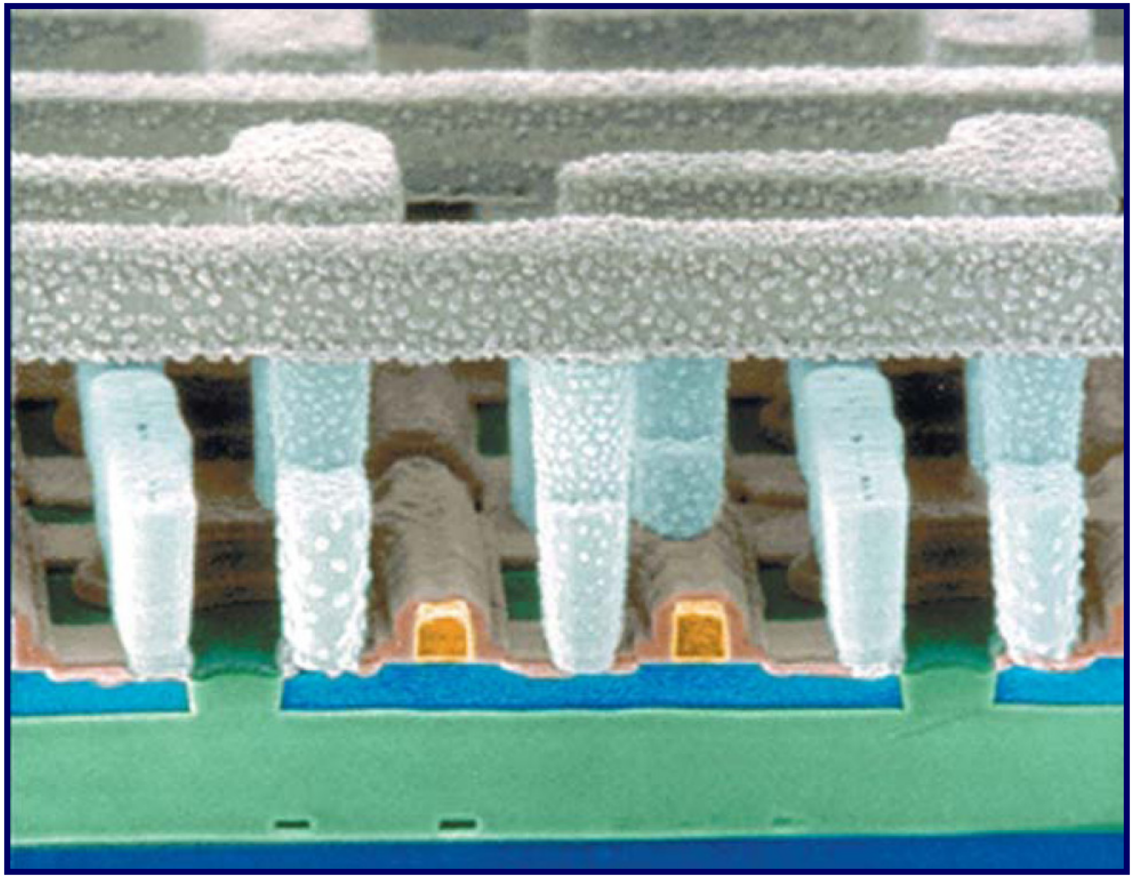
Nanomaterials

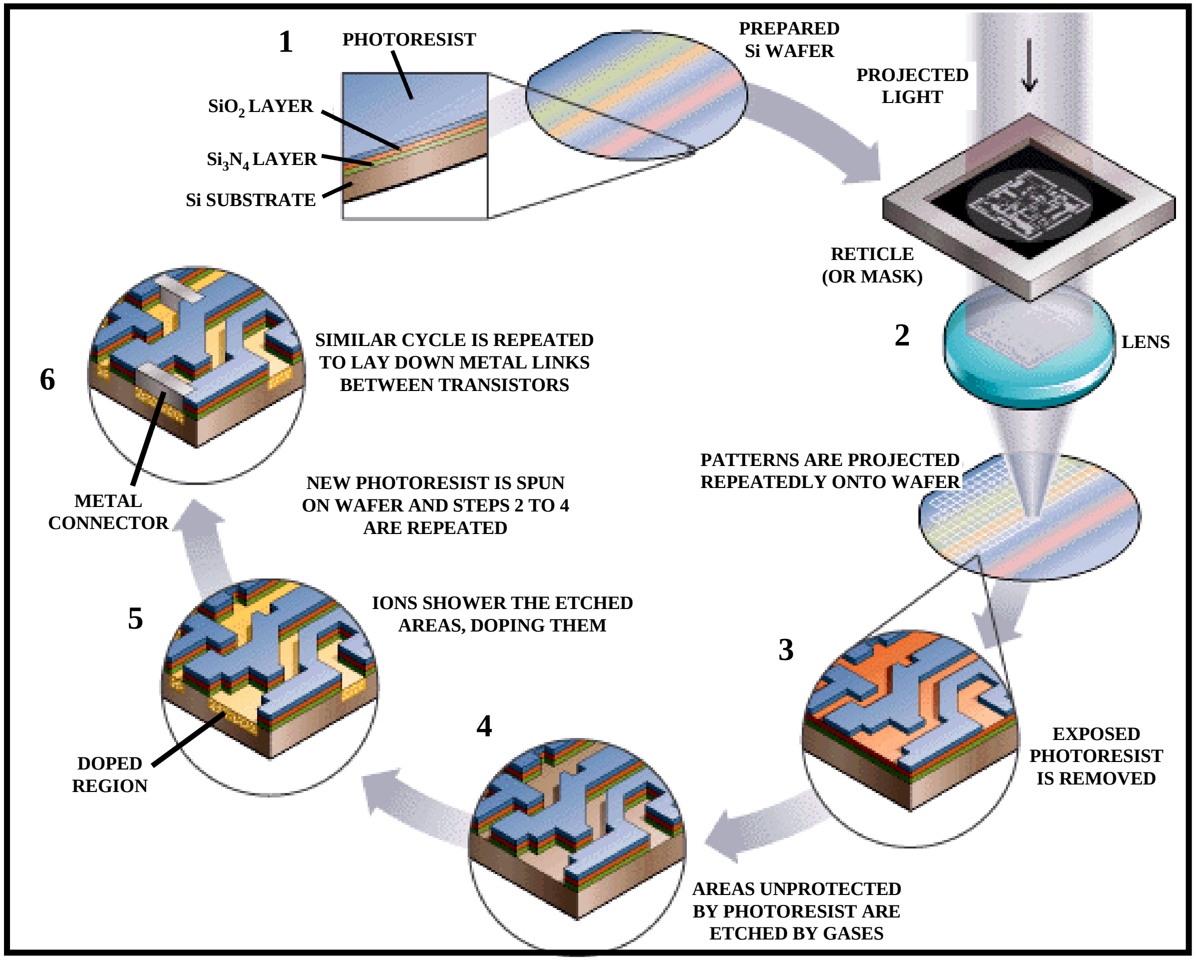
Lecture 2: Lithography

Lithography



G. D. Hutcheson, *et al.*, *Scientific American*, **290**, 76 (2004).

Typical Lithographic Process Flow



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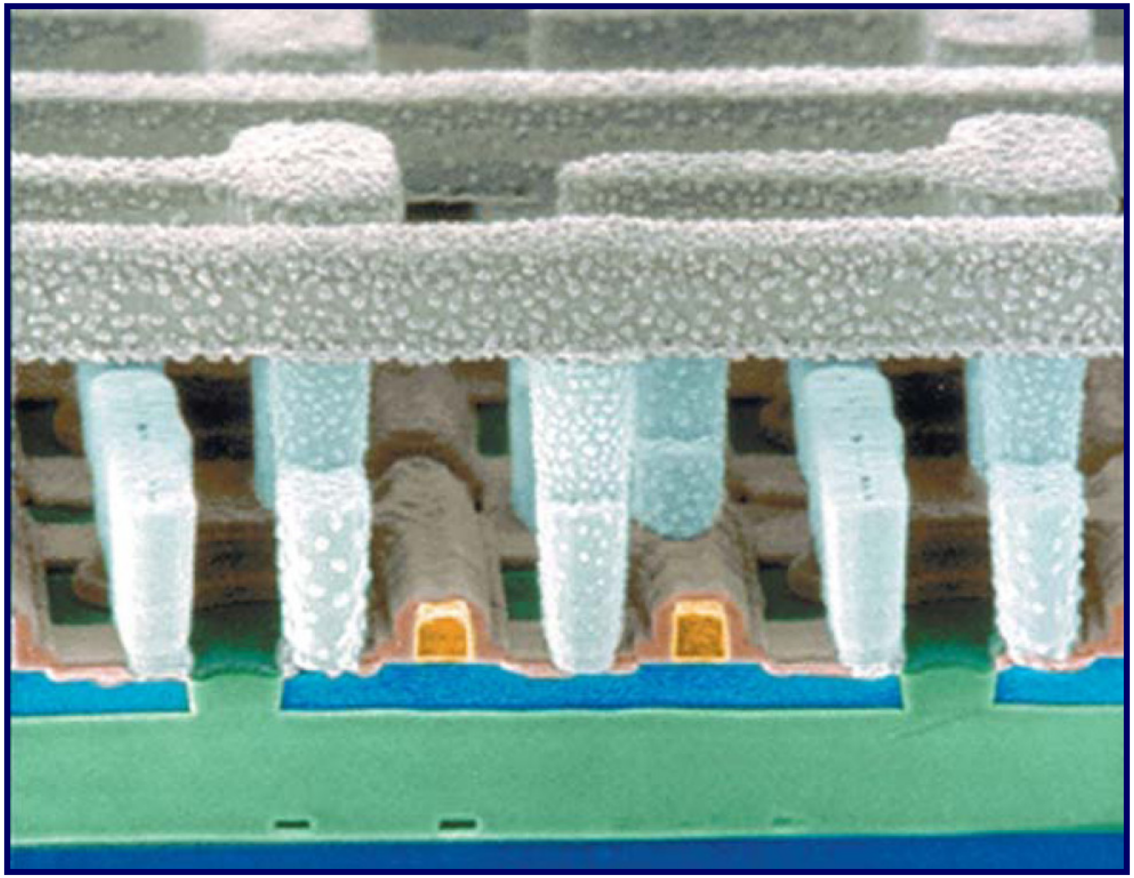
Lithography



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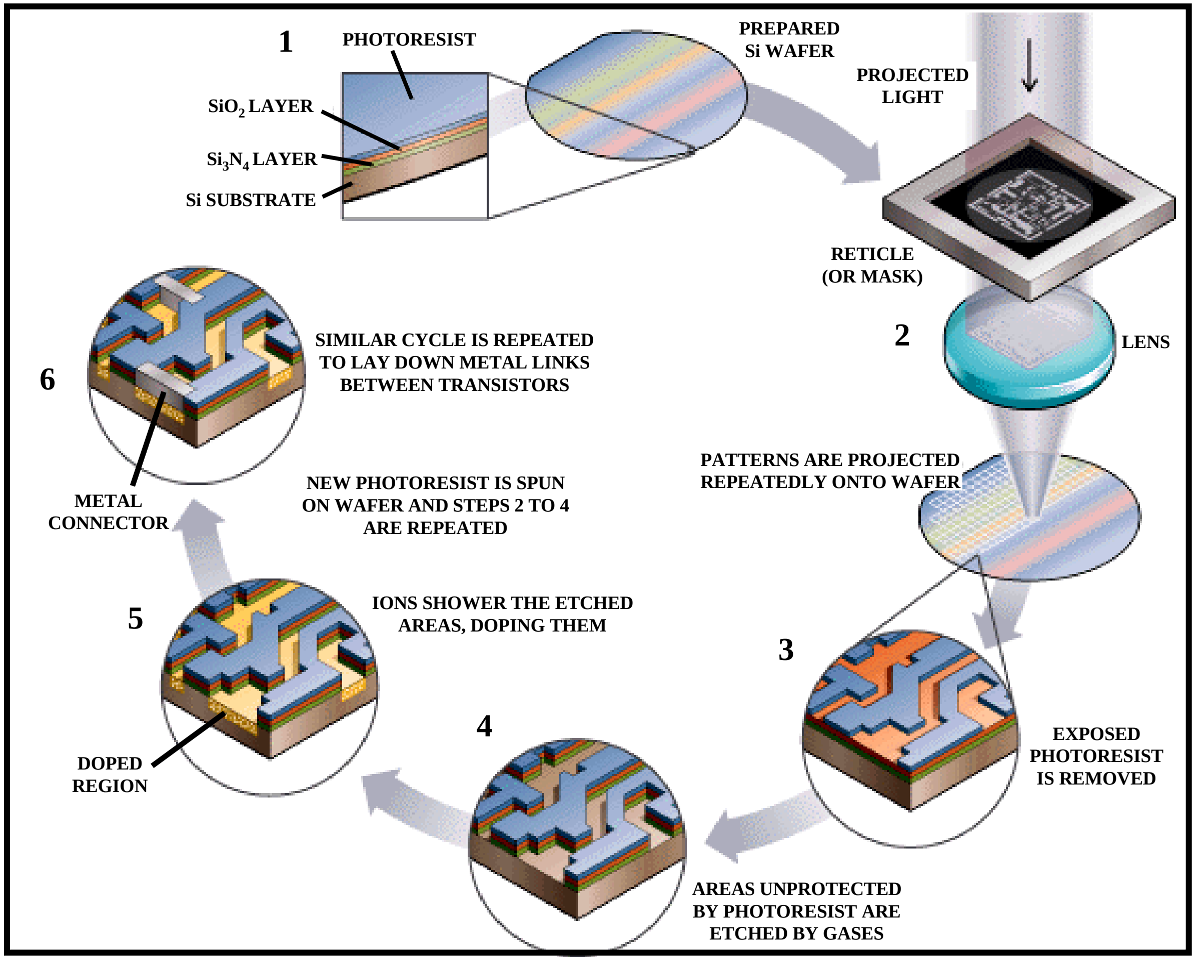

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Lithography Yield

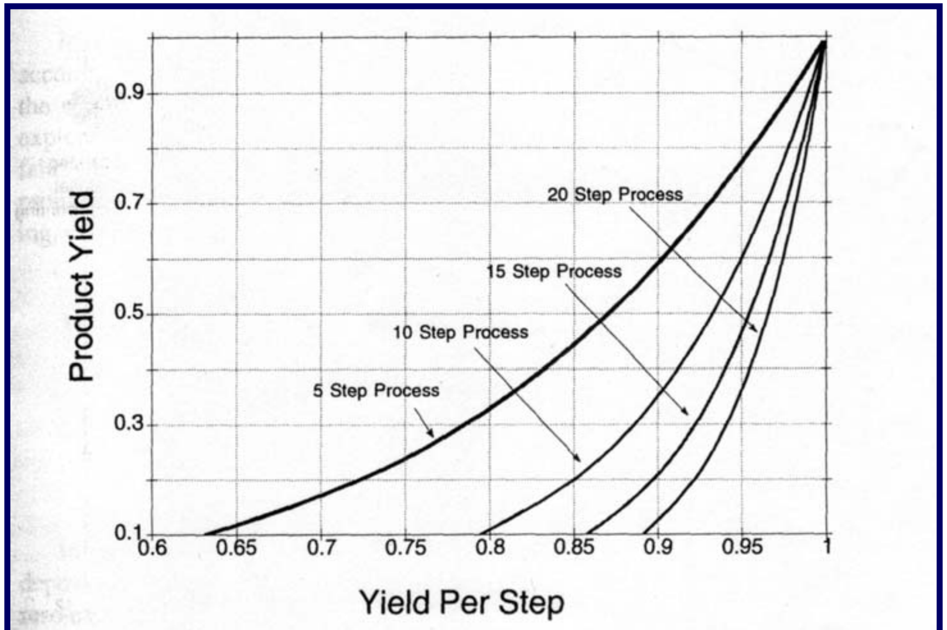

FIGURE 1. Plot of dependence of product yield on the average yield per lithography level shown for 5, 10, 15 and 20 step manufacturing processes.

NOTE: Typical fabrication facilities (fabs) have product yields > 95%
→ Lithography yield per step > 99%

Lithography is 90% of the production cost in modern day fabs

G. Timp, *Nanotechnology*, Chapter 4

Lithography Areal Throughput

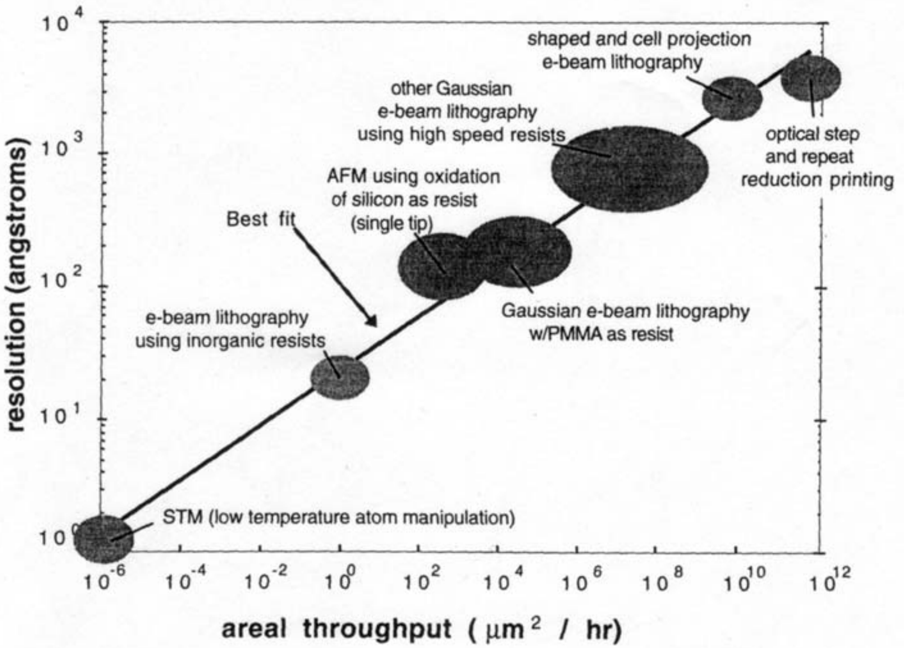

FIGURE 2. Plot showing areal throughput for 50% coverage (for example equal lines and spaces) at the plotted resolution for a wide range of lithographic methods which have been demonstrated to date. The solid line represents a phenomenological relationship between resolution and throughput given by the power law fit found in text.

Phenomenological Relationship:

Resolution (Å) ~ $23A_t^{0.2}$

(A_t = areal throughput in μm^2/hr)

This phenomenological relationship is essentially true over **18 orders of magnitude** in throughput!

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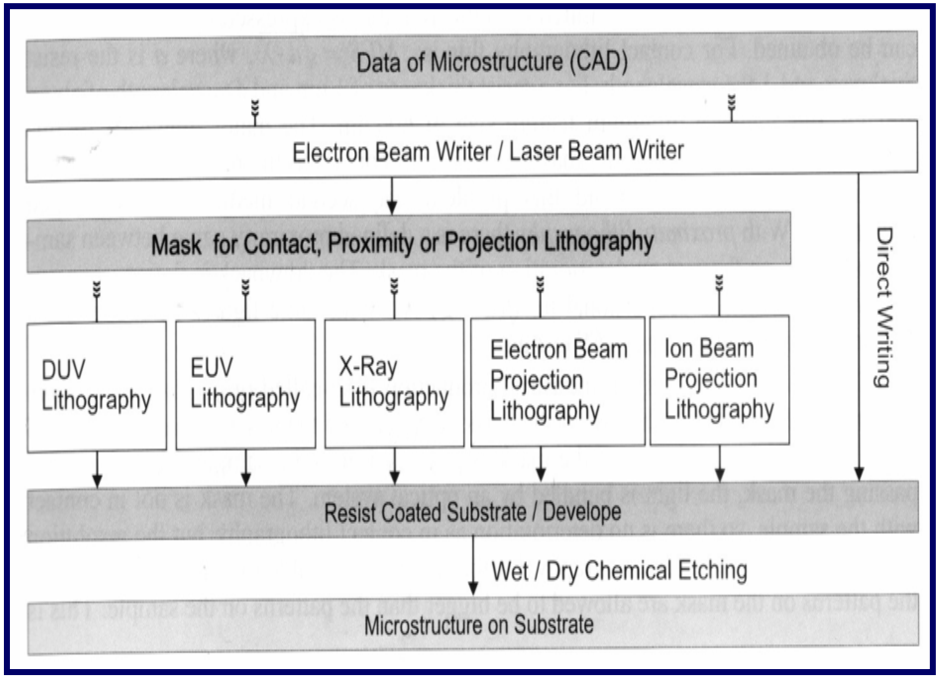
Requirements of a Lithography System

(1) Small dimensions (linewidth)
(2) Small variations in dimensions (linewidth control)
(3) Large depth of focus (tolerance of non-planar substrates and thick resists)
(4) Accurate alignment of subsequent patterns (registration)
(5) Low distortion of image and sample (high quality masks, projection systems)
(6) Low cost (high throughput)
(7) High reliability (high yield)
(8) Tolerance of contamination particles on mask and sample (clean room requirements)
(9) Uniformity over large areas (large wafers)

Lithography Pathways



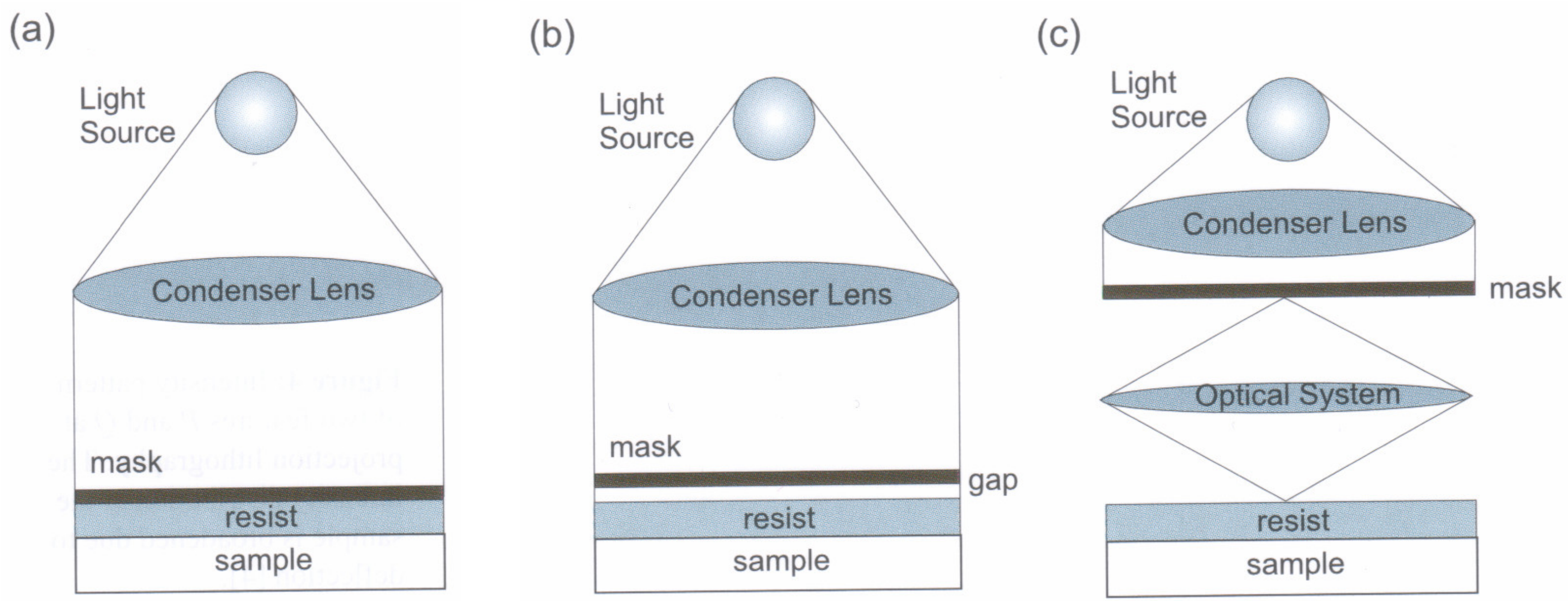
Pathways from pattern design to pattern transfer:

(1) Can be direct (e.g., e-beam or ion beam lithography)

(2) Usually a 2 step process
- (A) Generation of mask
- (B) Transfer of its pattern to a large number of substrates

R. Waser (ed.), *Nanoelectronics and Information Technology*, Chapter 9

Masking Methods



Contact **Proximity** **Projection**

R. Waser (ed.), *Nanoelectronics and Information Technology*, Chapter 9

Resists

Resists: (1) Positive → exposure degrades resist (dark field mask)
(2) Negative → exposure hardens resist (light field mask)

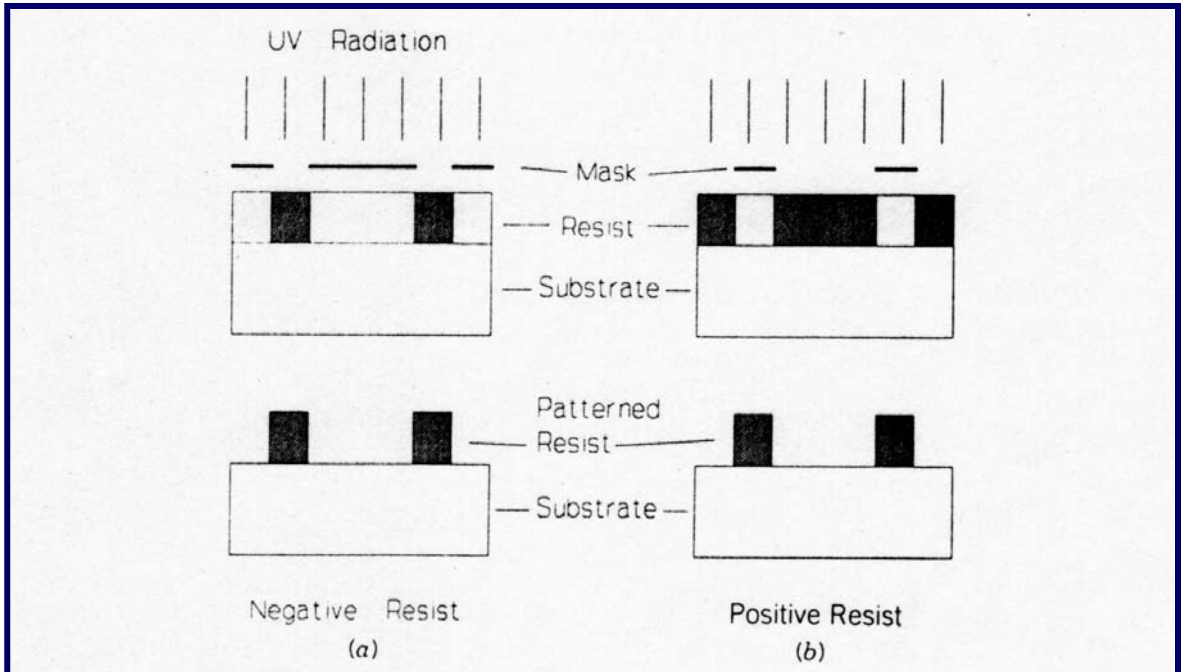


Fig. 10.2 Schematic of pattern transfer: (a) Negative resist and (b) positive resist.

Requirements of a Resist

(1) High sensitivity → less exposure time → lower cost

(2) Contrast (only brightly illuminated areas are affected)

(3) Adhesion to substrate

(4) Etch resistance (enables subsequent processing)

(5) Resist profile control (flexibility for lift-off)

Optical Lithography Process

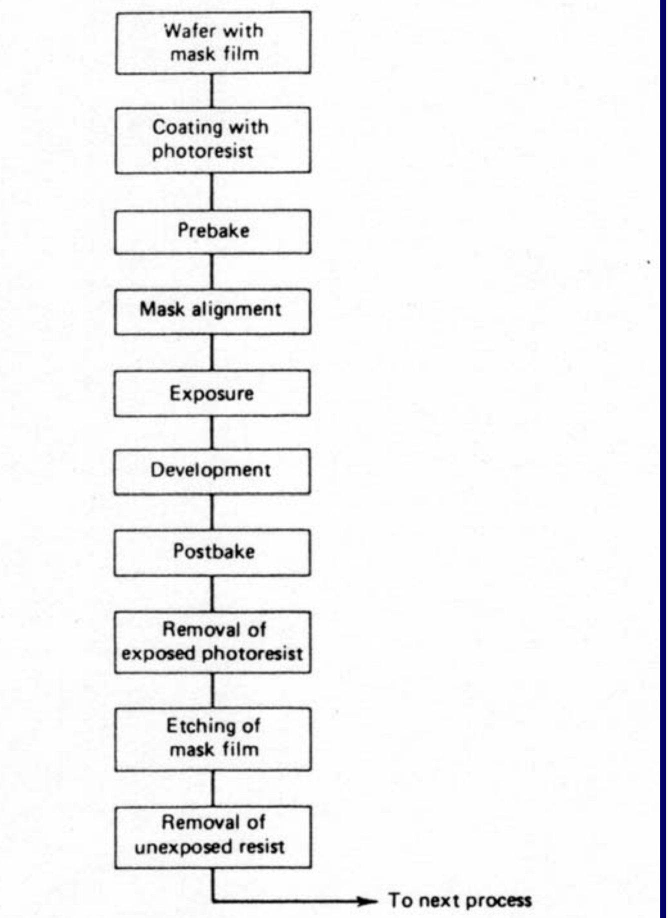


Fig. 10.5 Flow chart for the pattern transfer process.

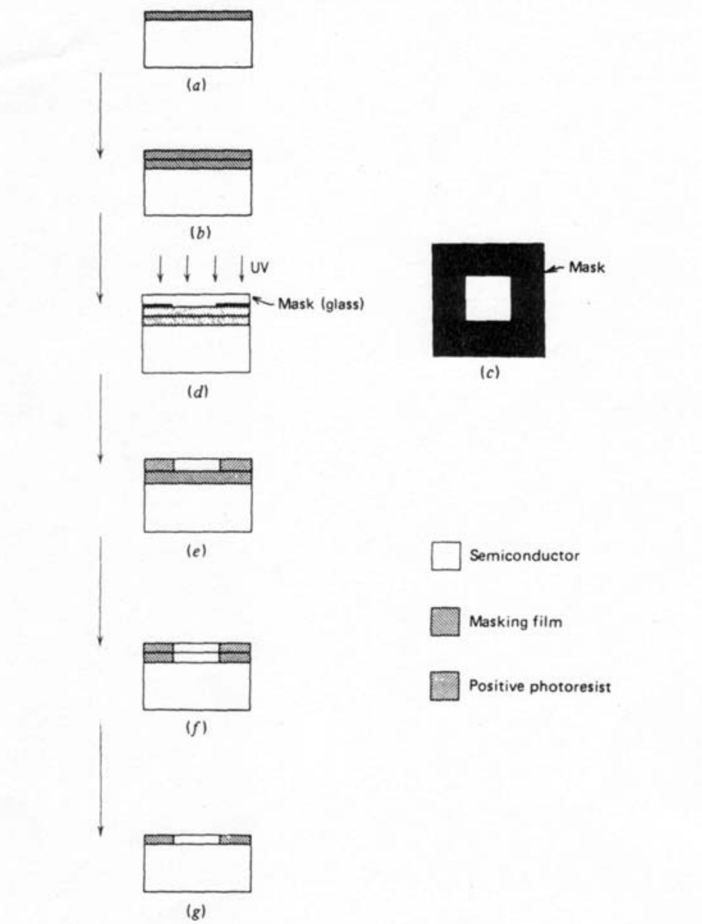


Fig. 10.6 Steps in opening a window in a masking film, using positive photoresist.

Etching versus Lift-off

Etching: (a) Develop resist on top of deposited layer
(b) Underlying material is removed by etching through openings in the mask

Lift-off: (a) Deposit material on top of developed resist
(b) Material is lifted-off when resist is removed

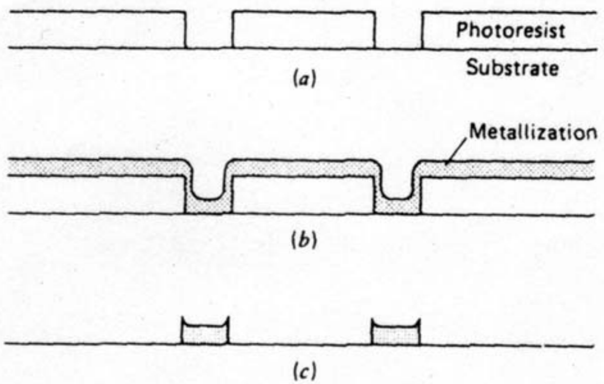


Fig. 10.9 The lift-off process.

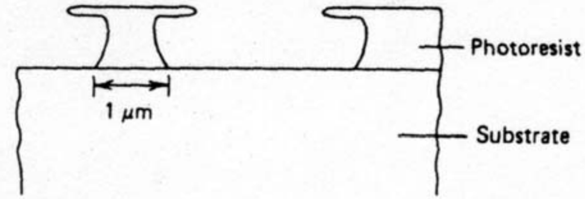


Fig. 10.10 Profile of photoresist using a chlorobenzene modification step prior to development. Adapted from Hatzakis et al [29].

Limitations of Optical Lithography

Minimum feature size = $k\lambda/\text{NA}$

where k = proportionality factor
(typically 0.5 for diffraction limited systems)
λ = wavelength
NA = numerical aperture = sin α
(2α = acceptance angle of lens at point of focus)
→ measure of light gathering power of lens

However, depth of focus = $\lambda/(\text{NA})^2$
→ important because wafers are not flat

Increasing NA is not the answer → reduce λ to reduce feature size