NT-5001 - MICROFLUIDICS

Tecnológico de Monterrey

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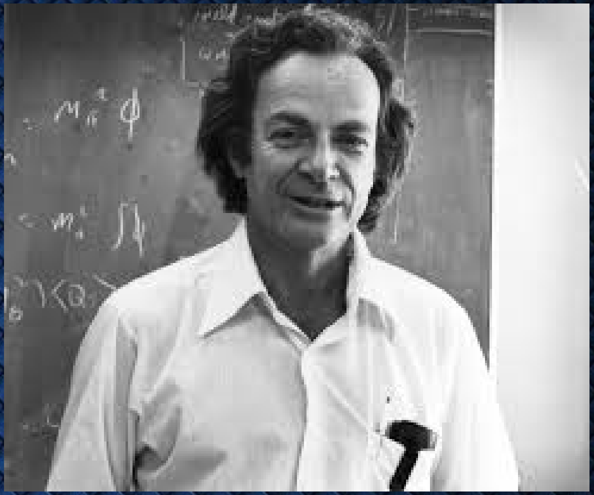
Micro and nanofabrication

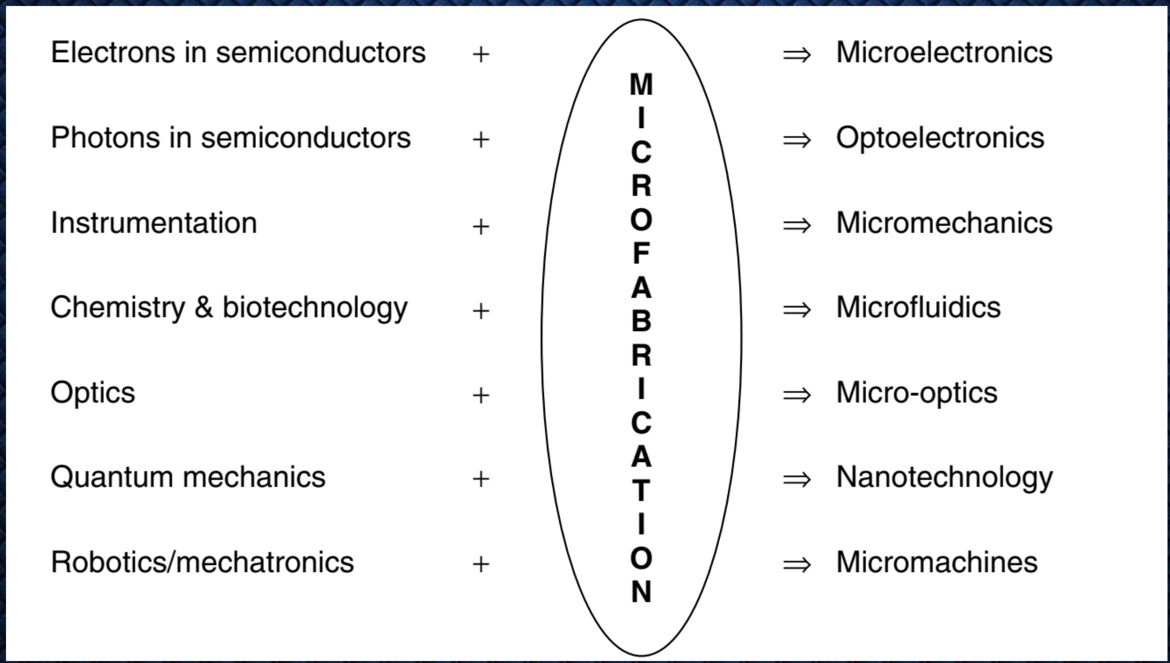
"I don't know how to do this on a small scale in a practical way, but I do know that computing machines are very large; they fill rooms. Why can't we make them very small, make them of little wires, little elements — and by little, I mean little. "



Richard Feynman
There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics
1959

Micro and nanofabrication

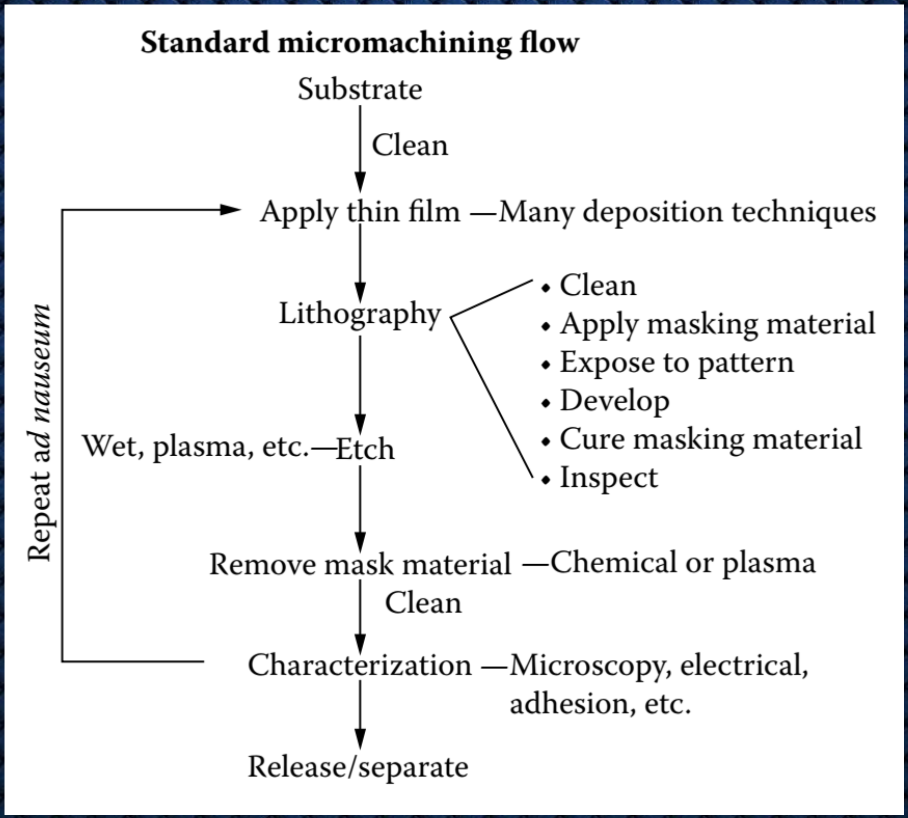
- The development of microfabrication is intimately related to the integrated circuit revolution.
- Today we find microfabrication in fields such as integrated circuits (ICs), MEMS, microfluidics, micro-optics, nanotechnology and countless others.



Franssila, S. (2010). *Introduction to microfabrication*. John Wiley & Sons.

Micro and nanofabrication

- The standard route followed to produce an integrated circuit. The same flowchart can be used for producing any microscale product made with silicon-based materials.



Jackson, M. J. (Ed.). (2005). Microfabrication and nanomanufacturing. CRC Press

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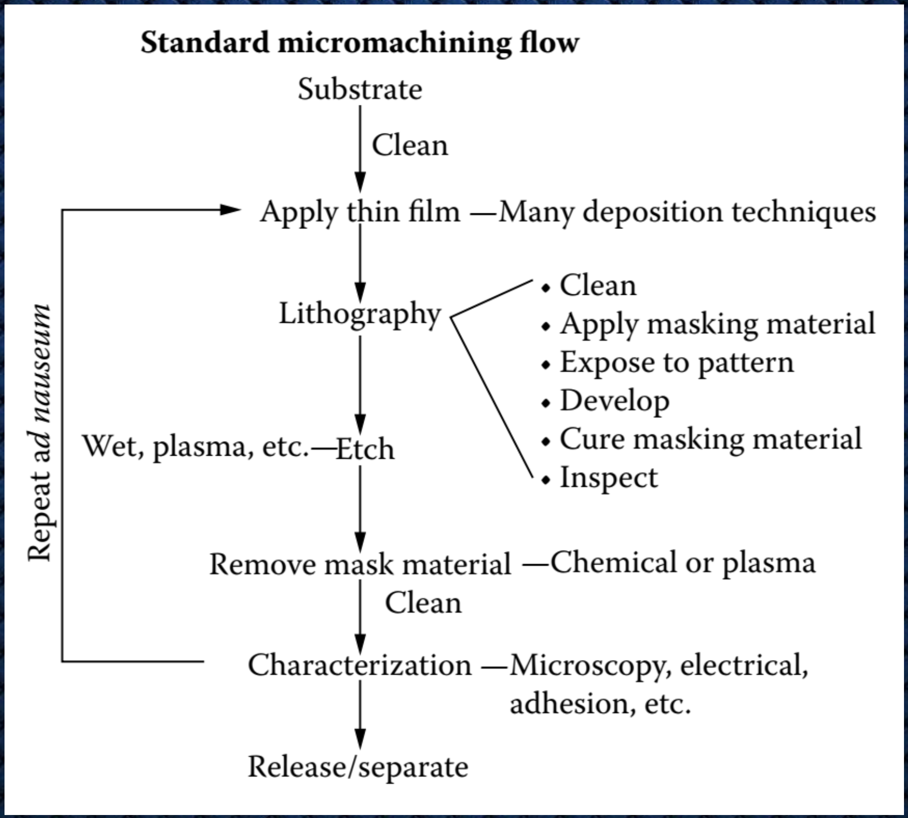

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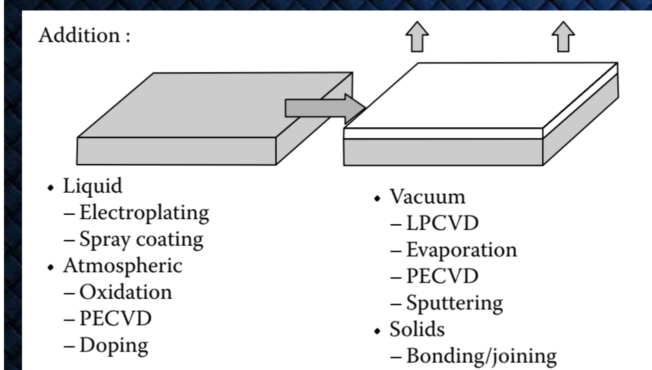
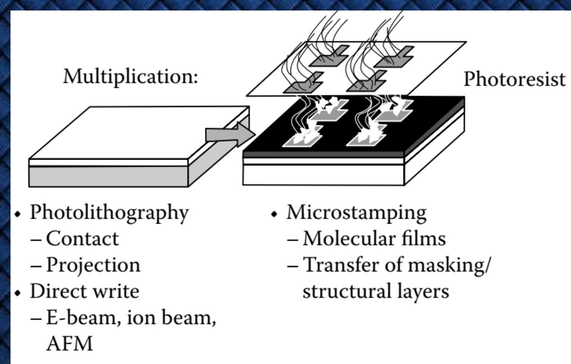
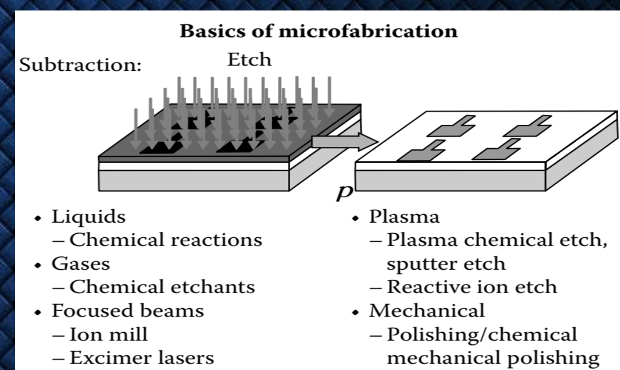
Micro and nanofabrication

- Fabrication at the microscale consist of three basic regimes: addition, multiplication and subtraction.
- Combinations of all of these techniques can be used to produce features of different size, shape, and scale.







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REQUIREMENTS

- Cleanroom

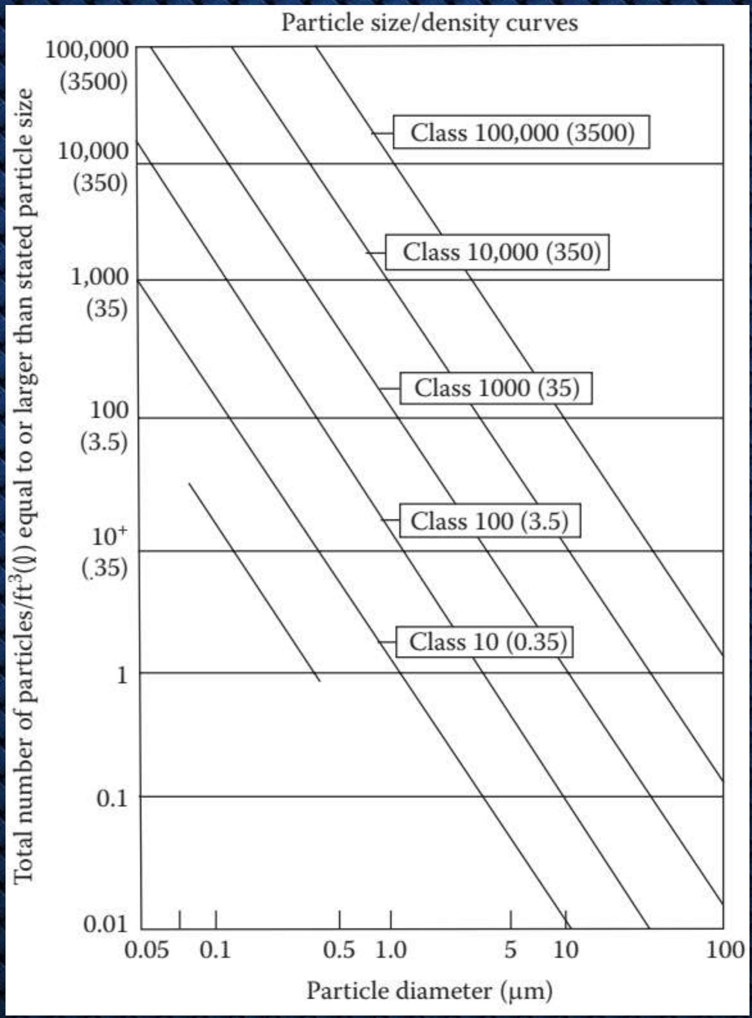
REQUIREMENTS

- Common cleanroom contaminant sources

• Location: a clean room near a refinery, smoke stack, sewage plant, cement plant spells big trouble
• Construction: the floor is an important source of contamination. Also, items such as light fixtures must be sealed, and room construction tolerances must be held very tight
• Wafer handling: transfer box
• Process equipment: never use fiberglass duct liner; always use 100% polyester filters, eliminate all nonessential equipment
• Chemicals: residual photoresist or organic coatings, metal corrosion
• Attire: only proper attire and dressing in the anteroom
• Electrostatic charge: clean room must have a conductive floor
• Furniture: only clean room furniture
• Stationary: use ballpoint pen instead of lead pencil, only approved clean room paper
• Operator: no eating, drinking, smoking, chewing gum, or makeup of any kind

REQUIREMENTS

- Cleanroom classifications



REQUIREMENTS

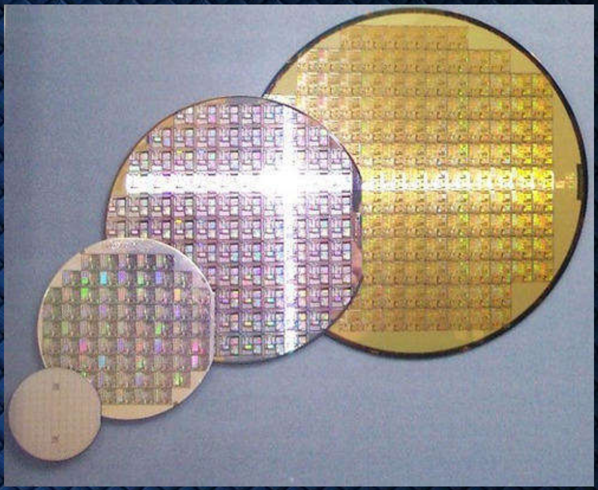
- Relative costs of IC production process

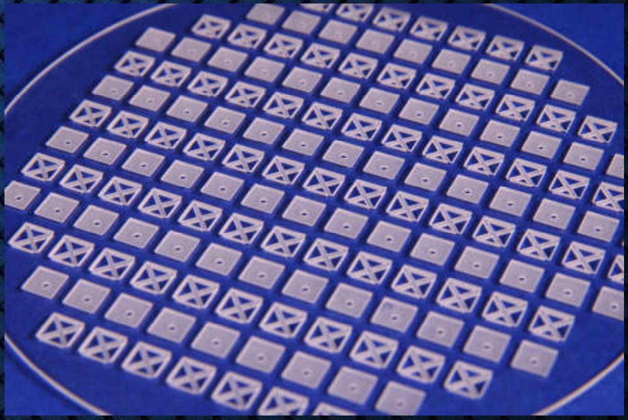
Manufacturing Process Step	Percentage of Wafer Processing Cost per Square Centimeter*
Lithography	35%
Multilevel materials and etching	25%
Furnaces and implants	15%
Cleaning/stripping	20%
Metrology	5%

*Excludes packaging, test, and design costs.

REQUIREMENTS

- **The substrate**
  1. **Silicon**: Most of the microfabrication processes for microfluidic are inherited from microelectronics fabrication, for which silicon is by far the most prevalent substrate material in use.
  2. **Glass**: is a very convenient substrate for microfluidic devices because many common types of glass are optically transparent, making glass favorable for applications that require imaging or optical methods of detection for fluids and/or suspended particles.





Photolithography

Photolithography

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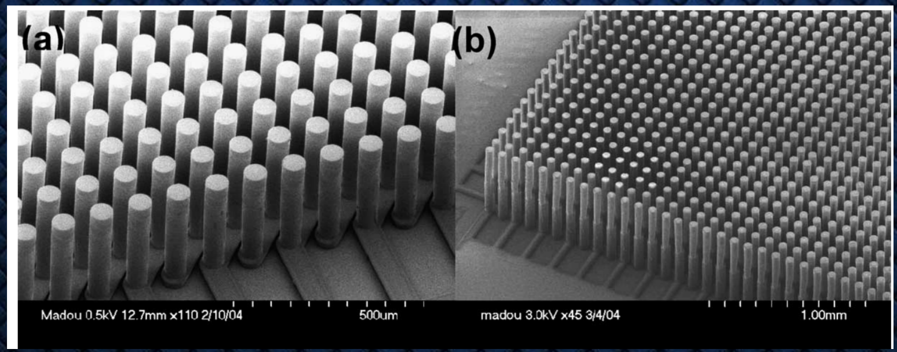
- Lithography is the most important technique for the fabrication of microstructures.

- Is the process of defining a prescribed latent image in a photosensitive material by selective exposure to radiation.

- Depending on the type of energy beam used, lithography can be sub-divided into:
  - **Photolithography**
  - Electron beam lithography
  - X-ray lithography
  - ion lithography

Photolithography

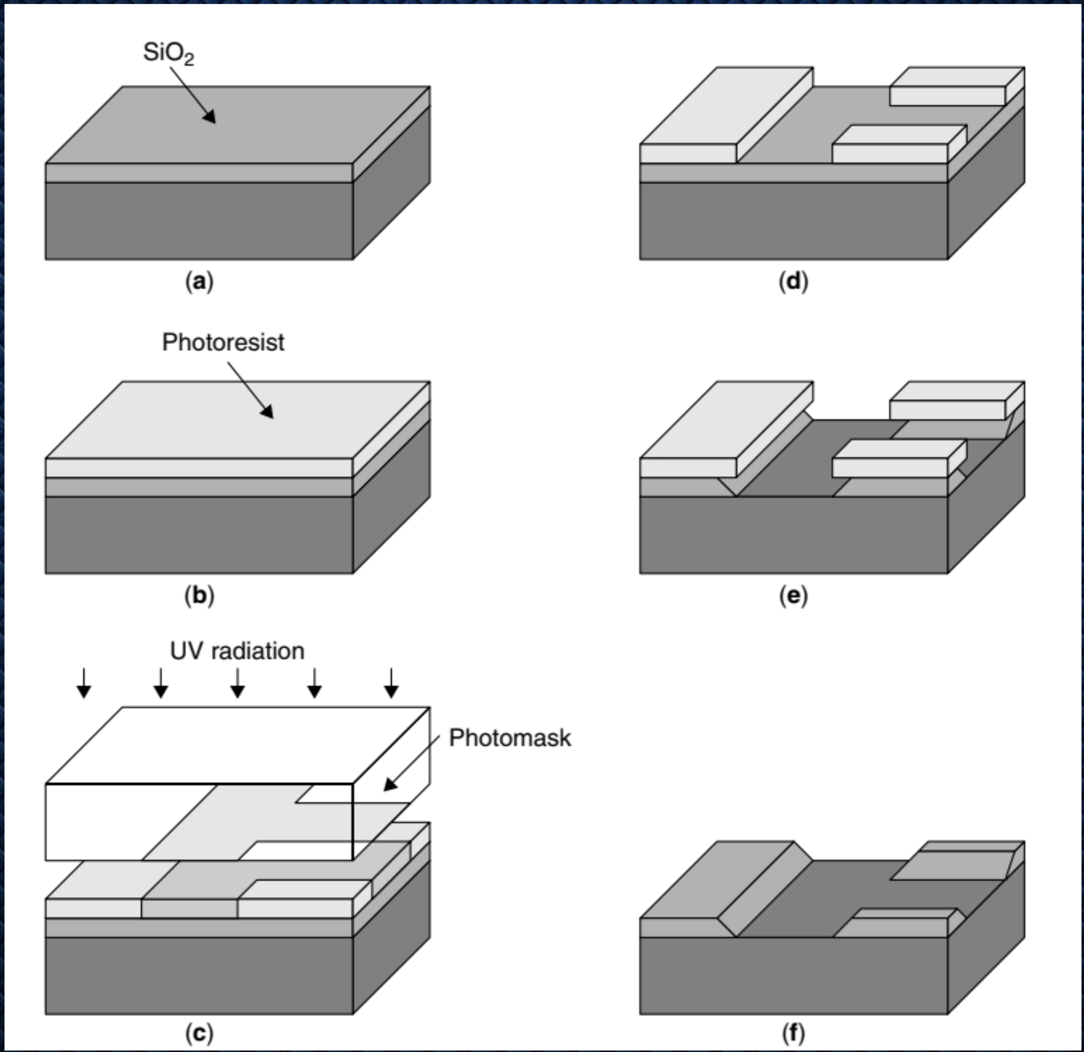
- The most widely used form of lithography is **photolithography**
- Most commonly, photolithography is understood to mean optical photolithography with UV light as the radiation source.
- Performance of a photolithographic process is determined by its resolution, the minimum feature size that can be transferred with high fidelity.
- Making closely spaced narrow lines is the main challenge in microlithography; not the making of individual narrow lines.



Wang, C., & Madou, M. (2005). From MEMS to NEMS with carbon. *Biosensors and bioelectronics*, *20*(10), 2181-2187.

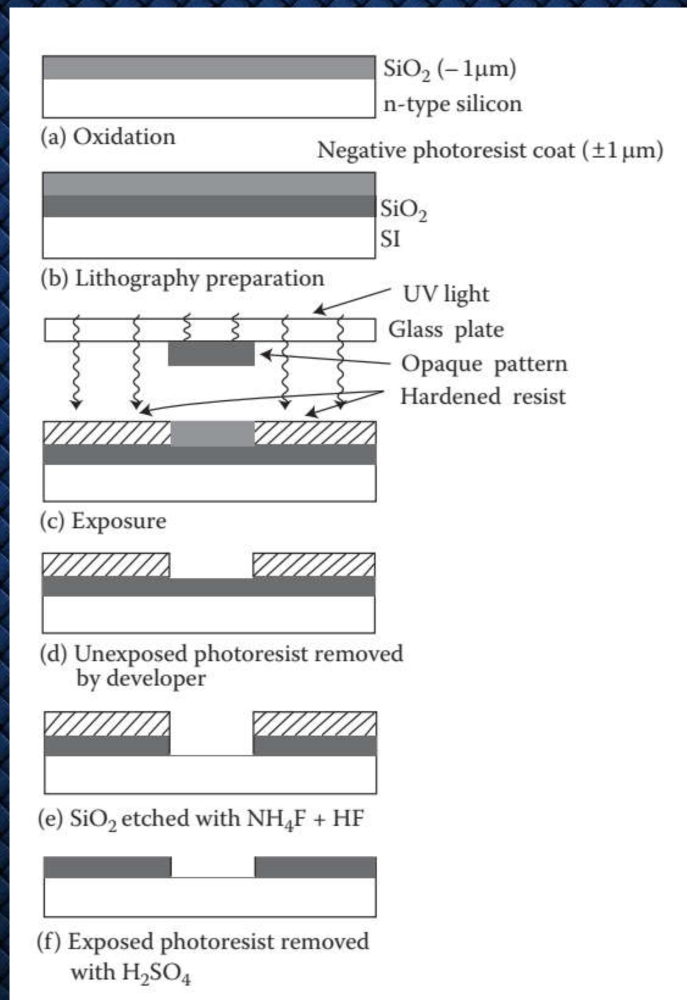
Photolithography

- Photolithography transfers a pattern from a mask to a photosensitive layer



Photolithography

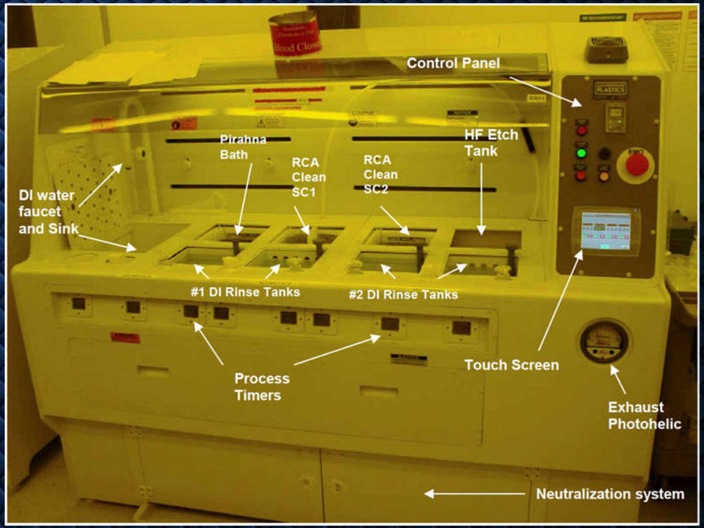
The steps in the photolithographic process:



Photolithography

Wafer/substrate Cleaning

- Before starting the photolithography process, a proper wafer clearing step is very important to achieve the expected result.
  - Particle contamination and poor adhesion are two common flaws encountered in the process if not properly cleaning is performed.
  - Among some standard cleaning methods we can mention RCA clean, piranha clean, vapor cleaning, thermal treatment, etc.
- Of course, the process must take place in cleanroom facilities (if possible).



Photolithography

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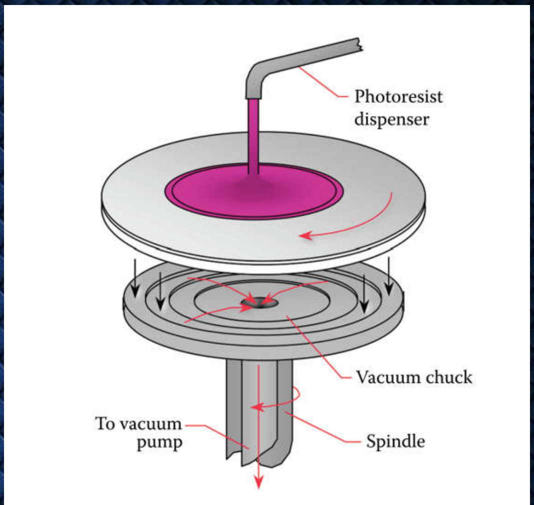
Coating (spin coating)

- The first step in the photolithography process, a thin layer of an organic polymer, a **photoresist** sensitive to UV radiation, is deposited on the substrate.

- Photoresist materials consist of a polymer resin, a UV-sensitive initiator, and solvent.

- Advances in photoresists technology enhance the capabilities of photolithography in terms of resolution, high aspect ratio, topography coverage, and etch resistance.

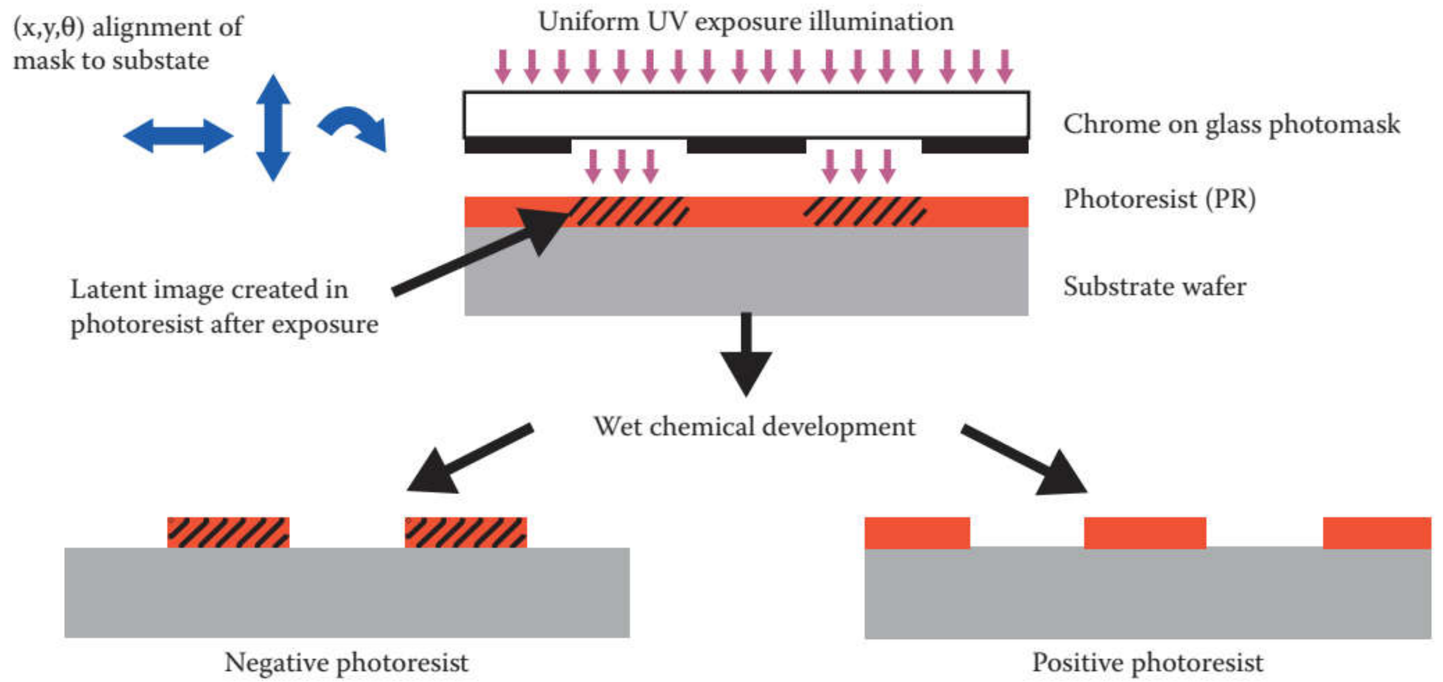
- For silicon ICs, the resist thickness after a prebake typically ranges between 0.5 and 2 µm. For miniaturized 3D structures (like microfluidics), greater resist thicknesses are often required



Photolithography

Coating (spin coating)

- The most fundamental distinction among photoresist materials is whether they are **positive** tone or **negative** tone



(a) Photoresist is photopolymerized where exposed and rendered insoluble to the developer solution.

(b) Exposure decomposes a development inhibitor, and developer solution only dissolves photoresist in the exposed areas.

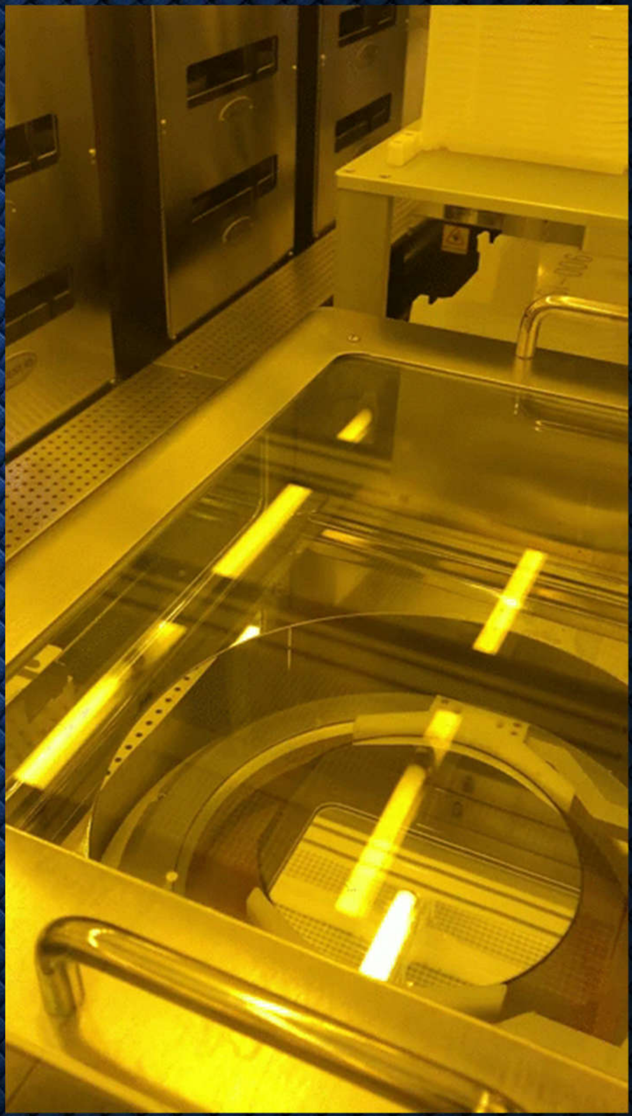
Photolithography

Coating (spin coating)

- The film thickness and consequently the height of our structure is determined by the viscosity of the photoresist, the spin speed and spin time, i.e. higher viscosity or lower spin speed results in a thicker resist film

- The quality of the resist coating determines the density of defects transferred to the device under construction.

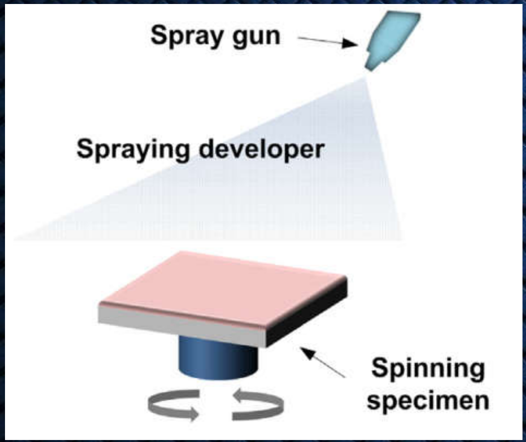
- The photoresist film must have a uniform thickness and must be chemically isotropic so that its response to exposure and development is uniform.

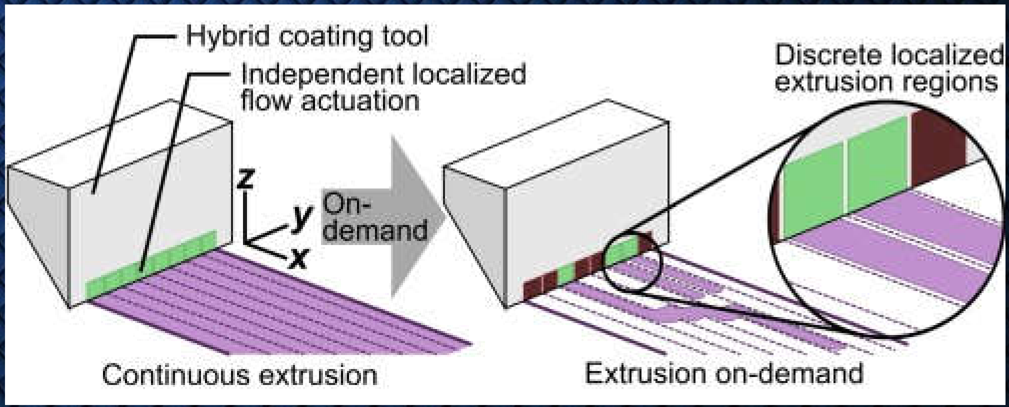


Photolithography

Coating

- Other techniques for photoresist deposition
  - Spray coating
  - Electrostatic spraying (electrodeposition)
  - Dip coating
  - Extrusion coating
  - And others





Kim, H., Kim, D., Lee, C., & Kim, J. (2014). Laser interference lithography using spray/spin photoresist development method for consistent periodic nanostructures. Current Applied Physics, 14(2), 209-214.

Parsekian, A. W., & Harris, T. A. (2016). Extrusion on-demand pattern coating using a hybrid manufacturing process. Chemical Engineering and Processing-Process Intensification, 109, 20-31.

Photolithography

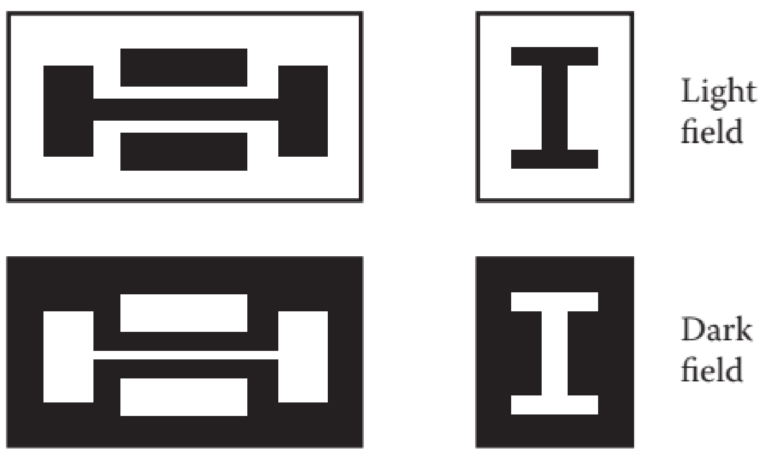
Pre-exposure soft bake

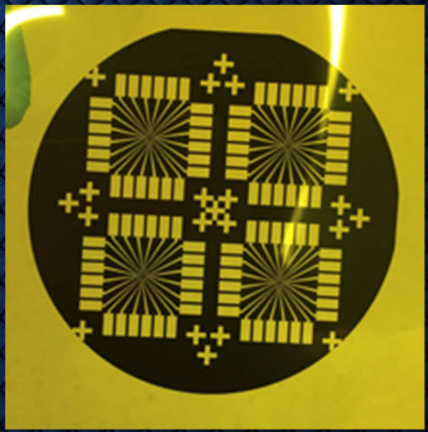
- After coating, the photoresist still contains a percentage of solvent, thus the film is soft baked to evaporate the remaining solvent.
- Soft bake can be carried out on a hot plate or in a convection oven.
- Under-soft baking will fail to correctly remove the solvent affecting the resulting profile.
- Over-soft baking can destroy photoactive compounds and reduce sensitivity during exposure.
- In high-aspect ratio structures gradual temperatures profiles are recommended to release residual stresses in the photoresist.

BASIC MICROTECHNIQUES

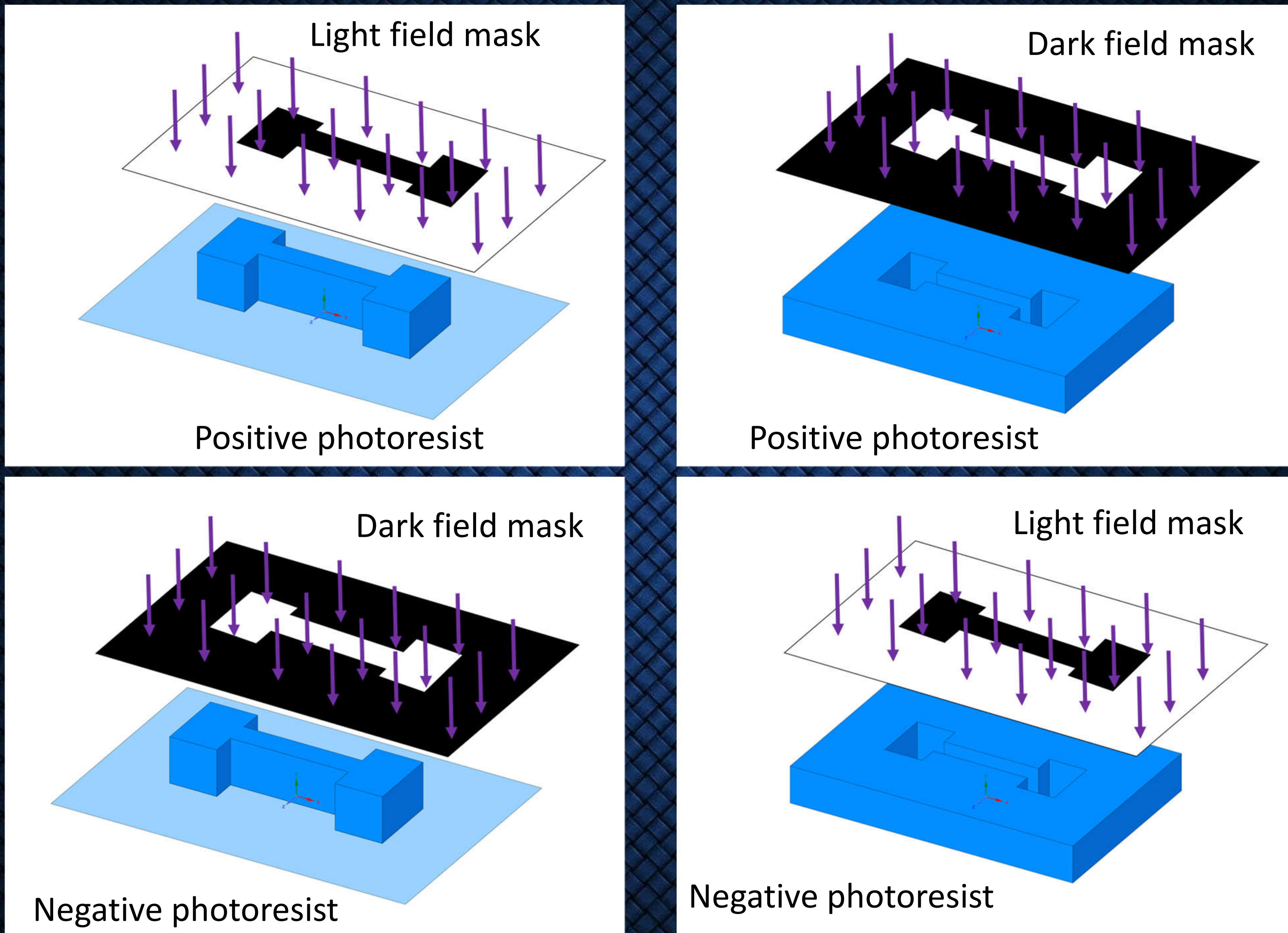
- Expose - Photolithography mask
  - The stencil used to repeatedly generate a desired pattern on resist-coated wafers is called a mask.
  - Like photoresists, masks can be positive or negative.
    - A positive or dark field mask is a mask on which the pattern is clear with the background dark.
    - A negative or clear field mask is a mask on which the pattern is dark with the background clear.

Mask-reticle polarities for a field effect transistor showing the gate and contacts.





Expose - Photolithography mask

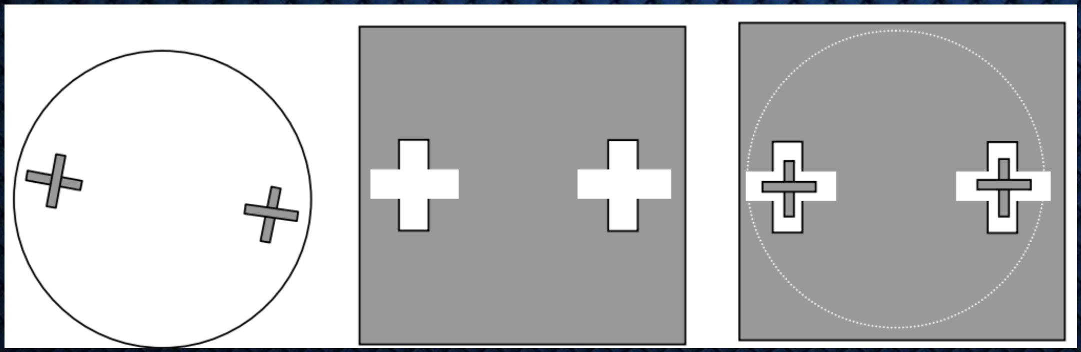


Photolithography

Alignment

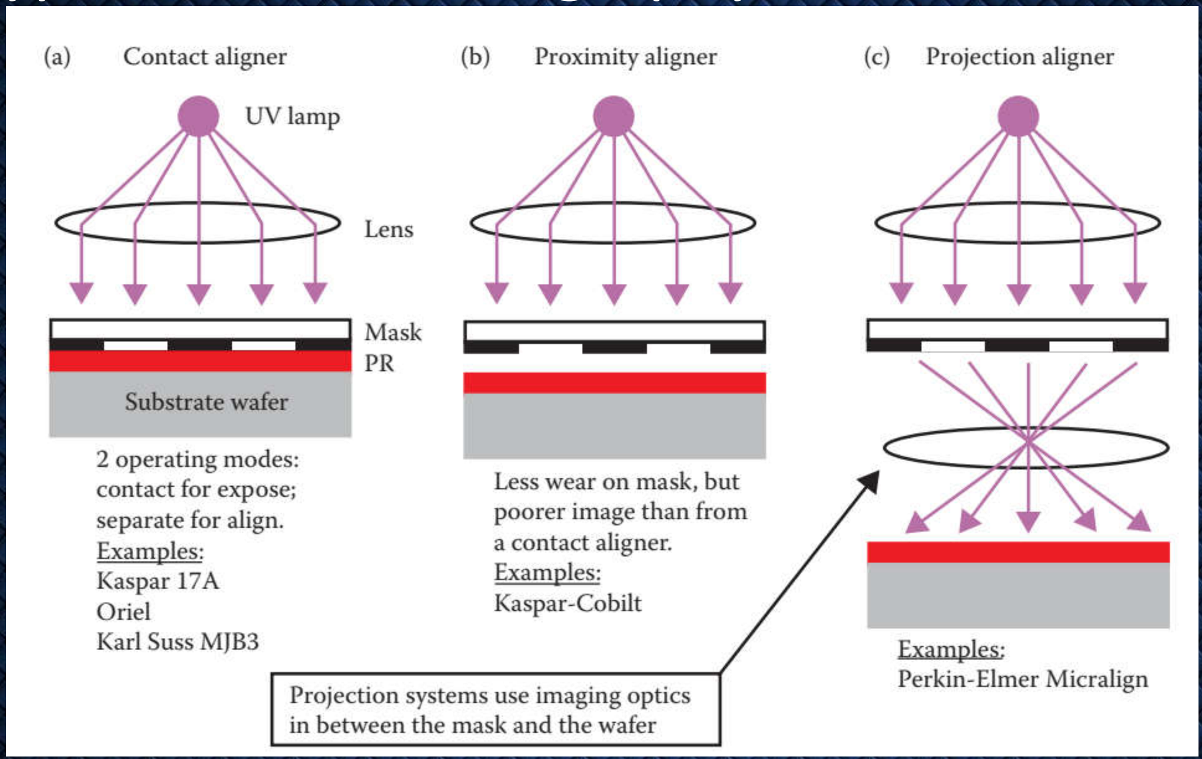
- For any lithographic technique to be of value, it must provide an alignment technique capable of a superposition precision of mask and wafer that is a small fraction of the minimum feature size of the devices under construction

- UV exposure is most routinely performed on a mask aligner, with the most common radiation sources being mercury-based lamps.



BASIC MICROTECHNIQUES

- Types of Photolithography



- Resolution: $b = 1.5\sqrt{\lambda s}$

Spectrum of Mercury Lamps

Types	*I-line*	*H-line*	*G-line*	*E-line*	—	—	—
Wavelength (nm)	365.0	404.7	435.8	546.1	577.0	579.1	623.4

Photolithography

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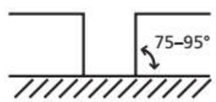
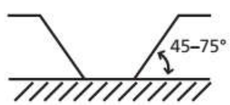
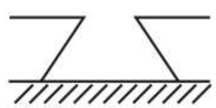
Exposure

- The purpose of the exposure is to deliver light with the proper intensity, directionality, spectral characteristics, and uniformity across the wafer, allowing a nearly perfect transfer or printing of the mask image onto the resist in the form of a latent image.
- The wavelengths of the light source used for exposure range from the very short wavelengths of extreme UV (10–14 nm) to deep UV(150–300 nm) to near UV (350–500 nm).
- In near UV, one typically uses the g-line (435 nm) or I line(365 nm) of a mercury lamp.
- The incident light intensity (in W/cm^2) multiplied by the exposure time gives the incident energy (J/cm^2) or dose across the surface of the resist film.

Photolithography

Exposure

- What are the consequences of a over-under exposure?
  - First, it depends of the profile we want
  - For microfluidics we desired flat profiles.

Profile	Dose	Developer Influence
Vertical 	Normal dose	Moderate
Normal or overcut 	Low	Dominant
Negative resists undercut 	Dominant	Little influence

Photolithography

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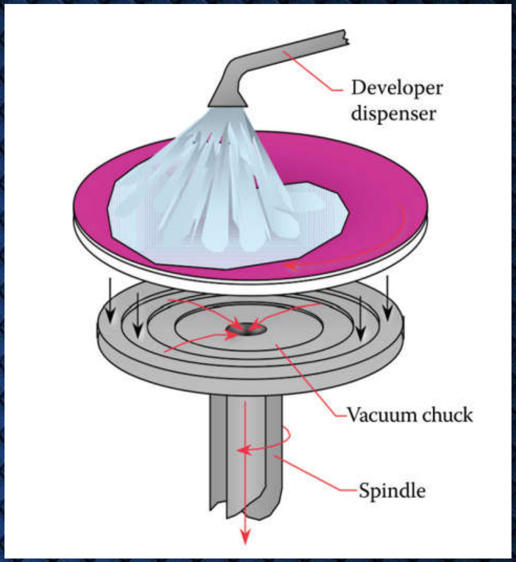
- Post exposure bake (PEB)

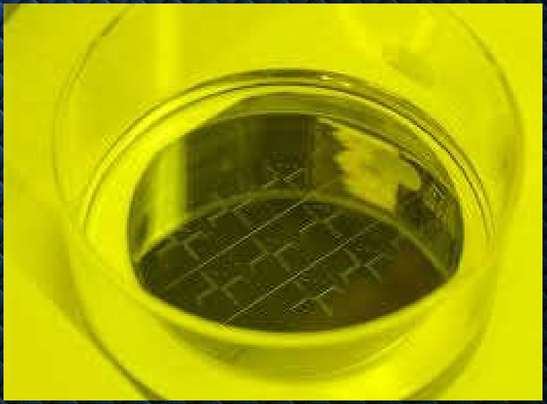
- A post-exposure treatment of the exposed photoresist is often desired because the reactions initiated during exposure might not have run to completion.
- A good PEB improves line-width control by improving adhesion, reduction of scumming (resist left behind after development), increasing contrast and resist profile.

Photolithography

Developing

- Is the step in which the uncured regions of photoresist are removed
- Immersion processes or spray processes can be used to develop the resist. Solvent-based developers, such as ethyl lactate and diaceton alcohol, dissolve areas that are not polymerized during exposure and PEB





Photolithography

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Post-develop "hard" bake

- Post-baking or hard baking removes residual coating solvent and developer and anneals the film to promote interfacial adhesion of the resist that has been weakened either by developer penetration along the resist/substrate interface or by swelling of the resist (mainly for negative resists).

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