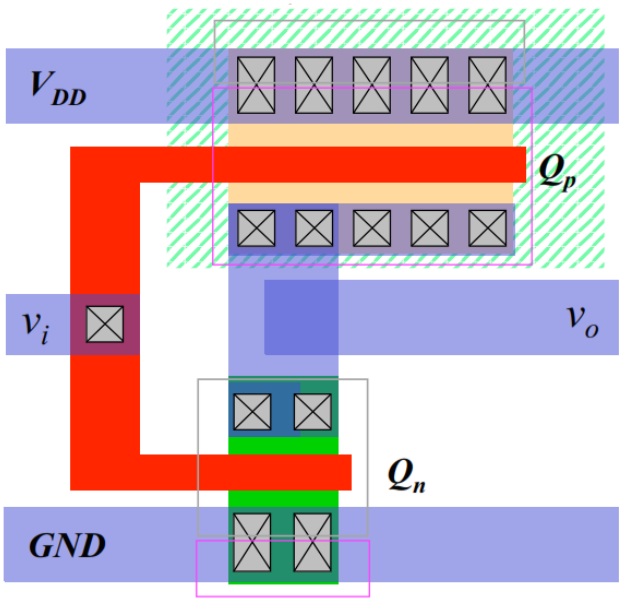
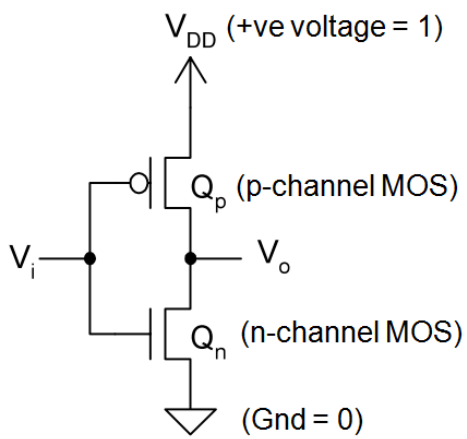
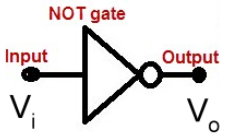
Building the IC using Photolithography

- ICs start with the circuit layout of the circuit
- Each device (transistor, inverter) is designed in 2D pattern
- But each part is actually a layer (metal lines, diffusion)
- Photolithography is the process of creating each layer pattern
- Simple chips 8 layers – current ~30 layers
- Each layer pattern is defined with many steps

Layout of MOS inverter





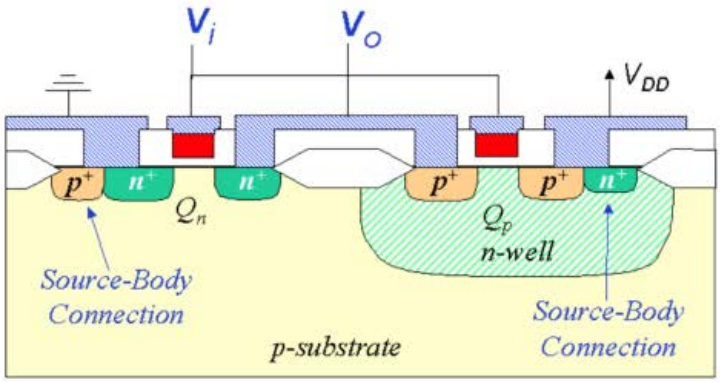


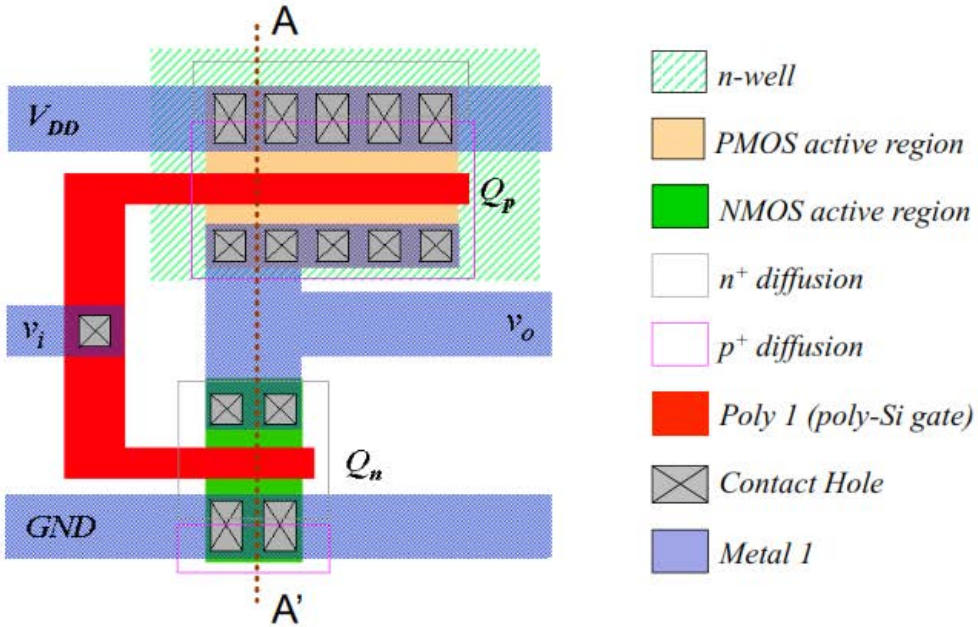
Truthtable	
Input	Output
1	0
0	1

- When $V_i = 1 \rightarrow Q_n$ is on $\rightarrow V_o = 0$
- When $V_i = 0 \rightarrow Q_p$ is on $\rightarrow V_o = 1$

Building the IC using Photolithography

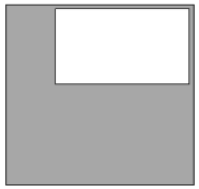
Layout and Cross-section of an inverter



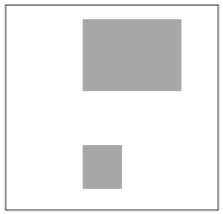


- To do MOS inverter, at least seven mask steps is needed

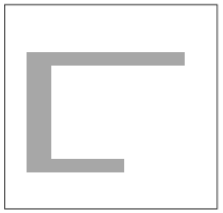
- *SiO_2* is etched using *Mask 1*.



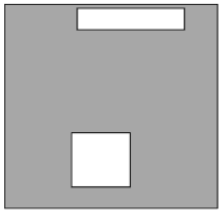
- *Mask 2 creates the active regions where the MOSFETs will be placed*



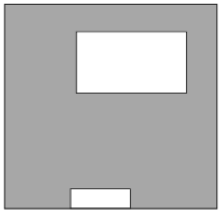
- *Mask 3* is used to deposit the polysilicon gate *(most critical step)*



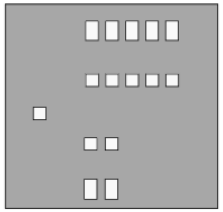
- *Mask 4* is used to control a heavy arsenic implant and create the source and drain of the n-channel devices.



- *Mask 5* is used to control a heavy Boron implant and create the source and drain of the n-channel devices.



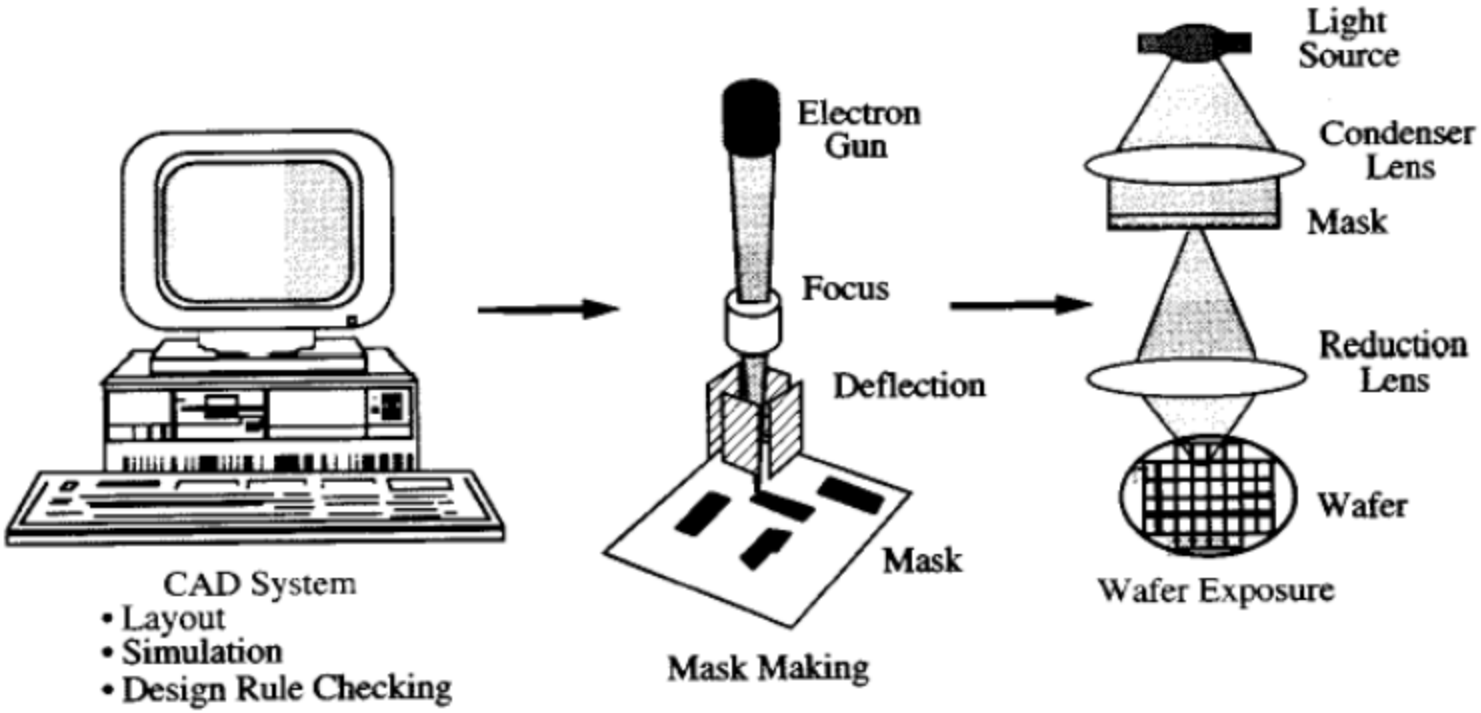
- *Mask 6* is used to pattern the contact holes
- Etching opens the holes.



- *Mask 7* is used to pattern the interconnection.
- A thin layer of aluminum is evaporated

The lithographic process

Design => Mask => Wafer

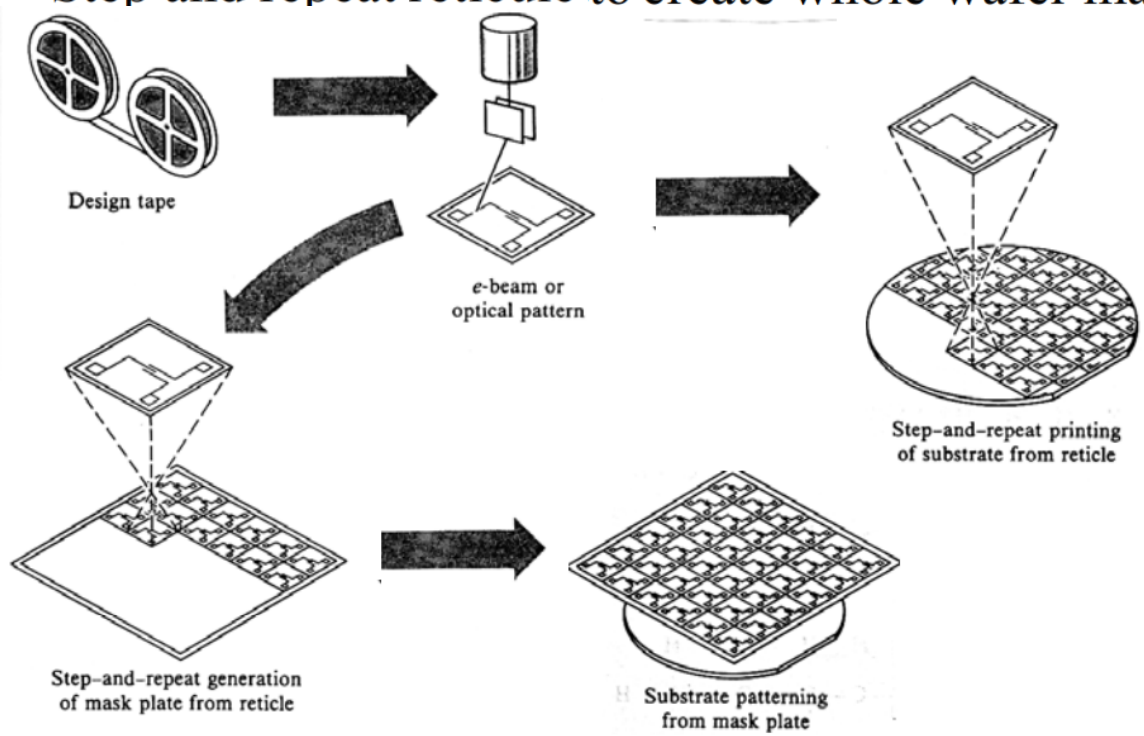


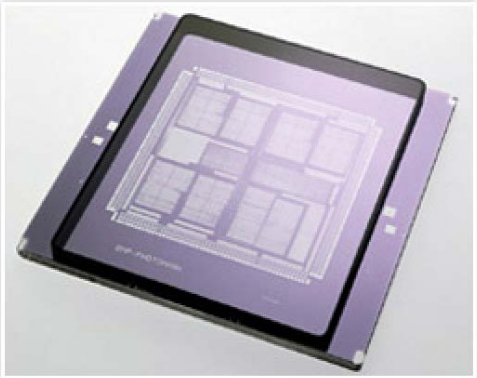
Creation of Photomasks for Photolithography

- Create chip design using CAD (Computer Aided Design) tools
- Laser or e-beam pattern generator writes chip (1:1 or 1:10)

3 possibilities:

- Create whole wafer mask this way (1:1)
- Write Reticule(1 or several chip designs)
  Reticules are 5 or 6 inch in size
  Reticules may cover 3x3 cm chips at reduced magnification 5 or 10x
  Step and repeated reduced pattern (5 or 10x) directly on wafer
- Step and repeat reticule to create whole wafer mask





Reticule mask

Photolithography or Patterning

- Creation of 3D structures, eg circuit lines
- Using photographic techniques to transfer the mask pattern
- Derived from creation of printing plates
- Usually starts with thin film on wafer (eg SiO_2, metal)
- Coat with photosensitive material (photoresist)
- Exposure: to UltraViolet Light through mask of structure
- Development of resist: leaves pattern of resist with openings
- Etching: removes film unprotected by resist
- Striping Resist: leave only patterned film

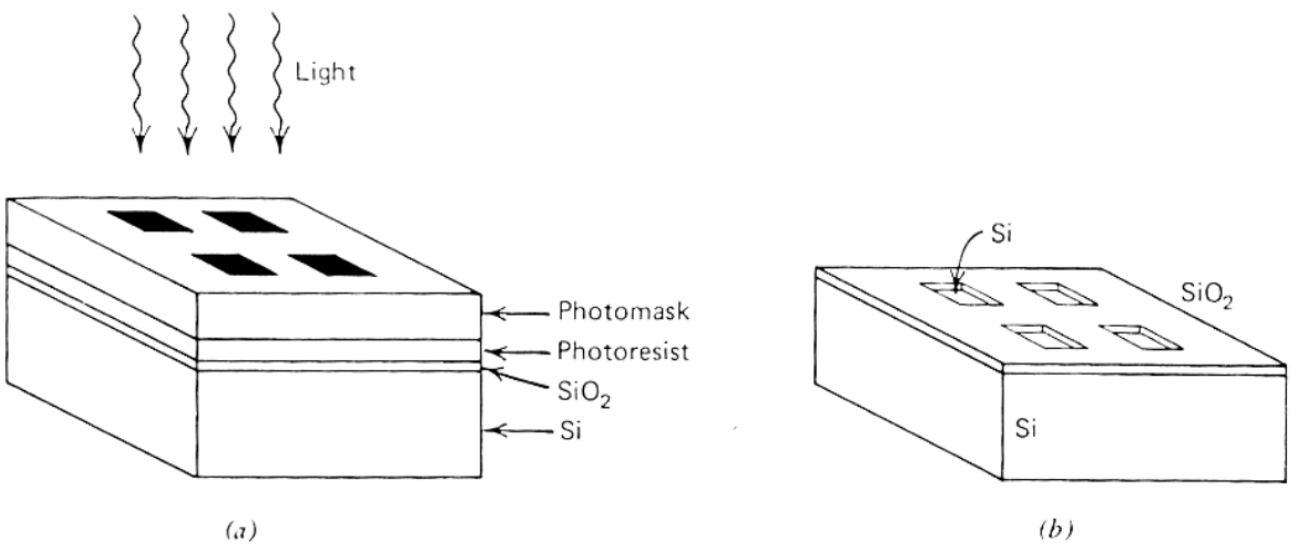
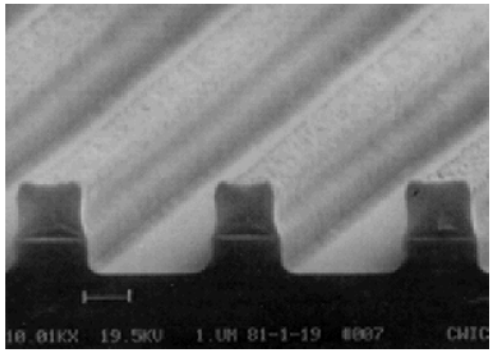
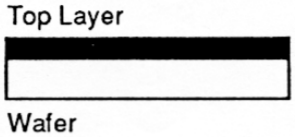
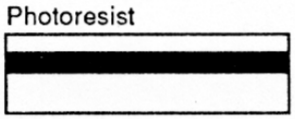
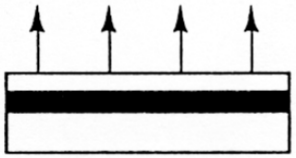
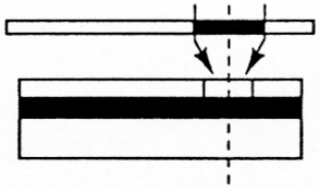


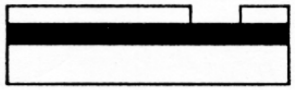
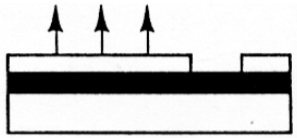
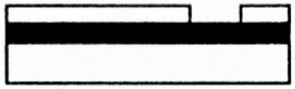
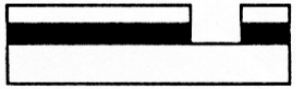
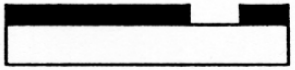
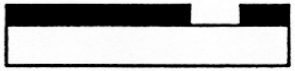
Figure The areas from which the oxide is to be etched are defined by polymerizing a light-sensitive resist through a photographic negative or mask.

Photolithography Basic Steps

- Creation of 3D structures using photographic techniques

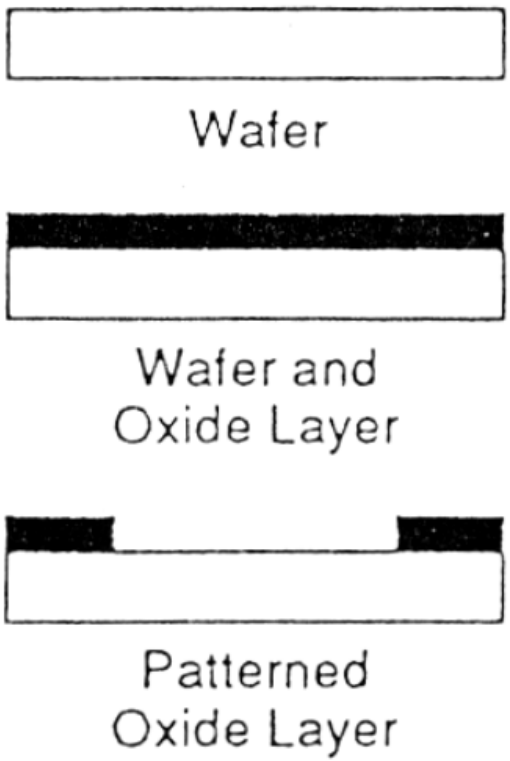


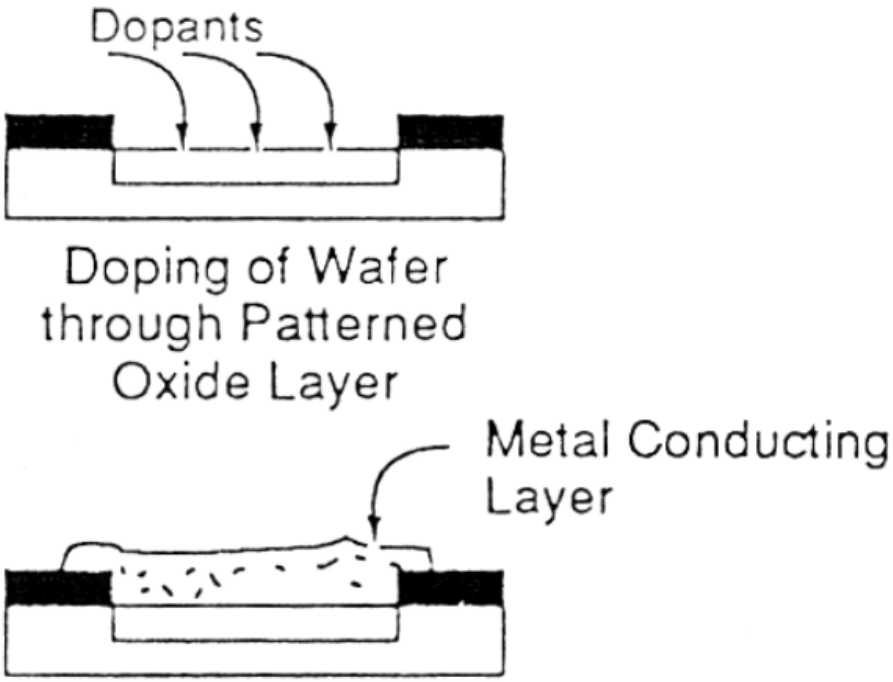
Process Step	Purpose	Cross Section
1. Surface Preparation	Clean and dry wafer surface	
2. Photoresist Apply	Apply a thin layer of photoresist to the wafer	
3. Softbake	Partial evaporation of photoresist solvents to promote adhesion	
4. Alignment and Exposure	Precise alignment of mask to wafer and exposure to u.v. light. Negative resist is polymerized.	

Process Step	Purpose	Cross Section
5. Development	Removal of unpolymerized resist.	
6. Hard Bake	Final Evaporation of Solvents	
7. Develop Inspection		
8. Etch		
9. Photoresist Removal		
10. Final Inspection		

Using Patterned Films as Masks

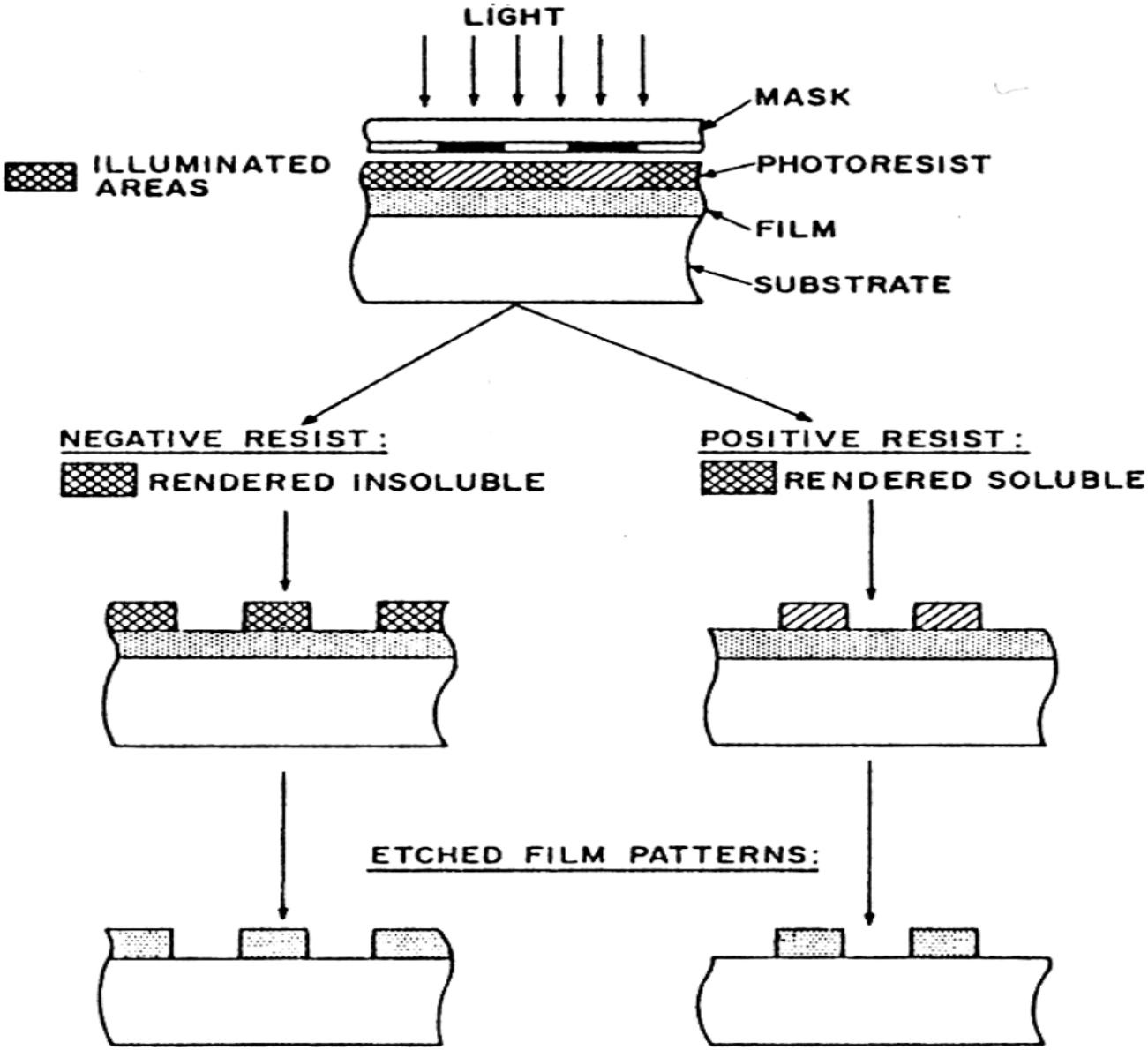
- Photolithography creates 3D patterned film
- Two possibilities
- Patterned film often final structure wanted
- Patterned film acts as a mask for additional processes
  eg oxide mask for doping process
- Sometimes one patterning does both





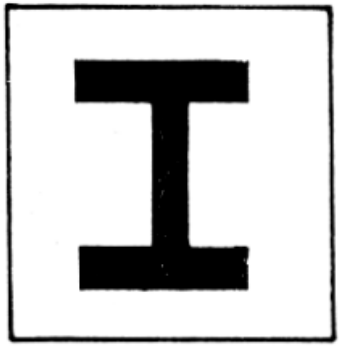
Two Types of Resist

- Negative: leaves resist where light exposure
- Positive: leaves resist where no light exposure



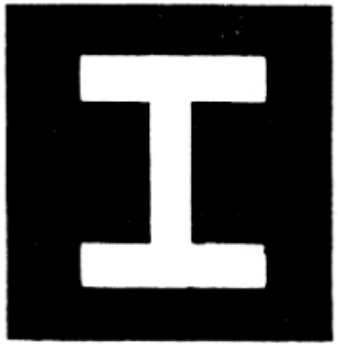
Different Mask Types

- Light field Mask



Light Field

- Dark field Mask



Dark Field

- The result may have Hole or Island depend on resist and mask types

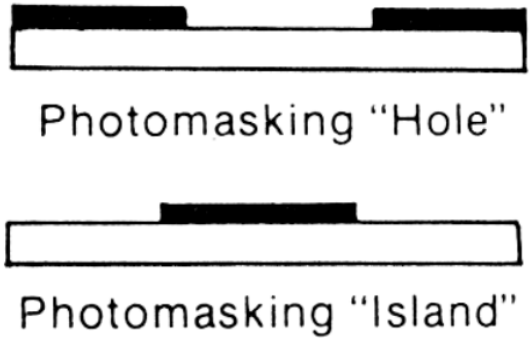


Figure Mask and photoresist polarity results.

		Photoresist Polarity	
		Negative	Positive
MASK POLARITY	Clear Field	HOLE	ISLAND
	Dark Field	ISLAND	HOLE

Parts of Photoresist

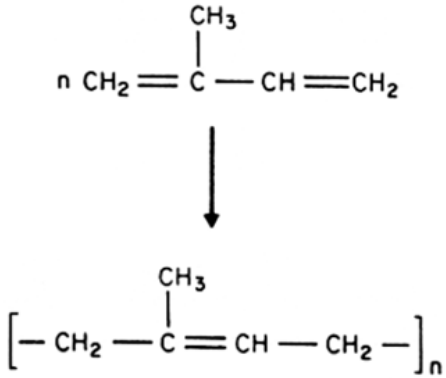
- Resist: photosensitive solid polymer dissolved in solvent
- Photoresists are resins (solids) in solvent
- Sensitizers and additives improve response

Component	Function
Polymer	Changes structure in reaction to energy (polymerization or photosolubilization)
Solvent	Allows spin application of thin layers
Sensitizers	Control of modification chemical reaction when exposed
Additives	Specific Needs

Figure Photoresist components.

Negative Photoresist

- Negative resists widely used until 3 micron resolution
- Limitation is that they swell during development
  hence resolution limited
- Basic material is synthetic rubber (polyisopreme)
  phenol-formaldehyde polymer (novolak resin)
- Compound is converted to a resin by cyclization
- Cyclized: turned into a benzene ring
  containing double bonded C atoms
- Sensitizer are PhotoActive Compounds (PAC):
  added for photosensitivity: eg. bis-aryl diazide



Isomeric after structure monacyclization.

Preparation of synthetic cis-1,4 polyisoprene

Negative Photoresist Exposure

- Under UV sensitizer on one polyisopreme cross links
  with another sensitizer on another polyisopreme
- Makes a polymer: long chain
- Exposed polymer resists the developer:
  hydrocarbon solvent: eg.Xylene
- Unexposed resist rapidly dissolved
- Needs light of about 360-400 nm, unaffected by 450 nm

Positive Resist

- VLSI needs positive resist for devices with <2 microns structures
- Again starts with a novolac resin
- PAC sensitizer carbon ring added with
  double bonded N_2 (diazide) and oxygen (ketone) groups

UV breaks N bond, forms 5 carbon with
  =C=O bond (ketene): very short lived:

- Ketene reacts with moisture (hydration)
  forms a carboxylic acid
- Carboxylic acid reacts with alkali to form soluble ester
- Thus exposed areas wash away in water based developer
- Typical resist: Shipley 1350J

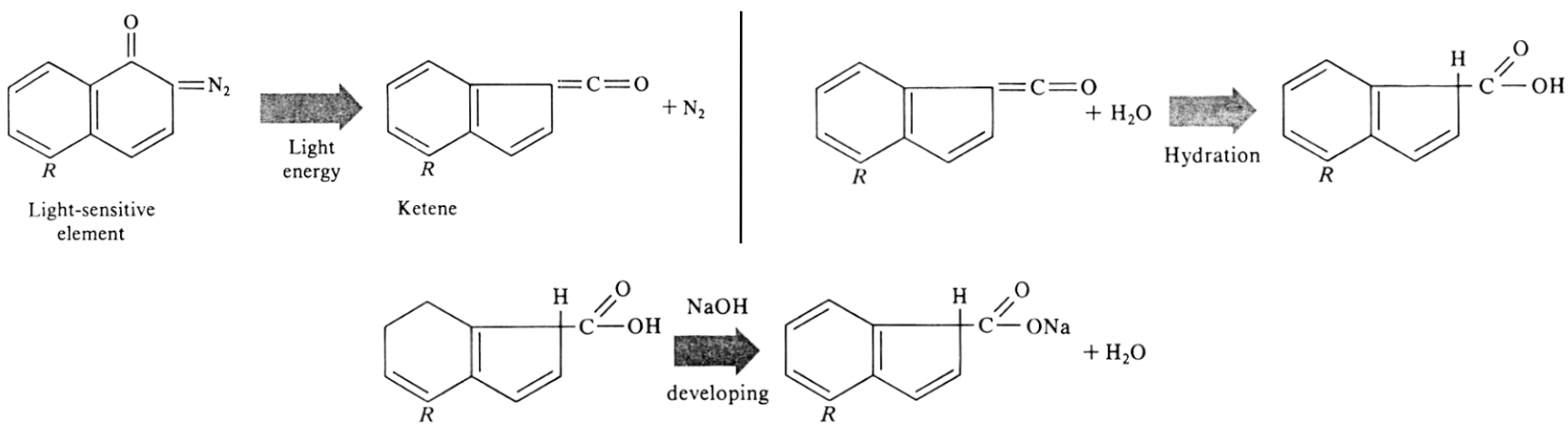


Figure The positive resist exposure reaction.

Relative Advantages of Resist type

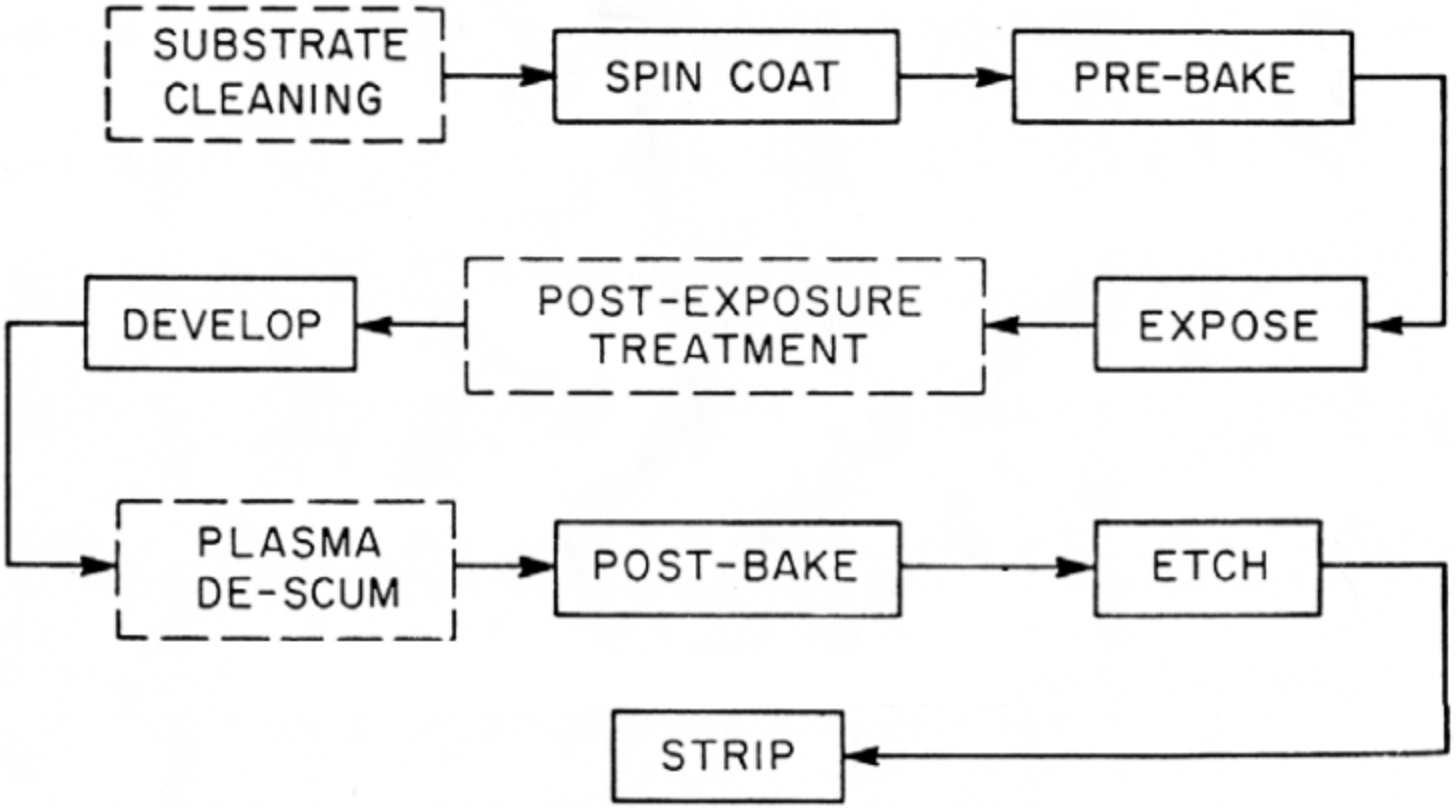
- Positive resists used in almost all processes now
- Positive resist has much higher resolution
- Resist is constantly changing: altered to fit the wavelength used
- Negative resists only used in specialized processes now
- Most important issues for any resist:
- What is the smallest structure resist can make
- What wavelengths it responds to
- How well does the resist cover the devices
- Low Pinholes – small openings in resist
- Good step coverage: coverage over structures on the wafer

Parameter	Negative	Positive
Aspect Ratio (Resolution)		Higher
Adhesion	Better	
Exposure Speed	Faster	
Pinhole Count		Lower
Step Coverage		Better
Cost		Higher
Developers	Organic Solvents	Aqueous
Strippers		
Oxide Steps	Acid	Acid
Metal Steps	Chlorinated Solvent Compounds	Simple Solvents

Figure Comparison of negative and positive resists.

Photolithography Steps

- Photolithography steps must be carefully followed
- General process is as below

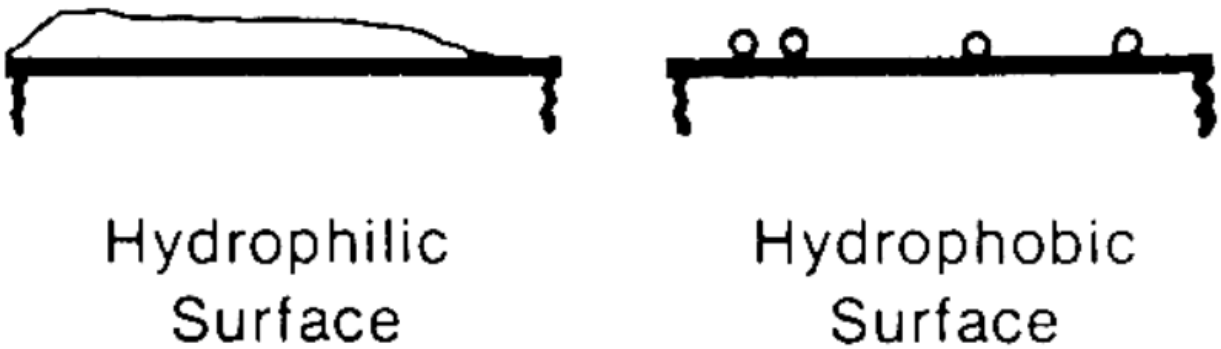


• 1st Photolithography Step: Substrate Preparation

• Must prepare wafers so resist adheres to surface → wafers must be hydrophobic (hating water)

• After exposure to water vapor in some process, some of wafers becomes hydrophilic → need to Return wafer to hydrophobic by a prebake removal of water. Example 120 ^{o}C for 20 min.

• Most commercial also use adhesion promoters, eg: HMDS hexamethyldisilazane



Spin Resist Application

- Place wafer on spinner (held down by vacuum)
- Resist applied to wafer: create a resist pool
- Spin wafer at high speed for thin film
- Rotation ramp up throws off excess resist
- Resist collects at wafer edge: Edge Bead
- Hard to remove edge bead so often add mask to overexpose edge

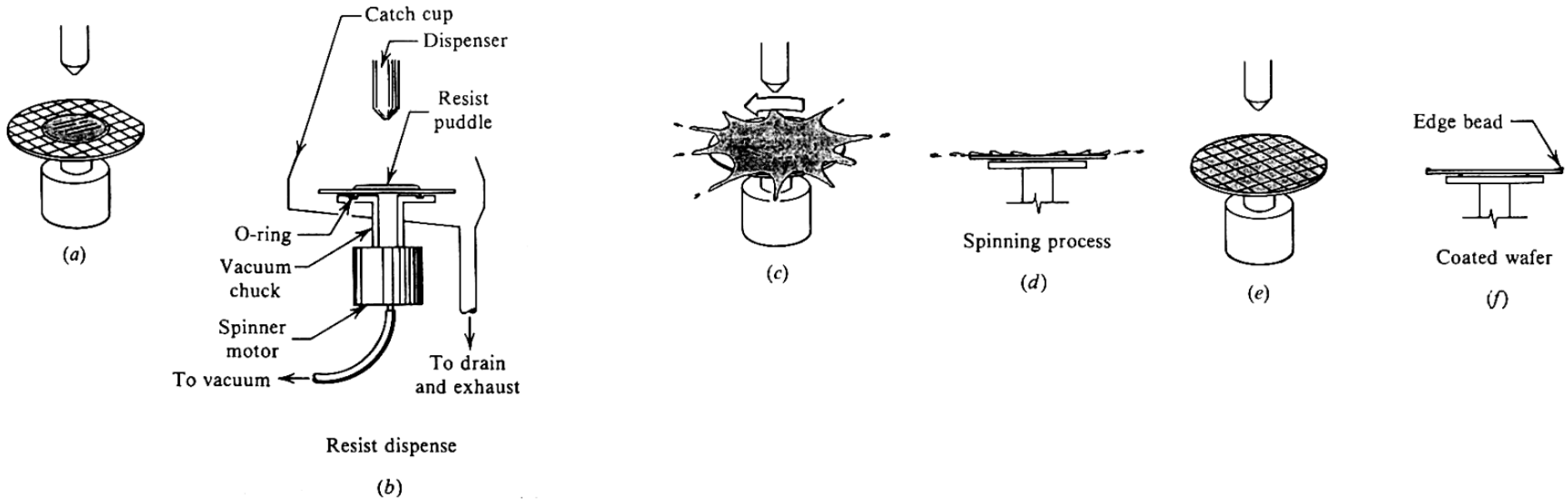
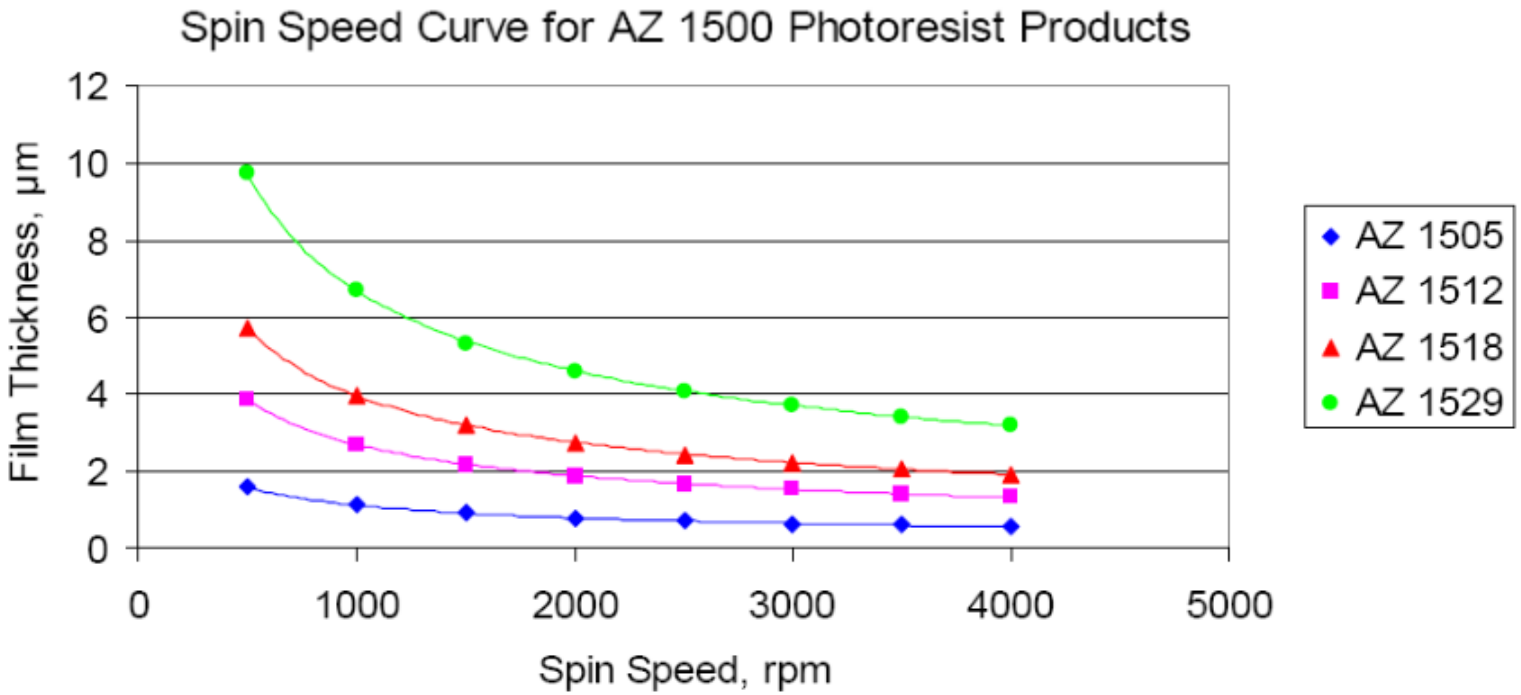


Figure Spin coating of resist. (*a*) Resist puddle applied to substrate. (*b*) Profile view of this step, showing some details of the spin coating equipment. (*c*) Spinning begins, throwing off most of resist. (*d*) Profile view of this step, showing waves in resist and function of catch cup. (*e*) Spinning complete, substrate coated. (*f*) Profile view of coated substrate, showing edge bead. Resist thickness is greatly exaggerated.

Resist Thickness

- Resist thickness is set by:
  - primarily resist viscosity
  - secondarily spinner rotational speed
- Resist thickness in μm is given by $t = kp^2/w^{1/2}$, where
  - k = spinner constant, typically 80-100
  - p = resist solids content in percent
  - w = spinner rotational speed in rpm/1000
- Most resist thicknesses are 1-2 μm for commercial Si processes.



Typical Commercial Resists

- Shipley, Hoechst, Hunt, Kodak

Table Commercially available photoresists

Resist	Solids content (%)	Viscosity	Specific gravity	Index of refraction	Flash point (°C)
Kodak Microresist 809	32 ± 1	23	1.045	1.560	58
Hunt Waycoat HPR 204	28	17.5	1.036	1.469	110
Hunt Waycoat HPR 206	33	41	1.055	1.482	110
MIT Superfine IC 528	28.5 ± 0.5	5 ± 0.5	1.010	1.484	—
Tokyo OKHA OFPR-800	Three available	20 ± 1.5 30 ± 1.5 50 ± 1.5	—	—	—
Shipley AZ-1370†	27	17 ± 1.5	1.025 ± 0.015	1.64 ± 0.01	41
Shipley AZ-1350J	31	30.5 ± 2.0	1.040 ± 0.010	1.64 ± 0.01	41
Shipley AZ-1470	27	15.7–18.3	1.025 ± 0.015	1.64 ± 0.01	41
Shipley AZ-1450J	31	28.0–33.1	1.040 ± 0.010	1.64 ± 0.01	41
Shipley AZ-1115	20	24.5 ± 1.5	0.990 ± 0.015	1.555	34
Shipley AZ-111H	25	70 ± 5	1.017 ± 0.015	1.555	39
Shipley AZ-2400	26	16.7–20.0	1.000–1.030	—	44

Wafer Track Spin Coaters

- Modern production uses wafer track system
- Automatic, cassette to cassette spin coaters
- All steps done automatically: unloaded from cassette
- Moved to prebake oven, then cooled on cooling plate
- Loads on spinner, automatically coated, then postbake to dry
- then reloaded into the cassette

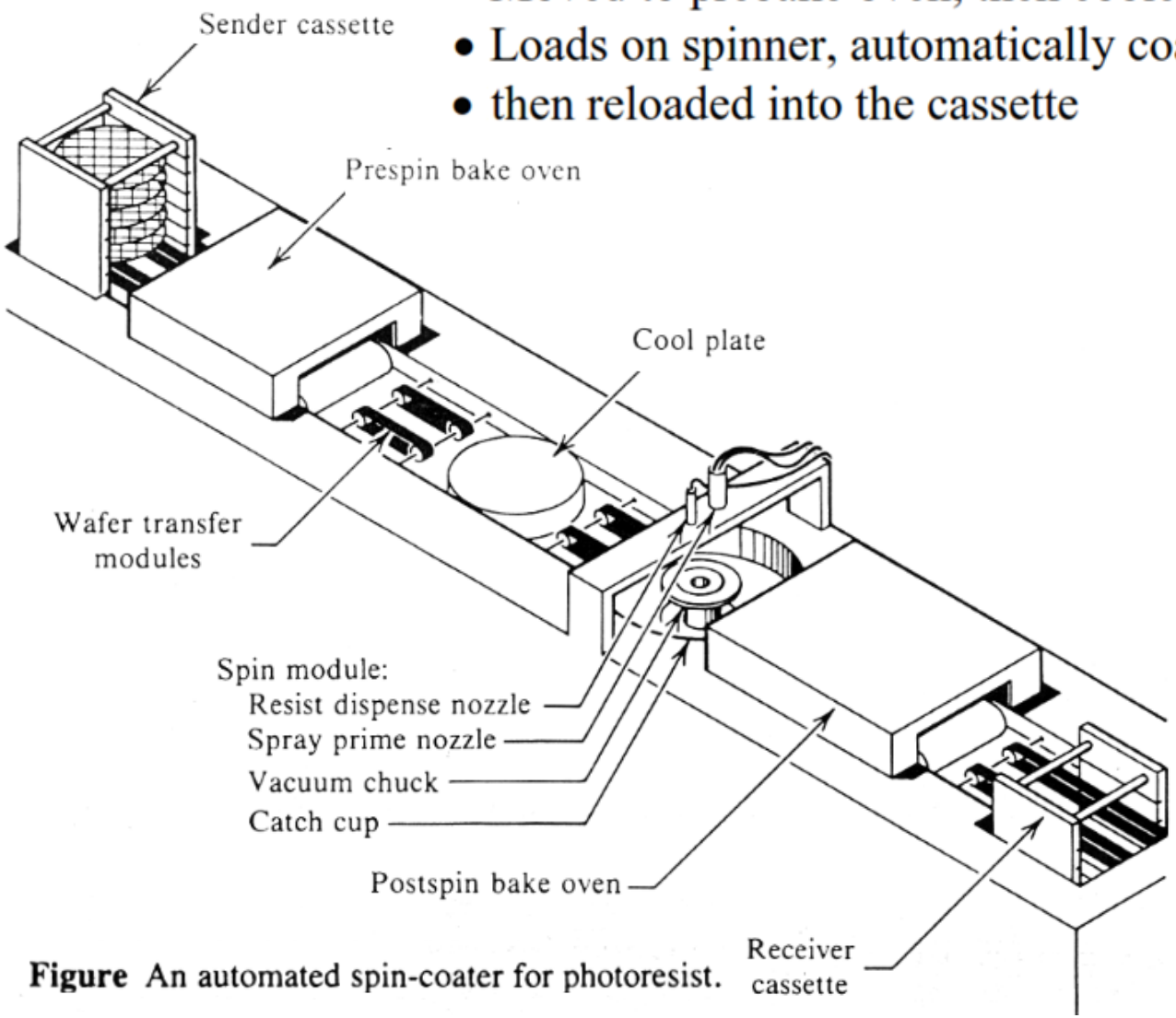


Figure An automated spin-coater for photoresist.