INRF BiON

Photolithography

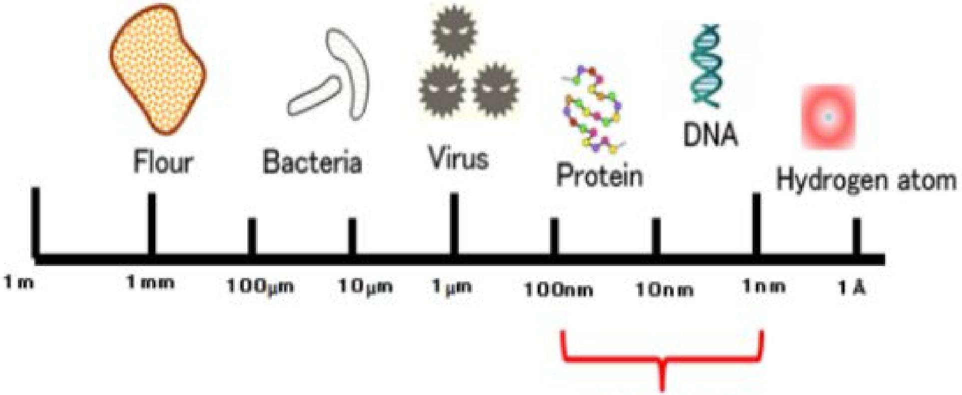
Lecture Day 3 Photolithography

Overall Process
- Photoresists
- Alignment
- Flood Exposure
- UV Exposure
- Developing

Types of Photolithography
- Contact
- Proximity
- Projection

Steppers
Mask Aligners

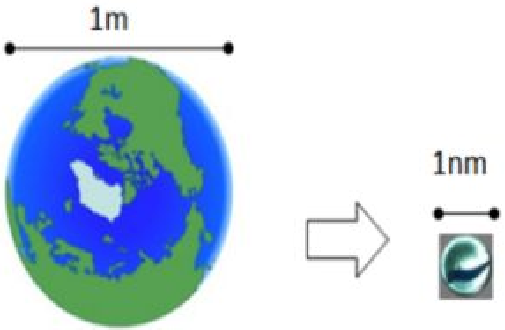
E-beam lithography
Nanoimprint Lithography



NANO particle

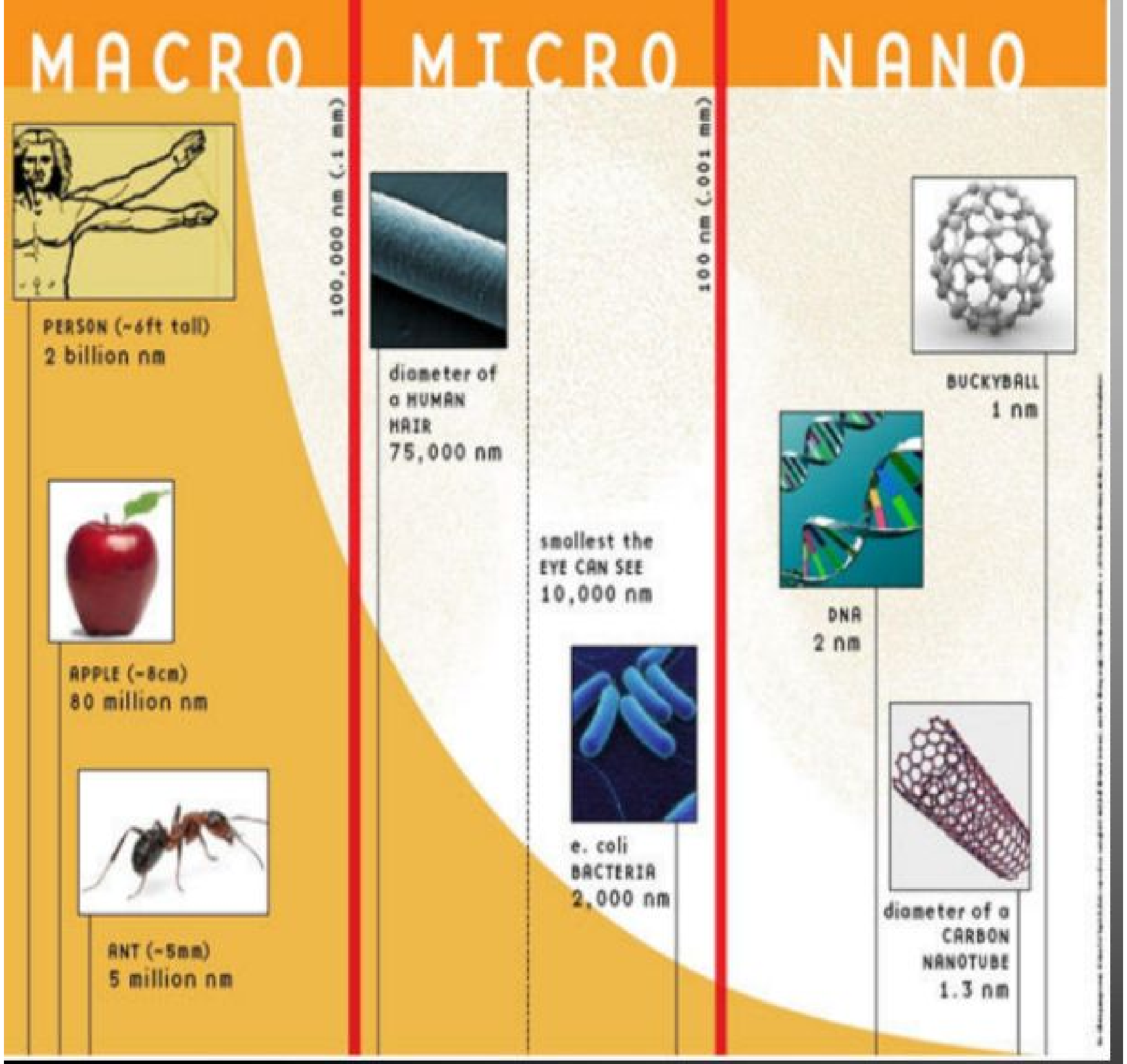
It is a size of 1 in 1 billion minutes.

If the size of a nanoparticle is compared



1 Nanometer is
The size of a marble

The diameter of the earth is 1 m.



MACRO

PERSON (~6ft tall)
2 billion nm

APPLE (~8cm)
80 million nm

ANT (~5mm)
5 million nm

100,000 nm (.1 mm)

MICRO

diameter of a HUMAN HAIR
75,000 nm

smallest the EYE CAN SEE
10,000 nm

e. coli BACTERIA
2,000 nm

100 nm (.001 mm)

NANO

BUCKYBALL
1 nm

DNA
2 nm

diameter of a CARBON NANOTUBE
1.3 nm

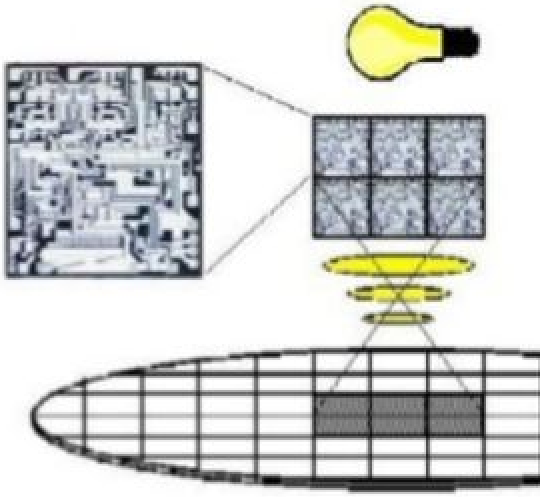
PHOTOLITHOGRAPHY ROOTS

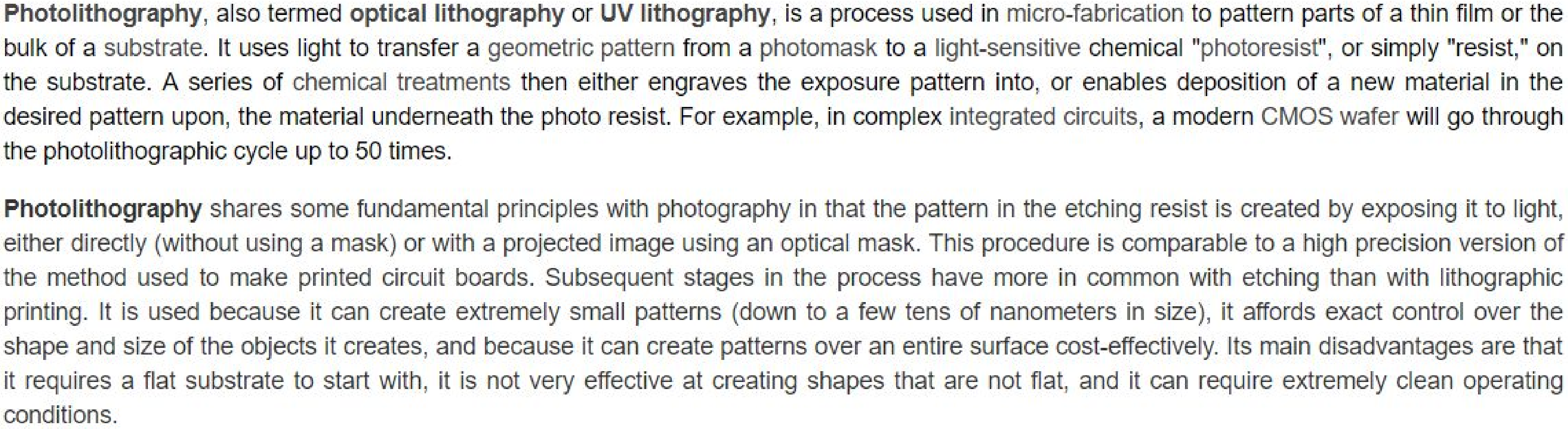
PHOTO–LITHO–GRAPHY

Printing with light

Photolithography

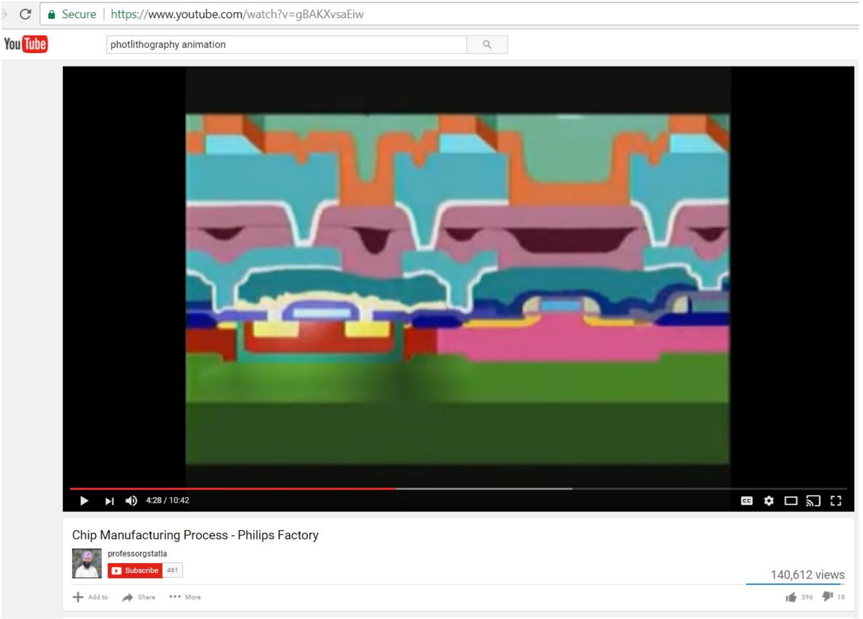
Photolithography is a technique that is used to define the shape of micro-machined structures on a wafer.





Photolithography, also termed **optical lithography** or **UV lithography**, is a process used in micro-fabrication to pattern parts of a thin film or the bulk of a substrate. It uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical "photoresist", or simply "resist," on the substrate. A series of chemical treatments then either engraves the exposure pattern into, or enables deposition of a new material in the desired pattern upon, the material underneath the photo resist. For example, in complex integrated circuits, a modern CMOS wafer will go through the photolithographic cycle up to 50 times.

Photolithography shares some fundamental principles with photography in that the pattern in the etching resist is created by exposing it to light, either directly (without using a mask) or with a projected image using an optical mask. This procedure is comparable to a high precision version of the method used to make printed circuit boards. Subsequent stages in the process have more in common with etching than with lithographic printing. It is used because it can create extremely small patterns (down to a few tens of nanometers in size), it affords exact control over the shape and size of the objects it creates, and because it can create patterns over an entire surface cost-effectively. Its main disadvantages are that it requires a flat substrate to start with, it is not very effective at creating shapes that are not flat, and it can require extremely clean operating conditions.



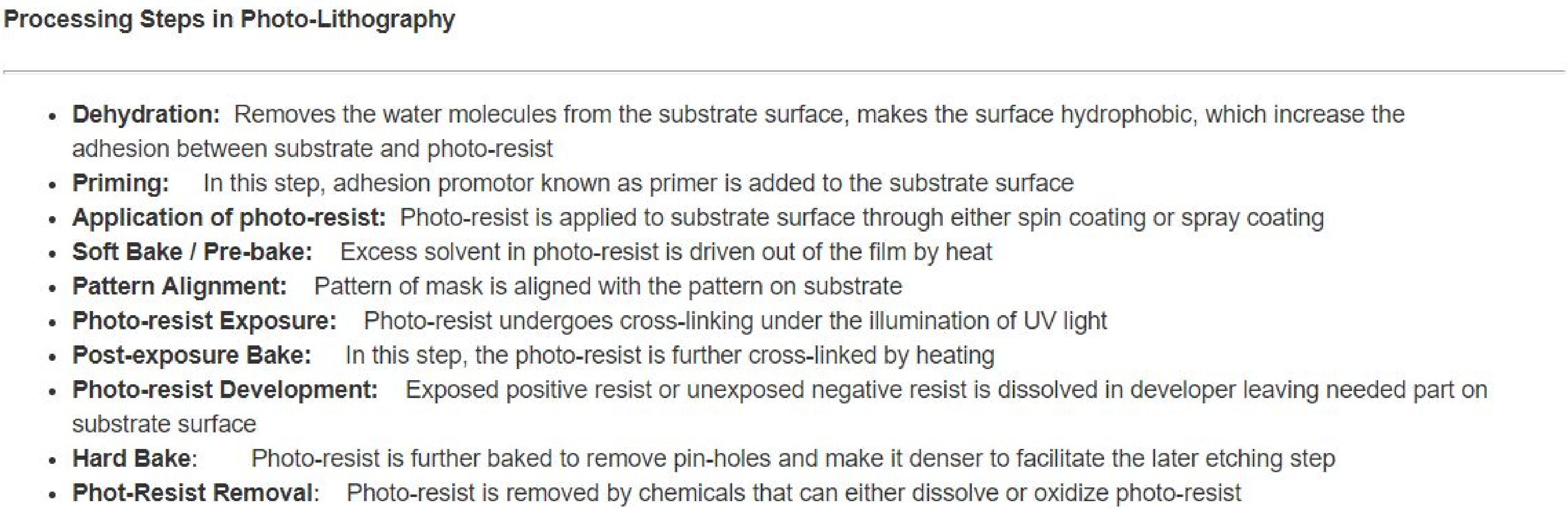
Secure | https://www.youtube.com/watch?v=gBAKXvsaEiw

photlithography animation

Chip Manufacturing Process - Philips Factory

professorgstatla

Play around the 4min mark for a minute or so to show/explain the patterning significance
https://www.youtube.com/watch?v=gBAKXvsaEiw



Processing Steps in Photo-Lithography

- **Dehydration:** Removes the water molecules from the substrate surface, makes the surface hydrophobic, which increase the adhesion between substrate and photo-resist
- **Priming:** In this step, adhesion promotor known as primer is added to the substrate surface
- **Application of photo-resist:** Photo-resist is applied to substrate surface through either spin coating or spray coating
- **Soft Bake / Pre-bake:** Excess solvent in photo-resist is driven out of the film by heat
- **Pattern Alignment:** Pattern of mask is aligned with the pattern on substrate
- **Photo-resist Exposure:** Photo-resist undergoes cross-linking under the illumination of UV light
- **Post-exposure Bake:** In this step, the photo-resist is further cross-linked by heating
- **Photo-resist Development:** Exposed positive resist or unexposed negative resist is dissolved in developer leaving needed part on substrate surface
- **Hard Bake**: Photo-resist is further baked to remove pin-holes and make it denser to facilitate the later etching step
- **Phot-Resist Removal**: Photo-resist is removed by chemicals that can either dissolve or oxidize photo-resist

- Surface Preparation
- Coating (Spin Casting)
- Pre-Bake (Soft Bake)
- Alignment
- Exposure
- Development
- Post-Bake (Hard Bake)
- Processing Using the Photoresist as a Masking Film
- Stripping
- Post Processing Cleaning (Ashing)

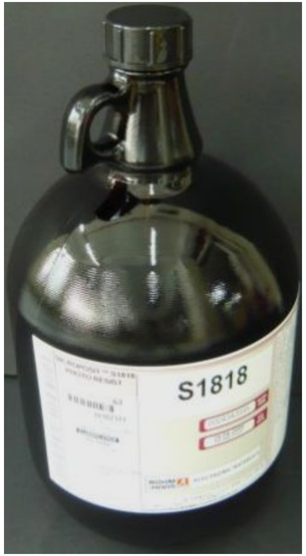
Photolithography Photoresist

The first step in the photolithography process is to develop a mask, which will be typically be a chromium pattern on a glass plate.

Next, the wafer is then coated with a polymer which is sensitive to ultraviolet light called a photoresist.

Afterward, the photoresist is then developed which transfers the pattern on the mask to the photoresist layer.

Photoresist Composition



- Polymer
- Solvents
- Sensitizers
- Additives

Changes solubility due to photochemical reaction when exposed to UV light.

Requirement of Photoresist

- **High resolution**
  - Thinner PR film has higher the resolution
  - Thinner PR film, the lower the etching and ion implantation resistance
- **High etch resistance**
- **Good adhesion**
- **Wider process latitude**
  - Higher tolerance to process conditions like spin rate, baking temperature and exposure flux

Photoresist Performance Factors :

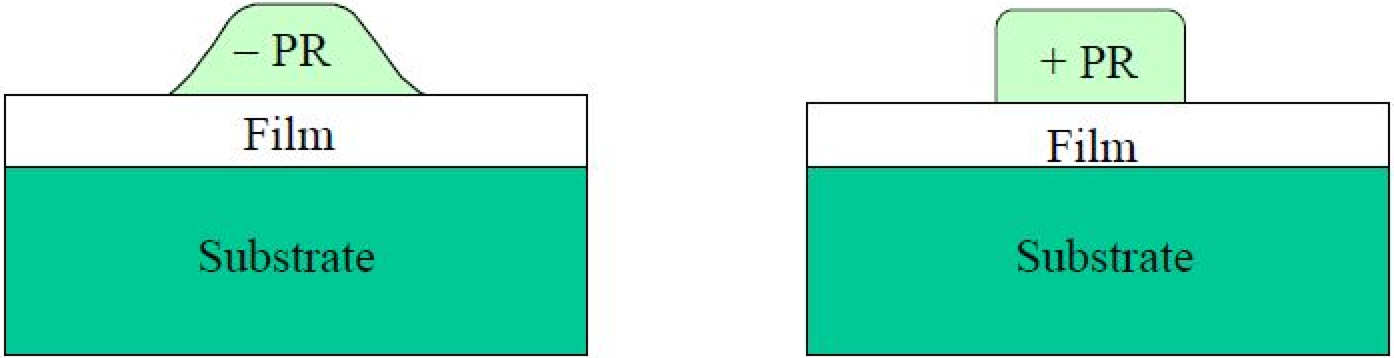
- Resolution
- Adhesion
- Expose rate, Sensitivity and Exposure Source
- Process latitude
- Pinholes
- Particle and Contamination Levels
- Step Coverage
- Thermal Flow

Positive and Negative Photoresist

There are two types of photoresist: positive and negative. For positive resists, the resist is exposed with UV light wherever the underlying material is to be removed. In these resists, exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer. The exposed resist is then washed away by the developer solution, leaving windows of the bare underlying material. In other words, "whatever shows, goes." The mask, therefore, contains an exact copy of the pattern which is to remain on the wafer.

Negative resists behave in just the opposite manner. Exposure to the UV light causes the negative resist to become polymerized, and more difficult to dissolve. Therefore, the negative resist remains on the surface wherever it is exposed, and the developer solution removes only the unexposed portions. Masks used for negative photoresists, therefore, contain the inverse (or photographic "negative") of the pattern to be transferred. The figure below shows the pattern differences generated from the use of positive and negative resist.

Comparison of Photoresists



In Short:

Negative Resist → Resist that is exposed to UV light REMAINS

Positive Resist → Resist that is exposed to UV light is REMOVED

(During Developing step)

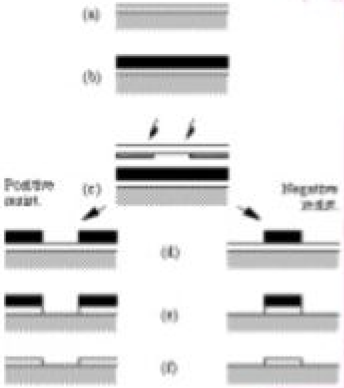
<60sec visual: https://www.youtube.com/watch?v=-pflilEyUIE

- Photoresist Types

- Positive Resist Shipley 1800 Series
- AZ 5200 series Image reversal
- AZ4620 Thick resist 10-20 microns
- Negative Resist SU8

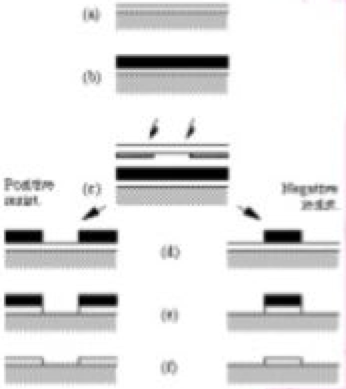
Photolithography Model

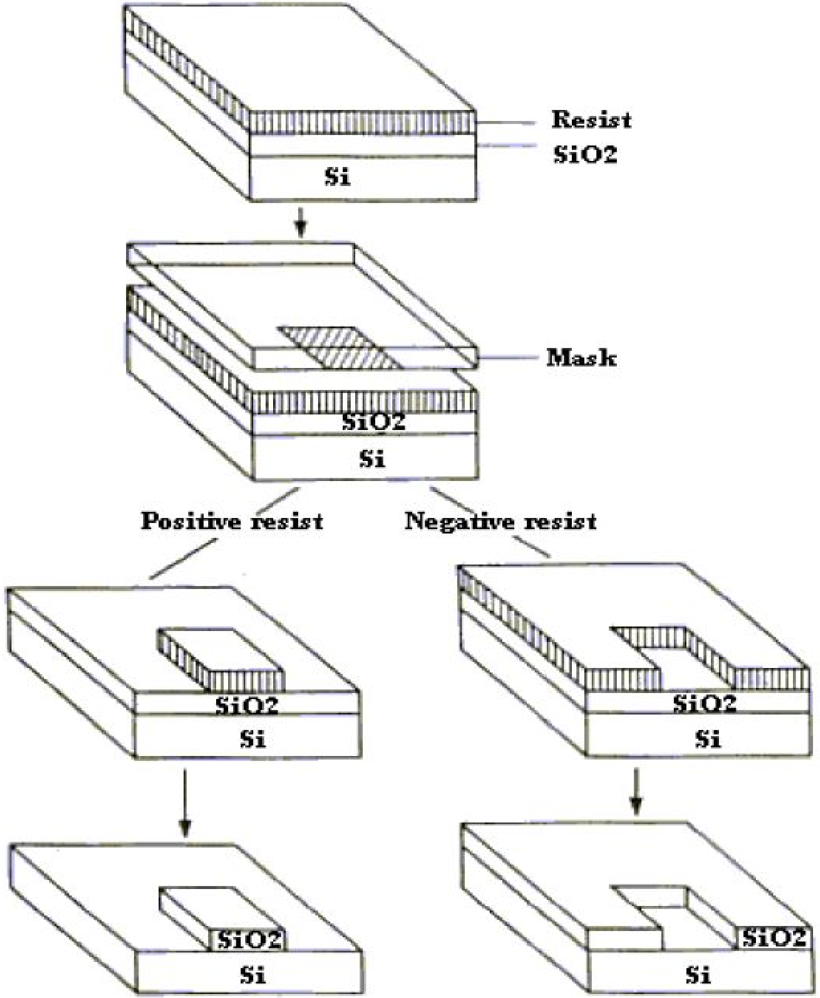
- Figure 1a shows a thin film of some material (eg, silicon dioxide) on a substrate of some other material (eg, a silicon wafer).
- Photoresist layer (Figure 1b)
- Ultraviolet light is then shone through the mask onto the photoresist (figure 1c).

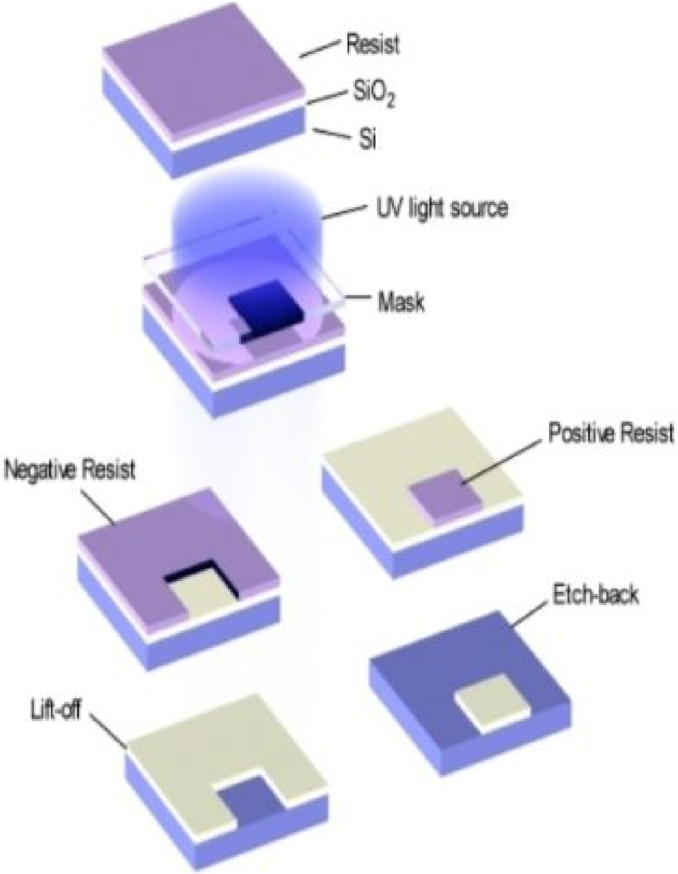


Photolithography Model

- The photoresist is then developed which transfers the pattern on the mask to the photoresist layer (figure 1d).
- A chemical (or some other method) is then used to remove the oxide where it is exposed through the openings in the resist (figure 1e).
- Finally the resist is removed leaving the patterned oxide (figure 1f).



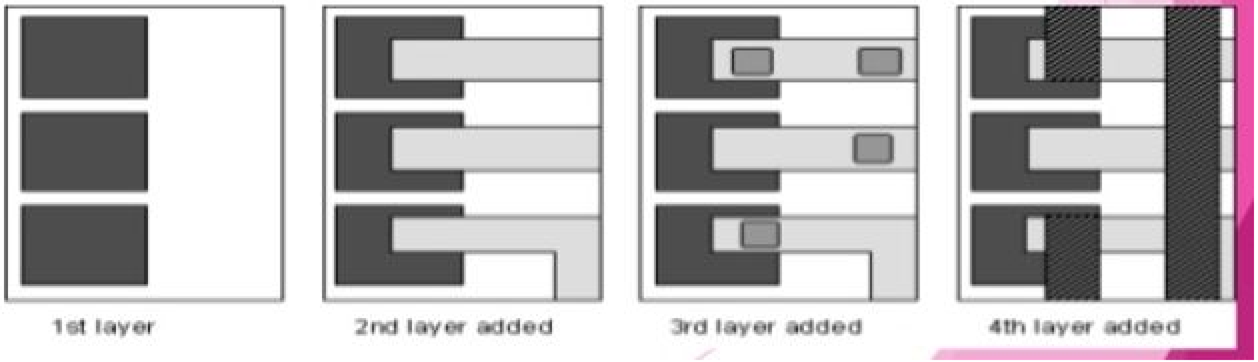

Resist
SiO2
Si
Mask
SiO2
Si
Positive resist
Negative resist
SiO2
Si
SiO2
Si
SiO2
Si
SiO2
Si


Resist
SiO$_2$
Si
UV light source
Mask
Positive Resist
Negative Resist
Etch-back
Lift-off

Photolithography
Photomasks and Reticles

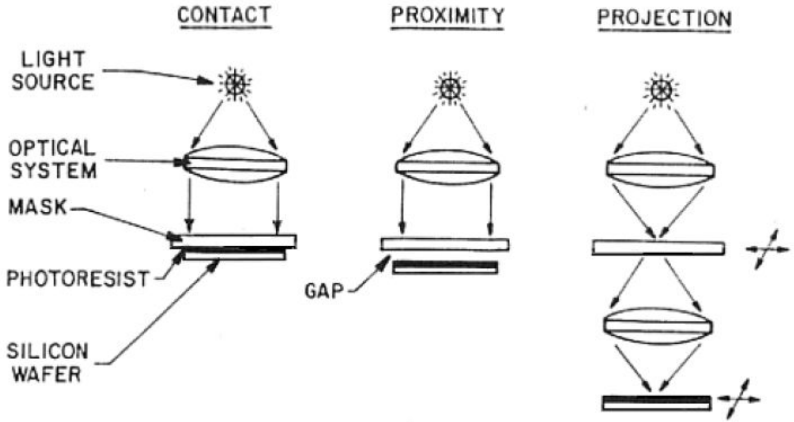
Photomask

This is a square glass plate with a patterned emulsion of metal film on one side. The mask is aligned with the wafer, so that the pattern can be transferred onto the wafer surface. Each mask after the first one must be aligned to the previous pattern.



Photolithography
Photomasks and Reticles

Once the mask has been accurately aligned with the pattern on the wafer's surface, the photoresist is exposed through the pattern on the mask with a high intensity ultraviolet light. There are three primary exposure methods: contact, proximity, and projection.



Photolithography Patterning

The last stage of Photolithography is a process called ashing. This process has the exposed wafers sprayed with a mixture of organic solvents that dissolves portions of the photoresist .

Conventional methods of ashing require an oxygen-plasma ash, often in combination with halogen gases, to penetrate the crust and remove the photoresist. Usually, the plasma ashing process also requires a follow-up cleaning with wet-chemicals and acids to remove the residues and non-volatile contaminants that remain after ashing. Despite this treatment, it is not unusual to repeat the "ash plus wet-clean" cycle in order to completely remove all photoresist and residues.

Contact Printing

In contact printing, the resist-coated silicon wafer is brought into physical contact with the glass photomask. The wafer is held on a vacuum chuck, and the whole assembly rises until the wafer and mask contact each other. The photoresist is exposed with UV light while the wafer is in contact position with the mask. Because of the contact between the resist and mask, very high resolution is possible in contact printing (e.g. 1-micron features in 0.5 microns of positive resist). The problem with contact printing is that debris, trapped between the resist and the mask, can damage the mask and cause defects in the pattern.

Proximity Printing

The proximity exposure method is similar to contact printing except that a small gap, 10 to 25 microns wide, is maintained between the wafer and the mask during exposure. This gap minimizes (but may not eliminate) mask damage. Approximately 2- to 4-micron resolution is possible with proximity printing.

Projection Printing

Projection printing, avoids mask damage entirely. An image of the patterns on the mask is projected onto the resist-coated wafer, which is many centimeters away. In order to achieve high resolution, only a small portion of the mask is imaged. This small image field is scanned or stepped over the surface of the wafer. Projection printers that step the mask image over the wafer surface are called step-and-repeat systems. Step-and-repeat projection printers are capable of approximately 1-micron resolution.

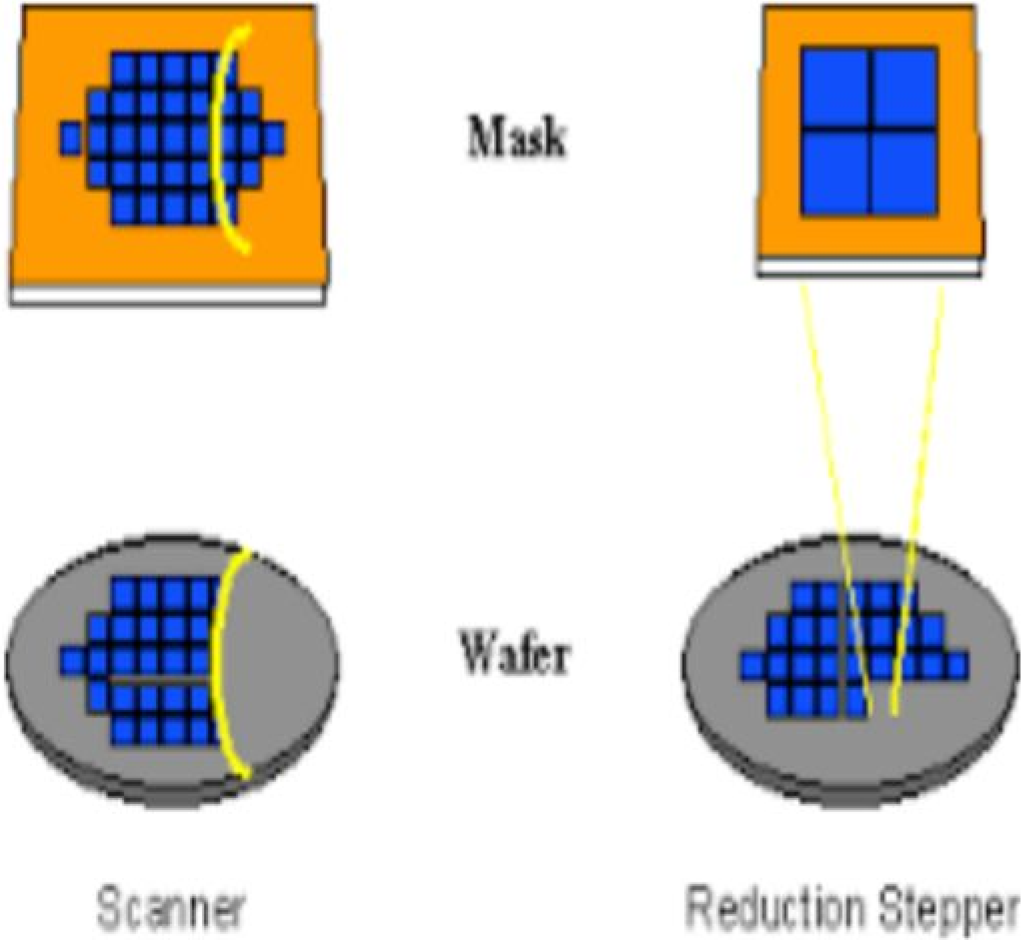
Projection exposure systems (steppers or scanners) project the mask onto the wafer many times to create the complete pattern.

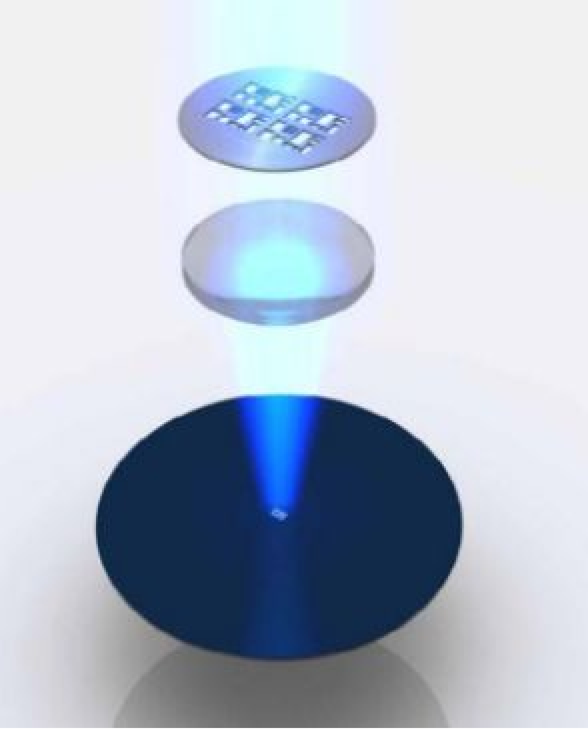

Emergency Exit Only
Do Not Enter
HITACHI


Canon
FPA-3000 i4
Fine Pattern Aligner
CAUTION
LASER INTERLOCKS HAVE BEEN DISABLED


Canon
FPA-3000
10/09/2010

A typical stepper has the following subassemblies: wafer loader, wafer stage, wafer alignment system, reticle loader, reticle stage, reticle alignment system, reduction lens, and illumination system. Process programs for each layer printed on the wafer are executed by a control system centering on a computer that stores the process program, reads it, and communicates with the various subassemblies of the stepper in carrying out the program's instructions. The components of the stepper are contained in a sealed chamber that is maintained at a precise temperature to prevent distortions in the printed patterns that might be caused by expansion or contraction of the wafer due to temperature variations.


Mask
Wafer
Scanner
Reduction Stepper



- For simple contact, proximity, and projection systems, the mask is the same size and scale as the printed wafer pattern.
  I.e. the reproduction ratio is 1:1.
- Projection systems give the ability to change the reproduction ratio. Going to 10:1 reduction allows larger size patterns on the mask, which is more robust to mask defects.
- Mask size can get unwieldy for large wafers.
- Most wafers contain an array of the same pattern, so only one cell of the array is needed on the mask.
  This system is called Direct Step on Wafer (DSW).
  These machines are also called "Steppers"
- Example: GCA-4800 (original machine)
- Advantage of steppers: only 1 cell of wafer is needed
- Disadvantage of steppers: the 1 cell of the wafer on the mask must be perfect-- absolutely no defects, since it gets used for all die.

- Higher end research systems go one step further and use Direct Write on Wafer (DWW) exposure systems.
- This can be accomplished using:
  - Excimer lasers for geometries down to 1-2 μm
  - Electron beams for geometries down to 0.1-0.2 μm
  - Focused ion beams for geometries down to 0.05-0.1 μm
- No mask is needed for these technologies.
- These are serial processes, and wafer cycle time is proportional to the beam writing time-- the smaller the spot, the longer it takes!

PHOTOLITHOGRAPHY

TEAM C
Conrad Mish, Daniel Bennett, Timothy Eikenberry

Mechanical & Industrial Engineering
UMass Amherst

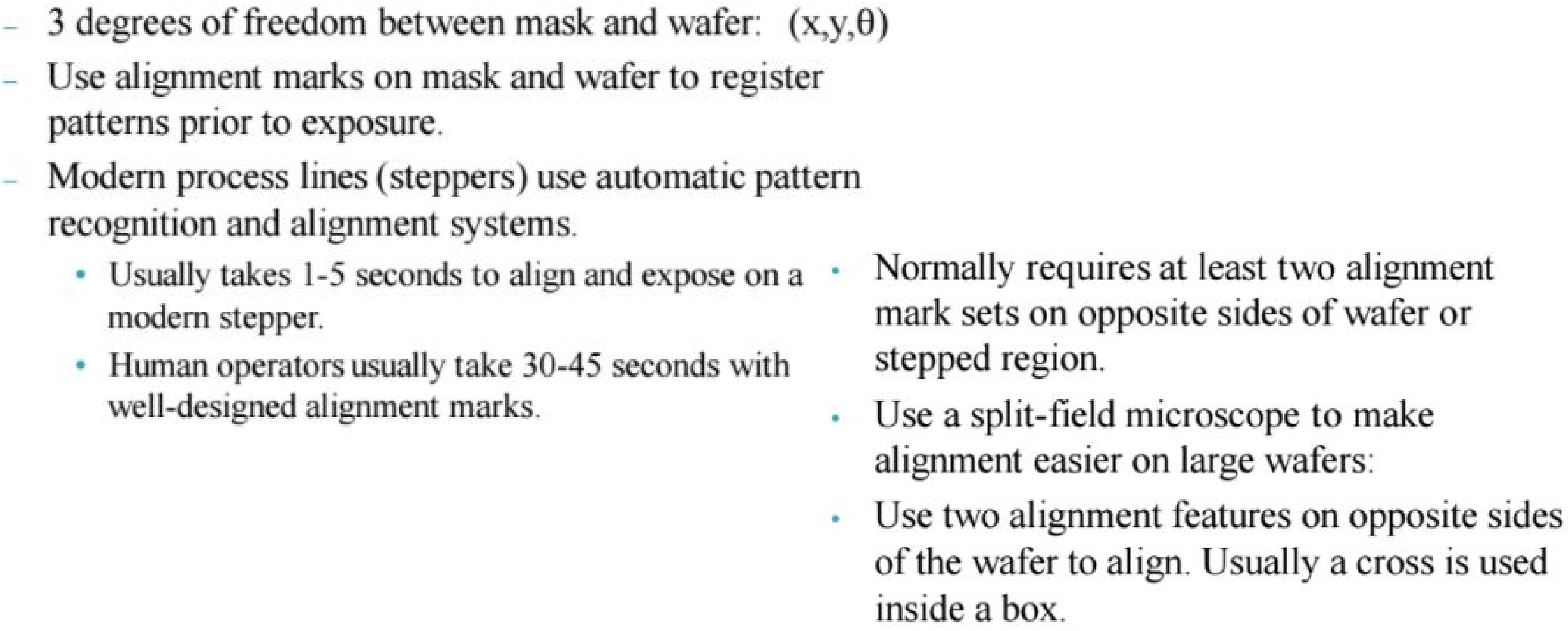
*Group Project for MIE597MM (2015)

Photolithography: Step by step

Jae-Hwang Lee

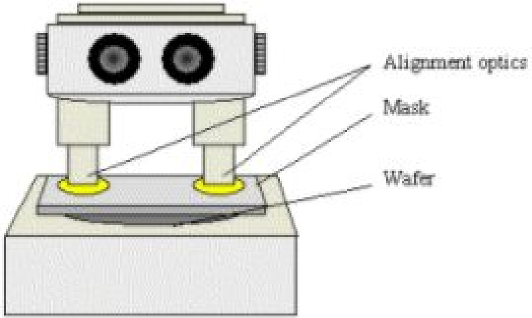
Play 1m15s to 4m10s then skim near the end: https://www.youtube.com/watch?v=oBKhN4n-EGI

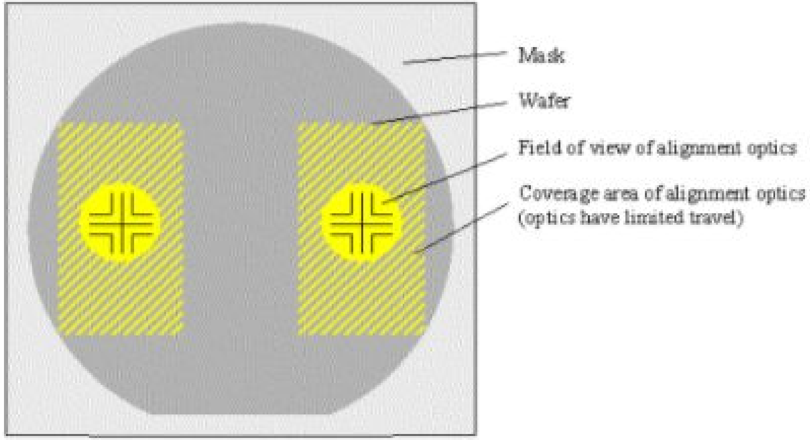
Alignment



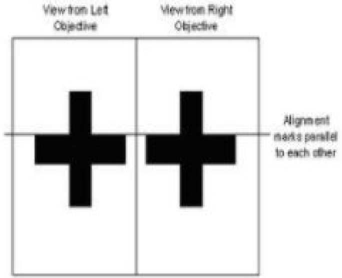
- 3 degrees of freedom between mask and wafer: (x,y,θ)
- Use alignment marks on mask and wafer to register patterns prior to exposure.
- Modern process lines (steppers) use automatic pattern recognition and alignment systems.
  - Usually takes 1-5 seconds to align and expose on a modern stepper.
  - Human operators usually take 30-45 seconds with well-designed alignment marks.
  - Normally requires at least two alignment mark sets on opposite sides of wafer or stepped region.
  - Use a split-field microscope to make alignment easier on large wafers:
  - Use two alignment features on opposite sides of the wafer to align. Usually a cross is used inside a box.

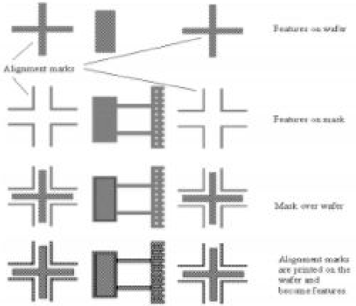
Alignment

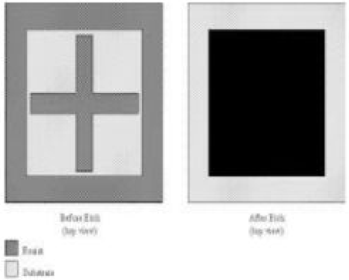


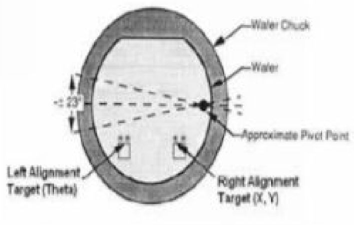


Contact lithography









- Contact Lithography
- Karl Suss Mask Aligner
- Quintel Mask Aligner
- Casper

Photolithography

Hua, Tiffany Phuong
Li, Andi
Liu, Yuanfeng

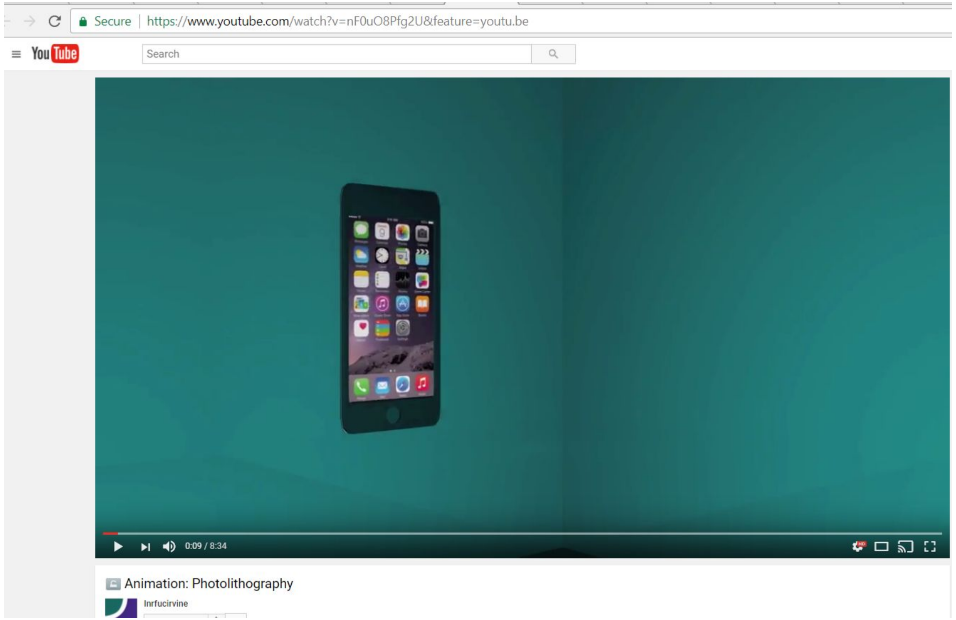
Mechanical & Industrial Engineering
UMass Amherst

* Group project for MIE 597MM/697MM(2015)

Photolithography: How it works.

Jae-Hwang Lee

<5min good Student User Perspective of Photolithography https://www.youtube.com/watch?v=ejS83D3L5XI

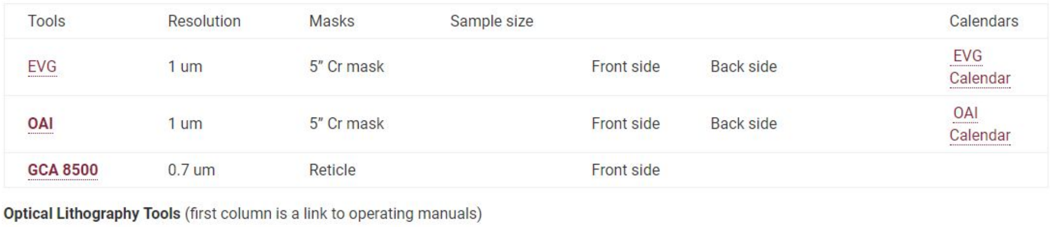


Animation: Photolithography

lnrfucirvine

8min: https://www.youtube.com/watch?v=nF0uO8Pfg2U&feature=youtu.be

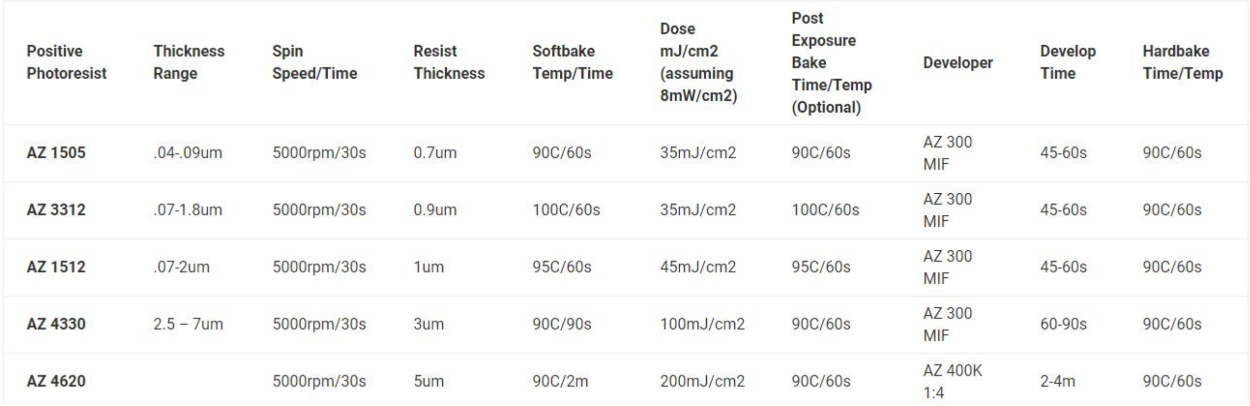
Spin Coat Resist



Description:

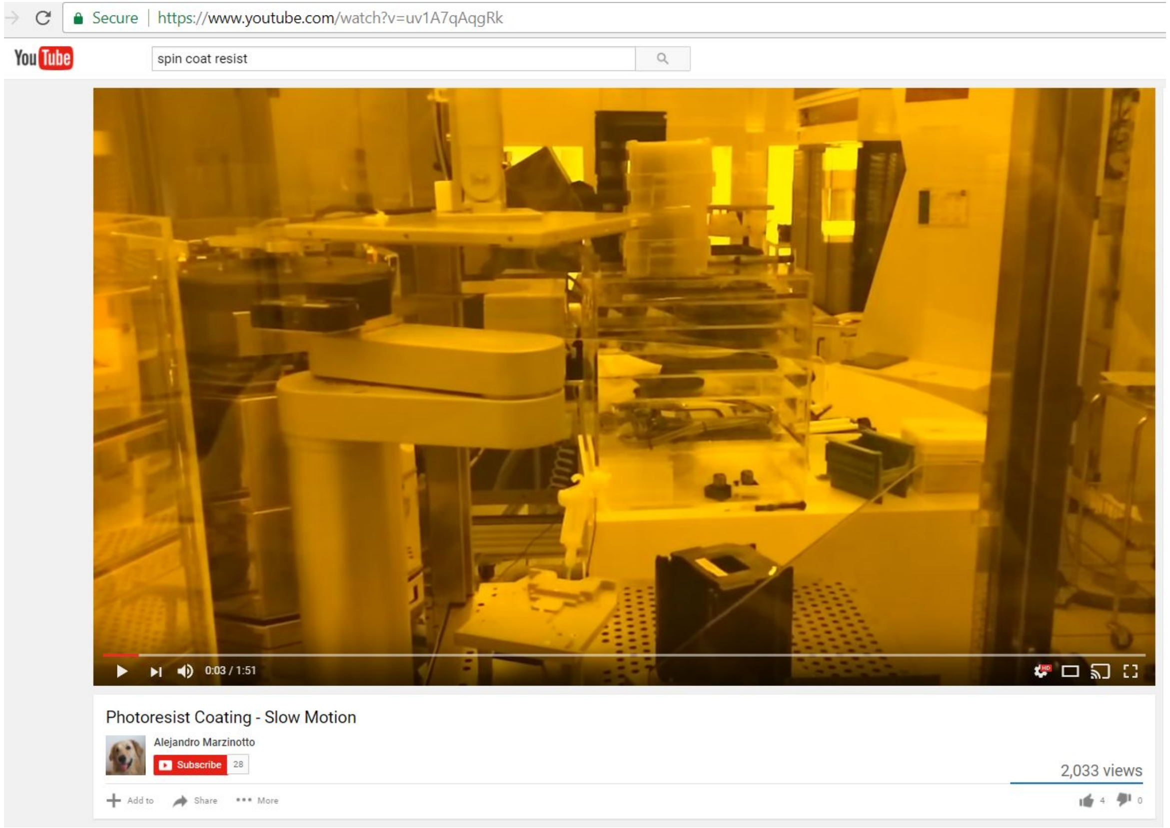
Tools	Resolution	Masks	Sample size		Calendars
EVG	1 um	5” Cr mask	Front side	Back side	EVG Calendar
OAI	1 um	5” Cr mask	Front side	Back side	OAI Calendar
GCA 8500	0.7 um	Reticle	Front side		

Optical Lithography Tools (first column is a link to operating manuals)



Positive Photoresist	**Thickness Range**	**Spin Speed/Time**	**Resist Thickness**	**Softbake Temp/Time**	**Dose mJ/cm2 (assuming 8mW/cm2)**	**Post Exposure Bake Time/Temp (Optional)**	**Developer**	**Develop Time**	**Hardbake Time/Temp**
AZ 1505	.04-.09um	5000rpm/30s	0.7um	90C/60s	35mJ/cm2	90C/60s	AZ 300 MIF	45-60s	90C/60s
AZ 3312	.07-1.8um	5000rpm/30s	0.9um	100C/60s	35mJ/cm2	100C/60s	AZ 300 MIF	45-60s	90C/60s
AZ 1512	.07-2um	5000rpm/30s	1um	95C/60s	45mJ/cm2	95C/60s	AZ 300 MIF	45-60s	90C/60s
AZ 4330	2.5 – 7um	5000rpm/30s	3um	90C/90s	100mJ/cm2	90C/60s	AZ 300 MIF	60-90s	90C/60s
AZ 4620		5000rpm/30s	5um	90C/2m	200mJ/cm2	90C/60s	AZ 400K 1:4	2-4m	90C/60s

Example Process Suggestion Table



Secure | https://www.youtube.com/watch?v=uv1A7qAqgRk

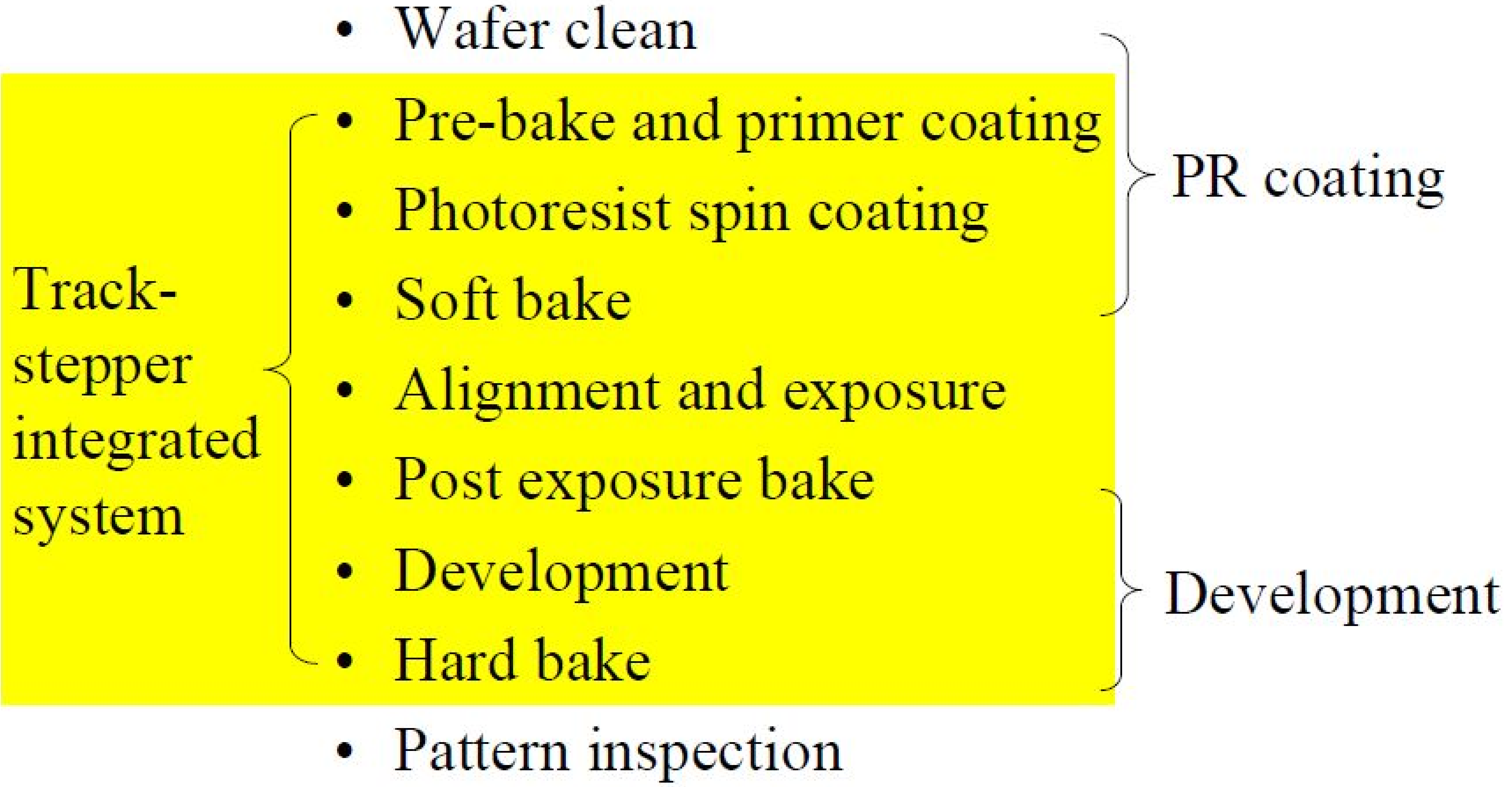
spin coat resist

Photoresist Coating - Slow Motion

Alejandro Marzinotto

2,033 views

<2min Automated Spin Coat Resist https://www.youtube.com/watch?v=uv1A7qAqgRk



- Wafer clean
- Pre-bake and primer coating
- Photoresist spin coating
- Soft bake
- Alignment and exposure
- Post exposure bake
- Development
- Hard bake
- Pattern inspection

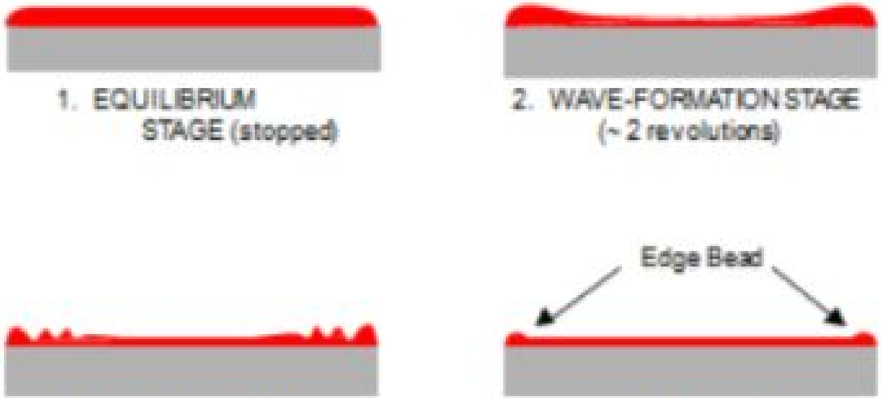
Track-stepper integrated system

PR coating

Development

- Wafer is held on a spinner chuck by vacuum and resist is coated to uniform thickness by spin coating.
- Typically 3000-6000 rpm for 15-30 seconds.
- Resist thickness is set by:
  - primarily resist viscosity
  - secondarily spinner rotational speed
- Resist thickness 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.

Stages of Resist Coating

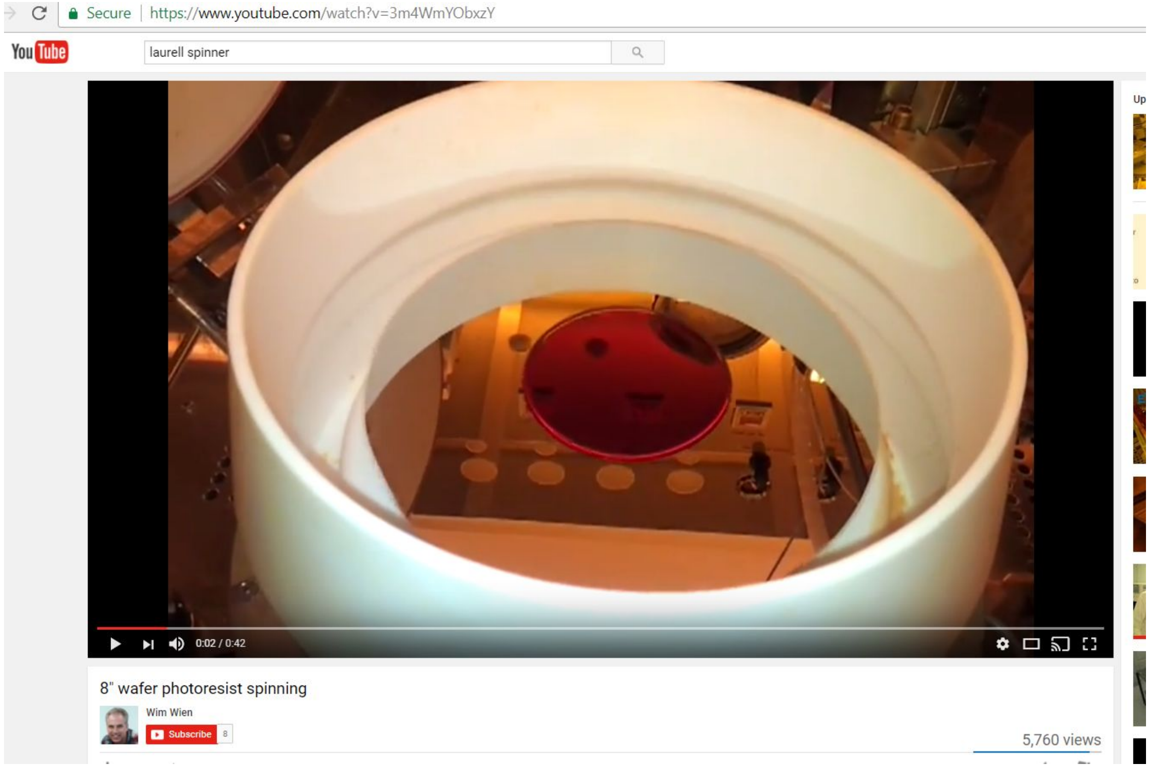


1. EQUILIBRIUM STAGE (stopped)

2. WAVE-FORMATION STAGE (~ 2 revolutions)

3. CORONA STAGE (~ 30 revolutions)

4. SPIRAL STAGE (~ 1000 revolutions)



Secure | https://www.youtube.com/watch?v=3m4WmYObxzY

laurell spinner

8" wafer photoresist spinning

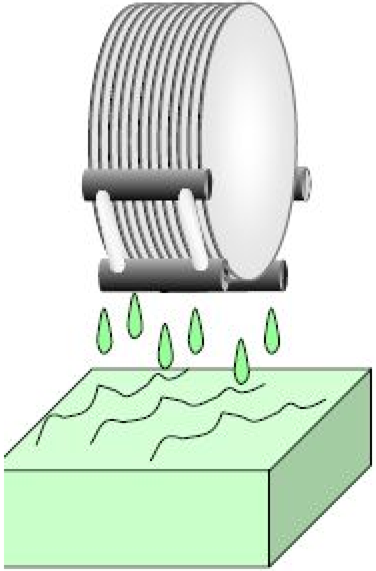
Wim Wien

5,760 views

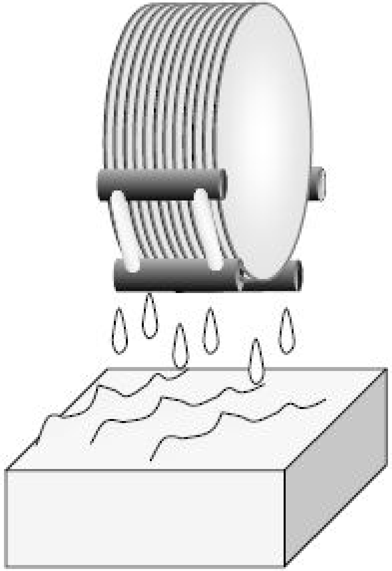
45sec 8” manual spin coat: https://www.youtube.com/watch?v=3m4WmYObxzY

Wafer Clean

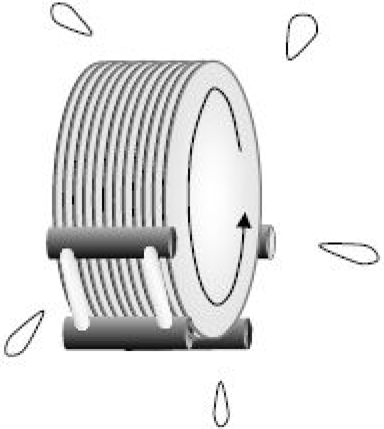
- Remove contaminants
- Remove particulate
- Reduce pinholes and other defects
- Improve photoresist adhesion
- Basic steps
  - Chemical clean
  - Rinse
  - Dry



Chemical Clean

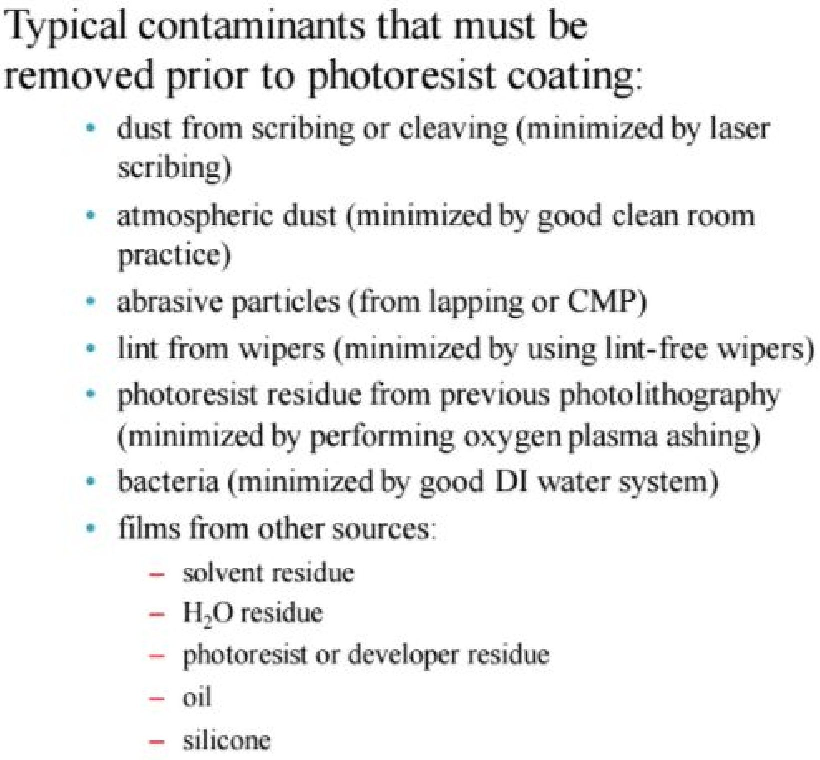


Rinse



Dry

Surface Prep / Cleaning



Typical contaminants that must be removed prior to photoresist coating:

- dust from scribing or cleaving (minimized by laser scribing)
- atmospheric dust (minimized by good clean room practice)
- abrasive particles (from lapping or CMP)
- lint from wipers (minimized by using lint-free wipers)
- photoresist residue from previous photolithography (minimized by performing oxygen plasma ashing)
- bacteria (minimized by good DI water system)
- films from other sources:
  - solvent residue
  - H_2O residue
  - photoresist or developer residue
  - oil
  - silicone

Standard degrease:

- 2-5 min. soak in acetone with ultrasonic agitation
- 2-5 min. soak in methanol with ultrasonic agitation
- 2-5 min. soak in DI H_2O with ultrasonic agitation
- 30 sec. rinse under free flowing DI H_2O
- spin rinse dry for wafers; N_2 blow off dry for tools and chucks

For particularly troublesome grease, oil, or wax stains:

- Start with 2-5 min. soak in 1,1,1-trichloroethane (TCA) or trichloroethylene (TCE) with ultrasonic agitation prior to acetone

Hazards:

- TCE is carcinogenic; 1,1,1-TCA is less so
- acetone is flammable
- methanol is toxic by skin adsorption

- RCA clean: use for new silicon wafers out of the box
  - 1. APW: NH_4OH (1) + H_2O_2 (3) + H_2O (15) @ 70°C for 15 min.
  - 2. DI H_2O rinse for 5 min.
  - 3. 10:1 BOE for 1 min.
  - 4. DI H_2O rinse for 5 min.
  - 5. HPW: HCl (1) + H_2O_2 (3) + H_2O (15) @ 70°C for 15 min.
  - 6. DI H_2O rinse for 5 min.
  - 7. Spin & rinse dry

Adhesion promoters are used to assist resist coating.

Resist adhesion factors:

  - moisture content on surface
  - wetting characteristics of resist
  - type of primer
  - delay in exposure and prebake
  - resist chemistry
  - surface smoothness
  - stress from coating process
  - surface contamination

Ideally want no H_2O on wafer surface

- Wafers are given a “singe” step prior to priming and coating
  - 15 minutes in 80-90°C convection oven

Used for silicon:

- primers form bonds with surface and produce a polar (electrostatic) surface
- most are based upon siloxane linkages (Si-O-Si)
  - 1,1,1,3,3,3-hexamethyldisilazane (HMDS), $(CH_3)_3SiNHSi(CH_3)_3$
  - trichlorophenylsilane (TCPS), $C_6H_5SiCl_3$
  - bistrimethylsilylacetamide (BSA), $(CH_3)_3SiNCH_3COSi(CH_3)_3$

Used for gallium arsenide:

- GaAs already has a polar surface
  - monazoline C
  - trichlorobenzene
  - xylene

Photolithography Process, Prebake

- Dehydration bake
- Remove moisture from wafer surface
- Promote adhesion between PR and surface
- Usually around 100 °C
- Integration with primer coating

Soft-Baking

Soft-baking is the step during which almost all of the solvents are removed from the photoresist coating. Soft-baking plays a very critical role in photo-imaging. The photoresist coatings become photosensitive, or imageable, only after softbaking. Oversoft-baking will degrade the photosensitivity of resists by either reducing the developer solubility or actually destroying a portion of the sensitizer. Undersoft-baking will prevent light from reaching the sensitizer. Positive resists are incompletely exposed if considerable solvent remains in the coating. This undersoft-baked positive resists is then readily attacked by the developer in both exposed and unexposed areas, causing less etching resistance.

Hard-Baking

Hard-baking is the final step in the photolithographic process. This step is necessary in order to harden the photoresist and improve adhesion of the photoresist to the wafer surface.

Postbake (Hard Bake) - 2

- Firm postbake is needed for acid etching, e.g. BOE.
- Postbake is not needed for processes in which a soft resist is desired, e.g. metal liftoff patterning.
- Photoresist will undergo plastic flow with sufficient time and/or temperature:
  - Resist reflow can be used for tailoring sidewall angles.

- Used to evaporate the coating solvent and to densify the resist after spin coating.
- Typical thermal cycles:
  - 90-100°C for 20 min. in a convection oven
  - 75-85°C for 45 sec. on a hot plate
- Commercially, microwave heating or IR lamps are also used in production lines.
- Hot plating the resist is usually faster, more controllable, and does not trap solvent like convection oven baking.

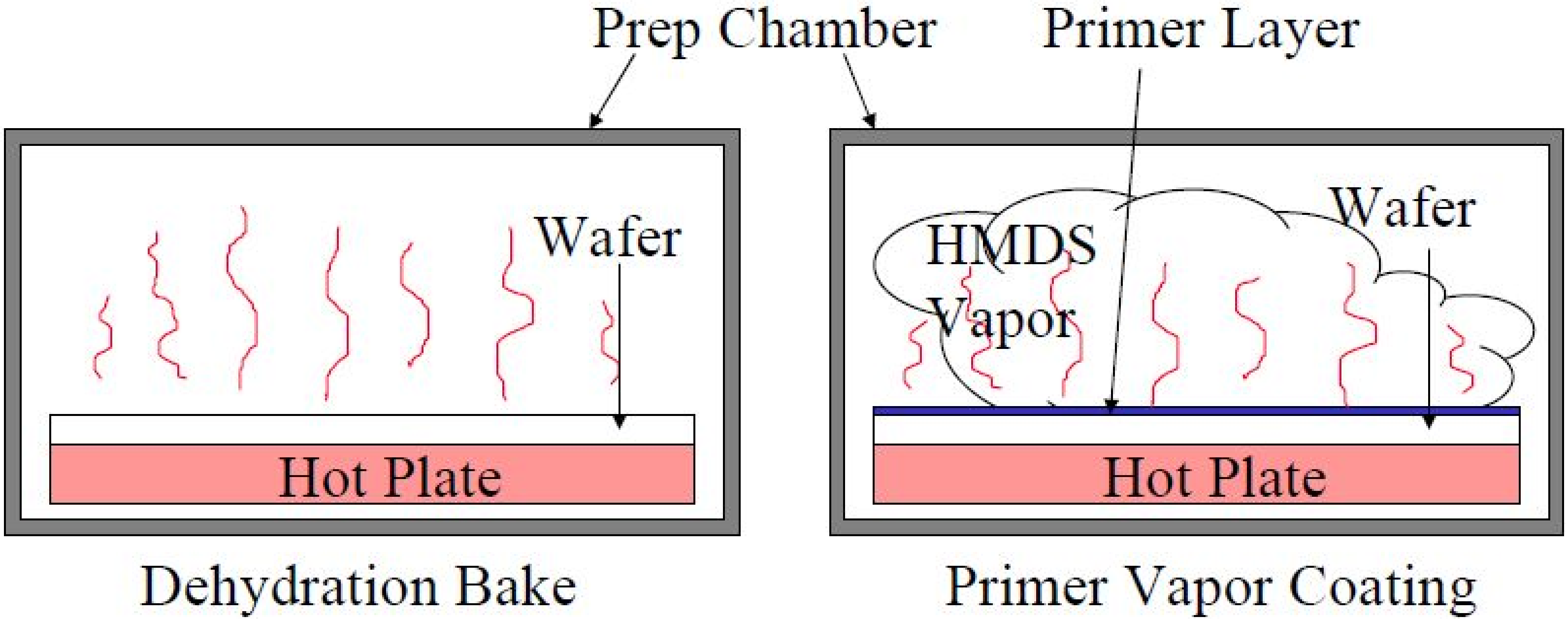
- A narrow time-temperature window is needed to achieve proper linewidth control.
- The thickness of the resist is usually decreased by 25 % during prebake for both positive and negative resists.
- Less prebake increases the development rate:

- Convection ovens:
  - Solvent at surface of resist is evaporated first, which can cause resist to develop impermeable skin, trapping the remaining solvent inside
  - Heating must go slow to avoid solvent burst effects
- Conduction (hot plate):
  - Need an extremely smooth surface for good thermal contact and heating uniformity
  - Temperature rise starts at bottom of wafer and works upward, more thoroughly evaporating the coating solvent
  - Generally much faster and more suitable for automation

Photolithography Process, Primer

- Promotes adhesion of PR to wafer surface
- Wildly used: Hexamethyldisilazane (HMDS)
- HMDS vapor coating prior to PR spin coating
- Usually performed in-situ with pre-bake
- Chill plate to cool down wafer before PR coating

Pre-bake and Primer Vapor Coating



Wafer Cooling

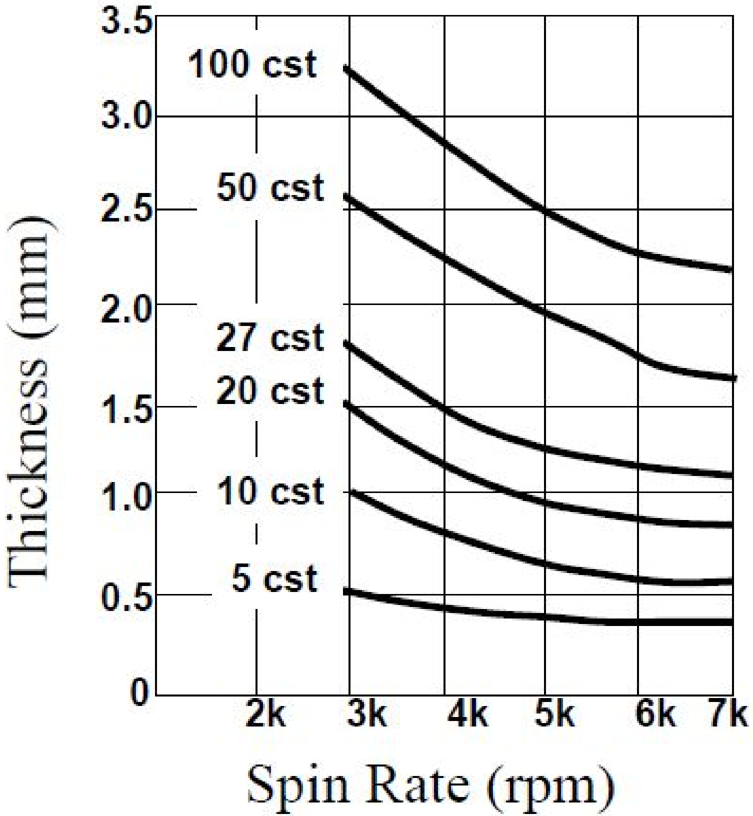
- Wafer need to cool down
- Water-cooled chill plate
- Temperature can affect PR viscosity
  - Affect PR spin coating thickness

Spin Coating

- Wafer sit on a vacuum chuck
- Rotate at high speed
- Liquid photoresist applied at center of wafer
- Photoresist spread by centrifugal force
- Evenly coat on wafer surface

to Spin Rate and Viscosity

- Flui
- Affe
- Rela
- Nee



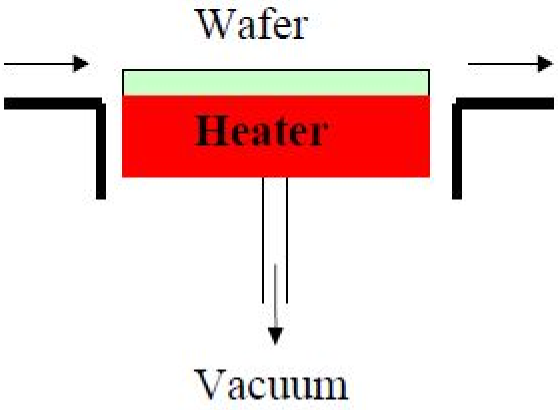
PR Spin Coater

- Photoresist spread on spinning wafer surface
- Wafer held on a vacuum chuck
- Slow spin ~ 500 rpm
- Ramp up to ~ 3000 - 7000 rpm

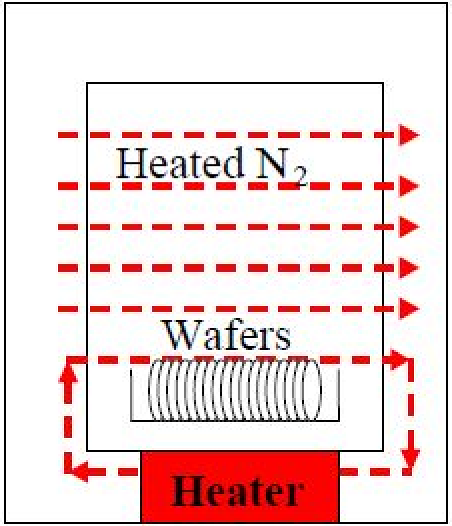
Soft Bake

- Evaporating most of solvent (> 80%) in PR
- Solvents help to make a thin PR but absorb radiation and affect adhesion
- Soft baking time and temperature are determined by PR types and specific process
- 90~110°C for 30 min. in oven; 10~15 min. for hotplate
- Over bake: polymerized, less photo-sensitivity
- Under bake: affect adhesion and exposure

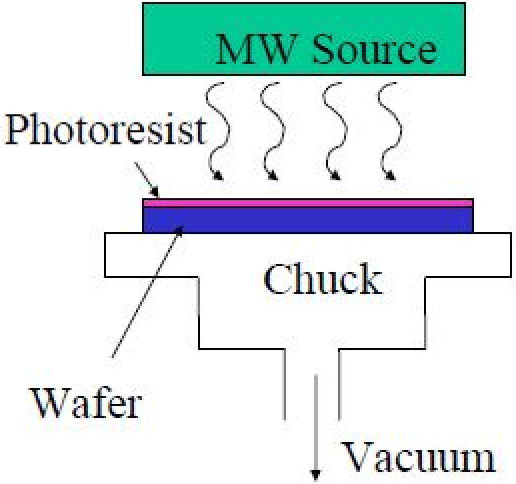
Baking Tools



Hot plate



Convection oven



Microwave oven

Wafer Cooling

- Need to cool down to ambient temperature after baking
- Water-cooled chill plate
- Silicon thermal expansion rate: $2.5\times10^{-6}/°C$
- For 8 inch (200 mm) wafer, 1°C thermal change causes 0.5 μm difference in diameter

Alignment and Exposure

- Most critical process for IC fabrication
- Most expensive tool (stepper) in an IC fab.
- Most challenging technology
- Determines the minimum feature size

Contact Printer

- Simple equipment. Widely used before mid-70s
- Resolution: capable for sub-micron
- Use of UV light source
- Image ratio 1:1
- Direct mask-wafer contact, limited mask lifetime
- Particle contamination issue

Proximity Printer

- 10 ~ 20 μm distance from wafer surface. No direct contact
- Use of UV light
- Image ratio 1:1
- Less particles and longer mask lifetime
- Resolution: > 2 μm

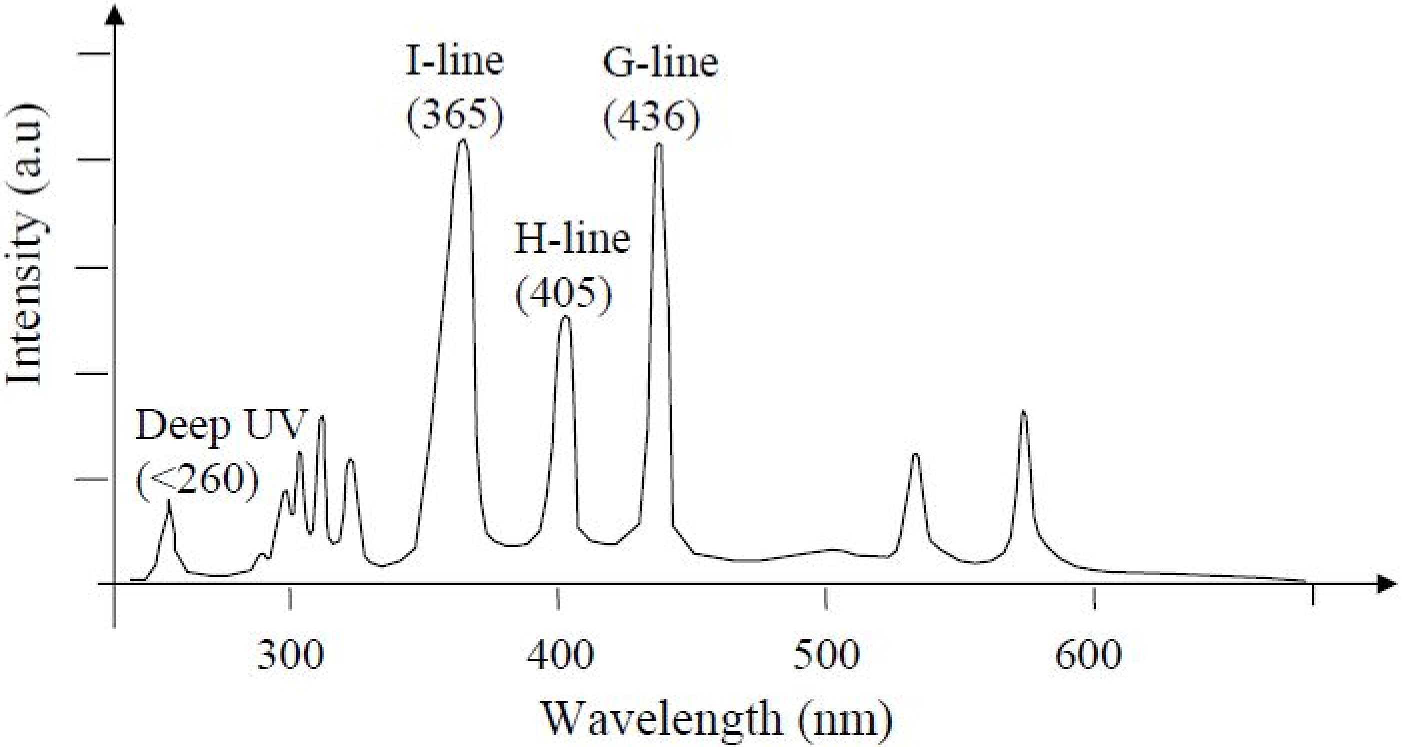
Projection Printer

- Works like an overhead projector
- Mask to wafer ratio, 1:1
- Resolution to reach at 1 μm
- The scanning projection exposure system
  - the mask and wafer stage move synchronously, allowing UV light source scanning across the mask to refocus and expose PR across the wafer

Stepper

- Most popular used photolithography tool in the advanced IC fabs
- Reduction of wafer image gives high resolution
- Use of deep UV light
- Reticle-to-wafer ratio ~ 10:1
- A reticle with 1.25 μm min. feature size say can achieve 0.125 μm min. feature size on wafer
- Very expensive ! (extremely complicated and precise)

Spectrum of the Mercury Lamp



Photolithography Light Sources

	Name	**Wavelength (nm)**	**Application feature size (μm)**
Mercury Lamp	G-line	436	0.50
	H-line	405	
	I-line	365	0.35 to 0.25
Excimer Laser	XeF	351	
	XeCl	308	
	KrF (DUV)	248	0.25 to 0.15
	ArF	193	0.18 to 0.13
Fluorine Laser	F_2	157	0.13 to 0.1

Exposure Control

- Exposure light flux is controlled by production of light intensity and exposure time
- Very similar to the exposure of a camera
- Intensity controlled by electrical power
- Adjustable light intensity
- Routine light intensity calibration is required.

Intensity, ***I***, measured in mW/cm^2

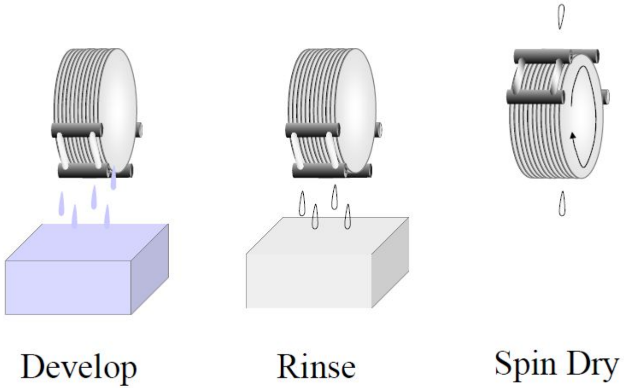
Post Exposure Bake Steps

- PEB normally uses hot plate at 110 to 130 °C for about 1 minute.
- For the same kind of PR, PEB usually requires a higher temperature than soft bake.
- Insufficient PEB will not completely eliminate the standing wave pattern,
- Overbaking will cause polymerization and affects photoresist development

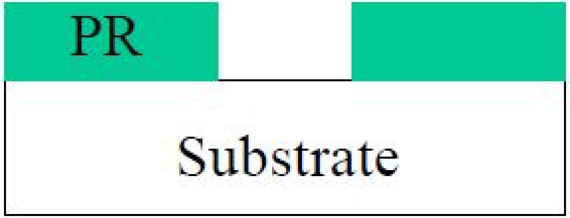
Development

- Developer solvent dissolves the softened part of photoresist
- Transfer the pattern from mask or reticle to photoresist
- Three basic steps:
  - – Development
  - – Rinse
  - – Dry

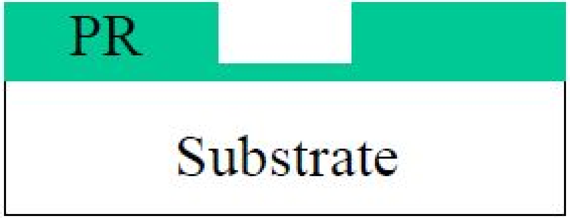
Development: Immersion



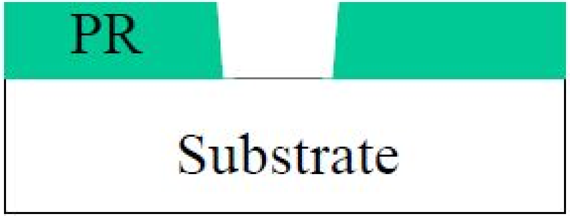
Development Profiles



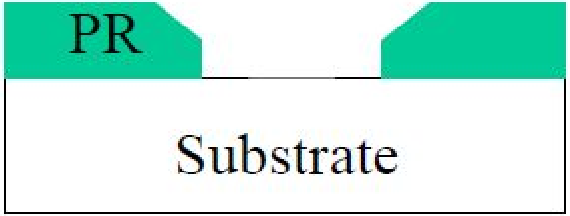
Normal Development



Incomplete Development



Under Development



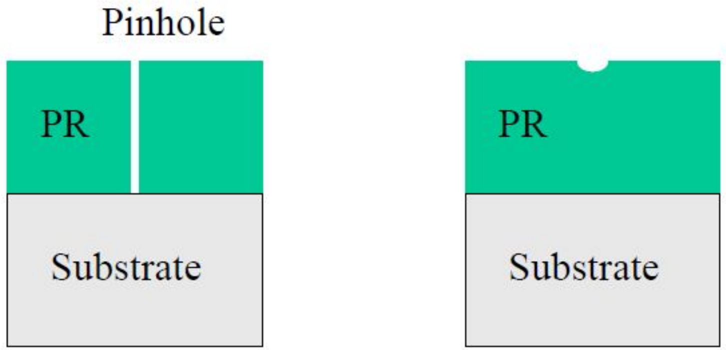
Over Development

Developer Solutions

	Positive PR	Negative PR
Developer	TMAH	Xylene
Rinse	DI Water	n-Butylacetate

Hard Bake

- Evaporating all solvents in PR
- Improving etch and implantation resistance
- Improve PR adhesion with surface
- Polymerize and stabilize photoresist
- PR flow to fill pinhole

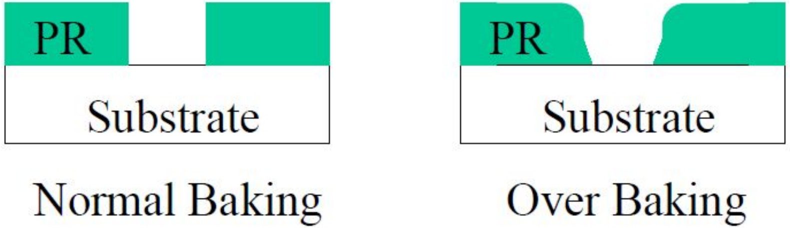


Hard Bake (cont.)

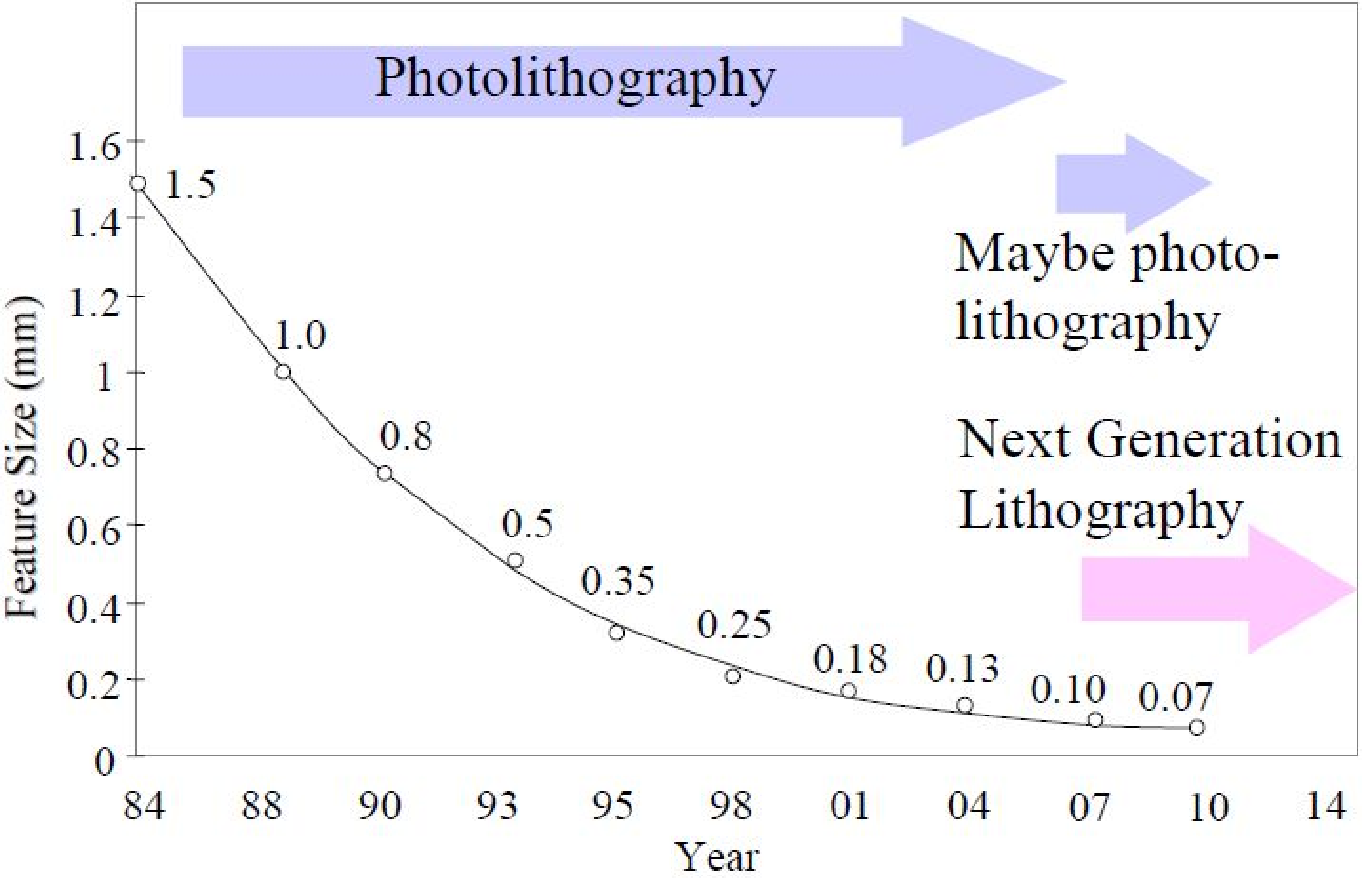
- Hot plate is commonly used
- Can be performed in a oven after inspection
- Hard bake temperature: 100 to 130 °C
- Baking time is about 1 to 2 minutes
- Hard bake temperature normally is higher than the soft bake temperature for the same kind of photoresist

Improper Hard Bake

- Under-bake
  - Photoresist is not filly polymerized
  - High photoresist etch rate
  - Poor adhesion
- Over-baking
  - PR flow and bad resolution



Future Trends

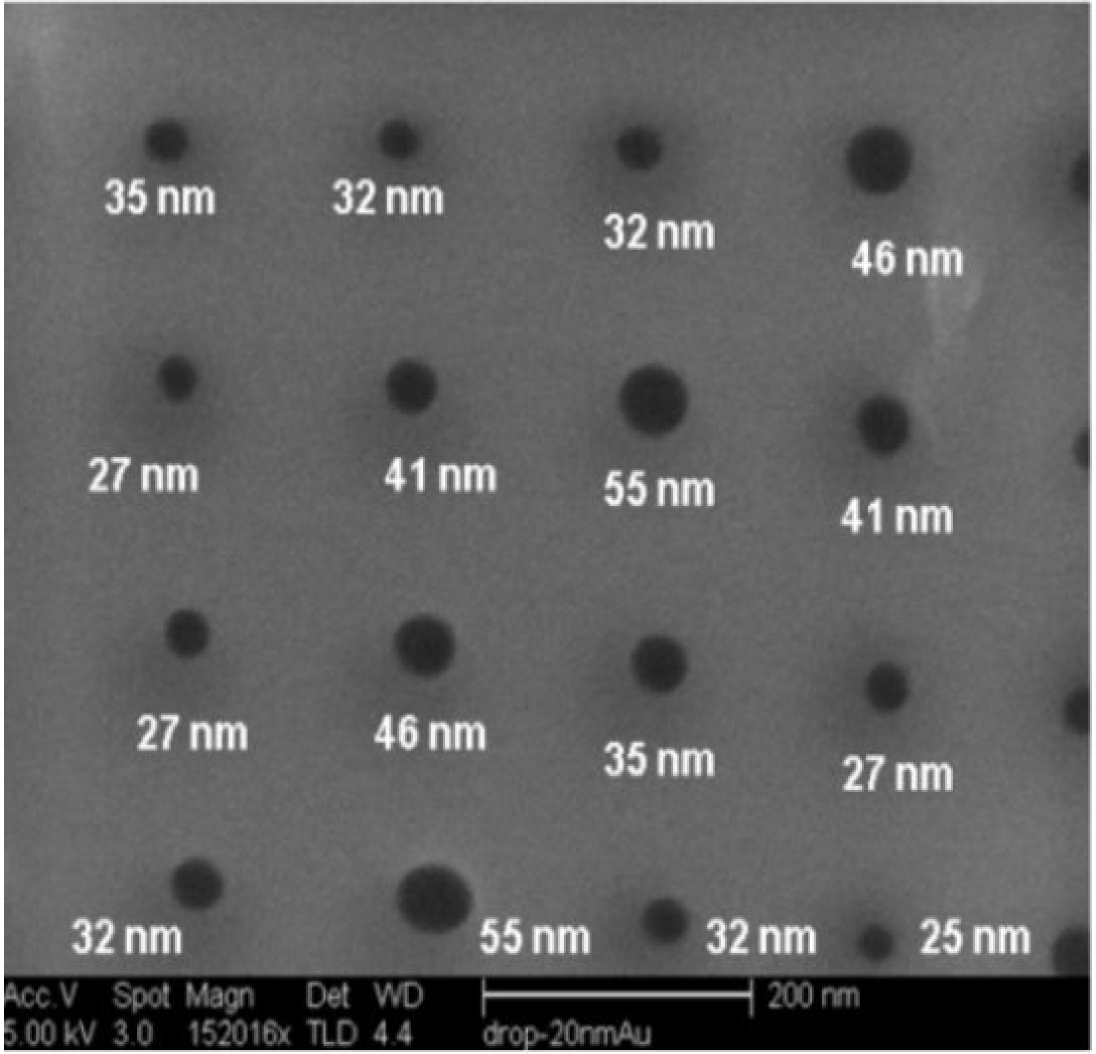


Major challenges (at this moment…)

½ -pitch	65 nm	45 nm	32 nm	22 nm	16 nm
	2007	2009	2012	2015	2018
Options	193nm-i NA>1.0	193-I NA=1.35	193-I high index fluids		
			EUV NA=0.25 ML2	EUV ML2	EUV?? ML2
			Disruptive low-cost approaches (Imprint, etc.)	Disruptive approaches (Imprint, etc.)	Disruptive approaches (Imprint, etc.)
Challenges	Irregular designs	Defectivity Resist technology Mask blank specs (birefringence) RET High-NA polarization effects Optics durability Overlay	**193-i** High-n fluid Polarization effects **EUV** Source power, lifetime etc Defect free masks Reticle protection Optics lifetime and contamination Optics quality **ML2** **Imprint** templates **Resist** (resolution, LER, sensitivity)	**EUV** RET **ML2:** Throughput **Imprint** 1:1 masks Overlay correction **Resist** limits	**EUV** High NA RET **ML2:** Throughput **Imprint** 1:1 masks Overlay correction **Resist** limits

The minimum feature size:

- The fundamental limit of optical lithography is not determined by the optical system alone but rather is an overall contributions from the optics, resist, develop and etching processes.


35 nm
32 nm
32 nm
46 nm
27 nm
41 nm
55 nm
41 nm
27 nm
46 nm
35 nm
27 nm
32 nm
55 nm
32 nm
25 nm
Acc.V Spot Magn Det WD
5.00 kV 3.0 152016x TLD 4.4
200 nm
drop-20nmAu

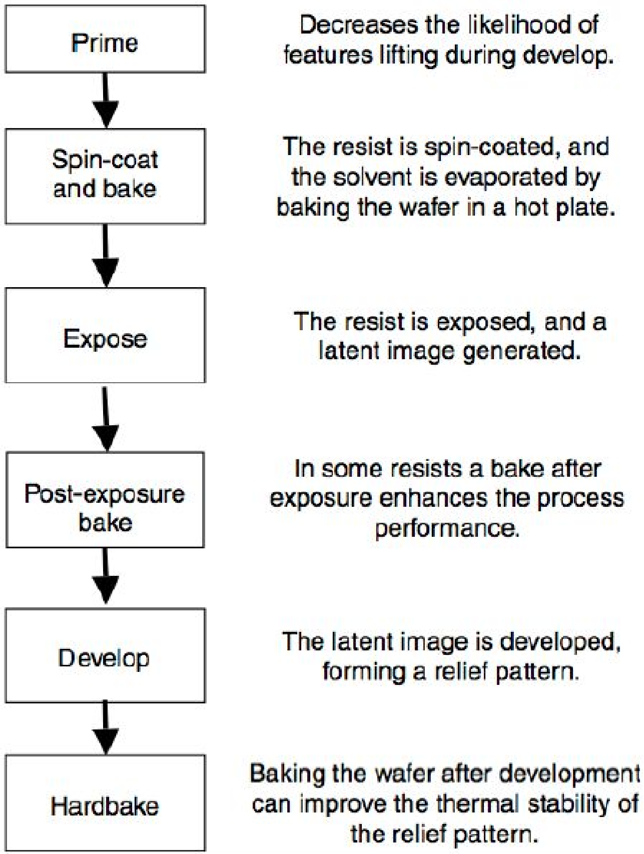
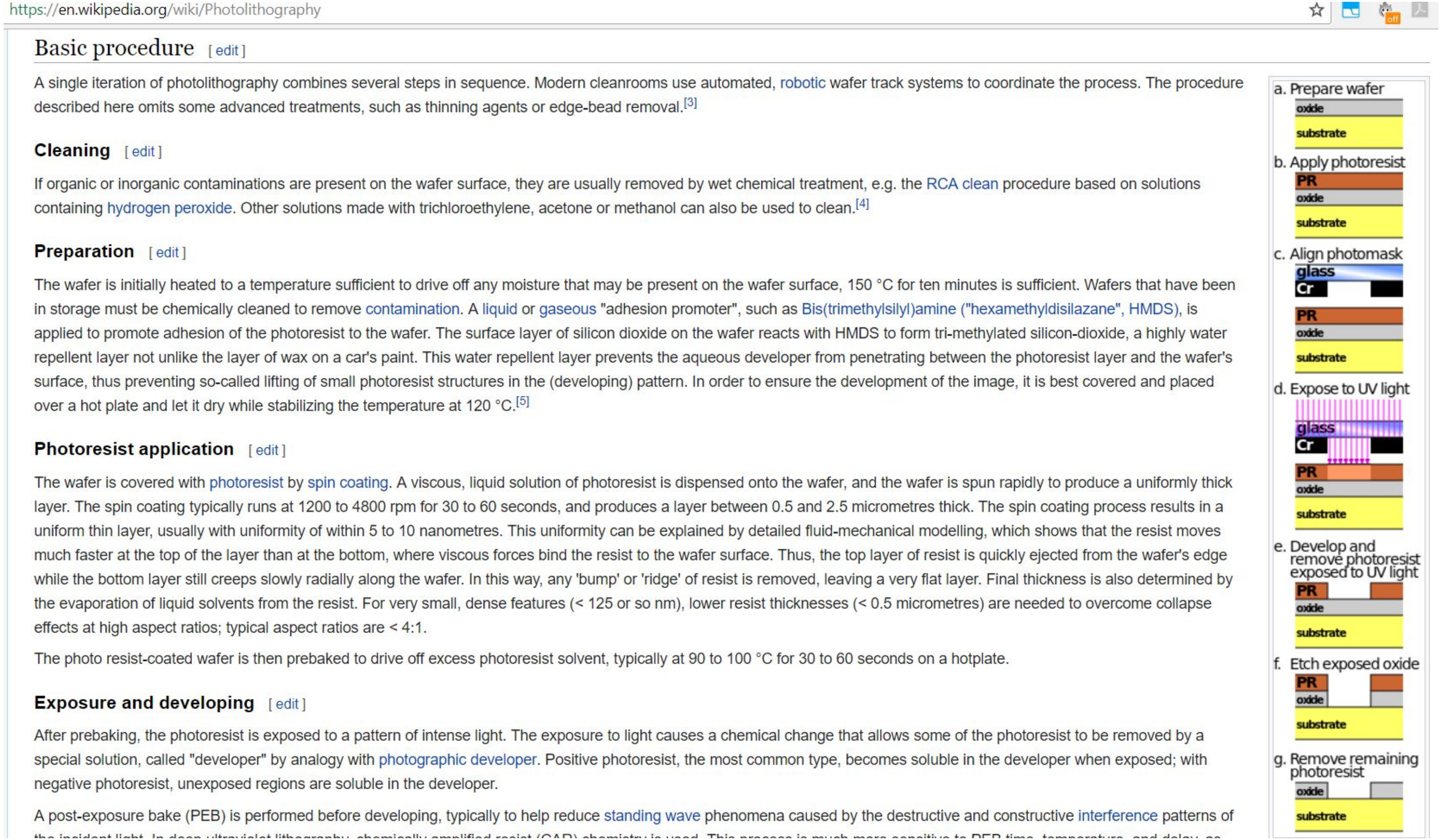


Figure 3: Flowchart of the micro - lithographic process. The post-exposure and hard-bake steps can be omitted, depending on the process [1].

Wikipedia is a great resource to start from



Basic procedure [edit]

A single iteration of photolithography combines several steps in sequence. Modern cleanrooms use automated, robotic wafer track systems to coordinate the process. The procedure described here omits some advanced treatments, such as thinning agents or edge-bead removal.[3]

Cleaning [edit]

If organic or inorganic contaminations are present on the wafer surface, they are usually removed by wet chemical treatment, e.g. the RCA clean procedure based on solutions containing hydrogen peroxide. Other solutions made with trichloroethylene, acetone or methanol can also be used to clean.[4]

Preparation [edit]

The wafer is initially heated to a temperature sufficient to drive off any moisture that may be present on the wafer surface, 150 °C for ten minutes is sufficient. Wafers that have been in storage must be chemically cleaned to remove contamination. A liquid or gaseous "adhesion promoter", such as Bis(trimethylsilyl)amine ("hexamethyldisilazane", HMDS), is applied to promote adhesion of the photoresist to the wafer. The surface layer of silicon dioxide on the wafer reacts with HMDS to form tri-methylated silicon-dioxide, a highly water repellent layer not unlike the layer of wax on a car's paint. This water repellent layer prevents the aqueous developer from penetrating between the photoresist layer and the wafer's surface, thus preventing so-called lifting of small photoresist structures in the (developing) pattern. In order to ensure the development of the image, it is best covered and placed over a hot plate and let it dry while stabilizing the temperature at 120 °C.[5]

Photoresist application [edit]

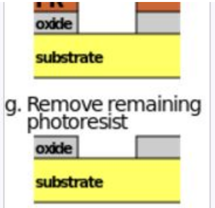
The wafer is covered with photoresist by spin coating. A viscous, liquid solution of photoresist is dispensed onto the wafer, and the wafer is spun rapidly to produce a uniformly thick layer. The spin coating typically runs at 1200 to 4800 rpm for 30 to 60 seconds, and produces a layer between 0.5 and 2.5 micrometres thick. The spin coating process results in a uniform thin layer, usually with uniformity of within 5 to 10 nanometres. This uniformity can be explained by detailed fluid-mechanical modelling, which shows that the resist moves much faster at the top of the layer than at the bottom, where viscous forces bind the resist to the wafer surface. Thus, the top layer of resist is quickly ejected from the wafer's edge while the bottom layer still creeps slowly radially along the wafer. In this way, any 'bump' or 'ridge' of resist is removed, leaving a very flat layer. Final thickness is also determined by the evaporation of liquid solvents from the resist. For very small, dense features (< 125 or so nm), lower resist thicknesses (< 0.5 micrometres) are needed to overcome collapse effects at high aspect ratios; typical aspect ratios are < 4:1.

The photo resist-coated wafer is then prebaked to drive off excess photoresist solvent, typically at 90 to 100 °C for 30 to 60 seconds on a hotplate.

Exposure and developing [edit]

After prebaking, the photoresist is exposed to a pattern of intense light. The exposure to light causes a chemical change that allows some of the photoresist to be removed by a special solution, called "developer" by analogy with photographic developer. Positive photoresist, the most common type, becomes soluble in the developer when exposed; with negative photoresist, unexposed regions are soluble in the developer.

A post-exposure bake (PEB) is performed before developing, typically to help reduce standing wave phenomena caused by the destructive and constructive interference patterns of



Simplified illustration of dry etching using positive photoresist during a photolithography process in semiconductor microfabrication (not to scale).

Exposure and developing [edit]

After prebaking, the photoresist is exposed to a pattern of intense light. The exposure to light causes a chemical change that allows some of the photoresist to be removed by a special solution, called "developer" by analogy with photographic developer. Positive photoresist, the most common type, becomes soluble in the developer when exposed; with negative photoresist, unexposed regions are soluble in the developer.

A post-exposure bake (PEB) is performed before developing, typically to help reduce standing wave phenomena caused by the destructive and constructive interference patterns of the incident light. In deep ultraviolet lithography, chemically amplified resist (CAR) chemistry is used. This process is much more sensitive to PEB time, temperature, and delay, as most of the "exposure" reaction (creating acid, making the polymer soluble in the basic developer) actually occurs in the PEB.[6]

The develop chemistry is delivered on a spinner, much like photoresist. Developers originally often contained sodium hydroxide (NaOH). However, sodium is considered an extremely undesirable contaminant in MOSFET fabrication because it degrades the insulating properties of gate oxides (specifically, sodium ions can migrate in and out of the gate, changing the threshold voltage of the transistor and making it harder or easier to turn the transistor on over time). Metal-ion-free developers such as tetramethylammonium hydroxide (TMAH) are now used.

The resulting wafer is then "hard-baked" if a non-chemically amplified resist was used, typically at 120 to 180 °C[*citation needed*] for 20 to 30 minutes. The hard bake solidifies the remaining photoresist, to make a more durable protecting layer in future ion implantation, wet chemical etching, or plasma etching.

Etching [edit]

Main article: Etching (microfabrication)

In etching, a liquid ("wet") or plasma ("dry") chemical agent removes the uppermost layer of the substrate in the areas that are not protected by photoresist. In semiconductor fabrication, dry etching techniques are generally used, as they can be made anisotropic, in order to avoid significant undercutting of the photoresist pattern. This is essential when the width of the features to be defined is similar to or less than the thickness of the material being etched (i.e. when the aspect ratio approaches unity). Wet etch processes are generally isotropic in nature, which is often indispensable for microelectromechanical systems, where suspended structures must be "released" from the underlying layer.

The development of low-defectivity anisotropic dry-etch process has enabled the ever-smaller features defined photolithographically in the resist to be transferred to the substrate material.

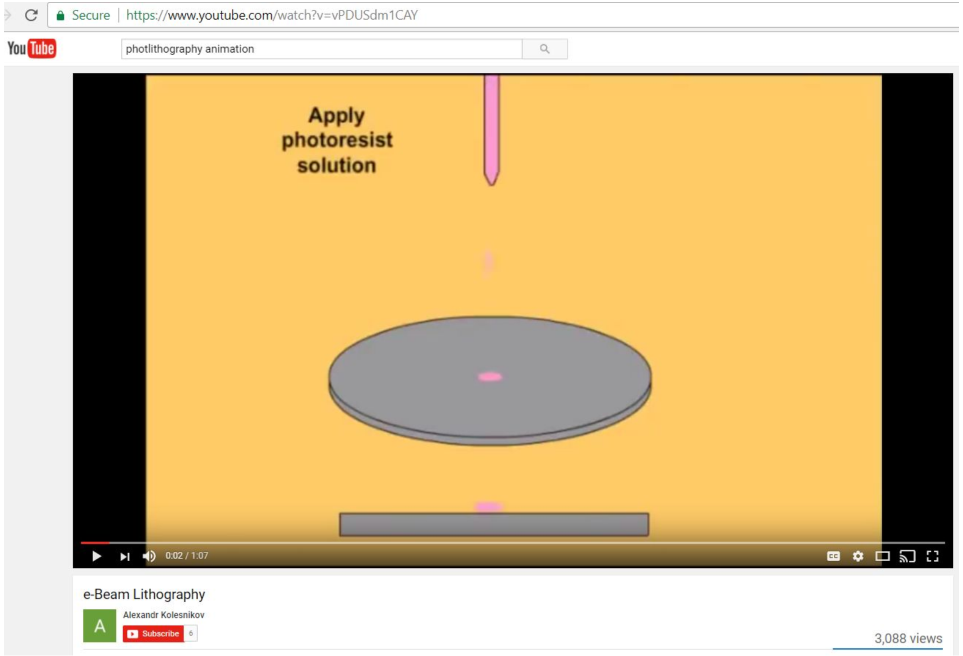
Photoresist removal [edit]

After a photoresist is no longer needed, it must be removed from the substrate. This usually requires a liquid "resist stripper", which chemically alters the resist so that it no longer adheres to the substrate. Alternatively, photoresist may be removed by a plasma containing oxygen, which oxidizes it. This process is called ashing, and resembles dry etching. Use of 1-Methyl-2-pyrrolidone (NMP) solvent for photoresist is another method used to remove an image. When the resist has been dissolved, the solvent can be removed by heating to 80 °C without leaving any residue.[7]

Photolithography is :

- Temporarily coat photoresist on wafer and Transfers designed pattern to photoresist
- Most important process in IC fabrication
- To consume 40 to 50% total wafer process time
- Determines the minimum feature size, e.g. 0.18um technology in 2000, 70nm technology in 2004

- High Resolution
- High PR Sensitivity
- Precision Alignment, say within 10% of minimum feature size
- Precise Process Parameters Control
- Low Defect Density



https://www.youtube.com/watch?v=vPDUSdm1CAY

photlithography animation

e-Beam Lithography

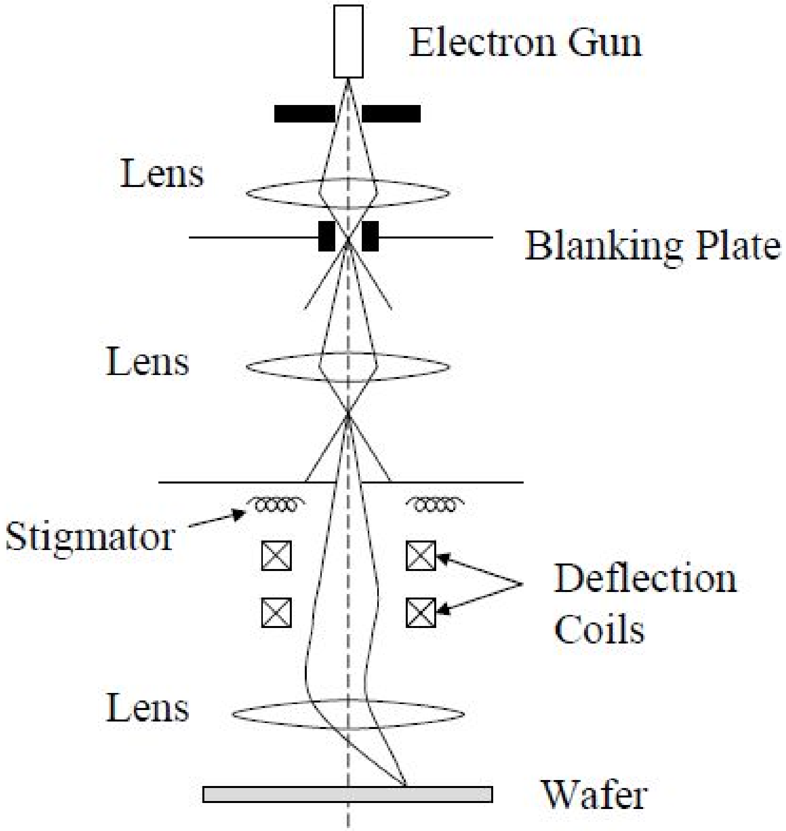
Alexandr Kolesnikov

3,088 views

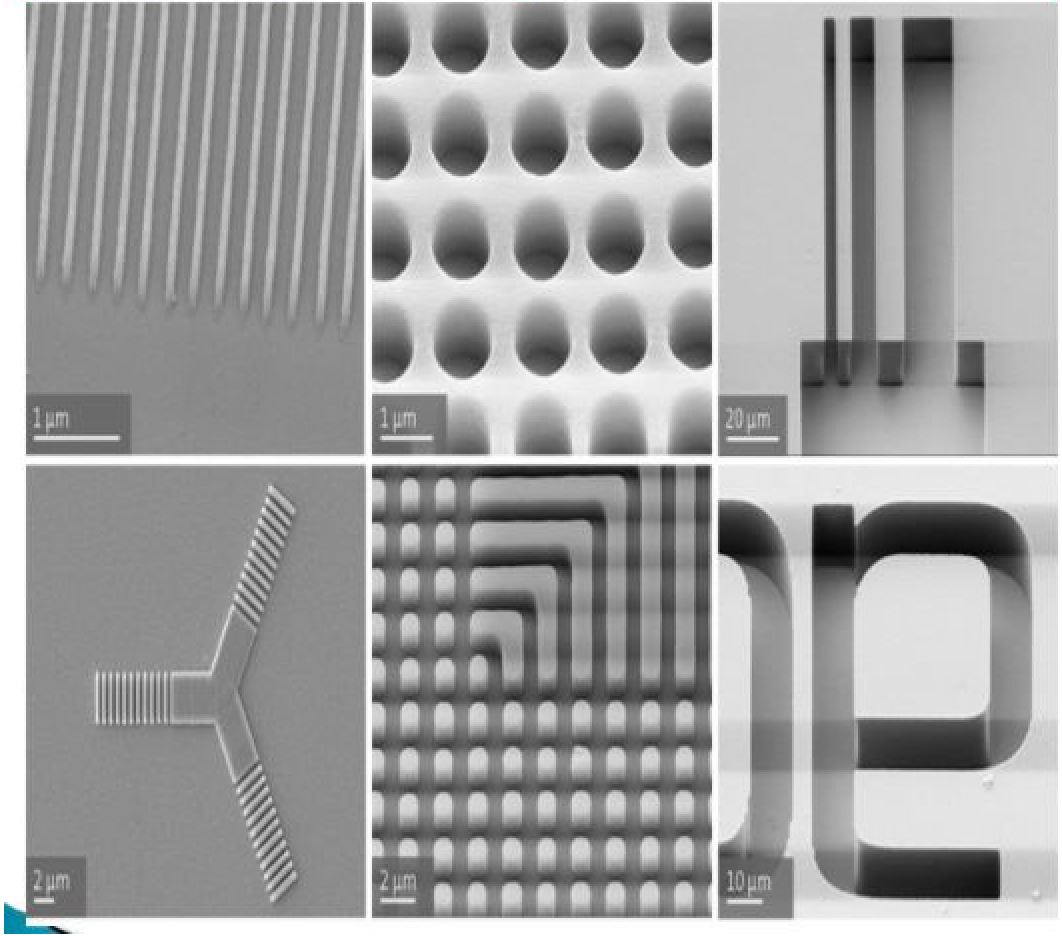
60sec good animation Litho vs E-beam Litho https://www.youtube.com/watch?v=vPDUSdm1CAY

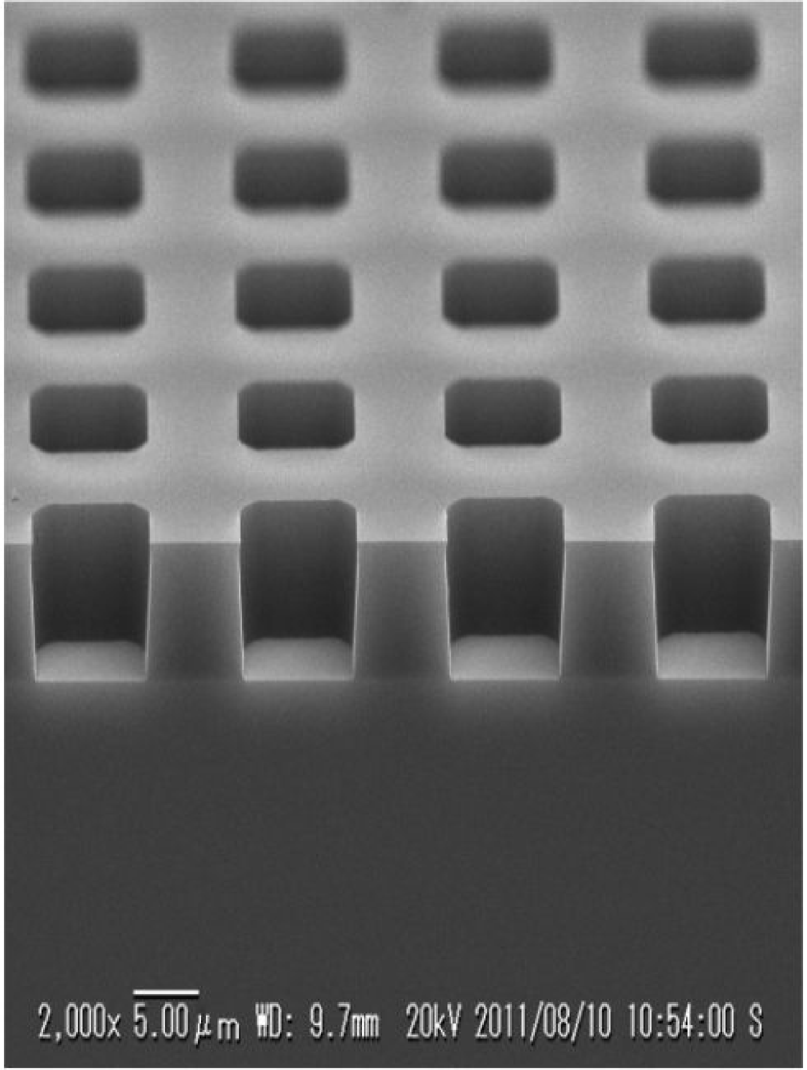
The primary advantage of electron-beam lithography is that it can draw custom patterns (direct-write) with sub-10 nm resolution. This form of maskless lithography has high resolution and low throughput, limiting its usage to photomask fabrication, low-volume production of semiconductor devices, and research & development.

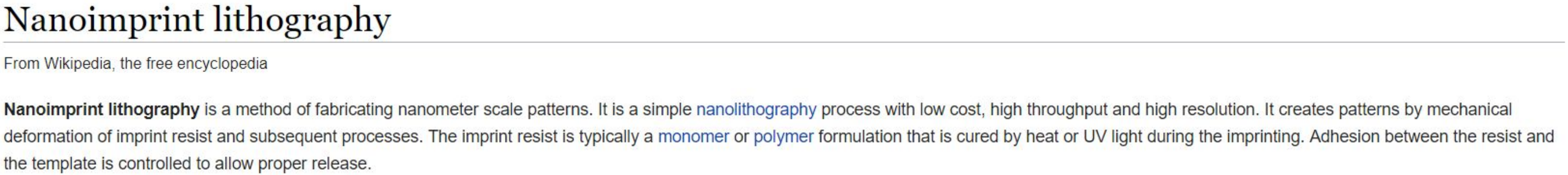
Electron Beam Lithography System



nano micro




2,000x 5.00μm WD: 9.7mm 20kV 2011/08/10 10:54:00 S



Nanoimprint lithography

From Wikipedia, the free encyclopedia

Nanoimprint lithography is a method of fabricating nanometer scale patterns. It is a simple nanolithography process with low cost, high throughput and high resolution. It creates patterns by mechanical deformation of imprint resist and subsequent processes. The imprint resist is typically a monomer or polymer formulation that is cured by heat or UV light during the imprinting. Adhesion between the resist and the template is controlled to allow proper release.

Introduction to

Photolithography

Close captioning is available on this video

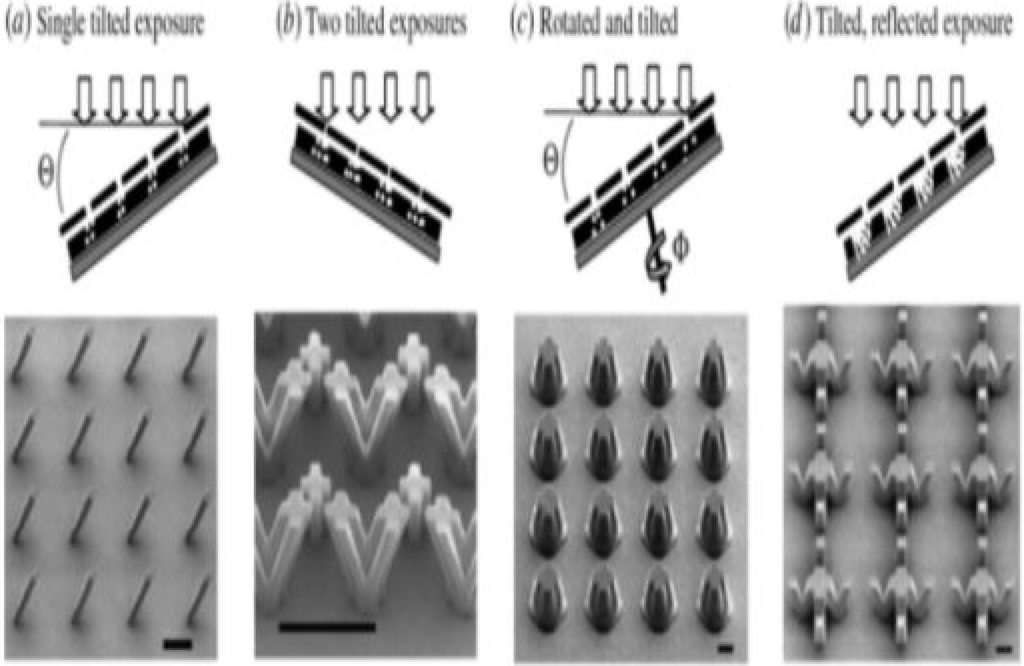
Introduction to Photolithography - (Negative or Positive Photoresist)

25min INRF tutorial on litho steps: https://www.youtube.com/watch?v=IF2pDoPBv10&t=1129s

Karl Suss MA6 Mask Aligner - Standard Operating Procedures

15min: https://www.youtube.com/watch?v=sl1-5-EviR0

Advanced Techniques



(*a*) Single tilted exposure

(*b*) Two tilted exposures

(*c*) Rotated and tilted

(*d*) Tilted, reflected exposure