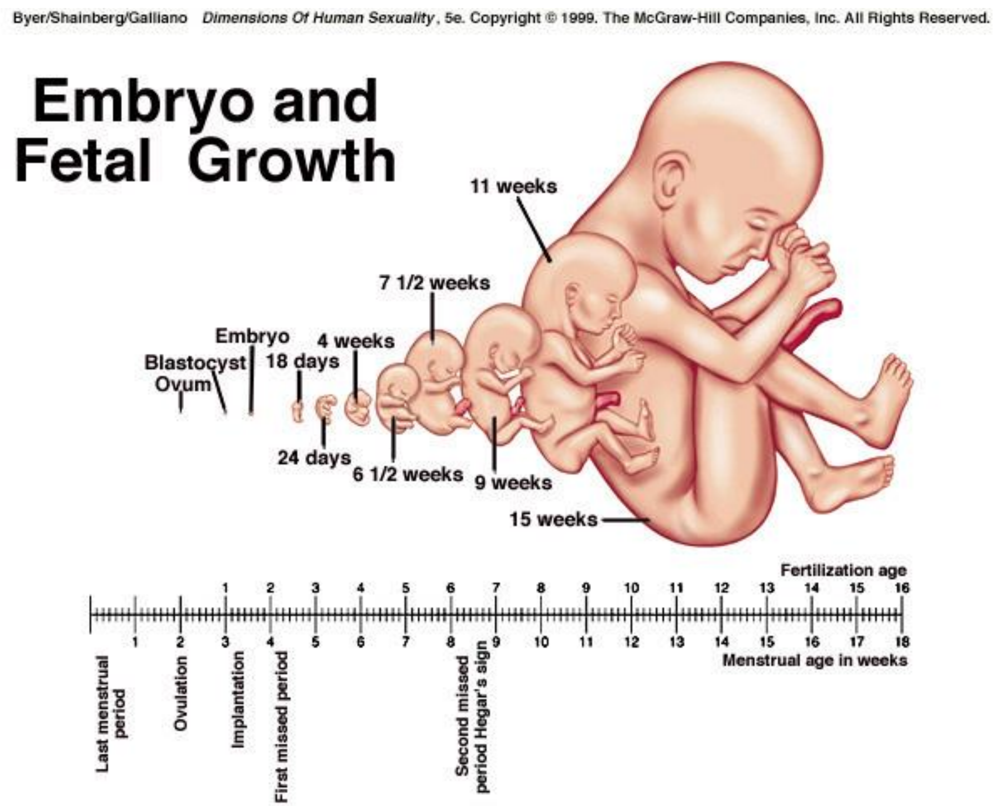
Top-down processes : one starts on the macro scale and proceeds to create fine features by processing the bulk on a fine scale - Microelectronics

More expensive as the feature dimensions become smaller

Bottom-up processes: starts at the smallest possible scale, at the atoms and molecules themselves, and builds complexity up from there. Processes controlled by self-assembly

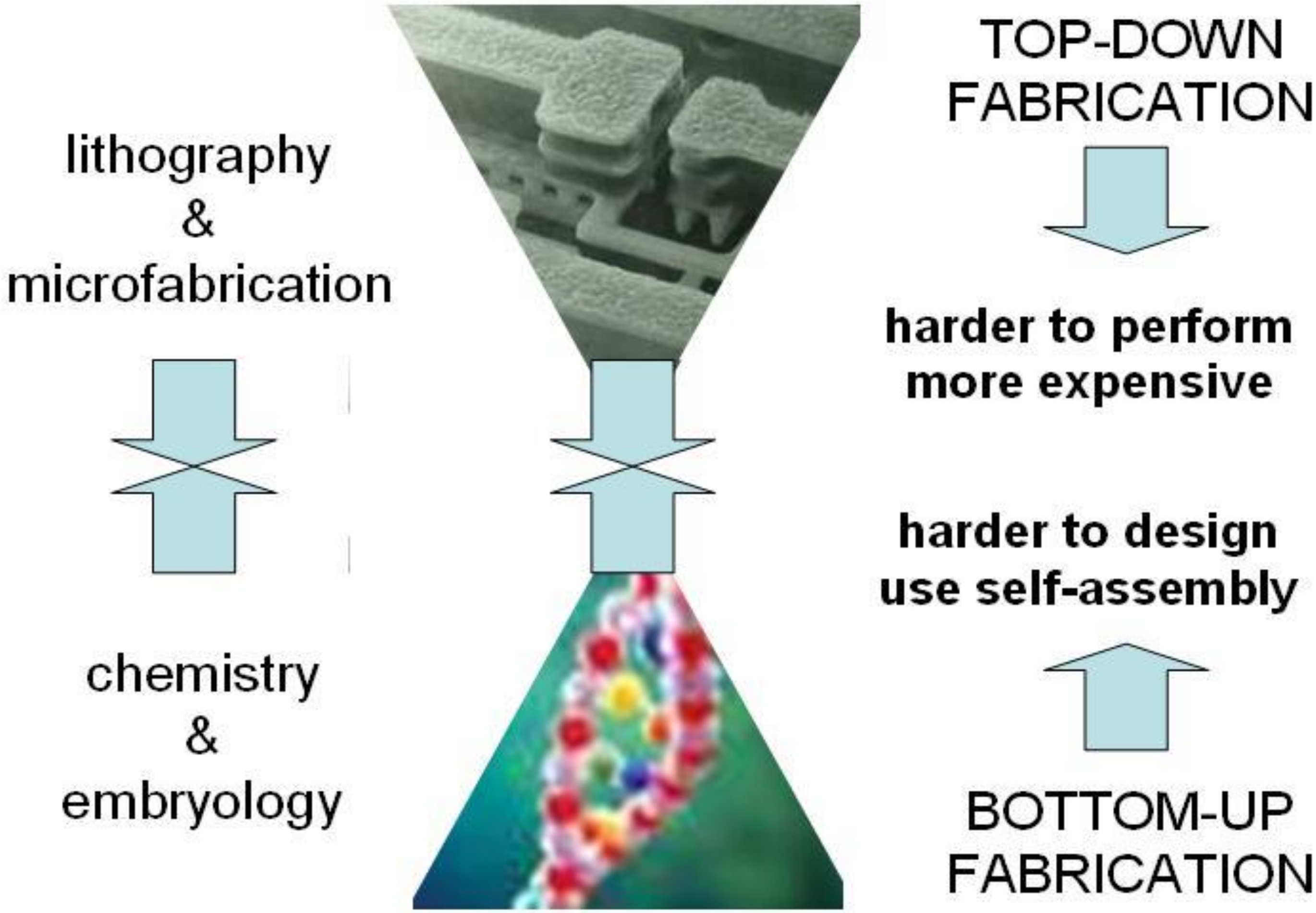
Embryology is the ultimate bottom-up process of producing a macro-scale complex entity by manipulation at the smallest scale possible.

Micro-Nano Manufacturing



Kailash Temple, Ellora

Top-down and Bottom-up Processes



Lithography – Basics

Photolithography –Printing with Light

- Lithography is a process that uses focused radiant energy on chemical films that are affected by this energy to create precise temporary patterns on silicon wafers or other materials.

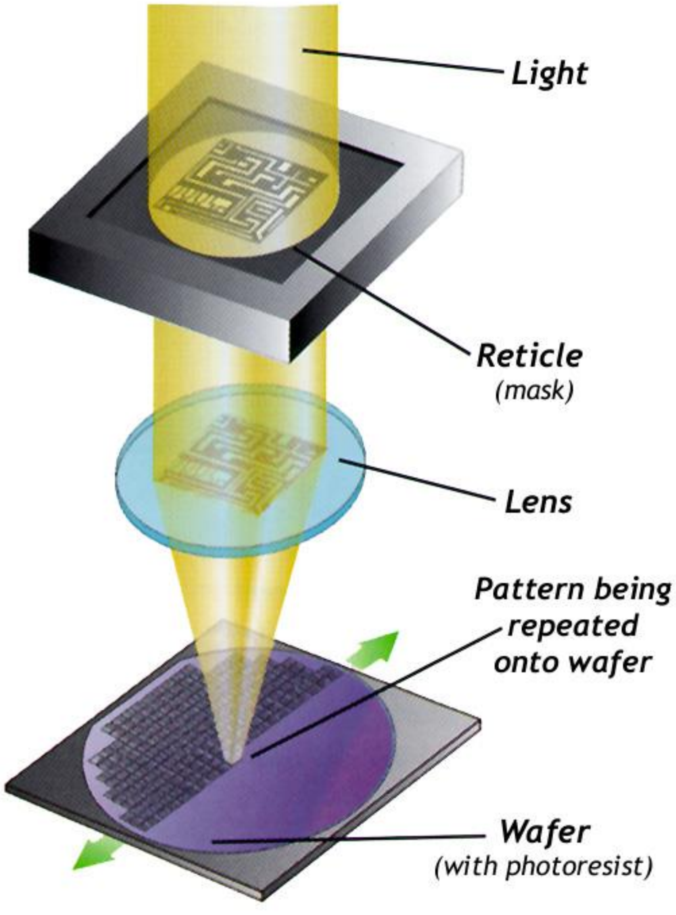
- These temporary patterns can be used to add or remove material from a given area

Lithography - Basics

- Lithography in the top-down approach
  - Lithography
  - Etching
  - Deposition
  - Doping
- In order to perform the other 3 processes, we must precisely define where to perform these operations
  - Lithography defines the space

Overview of the Photolithography Process

- Photolithography uses light energy passing through a patterned mask
- The light is focused onto the photosensitive surface
- Chemical changes in the surface coating
- Subsequent chemical development creates a temporary pattern on the surface.



Photolithography –Printing with Light

STEPS

1. Cleaning - RCA cleaning/Peroxide cleaning
2. Preparation – Heat + adhesion promoter
3. Photoresist application – Spin coating + baking - mm
4. Exposure and developing – UV + Metal ion free developers

   + post exposure bake
5. Etching – wet (liquid, isotropic) and dry (plasma, anisotropic)
6. Photoresist removal – resist stripper or plasma with O_2

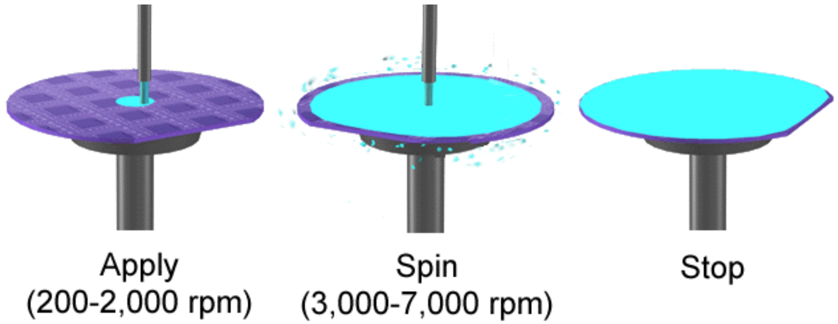
Limited by the wavelength of the light and the lens system minimum feature sizes 50 nm.

Steps in Lithography

- Silicon wafers are commonly used substrates in the top-down process.

- The first step is to coat the clean surface of the wafer with a light sensitive chemical emulsion known as photoresist

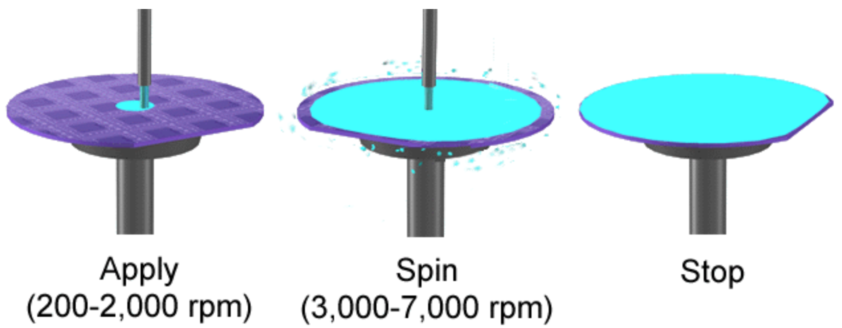
Photoresist Dispensing (Spinners)



Steps in Lithography

- Baking the resist causes it to form a solid layer.
- The chemical properties of the photoresist define what wavelengths of light will affect it.

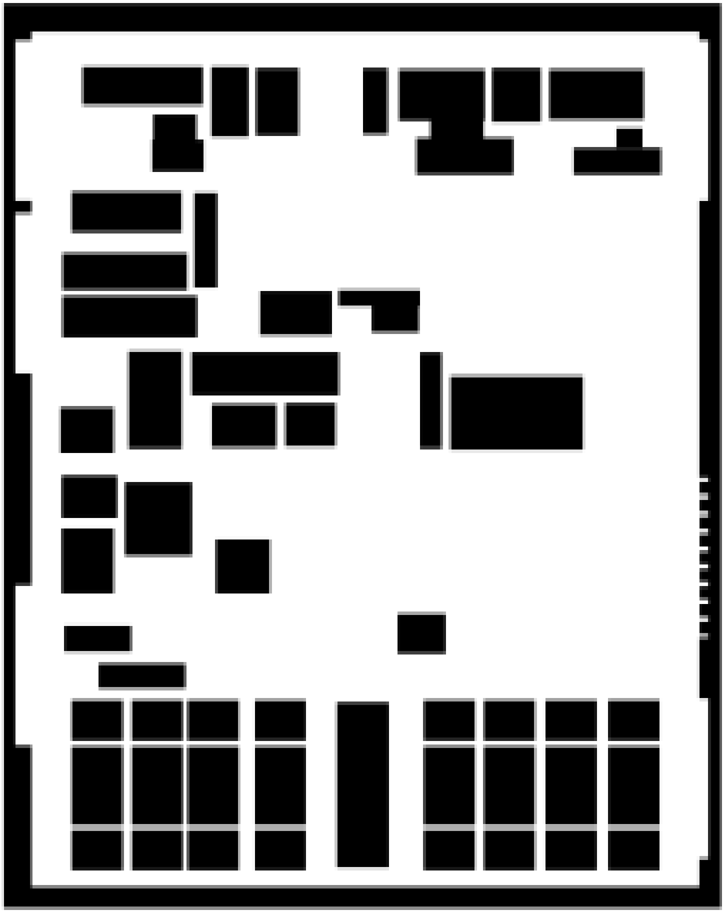
Photoresist Dispensing (Spinners)

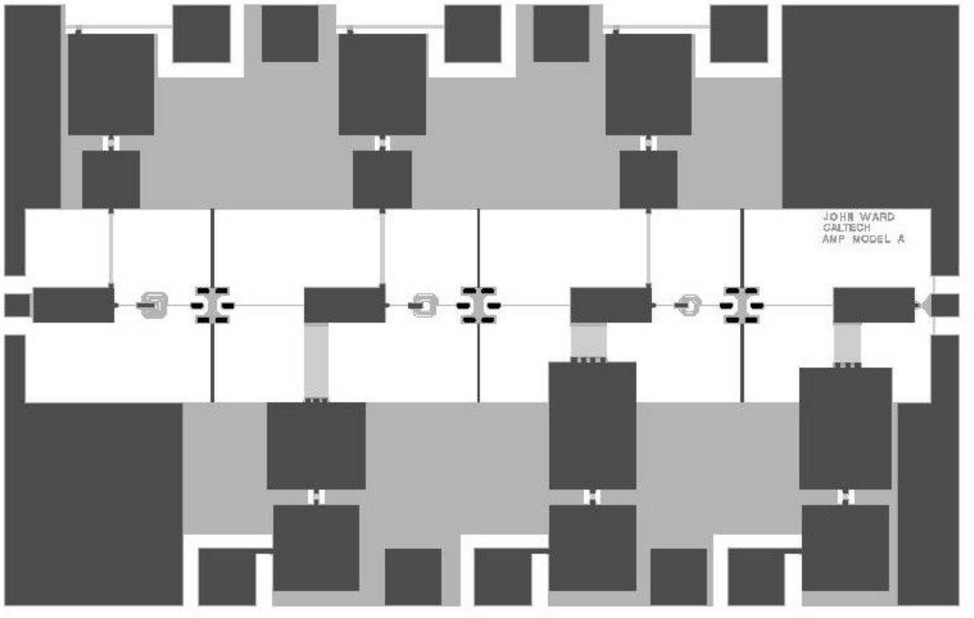


Steps in Lithography

- A photomask, typically made of quartz with a chrome plating, controls where the radiant energy will strike the photoresist.

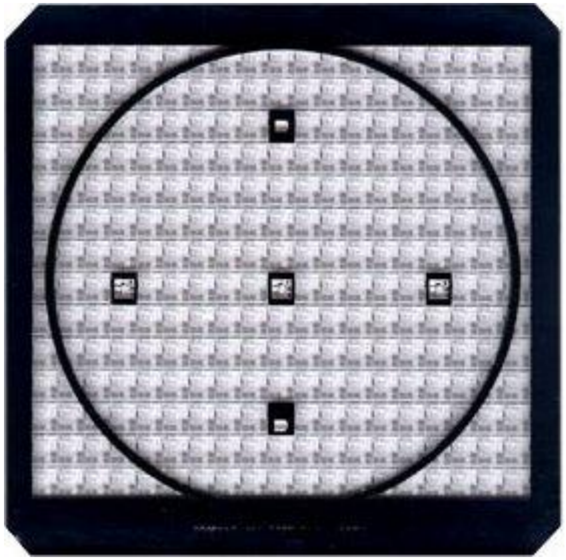
- Photomasks are often made with electon beam patterning tools

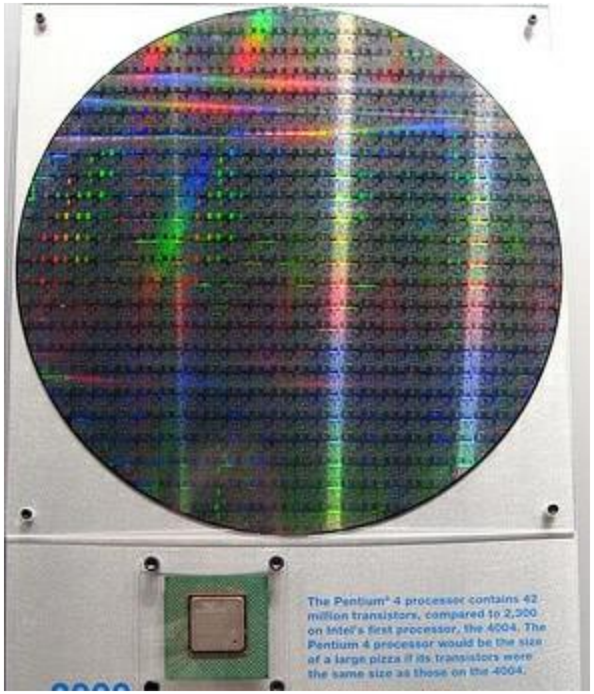


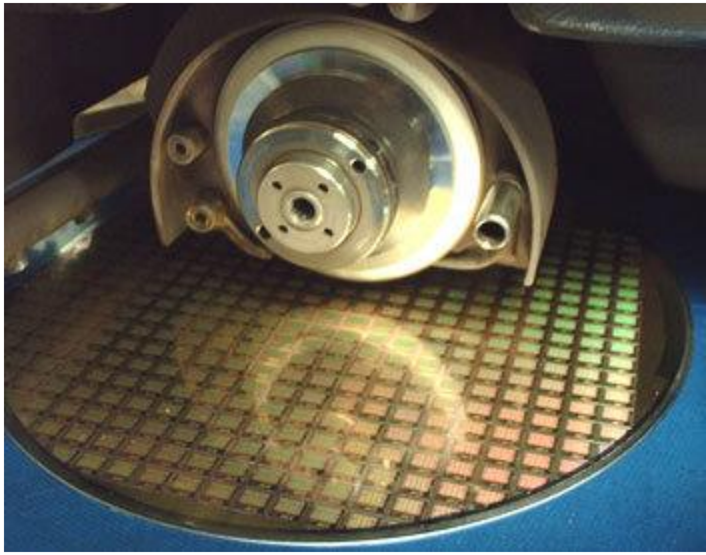


CAD layout of an entire circuit, eventually going
to be reduced to fit on a chip 2.5 x 3.8 mm

On a single chip, the width of those connecting lines in there is going to 0.014 microns or so. That's the limiting factor in device density today — the width on the chip of the smallest line we can transfer from a CAD layout pattern into actual metal on silicon.







Wafer mask for optical projection (one layer)

Wafer at the end of fabrication (many layers)

Wafer being cut up into chips after fabrication

Picture of a wafer after all the photolighography steps (depositing, masking, etching) are done

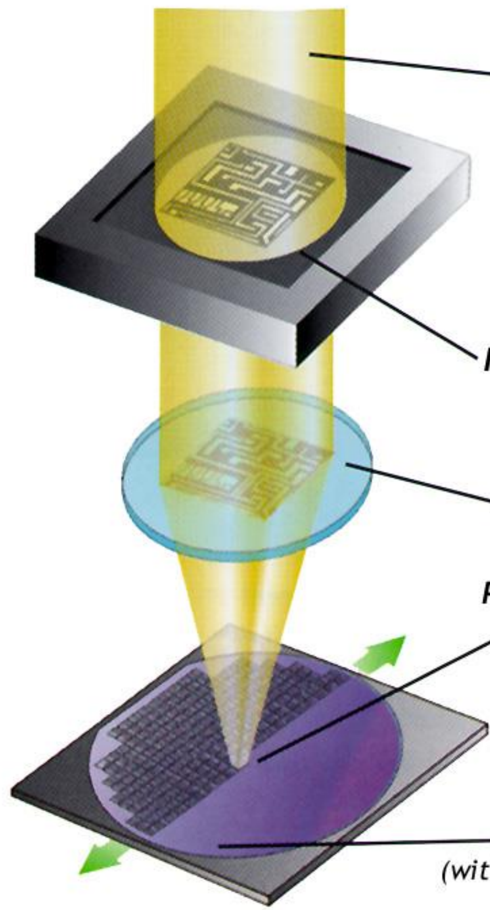
Role of Lithography in the Process

- With multiple etch, deposition, and doping processes taking place in the fabrication of a device, the lithography process is repeated many times.

- The precision and accuracy of lithography in the manufacturing process controls the success in building a device.

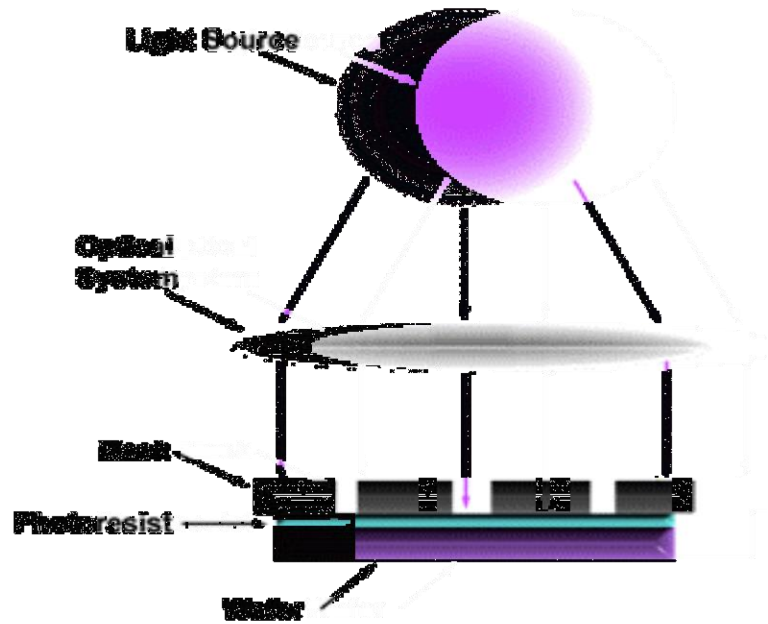
Steps in the Lithography Process - Exposure

- Exposure of the photoresist to the radiant energy pattern occurs next
- There are several ways to do this
  - Contact/proximity printing
  - Projection printing (shown here)
  - Projection scanning



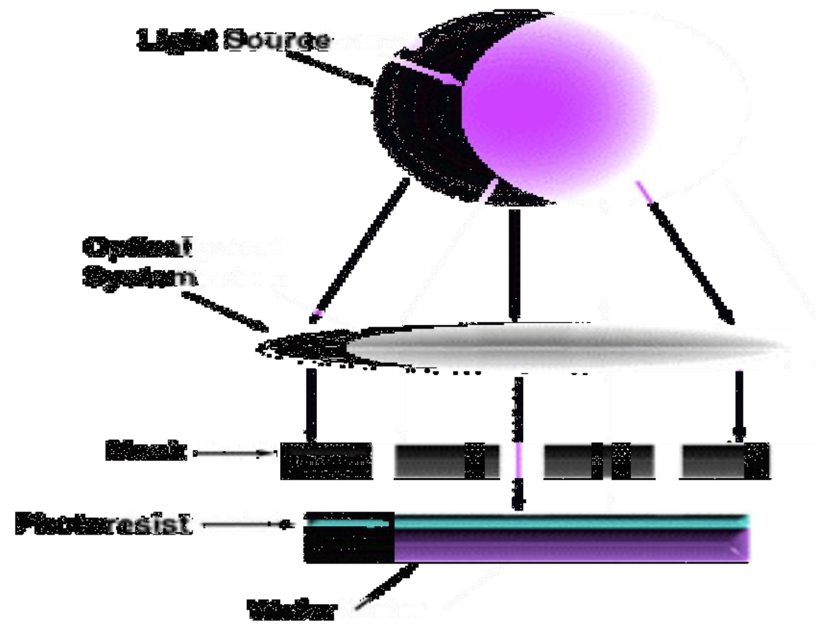
Contact Printing

- The mask is directly in contact with the wafer
- Advantages
  - Simple
  - Low Cost
- Disadvantages
  - Poor for small features
  - Mask damage may occur from contact
  - Defects from contaminants on mask or wafer due to contacting surfaces



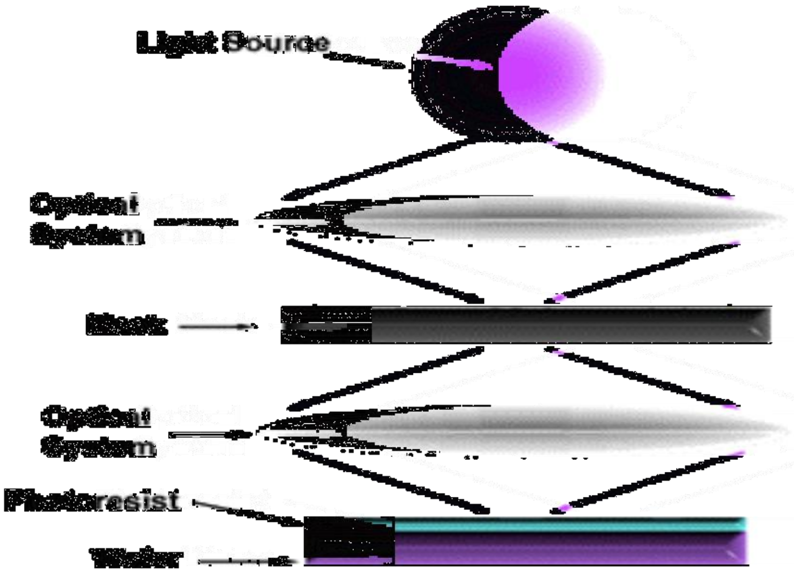
Proximity Printing

- The mask is above the wafer surface
- Advantages
  - Mask damage is minimal
  - Good registration possible
- Disadvantages
  - Poorer resolution due to distance from the surface
  - Defects from contaminants on mask or wafer due to contacting surfaces
  - Diffraction errors



Projection Printing (1)

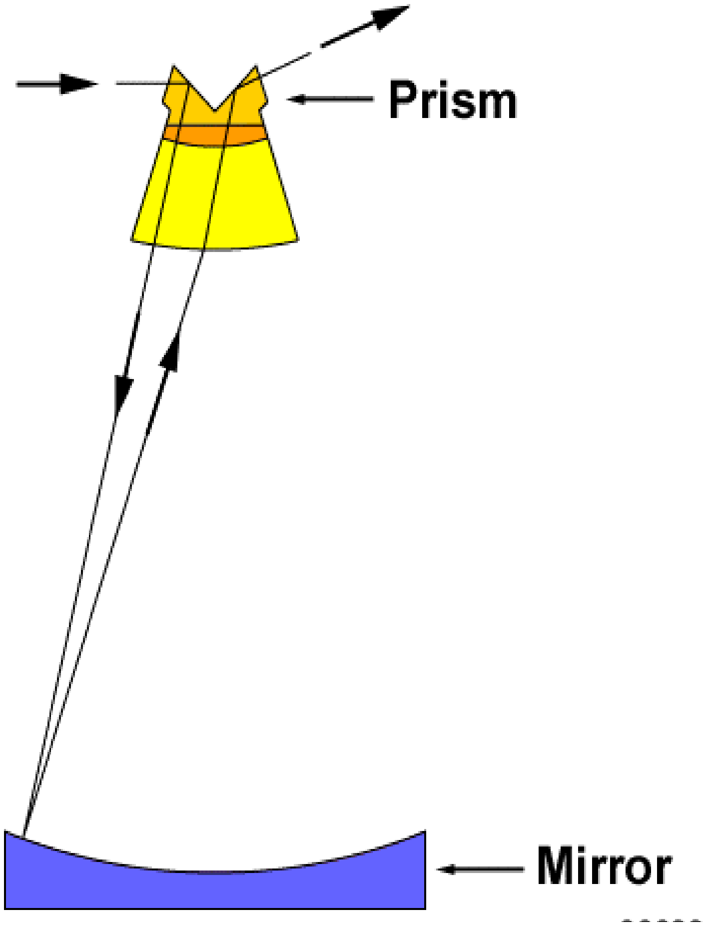
- An optical system focuses the light source and reduces the mask image for exposure on the surface
- Advantages
  - Higher resolution
  - Lens system reduces diffraction error
- Disadvantages
  - Errors due to focus of lens system may occur
  - Limiting factor in resolution can be due to optical system



The minimum feature size F = K (wavelength/NA) where K = process constant typically about 0.5. Numeric aperture is typically less than 1.

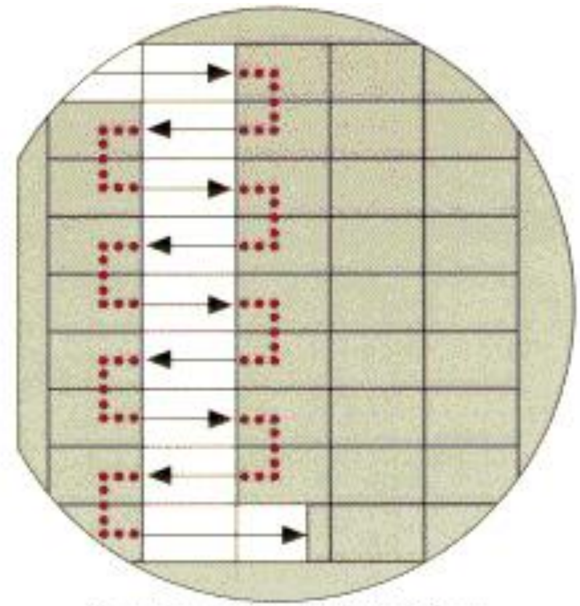
Projection Printing (2)

- Step and repeat aligner
  - Lens reduction
  - Good throughput but resolution limited to about 0.35 uM
- Cadiotropic System
- Mirror, folding prisms and lenses 1:1 ratio
- Less common than steppers



Step and Scan Aligner

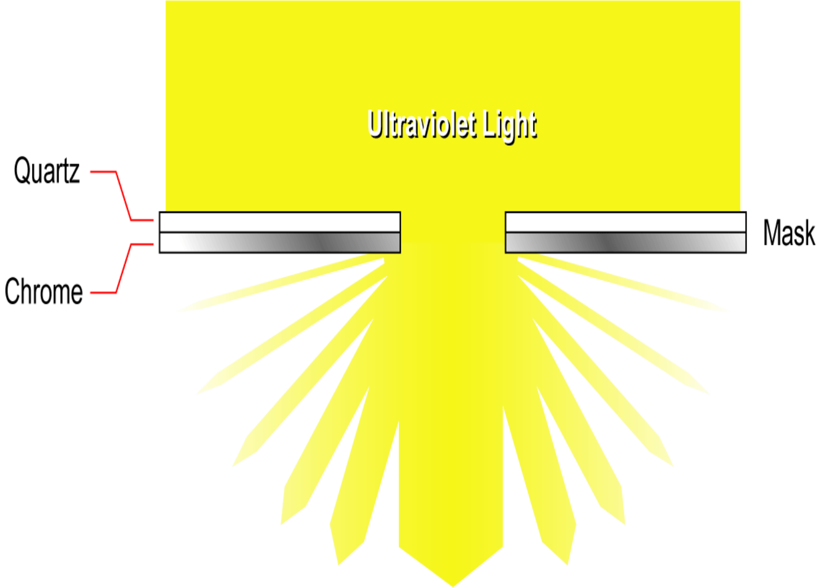
- Uses a spherical mirror and a scanning pattern
- Advantages
  - Improved throughput
  - Lens system aberration minimized
- Disadvantages
  - Complex motion system is required for alignment and precise tracing
  - Light source wavelength is still a factor limiting feature size



Courtesy of Silicon Valley Group

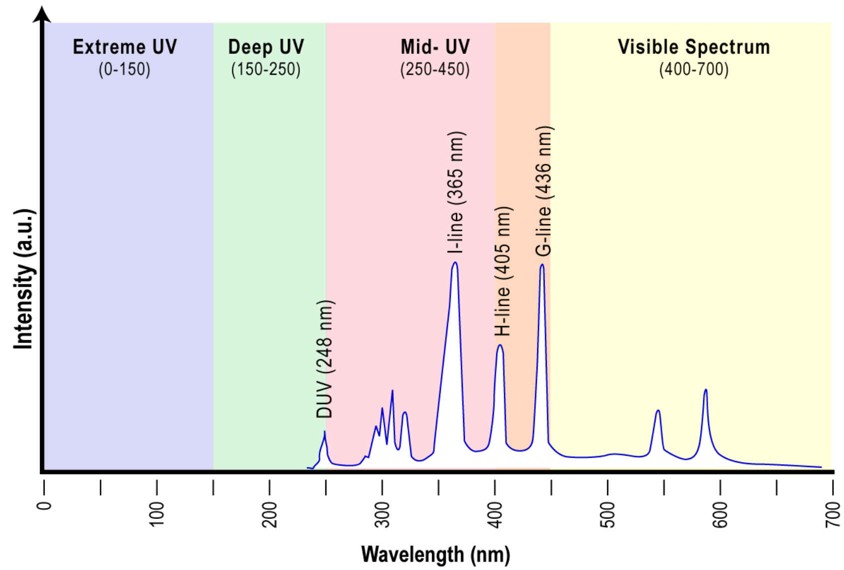
Diffraction

- As feature sizes shrink in the mask, the wavelength of the light used as a source becomes a factor.
- Shrinking feature sizes require shorter wavelengths of light
- The photoresist must be optimized to match the light source used.



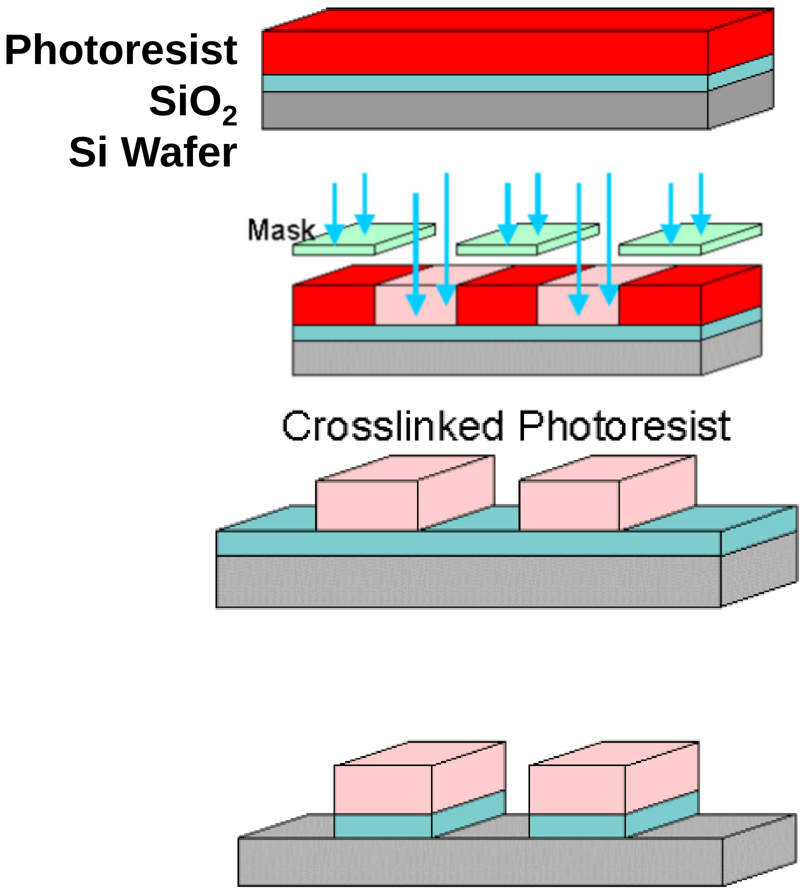
Diffraction (2)

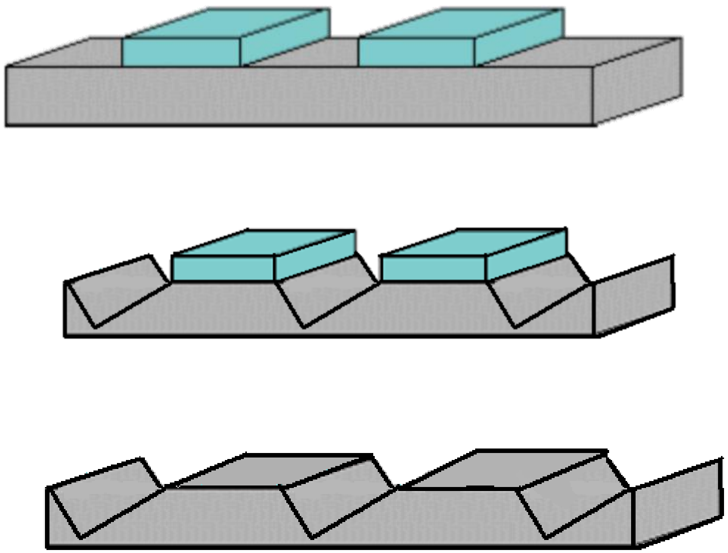
- The traditional mercury vapor lamp has peaks in certain ranges.
- The intensity of some UV peaks is low
- The photoresist must be optimized to match the light source used.



Top-Down Approach

Fabrication of V-grooves on Si wafer





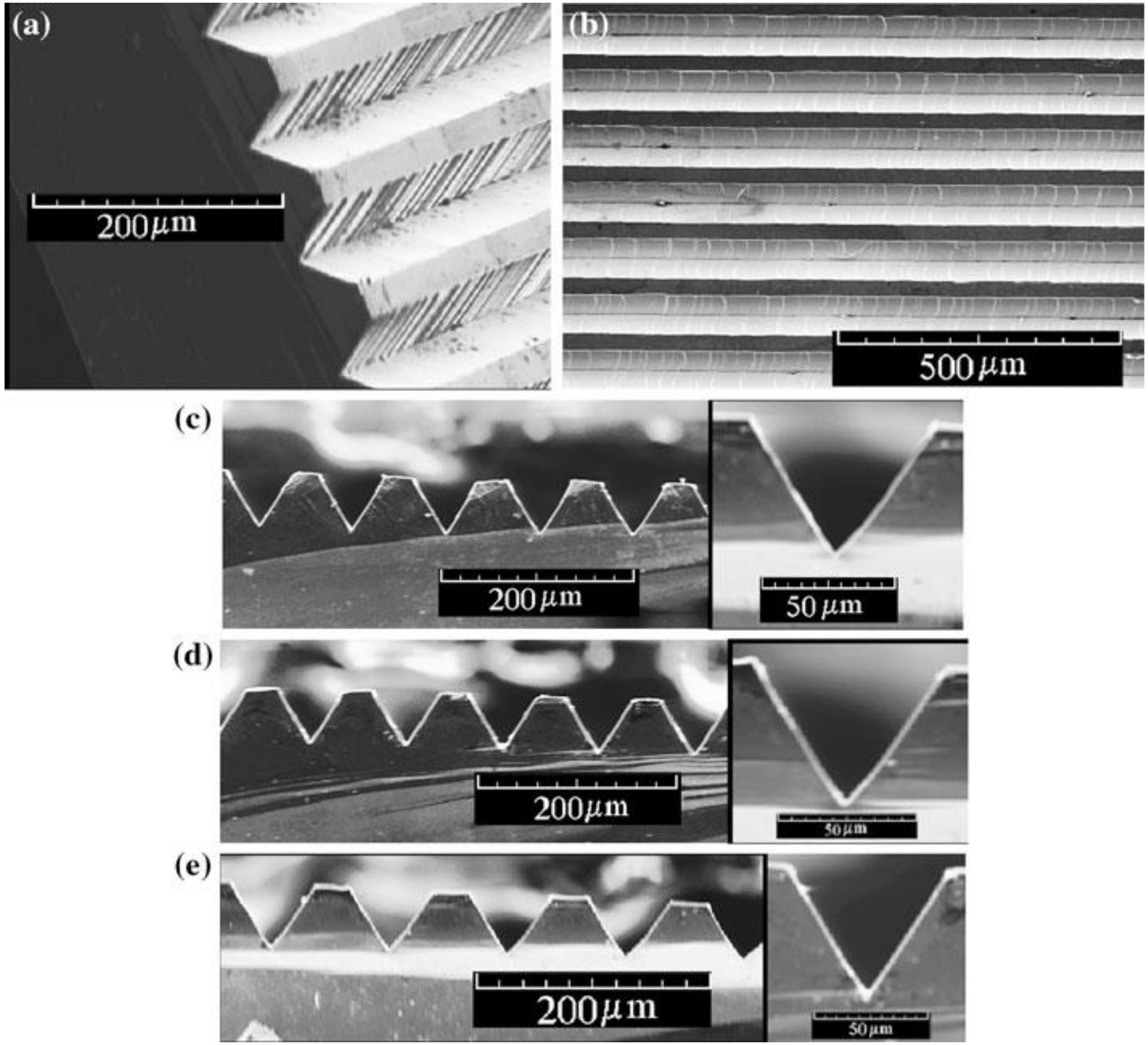
Photoresist

+ve - whatever shows, goes

-ve – opposite

+ve - better process controllability for small geometry features. Popular in VLSI fabrication processes.

Photolithography, limited by the resolution of lithography



SEM of microgrooves on silicon substrate a - angular view of the microgrooves; b top view of the microgrooves; c-e Cross sectional views at three different locations along the length of microgrooves

Problems of Top-down Process

- Cost of newer technologies.
- Physical limits of photolithography
- heat dissipation