

Photolithography

- Creation of three dimensional structures using photographic techniques
- Derived from creation of printing plates
- Usually starts with thin film on wafer (eg SiO_2)
- 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

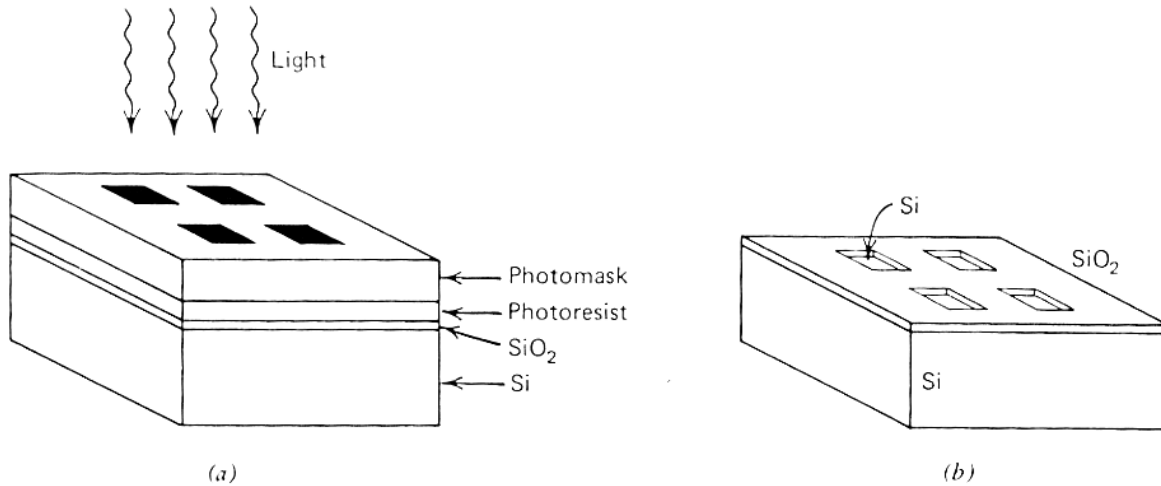
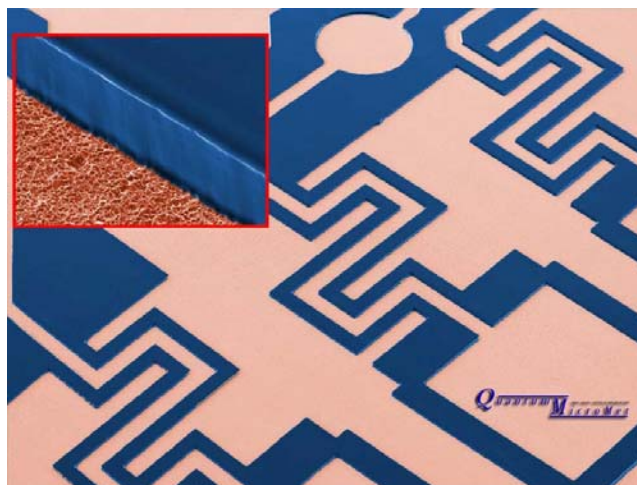


Figure 2.11 The areas from which the oxide is to be etched are defined by polymerizing a light-sensitive resist through a photographic negative or mask.



Photolithography Basic Steps

- Creation of 3D structures using photographic techniques

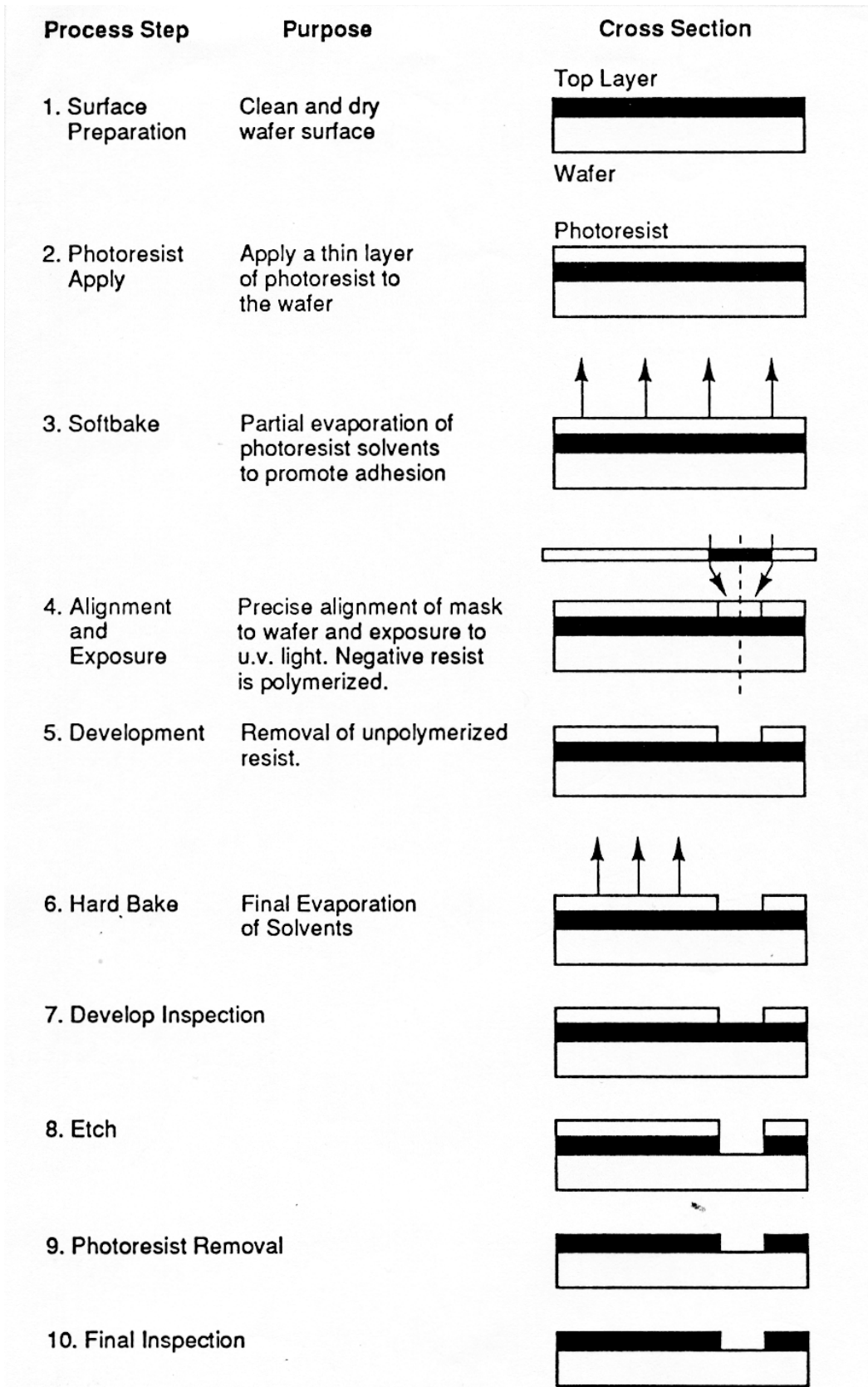
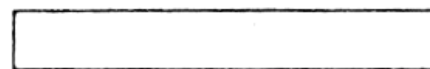


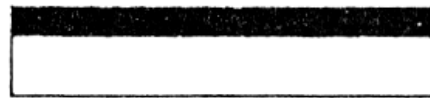
Figure 8.9 Ten-step photomasking process.

Using Patterned Films as Masks

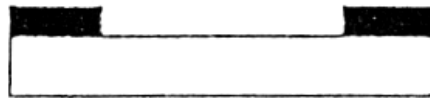
- Photolithography creates 3D patterned film
- Two possibilities
- Patterned film often final structure wanted
- Patterned film acts as a mask for additional processes
eg mask for doping process
- Sometimes one patterning does both



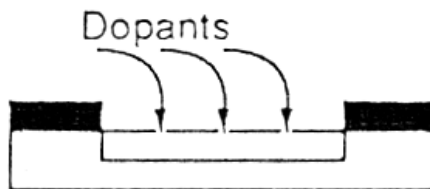
Wafer



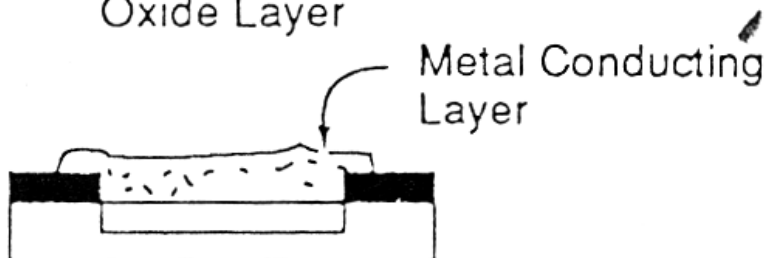
Wafer and
Oxide Layer



Patterned
Oxide Layer



Doping of Wafer
through Patterned
Oxide Layer



Creation of Photomasks

- 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: small area (1 or several chip designs)
- Reticules may cover 3x3 cm chips at 5 or 10x magnification
- Reticule are 5 or 6 inch in size
- Step and repeated reduced pattern (5 or 10x) directly on wafer
- Step and repeat for a mask (seldom done now)

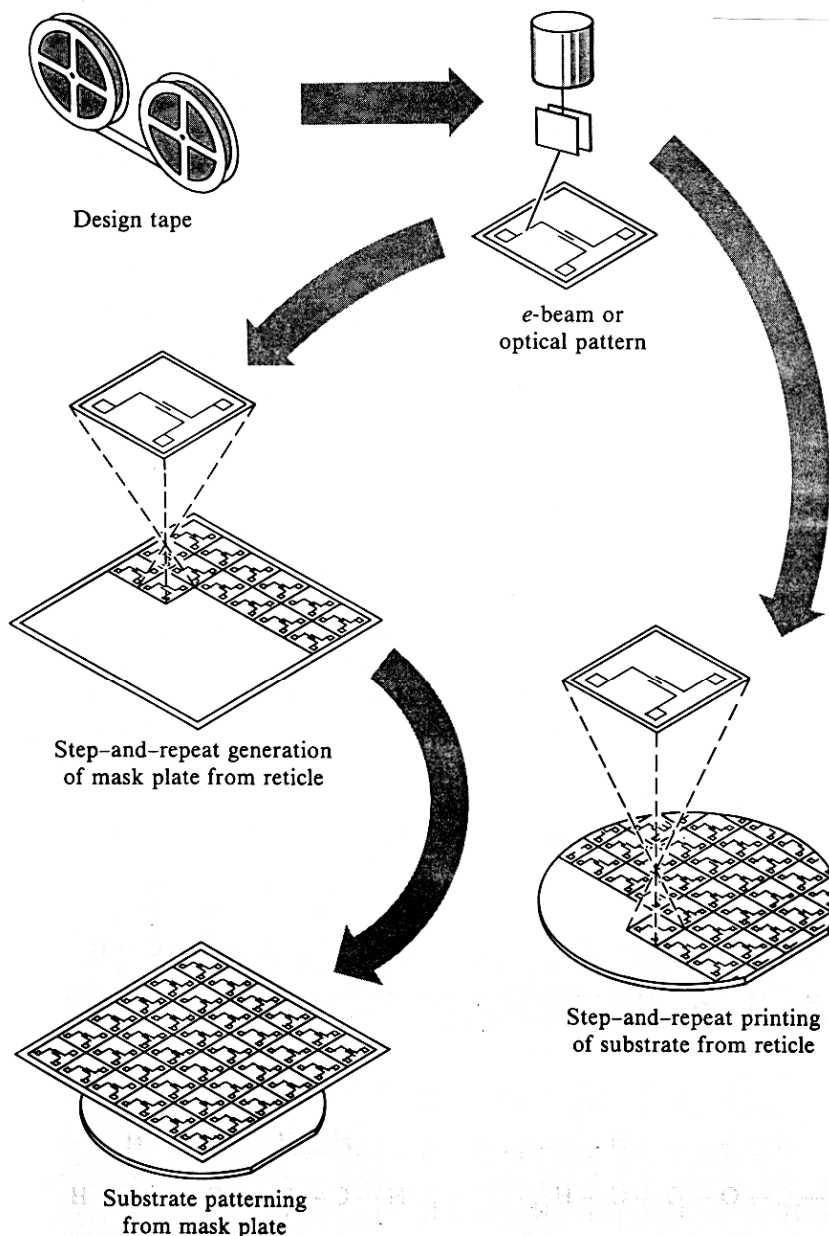
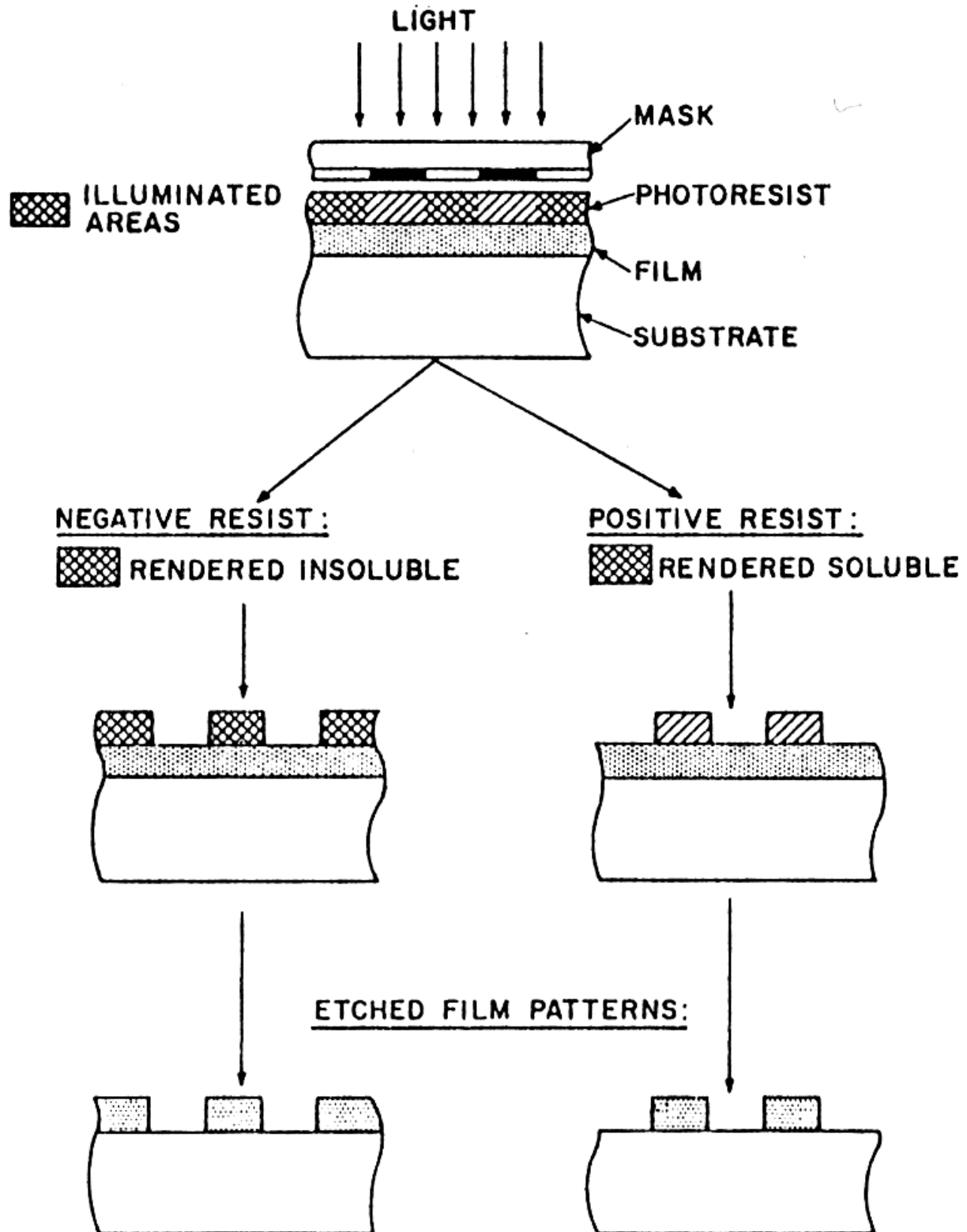


Figure 4-2 Masks, reticles, and mask making. A tape representing desired pattern is used to generate a reticle containing one cell of the pattern. The reticle pattern is repetitively generated on the substrate, either directly or through intermediate generation of a mask plate.

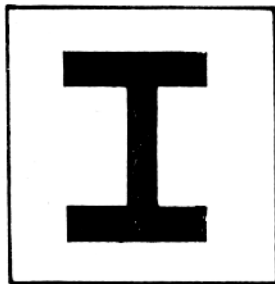
Two Types of Resist

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

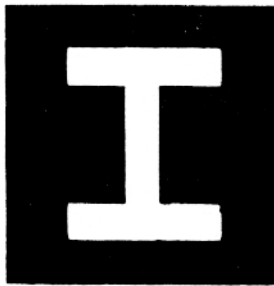


Different Mask Types

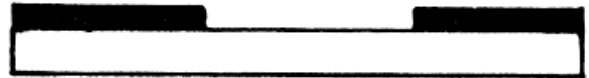
- Light field Mask: "islands" of lines in clear field
- Dark field Mask: "holes" in mostly dark area
- Type of resist determines mask type



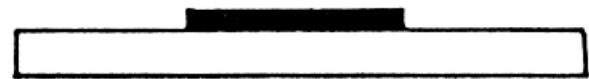
Light Field



Dark Field



Photomasking "Hole"



Photomasking "Island"

Figure 8.6 Photomasking hole and island.

Figure 8.5 Mask-reticle polarities.

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

Figure 8.8 Mask and photoresist polarity results.

Parts of Photoresist

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

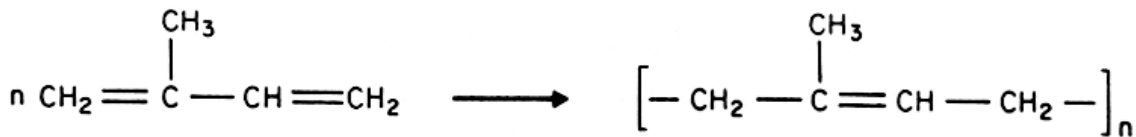
| Component | Function |
|-------------|---|
| Polymer | Changes structure in reaction to energy (polymerization or photosolubilization) |
| Solvent | Allows spin application of thin layers |
| Sensitizers | Control of modification chemical reaction when exposed |
| Additives | Specific Needs |

Figure 8.10 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 (polyisoprene)
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:
added for photosensitivity: eg. bis-aryl diazide



Preparation of synthetic cis-1,4 polyisoprene

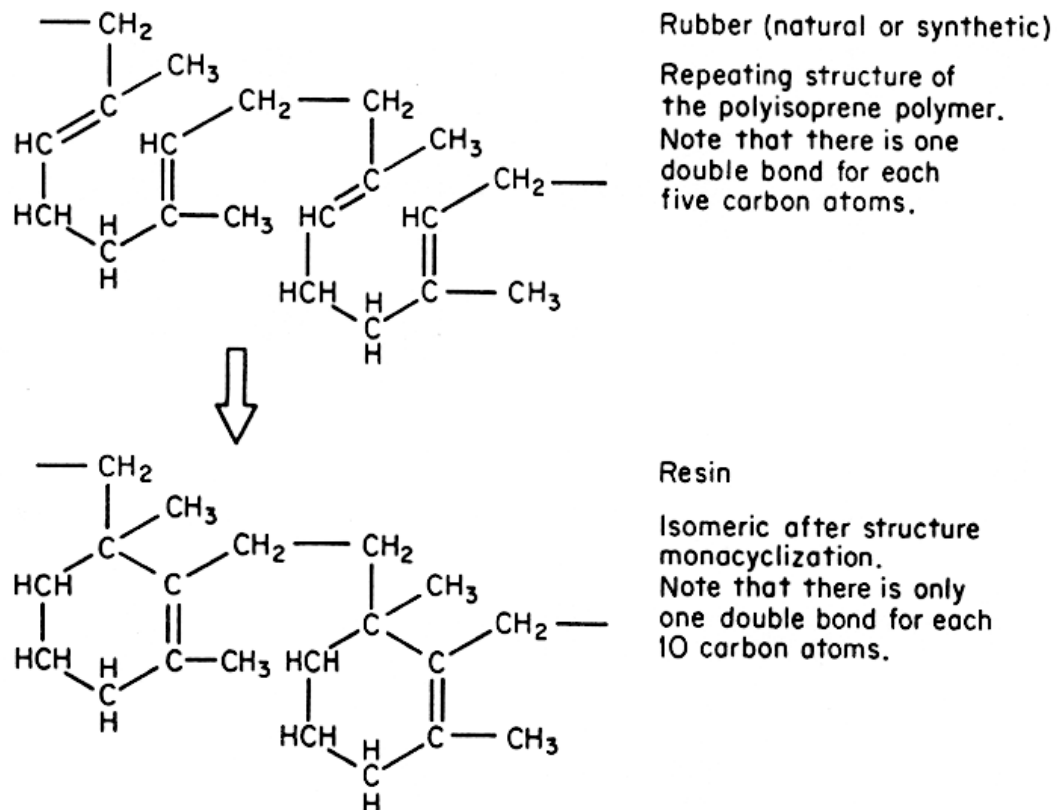


Figure 8.1 Polyisoprene resin formation.¹

Negative Photoresist Exposure

- Under UV sensitizer on one polyisoprene cross links with another sensitizer on another polyisoprene
- 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
- Hence yellow lights do not affect
- Yellow filters in photolith lab to remove UV from fluorescents

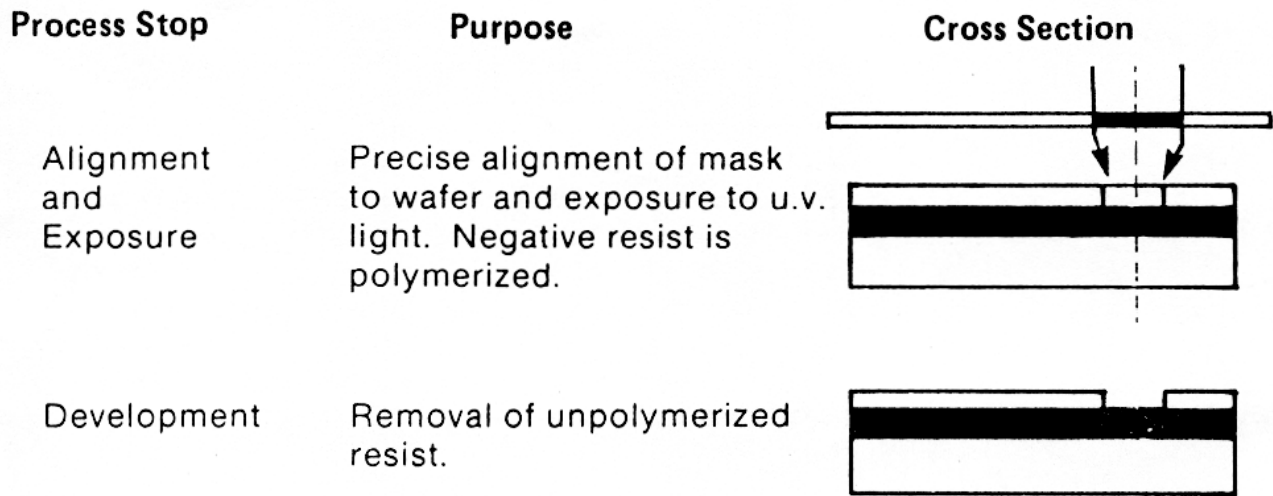


Figure 8.3 First pattern transfer—from mask to resist layer.

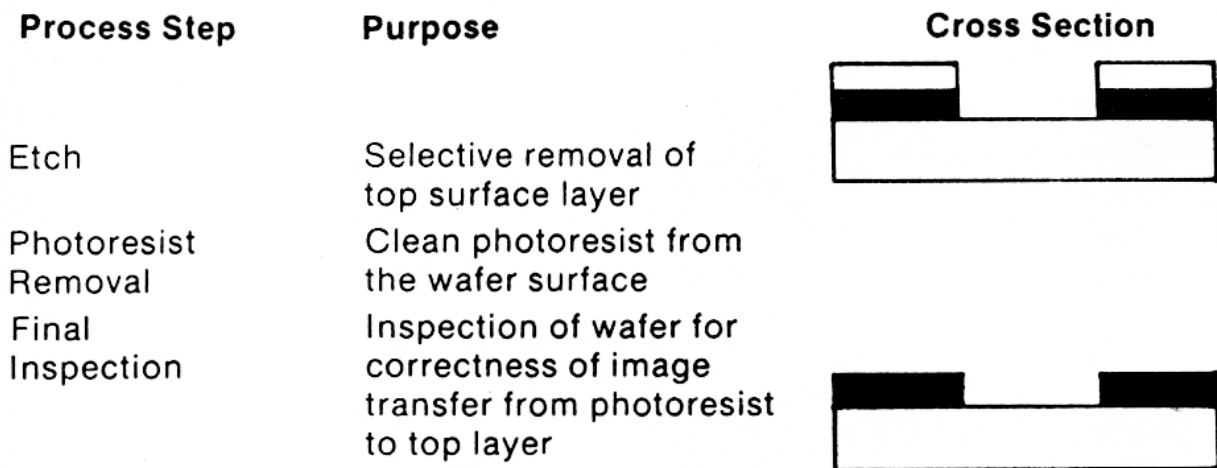


Figure 8.4 Second image transfer.

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 N₂ (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

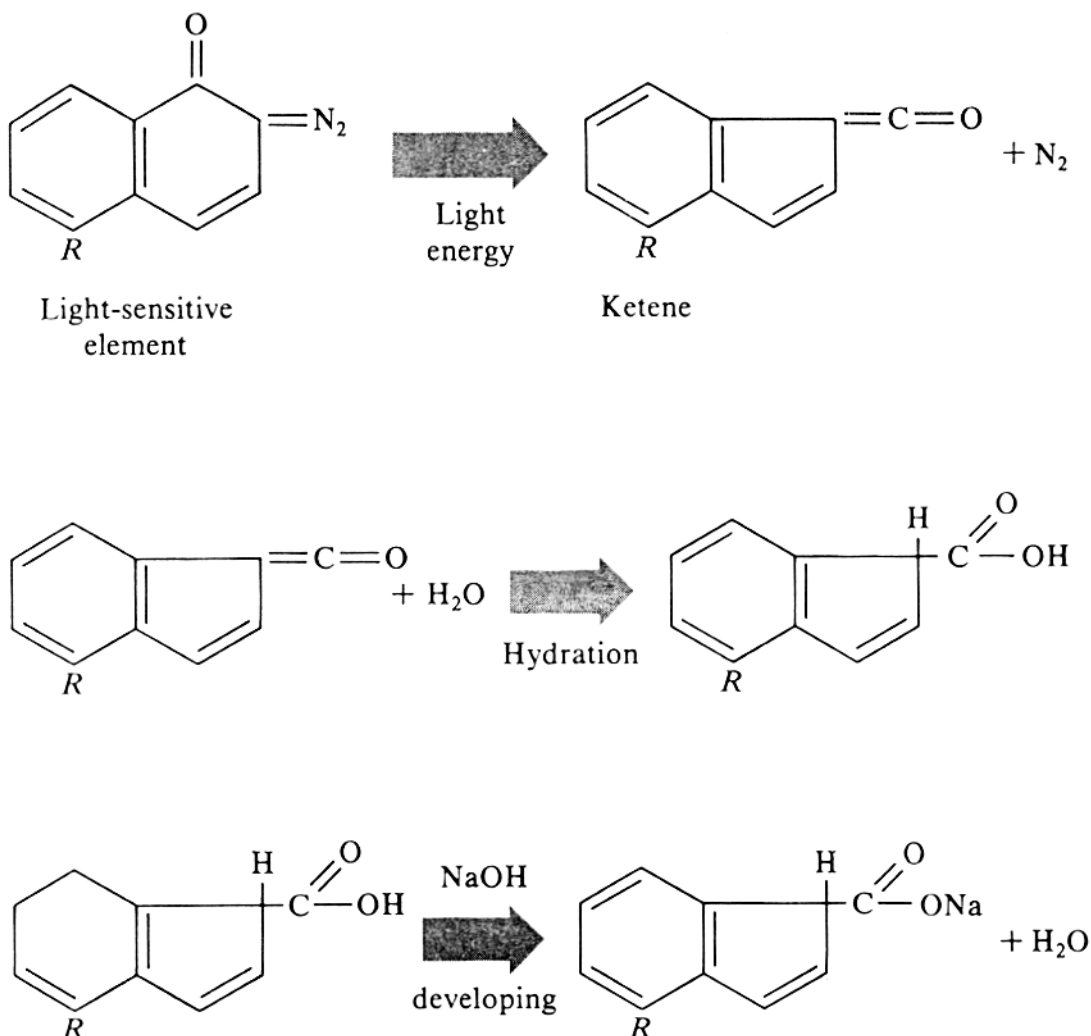


Figure 4-7 The positive resist exposure reaction. (Reference 5, used by permission. Copyright 1975,

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 8.20 Comparison of negative and positive resists.

Photolithography Steps

- Photolithography steps must be carefully followed
- General process is as below
- But details of process parameters vary with each resist
- Changing those parameters often means resist problems
- All resists sensitive to Violet/UV but not yellow light
- Hence Yellow lights in photoresist rooms
- Always keep wafers away for regular fluorescent lights
- Cover tray with resist wafers if bring outside of yellow rooms

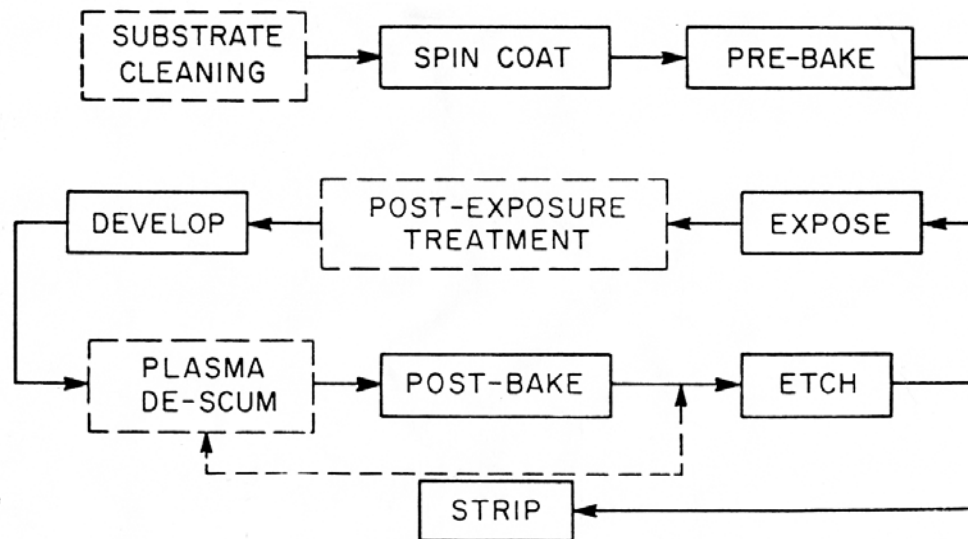


Fig. 14 Flow chart of a typical resist process. Steps in broken lines are not used for materials. Reprinted from Ref. 8 with permission of the American Chemical Society. ✍



ENSC Batch No. _____ Wafers Started _____ Date _____
 Material _____ Orientation _____ Size _____ Thickness _____
 Resistivity _____ Type _____
 Wafer Vendor _____ Vendor Batch # _____ SFU P.O. _____

| Process Step # | Process Conditions | Oper & Wafer # | Comments |
|----------------|--|----------------|---|
| ___A | Prebake (Optional) Temp = 100C. Time = 20 min Cool to room temp before spinning photoresist. | | <u>Optional</u> , depending on recent history of wafers. |
| ___B | Spin Primer, Back Side (Optional) ShIPLEY Microposit. Flood surface. 4000 RPM. 30 seconds. Be sure chuck is clean, to avoid contaminating front of wafer. | | <u>Optional Steps, Back Side Processing</u> : Back side processing, consisting of steps B(optional), C and D, is normally performed only for micromachining applications where the back of the wafer is to be processed or protected. <u>Optional Step</u> : HMDS (hexamethyldisilazane) is an adhesion promoter. Normally used only on wafers that have already been processed in EDP. Occasionally used on other wafers if resist adhesion is a problem. |
| ___C | Spin Photoresist, Back Side (Optional) ShIPLEY SPR2. Flood surface. 4000 RPM. 30 seconds. As above, chuck must be clean. | | <u>Optional Step, Back Side Processing</u> |
| ___D | Soft Bake, Back Side (Optional) Temp = 100C. Time = 5 min | | <u>Optional Step, Back Side Processing</u> |
| ___E | Spin Primer, Front Side (Optional) ShIPLEY Microposit. Flood surface. 4000 RPM. 30 sec | | <u>Optional Step</u> : As in Step B, primer is used only if required because of actual or potential adhesion problems. Be careful not to scratch coating on back side, if present. |
| ___F | Spin Photoresist, Front Side ShIPLEY SPR2. Flood surface. 4000 RPM. 30 seconds. | | Be careful not to scratch resist on back side, if present. |
| ___G | Soft Bake Temp = 100C. Time = 20 min | | |
| ___H | Inspect (Optional) Microscope with yellow light | | <u>Optional</u> inspection for obvious resist problems. |
| ___I | Exposure Tests (Optional) If correct exposure not known. | | Exposure varies with surface and mask type. An Al surface might require 8 seconds with a chrome mask and about 15 seconds with an emulsion mask. An oxide surface might require about 30 seconds with an emulsion mask. |

| | | | |
|------|---|--|--|
| ___J | Align and Expose Use test results or experience. | | |
| ___K | Develop to endpoint MF319, undiluted. Room temp. Slight agitation until no more resist is being removed. About 60 seconds is typical time. | | |
| ___L | Rinse Running DI H2O for > 3 min | | |
| ___M | Dry Do not spin. Resist contaminates chuck. Blow dry with dry N2 and bake briefly in soft bake oven if necessary. | | |
| ___N | Inspect Microscope with yellow light. Look for complete development and/or damage. | | Undeveloped resist may show as deposits in corners of developed areas. |
| ___O | Hard Bake Temp = 120C. Time = 20 min | | Excessive hard bake can compromise resist strip. Too little hard bake can reduce resistance to etchants. |
| ___P | Inspect Microscope with yellow light and measurement capability. Be sure that resist is properly exposed and developed and is in suitable condition to carry out your subsequent process steps. Measure resist if required. | | <u>Measurement optional.</u> Check lab requirements. |

1st Photolith Step: Substrate Preparation

- Must prepare wafers so resist adheres to surface
- After most processing wafers hydrophobic: water hating
water beads up on surface
- hydrophobic best for resist adhesion
- After exposure to water vapour wafers hydrophilic
water loving: water spreads over wafer surface
- Return wafer to hydrophobic by a prebake removal of water
- eg 120°C, 20 min.
- Most commercial also use adhesion promoters
eg: HMDS hexamethyldisilazane

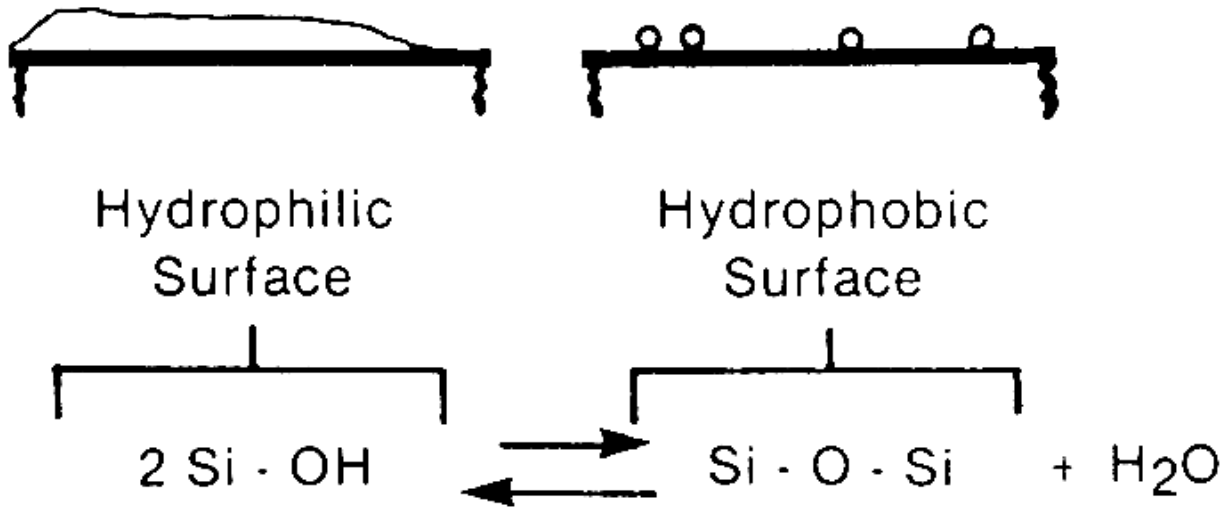


Figure 8.25 Hydrophilic versus hydrophobic surfaces.

Spin Resist Application

- Place wafer on spinner (held down by vacuum)
- Resist applied to wafer: create a resist puddle
- 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

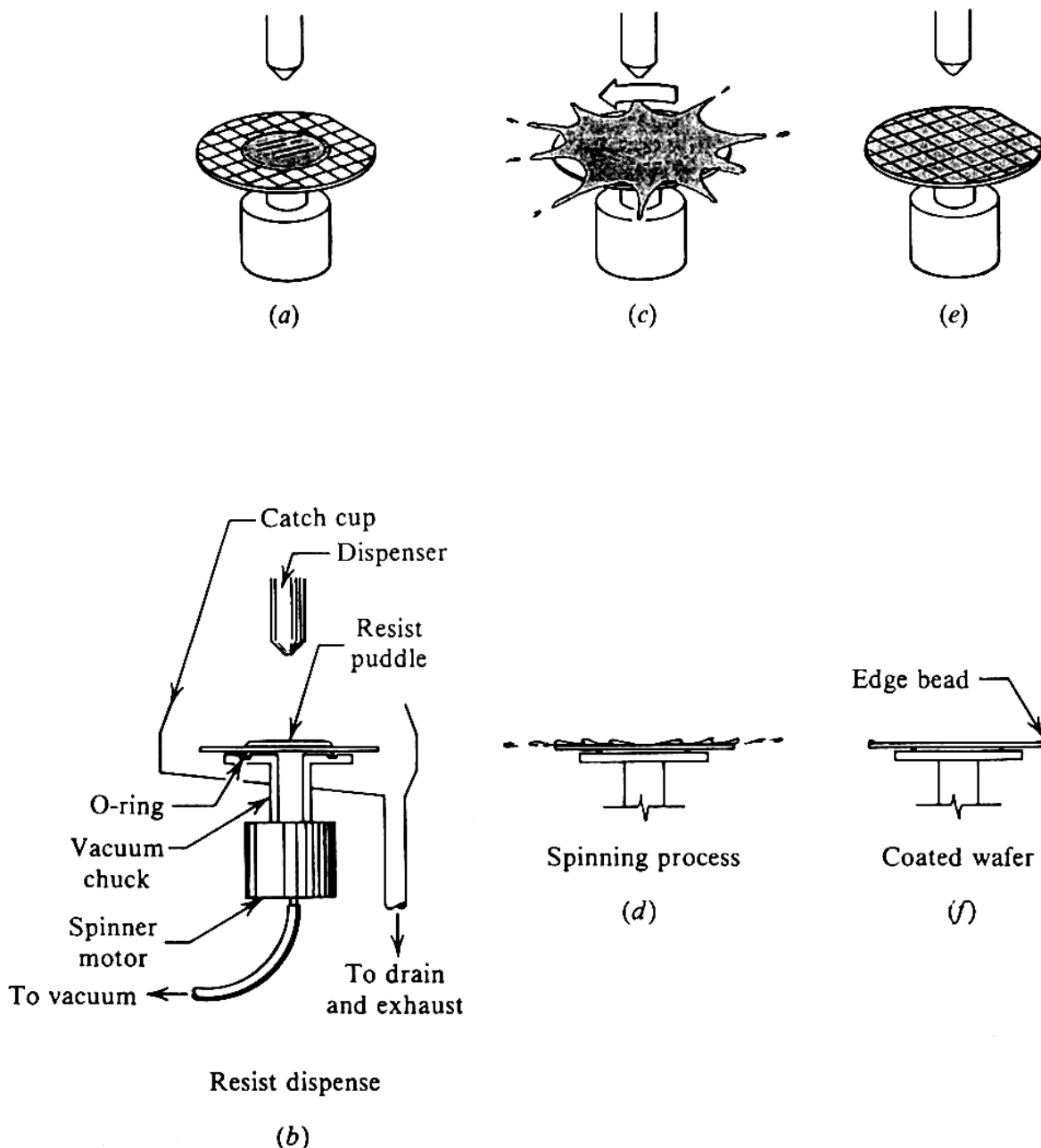


Figure 4-11 Spin coating of resist. (a) Resist puddle applied to substrate. (b) Profile view of this step, showing some details of the spin coating equipment. (c) Spinning begins, throwing off most of resist. (d) Profile view of this step, showing waves in resist and function of catch cup. (e) Spinning complete, substrate coated. (f) Profile view of coated substrate, showing edge bead. Resist thickness is greatly exaggerated.

Resist Thickness

- Thickness function of resist type, viscosity, spin speed
- Viscosity controlled by fraction of solids in resist
- Higher spin speed more centripetal force vs gravity
- Higher viscosity harder to throw off resist
- Empirical formula:

$$z = \frac{kP^2}{\sqrt{\omega}}$$

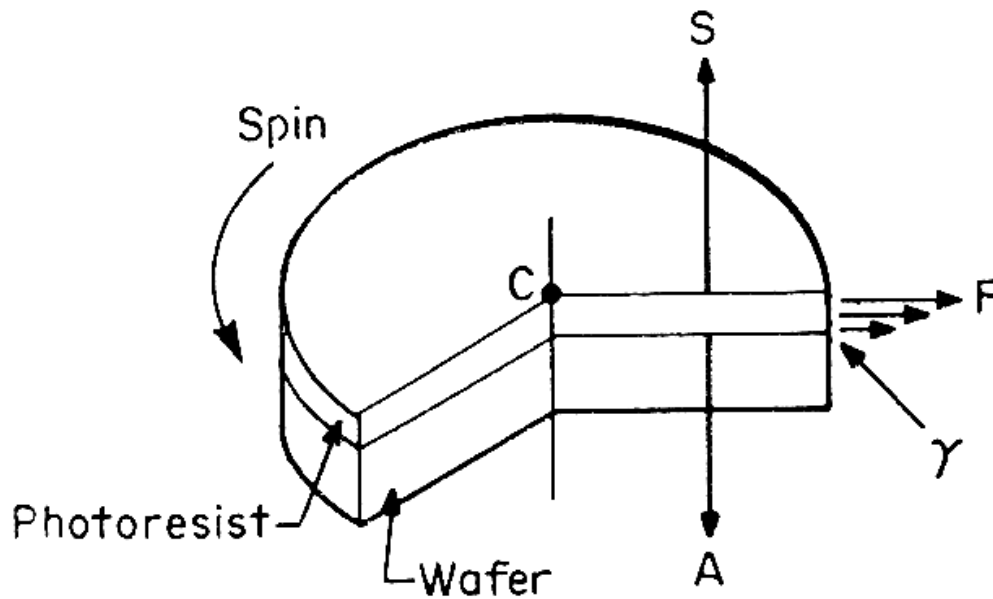
where z = film thickness in microns

P = % solids in resist

ω = angular velocity

k = constant in microns/sec^{0.5}

- k different for each resist



Resist Thickness of Different % Solids vs Spin Speed

- These charts very resist specific: this for Kodak 820

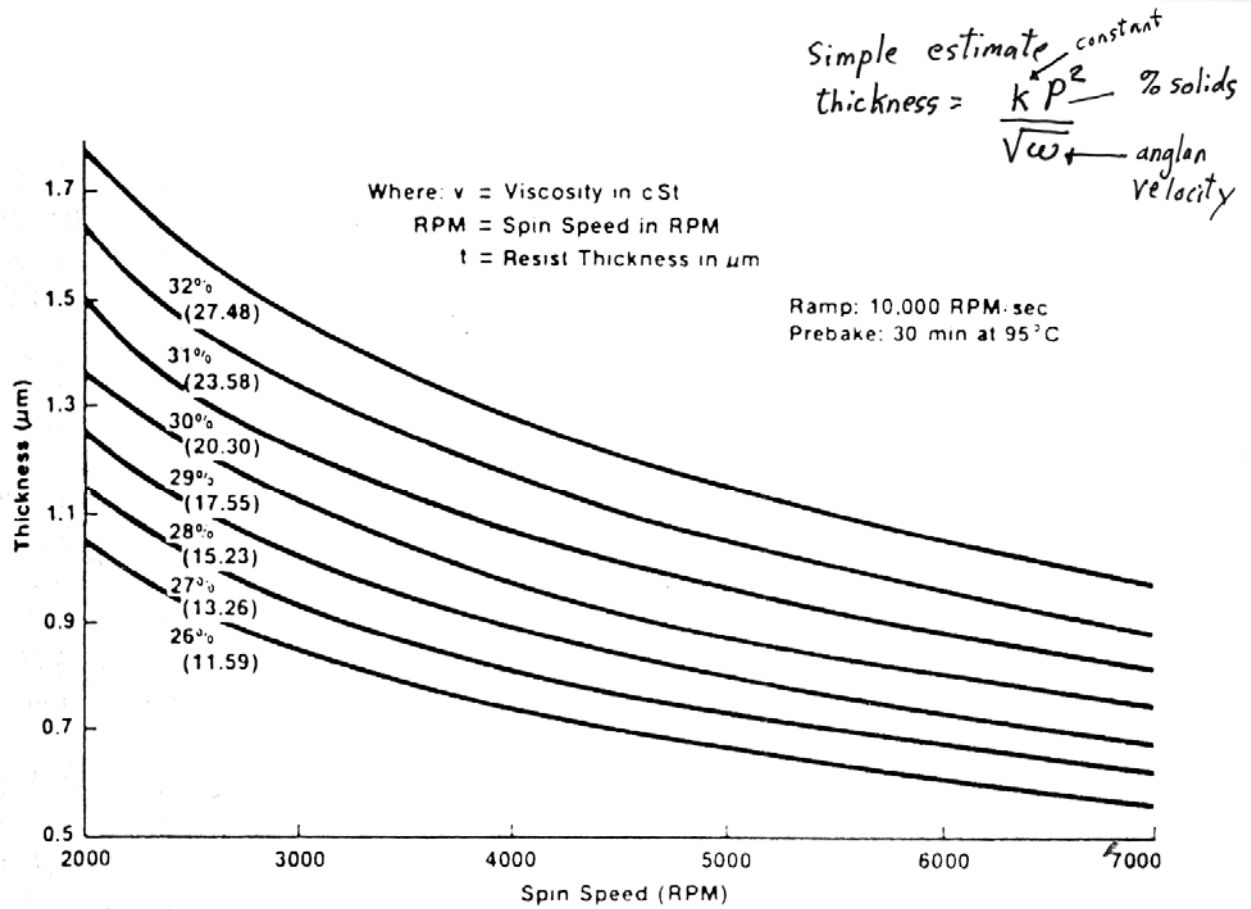


Fig. 17 Thickness vs spin speed of Kodak 820 resist. Courtesy of Eastman-Kodak Company.



Typical Commercial Resists

- Shipley, Hoechst, Hunt, Kodak
- In lab use SPR2 which is similar to Shipley 1350J

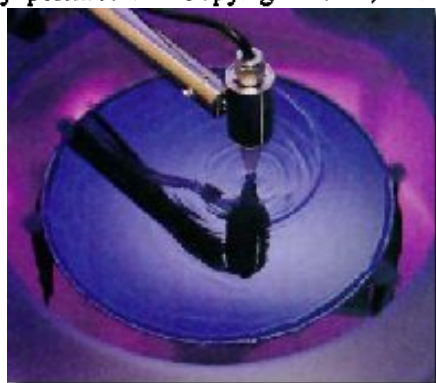
Table 4-1 Commercially available photoresists

| 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 |

† AZ is a trademark of the Azoplate Division of American Hoechst Corporation.

Note: Resist properties are subject to change by the manufacturer.

Source: Reference 8, used by permission. Copyright 1982, McGraw-Hill.



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
- For development track unloads from cassette again
- Own now becomes post exposure bake, followed by cooling plate
- Development is on the spin coater (sprays on developer)
- Then post development bake to dry
- In either case then reloaded into the cassette

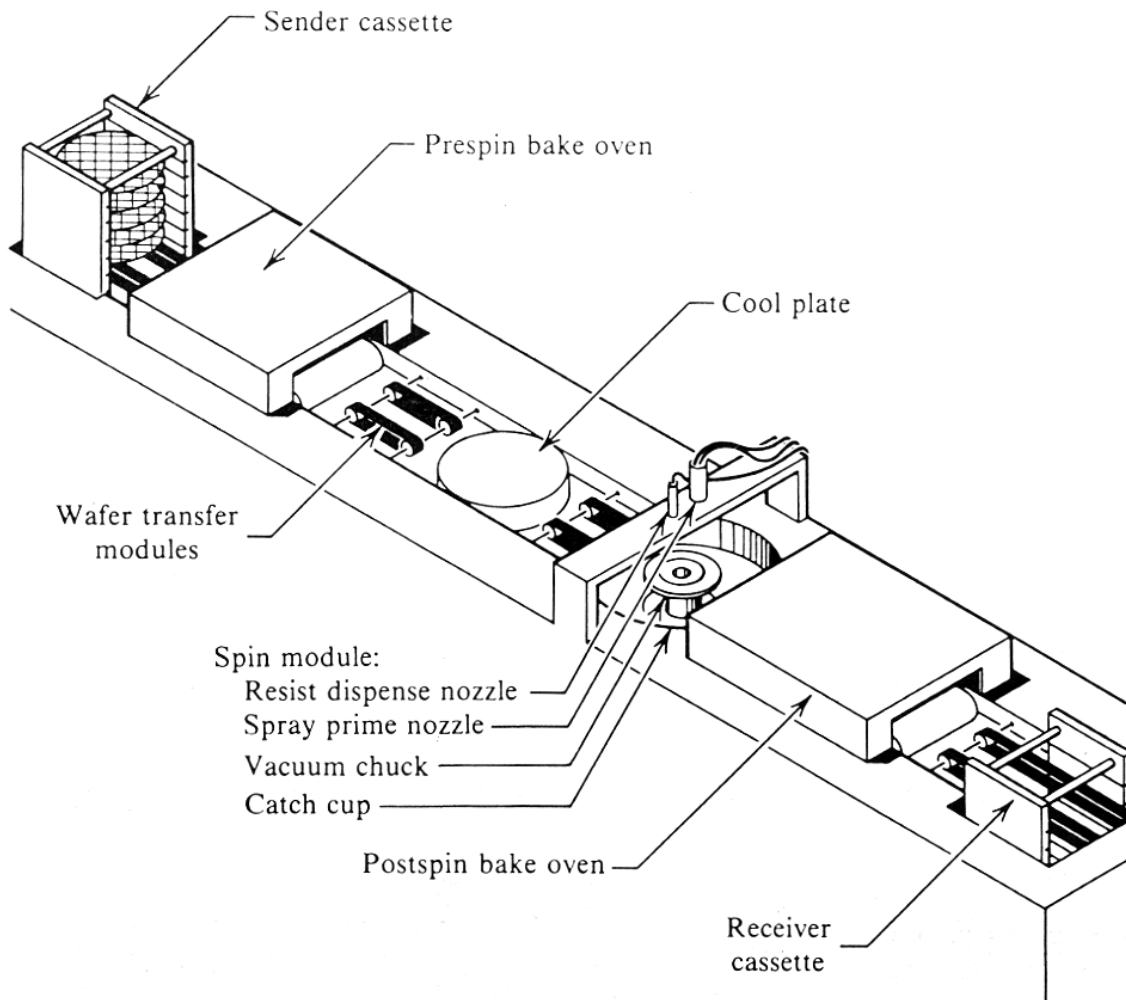


Figure 4-16 An automated spin-coater for photoresist. This sketch is conceptual in nature and is not meant to accurately represent any specific piece of equipment; in fact, it combines features from several different manufacturers.

Automatic Resist Spreading

- Automatic resist spinners use autodisperment
- In addition to puddle method use:
- Dynamic Spin (resist put on at low speed)
often in spiral pattern, then ramp up to full speed
- Moving arm: dispenser arm spreads resist around
sometimes with slow spin, then ramp up

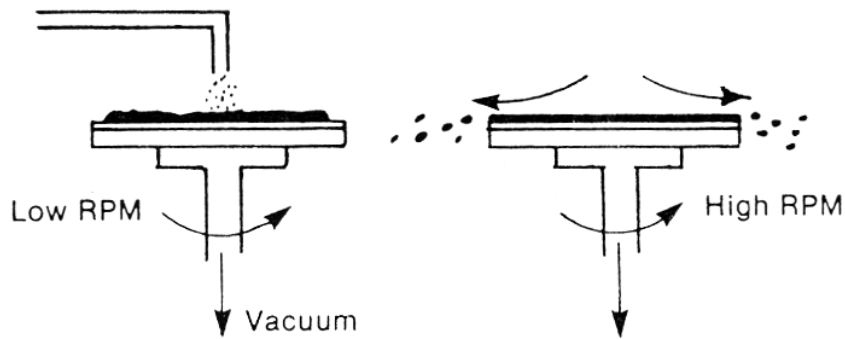


Figure 8.31 Dynamic spin dispense.

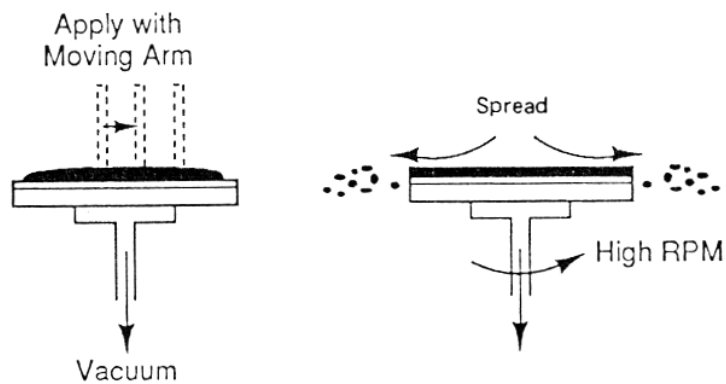
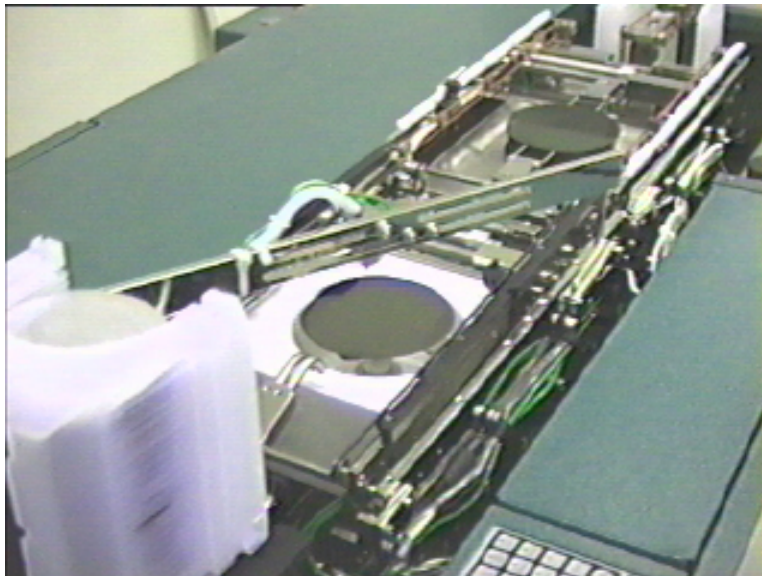


Figure 8.32 Moving-arm dispense



Wafer Track Spin Coaters

- Wafer Coater/Developers cost \$0.3-1 Million
- Same wafer track design used for coat or development
- Problem – if not used often resist lines clog



Figure 4-17 A photograph of an automated spin-coater. There are three parallel tracks for processing. At the left-hand end are three "sender" wafer cassettes, partially raised; at the right are three empty "receiver" cassettes that are lowered almost flush with the machine surface. Wafers move from left to right, through the spin and bake modules. A keyboard and CRT screen allow entry and monitoring of process variables. (Photograph courtesy of GCA Corporation, Bedford, Massachusetts. Wafertrac® is a registered trademark of GCA Corporation.)



Resist Soft Bake

- After coating soft bake resist
- Drives off extra solvents
- Resist still soft, best for development
- Typical values in oven 100°C, 20 min.
- Automatic systems faster
- Use bake ovens in our cleanroom – better for small batches

| Method | Bake Time Min. | Temperature Control | Productivity Type | Rate Waf/Hr. | Queing |
|------------------------|----------------|---------------------|-----------------------|--------------|--------|
| Hot Plate | 5-15 | Good | single to small batch | 60 | Yes |
| Convection Oven | 30 | Average - Good | Batch | 400 | Yes |
| Vacuum Oven | 30 | Poor - Average | Batch | 200 | Yes |
| I.R. Moving Belt | 5-7 | Poor - Average | Single | 90 | No |
| Conductive Moving Belt | 5-7 | Average | Single | 90 | No |
| Microwave | 0.25 | Poor Average | Single | 60 | No |

Figure 8.41 Soft bake chart.



Cassette

spin/coater

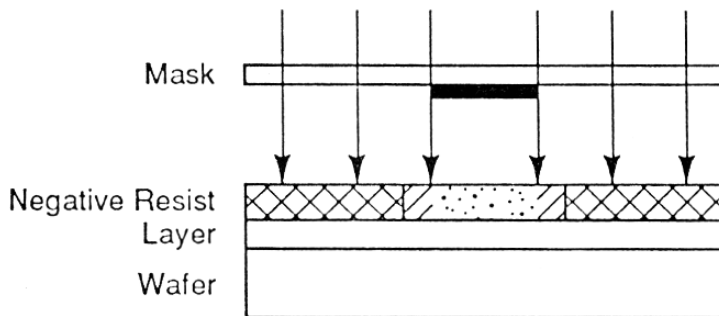
Bake oven

cooling

Cassette

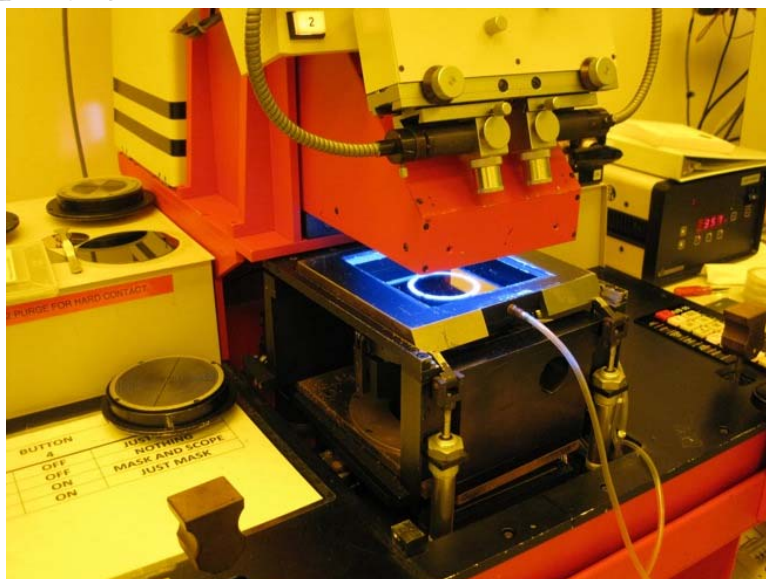
Resist Exposure

- Wafers exposed within 2-3 days of soft bake otherwise strip and recoat
- Several exposure systems: simplest mask aligner
- Wafers placed in mask aligner, moved under mask
- Mask very close to resist (possibly in contact with resist)
- Contact may cause resist to stick to mask
- Then mask needs to be cleaned
- Photoresist is very sticky – like fly paper
- But separation needs to be close otherwise line shadow spreads
- Exposure to UV: mask blocks light to desired areas



- ☒ Polymerized Resist
- ▨ Partially Polymerized Resist
- Unpolymerized Resist

Figure 9.3 Transition region at resist image edge.



UV Light Source

- Most aligner UV sources mercury vapour lamp
- Emission Lines 450, 400 and 365 nm absorbed by resist
- Exposure time set by light intensity, resist type and thickness, reflectivity of layer below

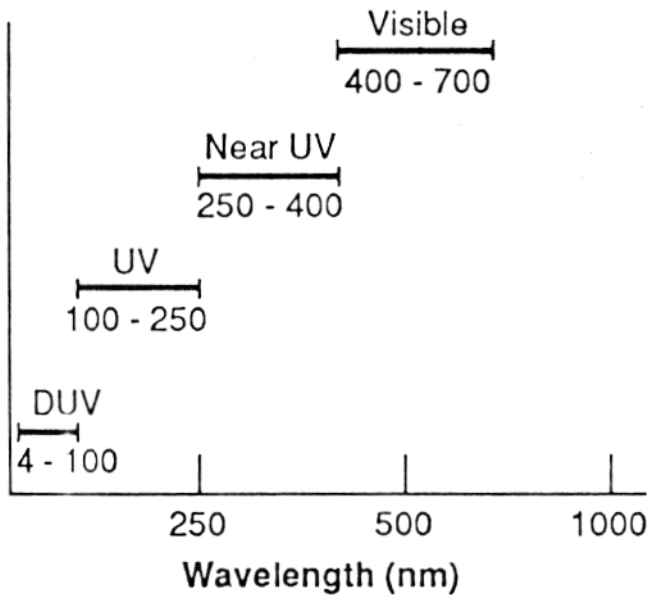


Figure 8.17 Ultraviolet and visible spectrum. (After Elliott.⁷)

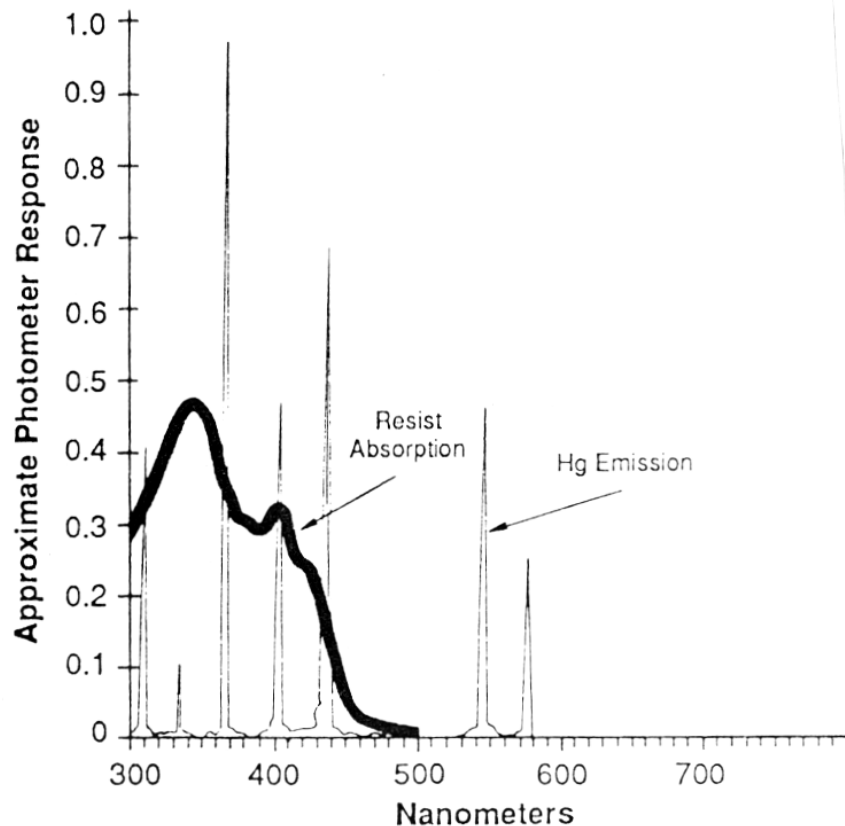


Figure 8.18 Exposure response of Hunt chemical HPR resist. (Courtesy of Hunt Chemicals.)

Mask Aligner

- Laboratory aligner Quintell 4000 about \$300K
- Other major manufacturer Karl Suss \$500K - \$1M



Alignment of Layers

- Most important Photolith step: Alignment of layers
- Rough alignment – use the wafer flat
- Only rough at first level: all other levels align relative to previous
- IC patterns are repeated across wafer – each has alignment marks
- Must get new mask aligned with devices on wafer
- Use two objectives with large separation
- Structures aligned in both fields
- This prevents rotational errors

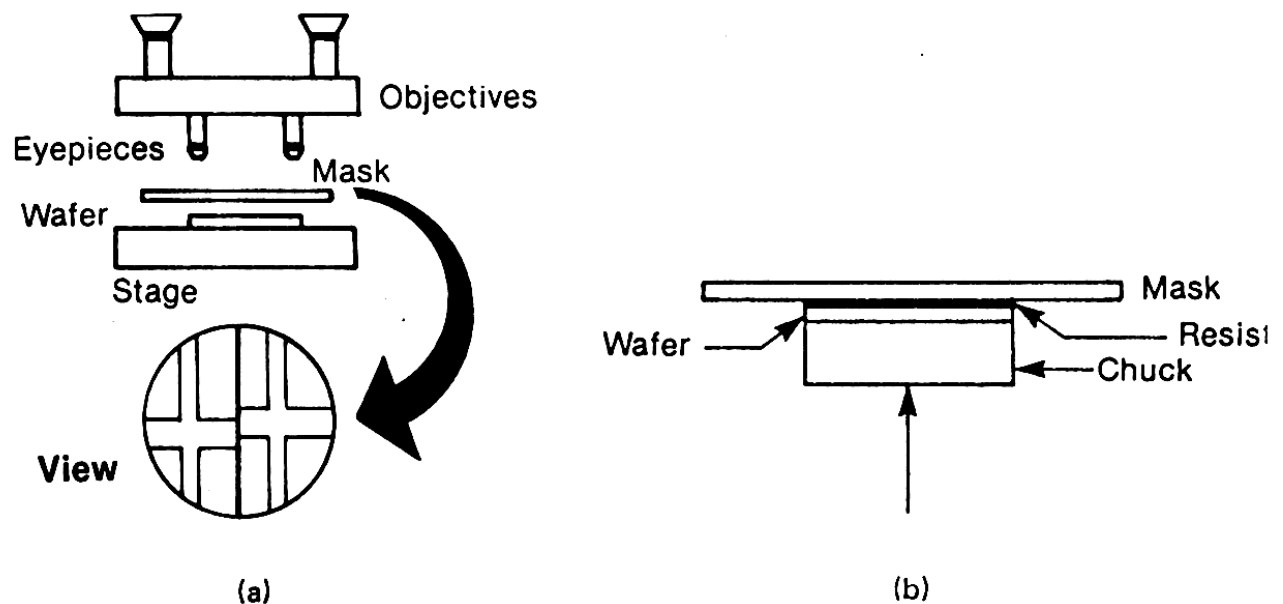
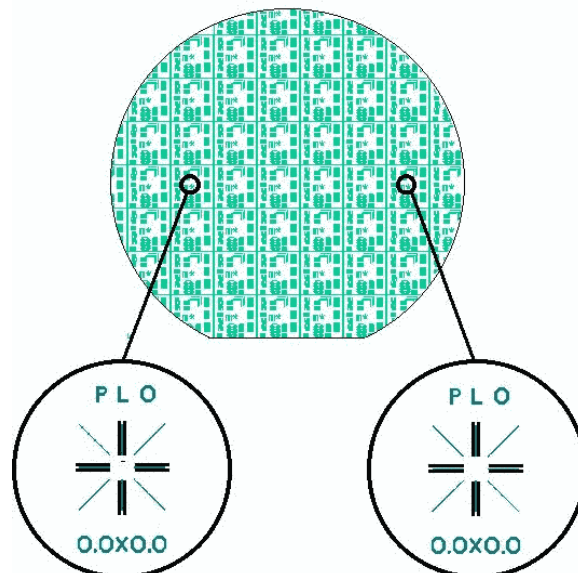


Figure 8.49 Contact aligner system. (a) Alignment stage; (b) contact stage.



Missalignment Errors

- Use special alignment structures
 - boxes within boxes, or crosses within crosses
- New layer aligned within layer below
- Watch for 3 types of errors
- X/Y displacement: error in position
- Rotation errors: alignment different in each box
- Run out: (mask problem) displace changes with position

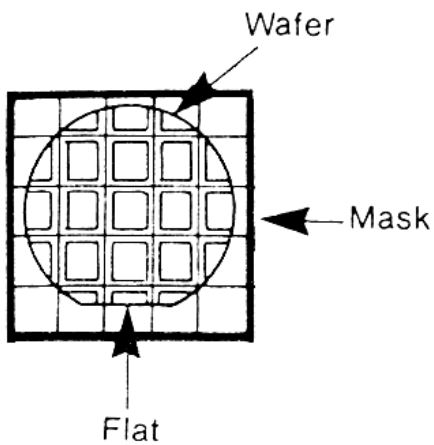


Figure 8.46 First mask alignment.

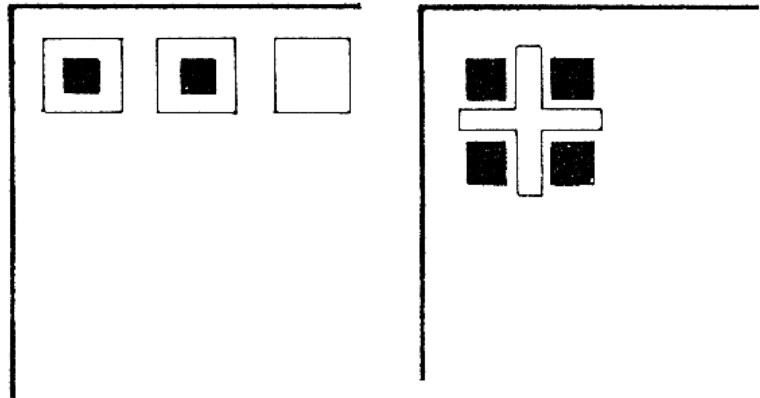


Figure 8.47 Types of alignment marks.

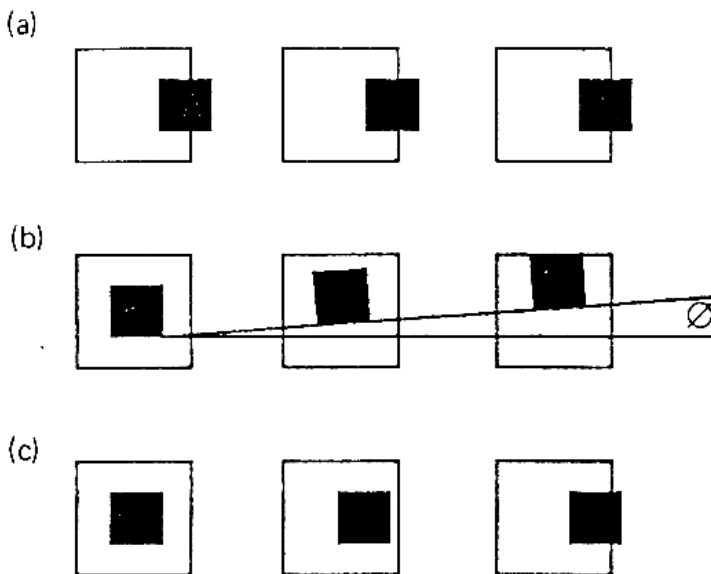
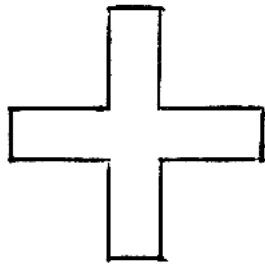


Figure 8.48 Misalignment types. (a) x direction; (b) rotational; (c) run-out.

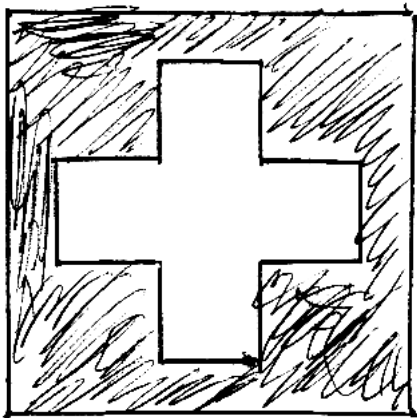
Alignment Marks in Mask

- Each level has its own alignment mark
- Type depends on Mask Type
- Generally "plus" sign type
- Light field mask: dark plus on field alignment mark
- Dark field mask: open plus in field alignment mark
- Smallest alignment marks minimum geometry width

Alignment Marks



Light Field



Dark Field

Alignment Marks: Level to level

- Next level must be able to align to level below
- Upper level marks is wider
by minimum geometer on each side
- Light field centre upper level in lower
- Dark field centre lower level in upper
- More complicated when mix differ level types

