B.Tech (ECE) VI Sem

Unit-3

VLSI Technology (BEC-350

Introduction Crystal Growth, Lithography and Etching

Part-II

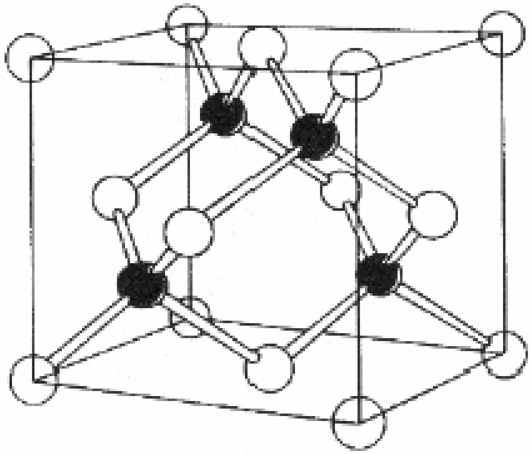
March-April 2020

Objectives of PPTs

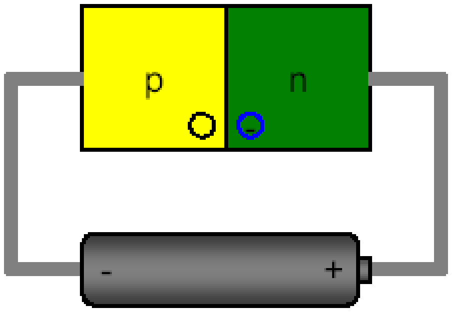
- Be able to describe the basic processes of fabrication
- Be able to explain the principles of Photolithography.
- Be able to describe the basic mechanisms of the additive processes (Oxidation, PVD & CVD), including relative comparisons among them.
  - Physical Vapor Deposition (**Evaporation & Sputtering**)
  - Chemical Vapor Deposition
- Be able to describe the basic mechanisms of the subtractive processes (Dry & Wet Etching), including relative comparisons among them.
  - Wet Etching (Isotropic & Anisotropic)
  - Dry Etching (Physical, Chemical, Physical-chemical)
- Be able to describe the process of bonding and packaging

Silicon Review

- In a perfect crystal, each of silicon's four outer electrons form covalent bonds, resulting in poor electron mobility (i.e. insulating)



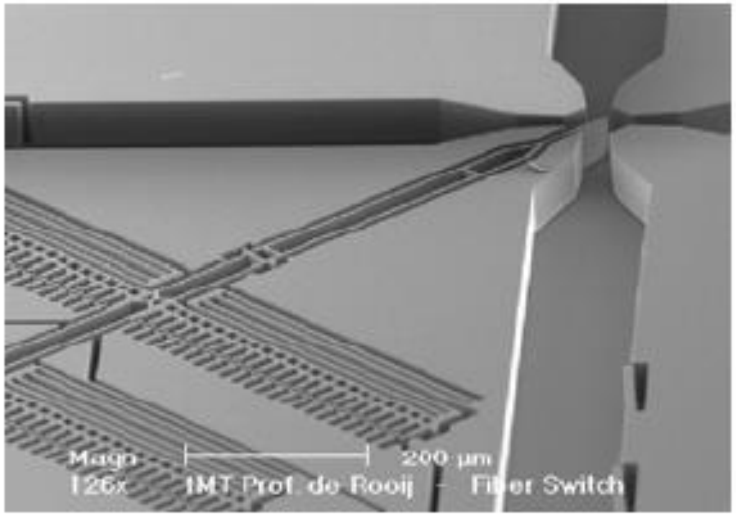
- Doping silicon with impurities alters electron mobility (i.e. semiconducting)
  - Extra electron ("N-type", with phosphorous, for example)
  - Missing electron ("P-type", with boron, for example)



Silicon Micromachines

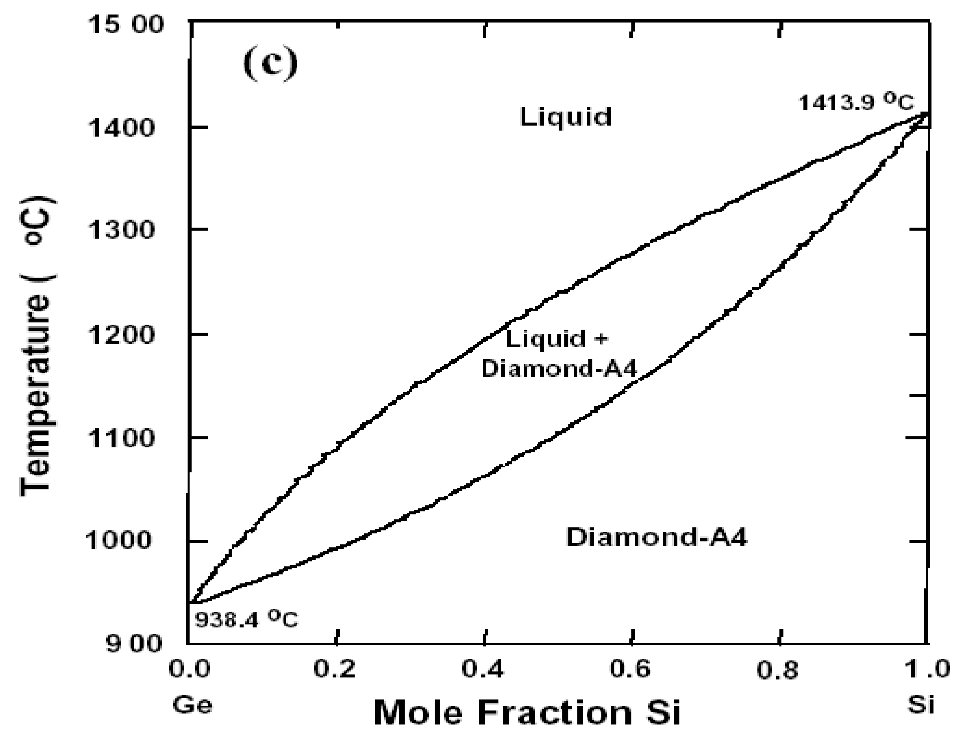
- The other application is micromachines, also called the microelectric mechanical system (MEMS), which have the potential of making the computer obsolete.

- The micromachines include:
  - Fuel cells
  - DNA chips
  - ……

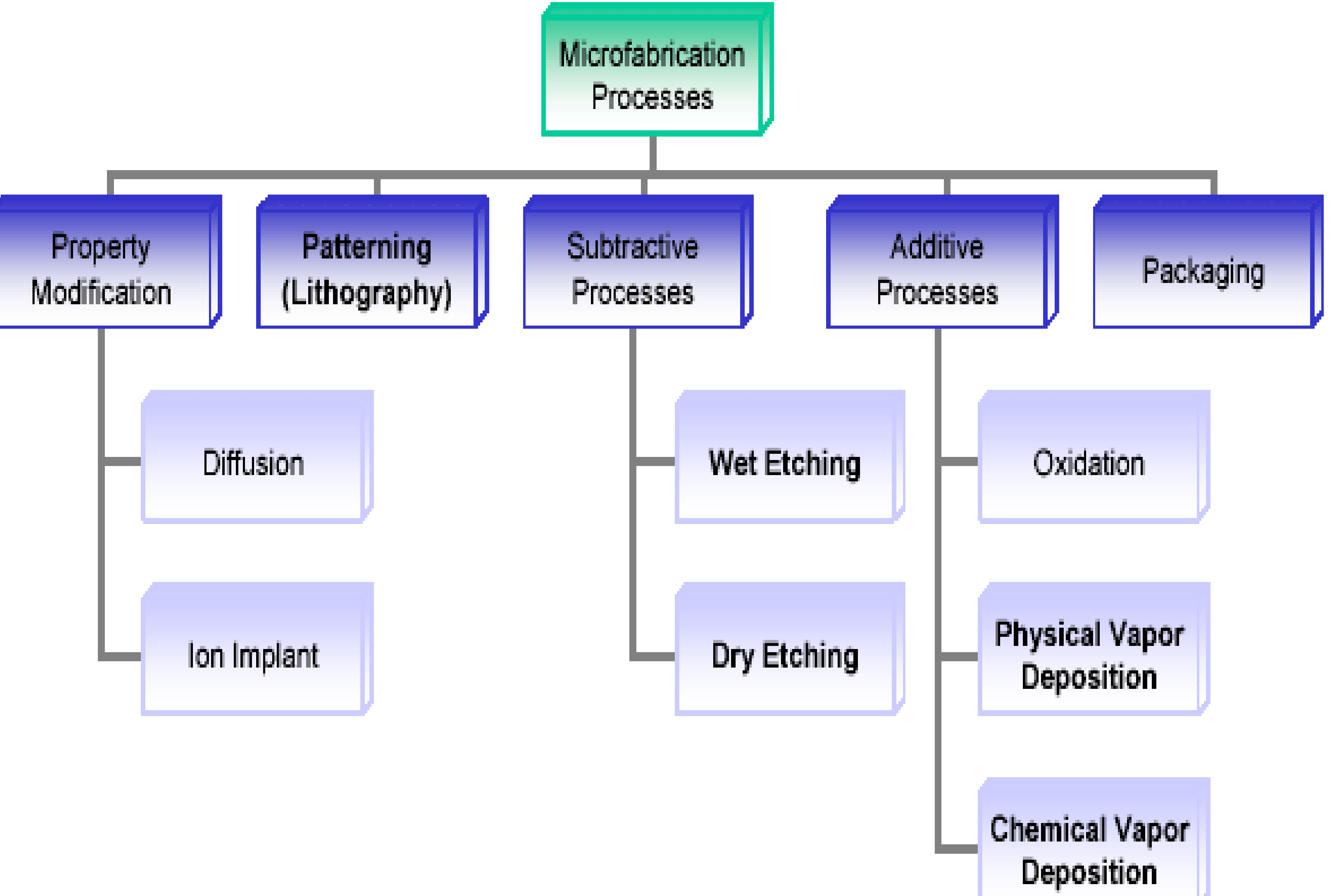


Fabrication

- Silicon crystal structure is regular, well-understood, and to a large extent controllable.
- It is all about control: the size of a transistor is 1 μm, the doping must therefore less than have of that
- How to control?



Fabrication Techniques



Microfabrication Processes

Property Modification

Patterning (Lithography)

Subtractive Processes

Additive Processes

Packaging

Diffusion

Ion Implant

Wet Etching

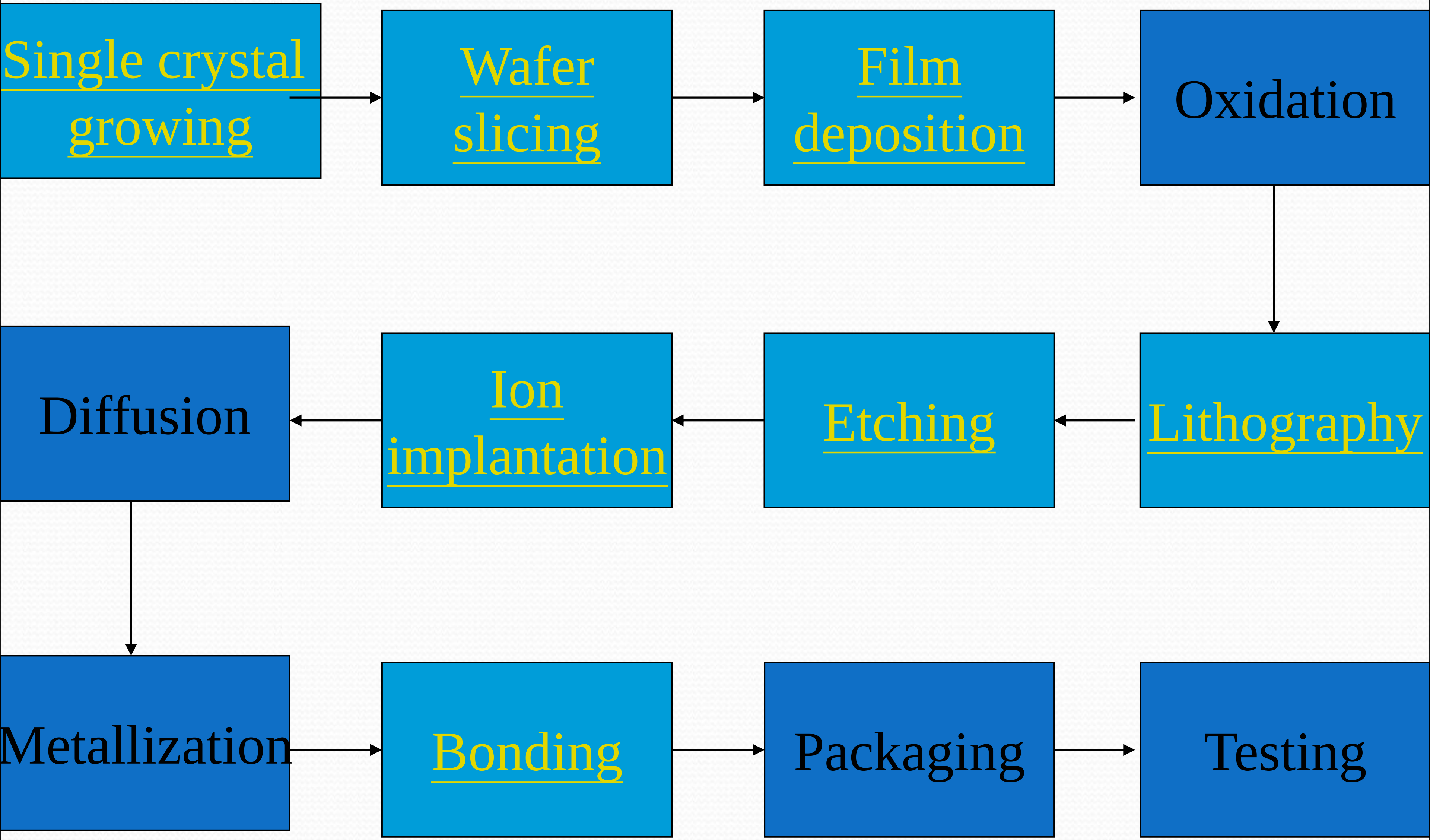
Dry Etching

Oxidation

Physical Vapor Deposition

Chemical Vapor Deposition

Fabrication Process of Si Devices



Single crystal growing

Wafer slicing

Film deposition

Oxidation

Lithography

Etching

Ion implantation

Diffusion

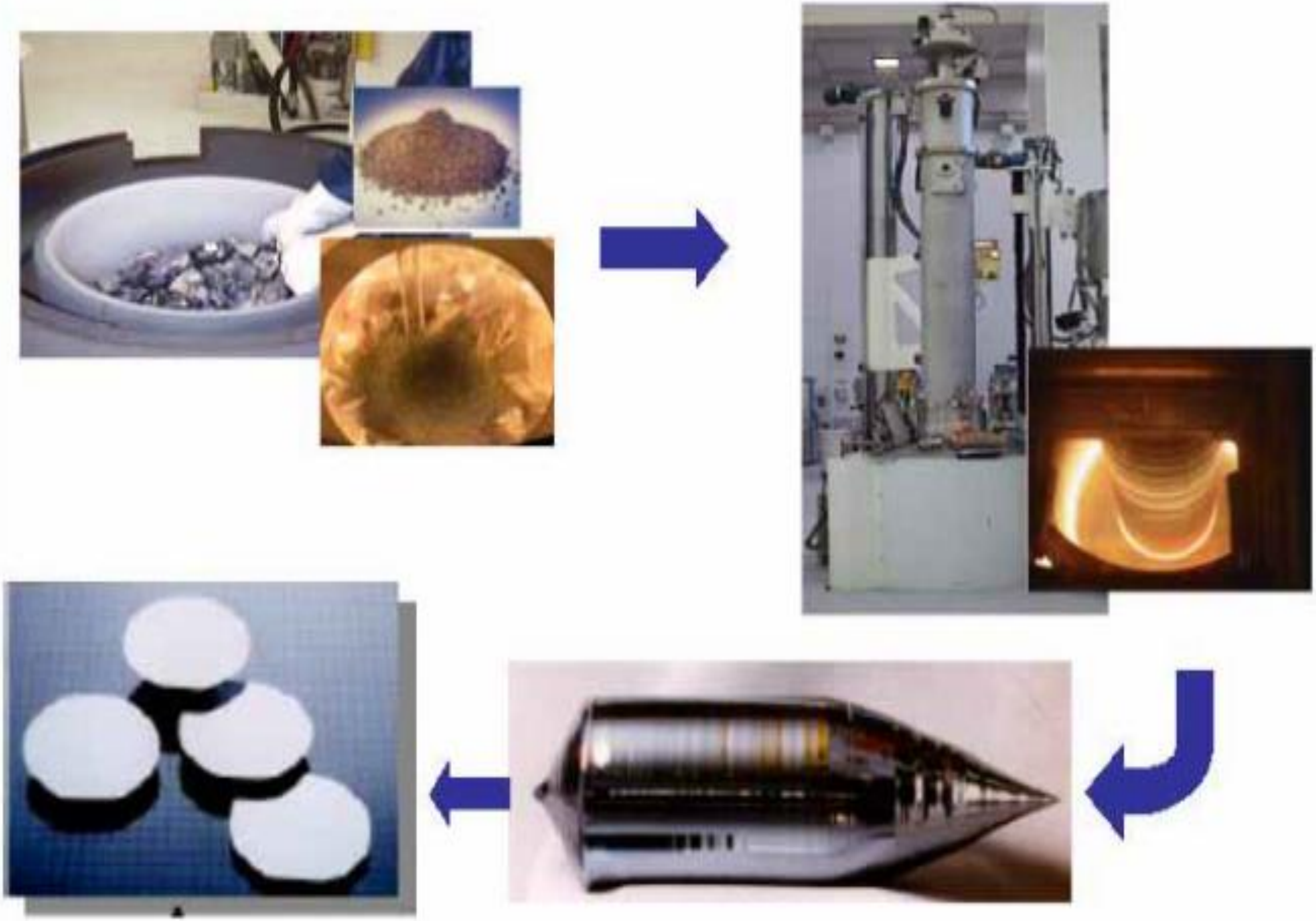
Metallization

Bonding

Packaging

Testing

Silicon Wafer Fabrication



Crystal Growing

- Silicon occurs naturally in the forms of silicon dioxide and various silicates and hence, must be purified
- The process of purifying silicon:
  - Heating to produce 95% ~ 98% pure polycrystalline silicon
  - Using Czochralski (CZ) process to grow single crystal silicon

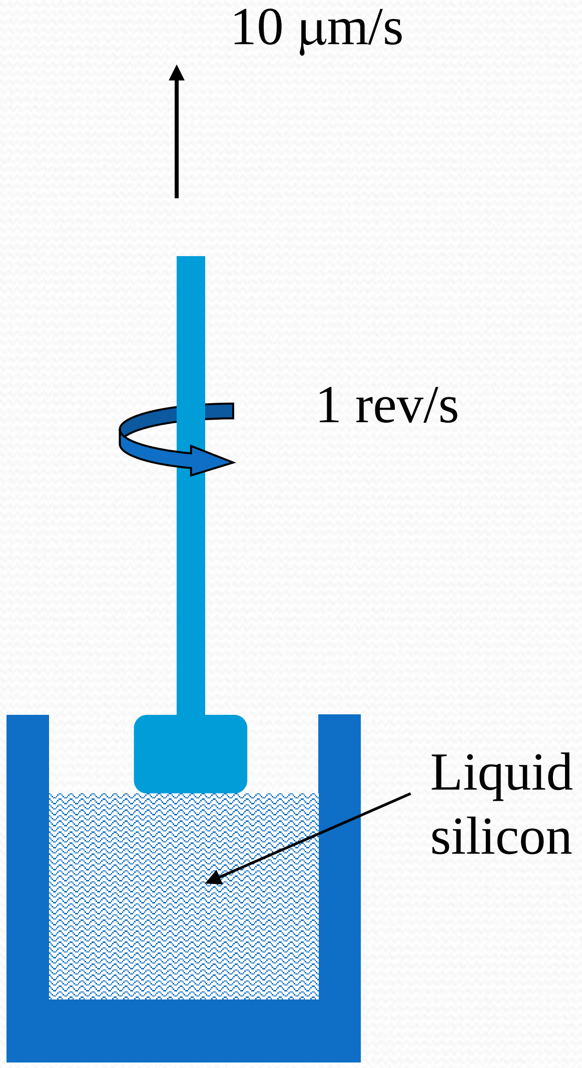
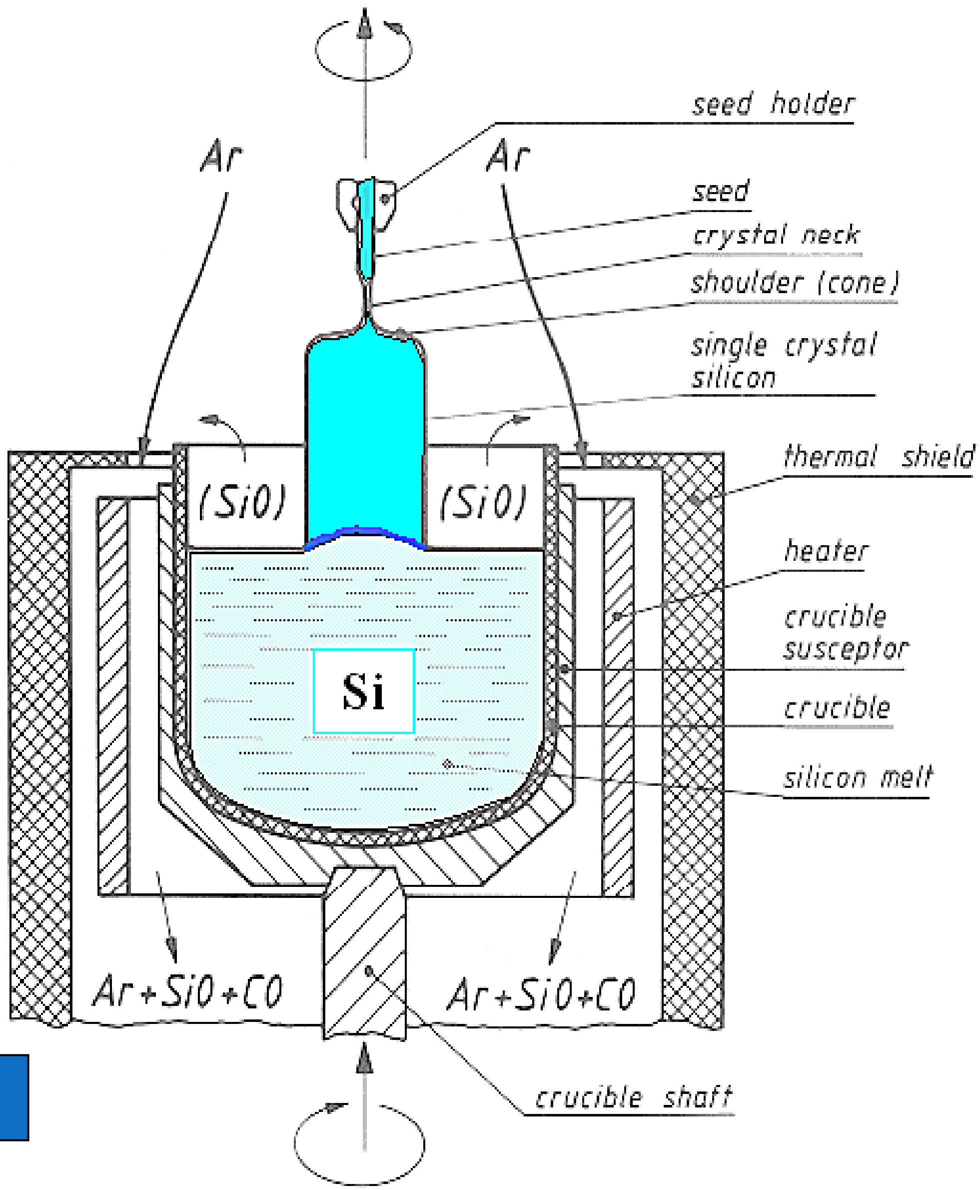


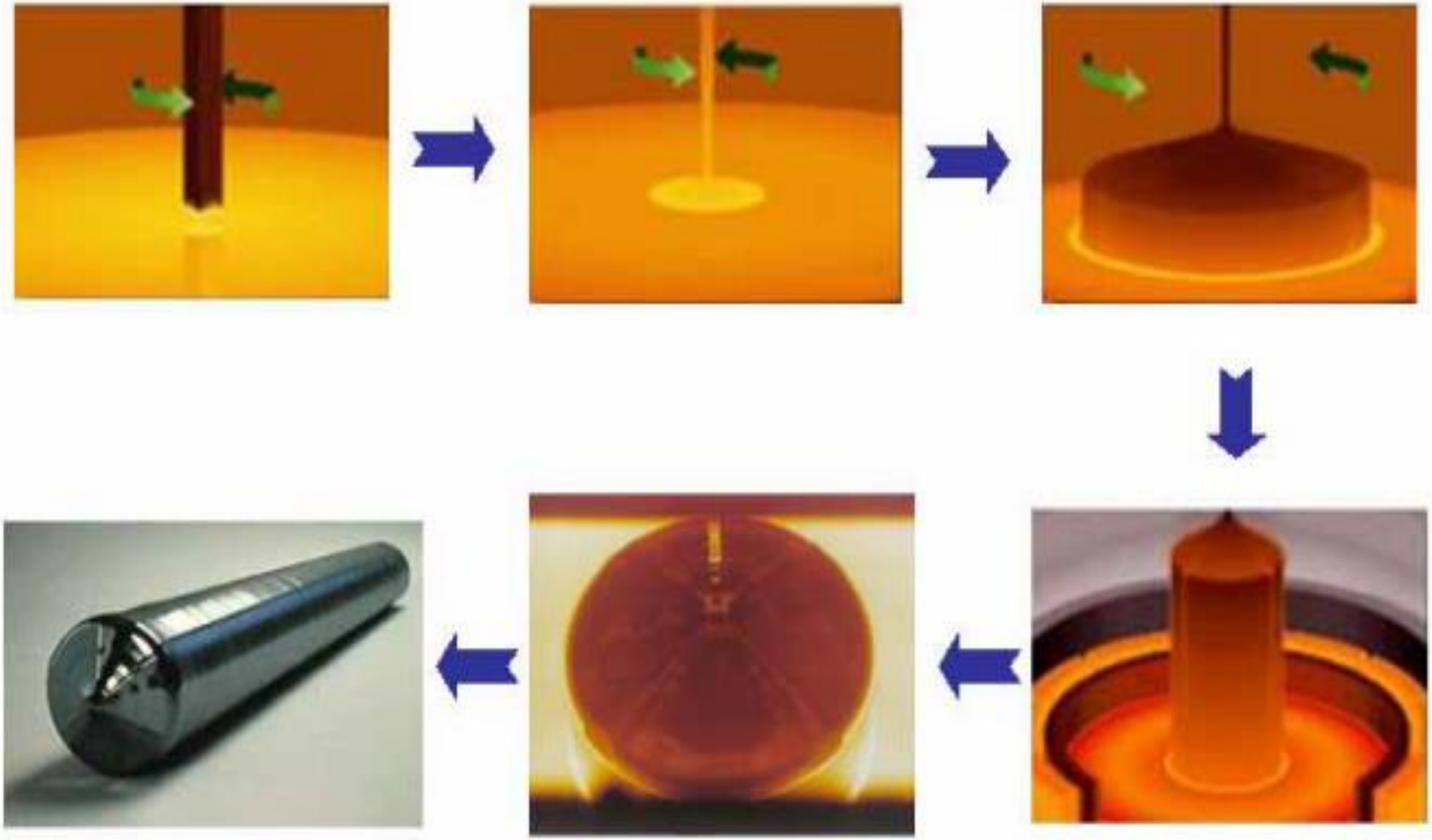
Illustration of CZ process

Crystal Growing

Beginning of crystal growth



Czochralski (CZ) Method



Source: http://www.fullman.com/semiconductors/_crystalgrowing.html

Wafer Slicing

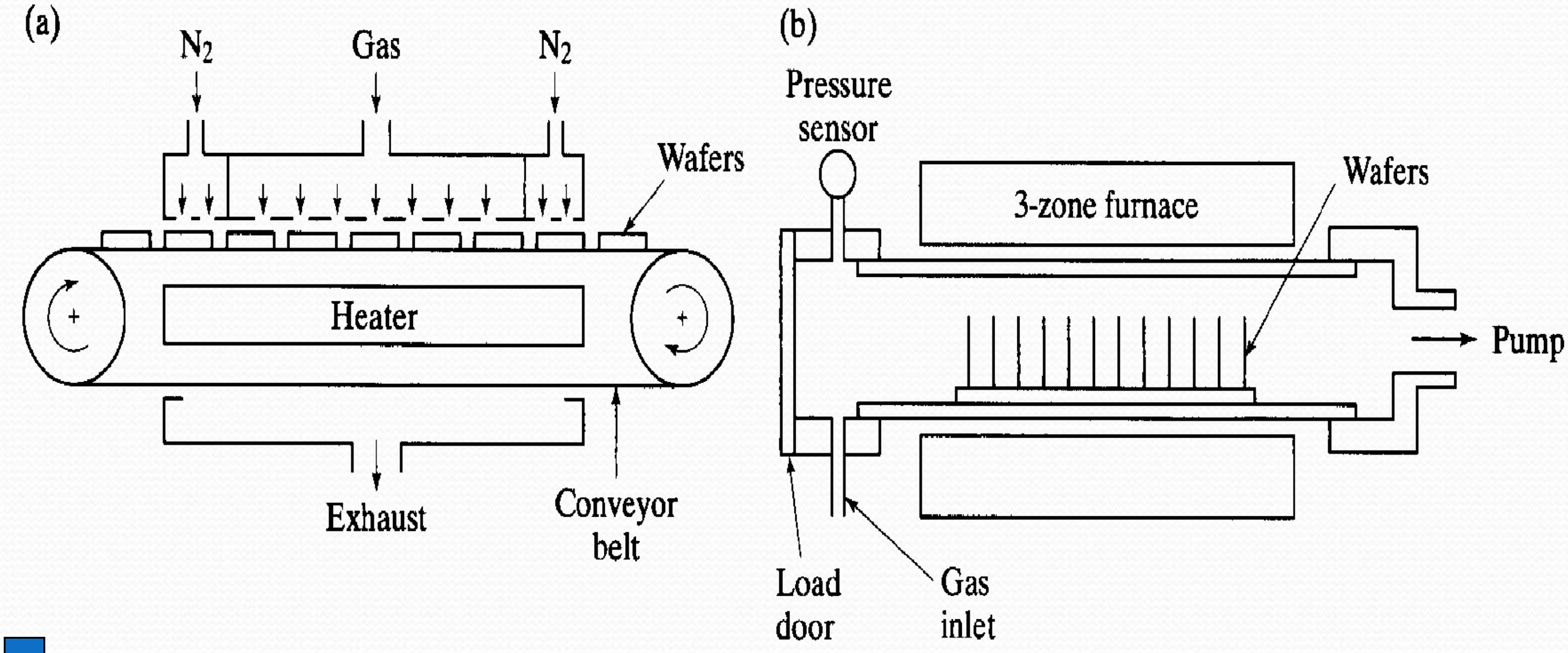
- This step includes
  - Slice the ingot into slices using a diamond saw
  - Polish the surface, and
  - Sort

Film Deposits

- This step is used to add a **special layer on the surface of the silicon for masking**
- Many types of films are used for insulating / conducting, including polysilicon, silicon nitride, silicon dioxide, tungsten, and titanium.
- **Films may be deposited using various method, including**
  - **Evaporation**
  - **Sputtering**

Film Deposits

- The process of CVD
  - (a) Continuous, atmospheric-pressure CVD
  - (b) Low-pressure CVC



Photolithography

Clean wafer

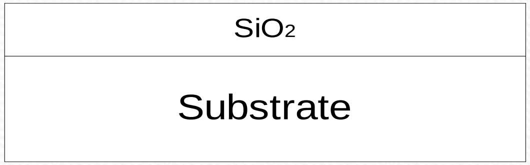
Deposit barrier layer

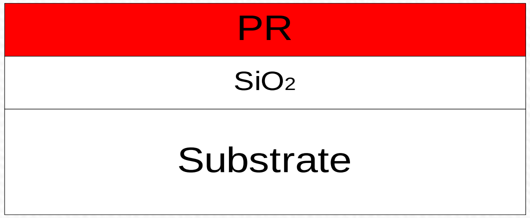
SiO_2, Si_3N_4, metal

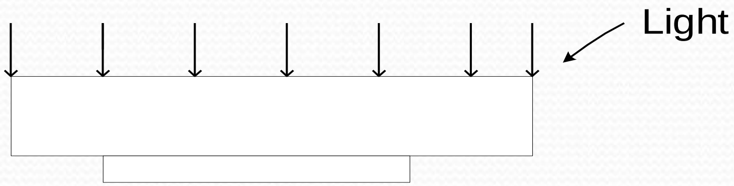
Coat with photoresist

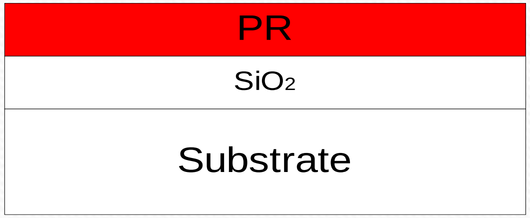
Soft bake

Align masks









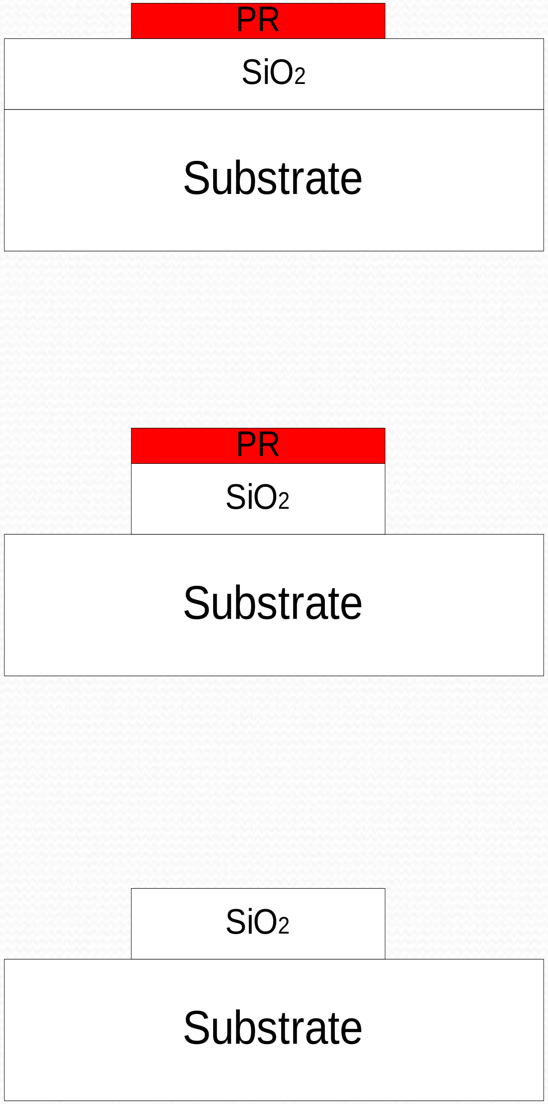
Expose pattern

Develop photoresist

Hard bake

Etch windows in barrier layer

Remove photoresist



Photolithography

- **Si wafer cleaning procedure**
  - Solvent removal
  - Removal of residual organic/ionic contamination
  - Hydrous oxide removal
  - Heavy metal clean

Photolithography

- **Barrier layer formation**
  - The most common material: SiO_2
  - Si_3N_4, polysilicon, photoresist and metals are used at different points in a process flow
  - Thermal oxidation, CVD, Sputtering and Vacuum Evaporation.

Photolithography

- **Photoresist Application:**
  - Surface must be clean and dry for adhesion
  - A liquid adhesion promoter is often applied
  - To make 2.5 to 0.5 µm thick layer, 1000 to 5000 RPM for 30 to 60 sec
  - The actual thickness $\propto$ viscosity

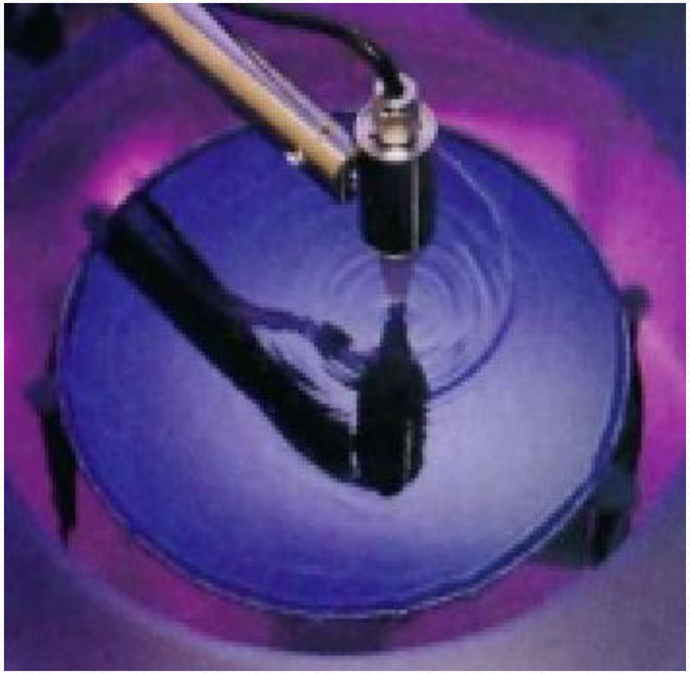
    $\propto 1/(\text{spinning speed})^{0.5}$

Photolithography

- **Photolithography:** is a process by which an image is optically transferred from **one surface to another,** most commonly by the projection of **light through a mask** onto a **photosensitive material (Photoresist material)**.
- **Photoresist:** is a material that changes molecular structure when exposed to radiation (e.g. **ultraviolet light**). It typically consists of a polymer resin, a radiation sensitizer, and a carrier solvent.

Photolithography-spin-coating

- Adding a photoresist layer on the wafer
- A **Photomask** is typically manifested as a glass plate with a thin metal layer, that is selectively patterned to define opaque and transparent regions.



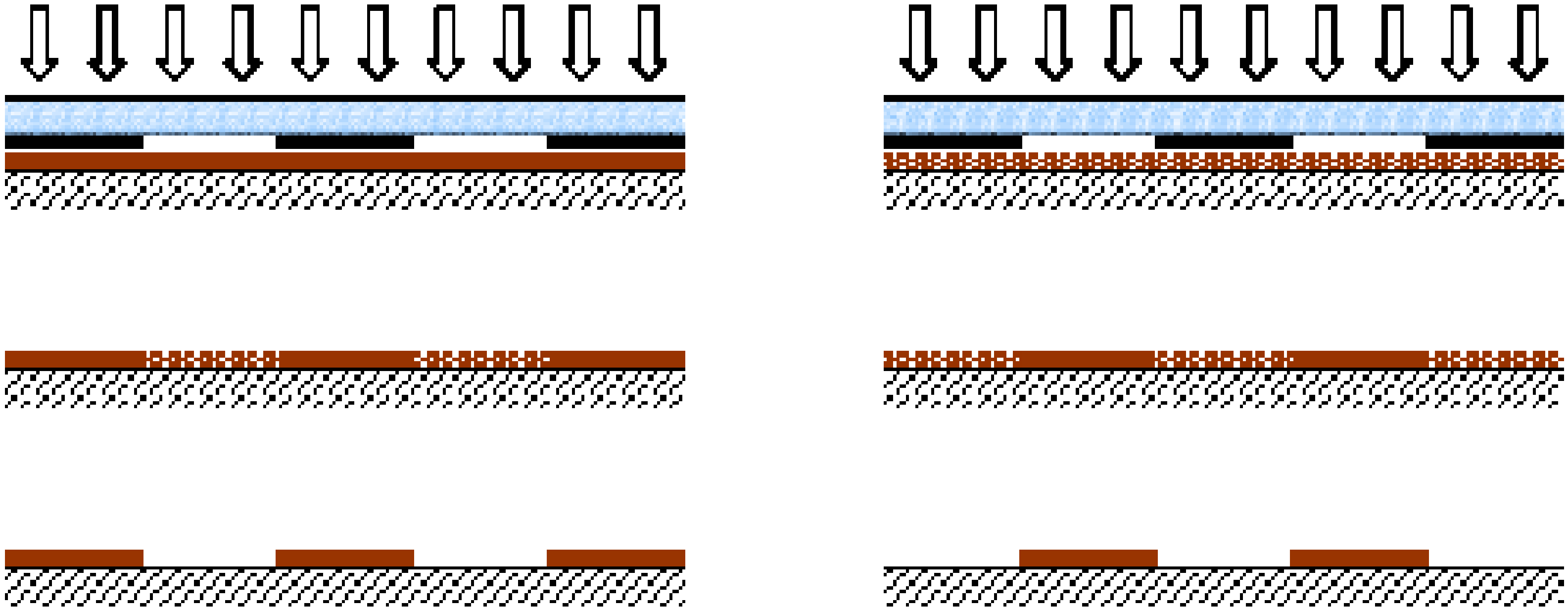
Photolithography

- **Photoresist Exposure and Development**
  - The photoresist is exposed through the mask with a proper light
  - The photoresist is developed with a developer supplied by the manufacturer
  - **A positive resist and a negative resist**
    - The positive resist yields better process control in small-geometry structures

Photolithography

A **positive** photoresist is weakened by radiation exposure, so the remaining pattern after being subject to a developer solution looks just like the opaque regions of the mask

A **negative** photoresist is strengthened by radiation exposure, so the remaining pattern after being subject to a developer solution appears as the inverse of the opaque regions of the mask.



Processing Equipments

Wafer aligner and exposure tool:

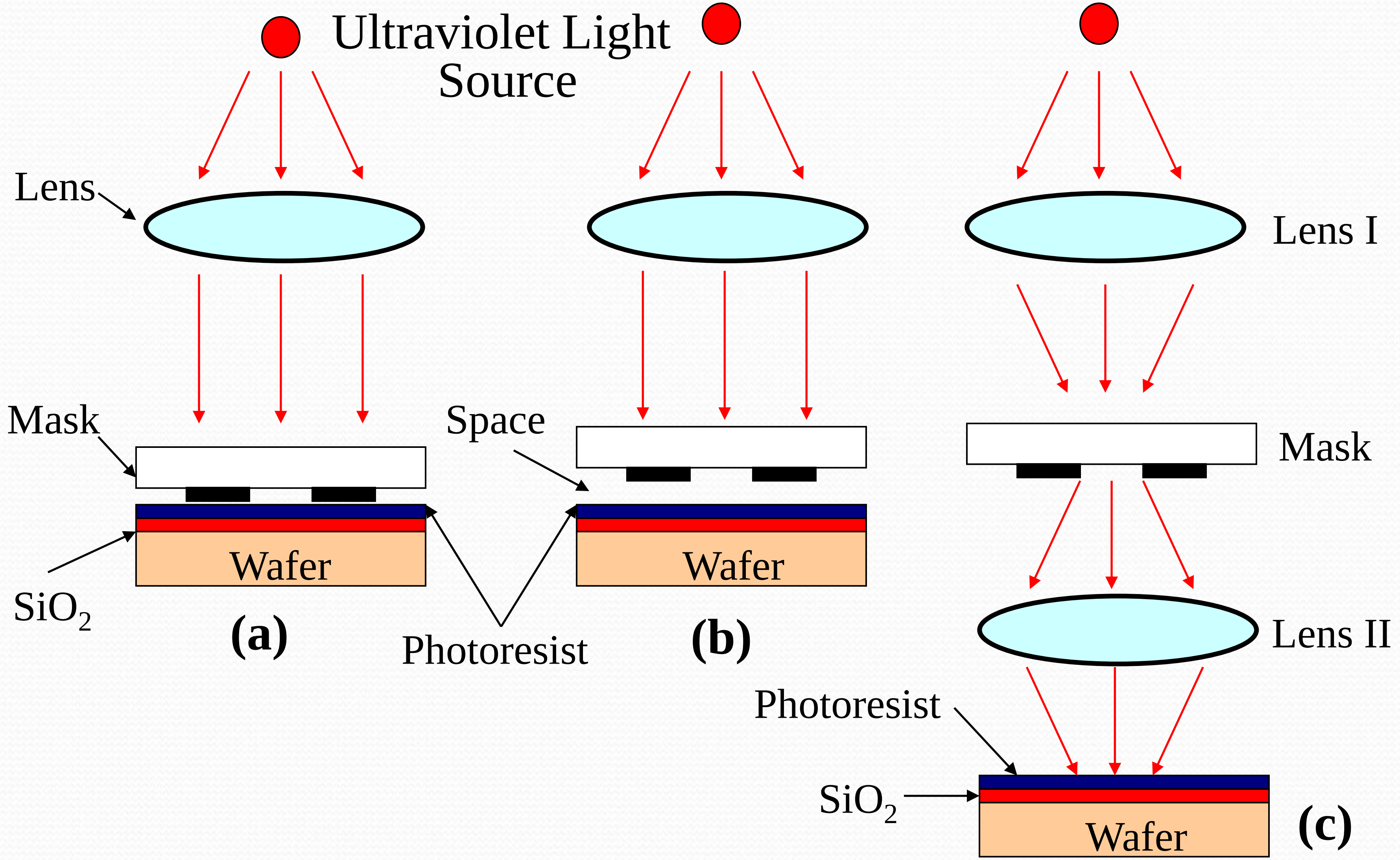
Photolithography-exposure

- **Mask alignment:**
  - Square glass plate with a patterned emulsion or metal film is placed 25 to 125µm over the wafer
  - With manual alignment, the wafer is held on a vacuum chuck and carefully moved into position
  - Computer-controlled alignment equipment achieves high precision alignment
  - Alignment marks are introduced to align each new mask level to one of the previous levels.

UV Exposure:

- **Light Source**
  - High pressure mercury arc lamp → UV
  - Mercury/Xenon lamp → UV
  - Excimer laser (KrF, ArF) → DUV (KrF : 248 nm)
  - Electron beams
  - X-ray
- **Exposed Energy**
  - Energy(mJ) = Light intensity(mW) * time(s)
- **Light Spectrum**
  - i line : 365 nm
  - g line : 436 nm
  - h line : 405 nm

Various Printing Techniques



(a) Contact printing, (b) Proximity printing, (c) Projection printing

Photolithography-Baking

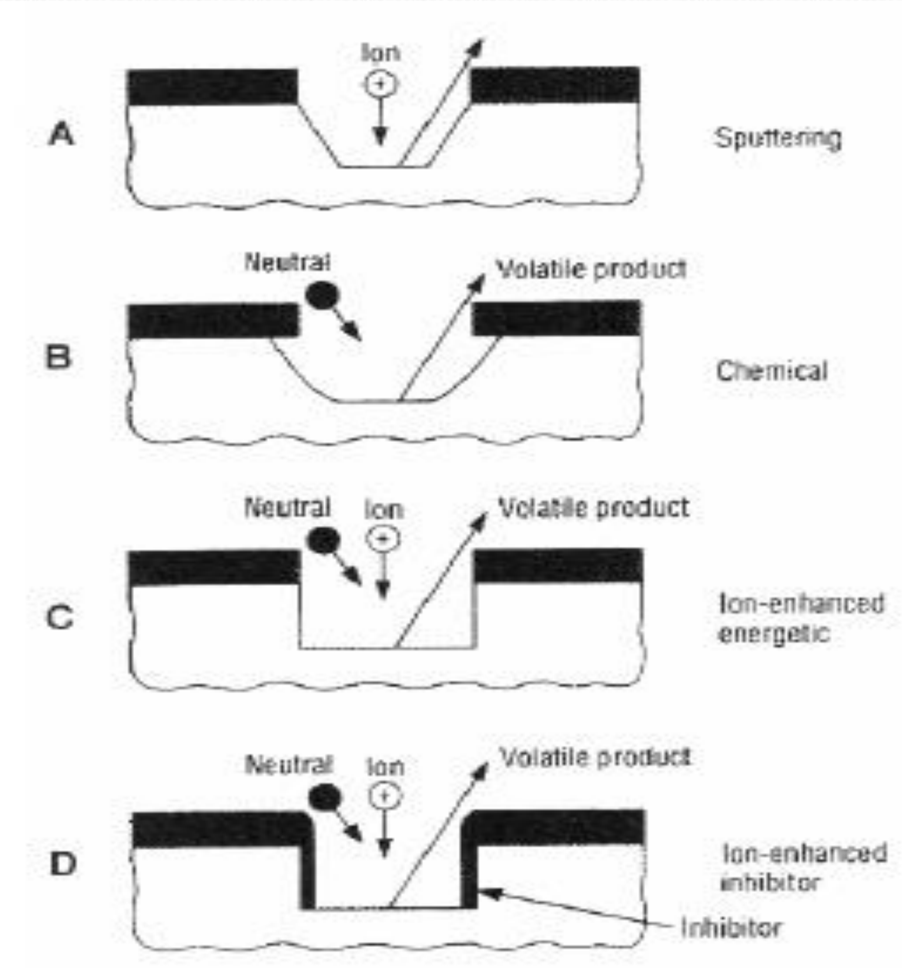
- **Soft Baking (Pre-baking)**
  - To improve adhesion & remove solvent from PR
  - 10 to 30min. in an oven at 80 to 90 ºC
  - Manufacturer’s data sheets
- **Hard Baking**
  - To harden the PR and improve adhesion to the substrate
  - 20 to 30 min. at 120 to 180 ºC
  - Manufacturer’s data sheets

Photolithography-Etching

- **Etching techniques**
  - Wet chemical etching
  - Dry etching
    - Plasma, sputter, RIE, CAIBE, ECR
  - **Photoresist removal**
    - Liquid resist strippers cause the resist to swell and lose adhesion to the substrate
    - Resist ashing: oxidizing(burning) it in an oxygen plasma system

Dry Etching Mechanisms

- **Physical**
  - Removal based on impact & momentum transfer
  - Poor material selectivity
  - Good directional control
  - High excitation energy
  - Lower pressure, <100 mTorr



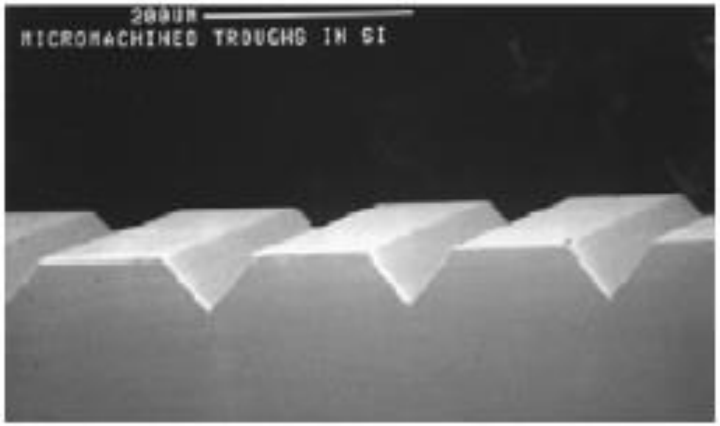
- **Chemical**
  - Highest removal rate
  - Good material selectivity
  - Generally isotropic
  - Higher pressure, >100 mTorr
- **Physical/Chemical**
  - 1. Good directional control & 2. Intermediate pressure, ~100 mTorr

Isotropic Wet Etching

- Etch occurs in all crystallographic directions at the same rate.
- Most common formulation is mixture of hydrofluoric, nitric and acetic acids (“HNA”: HF + HNO3 + CH3COOH).
- Etch rate may be very fast, many microns per minute.
- Masks are undercut.
- High aspect ratio difficult because of diffusion limits.
- Stirring enhances isotropy.
- Isotropic wet etching is applicable to many materials besides silicon.

Anisotropic Wet Etching

- Etch occurs at different rates depending on exposed crystal
- Usually in alkaline solutions (KOH, TMAH).
- Heating typically required for rate control (e.g. > 80 ^{o}C).
- Etch rate typically ~1 µm/min, limited by reactions rather than diffusion.
- Maintains mask boundaries without undercut.
- Angles determined by crystal structure (e.g. 54.7^{o}).
- Possible to get perfect orthogonal shapes outlines using 1-0-0 wafers.



Etching –Comparison

ISOTROPIC

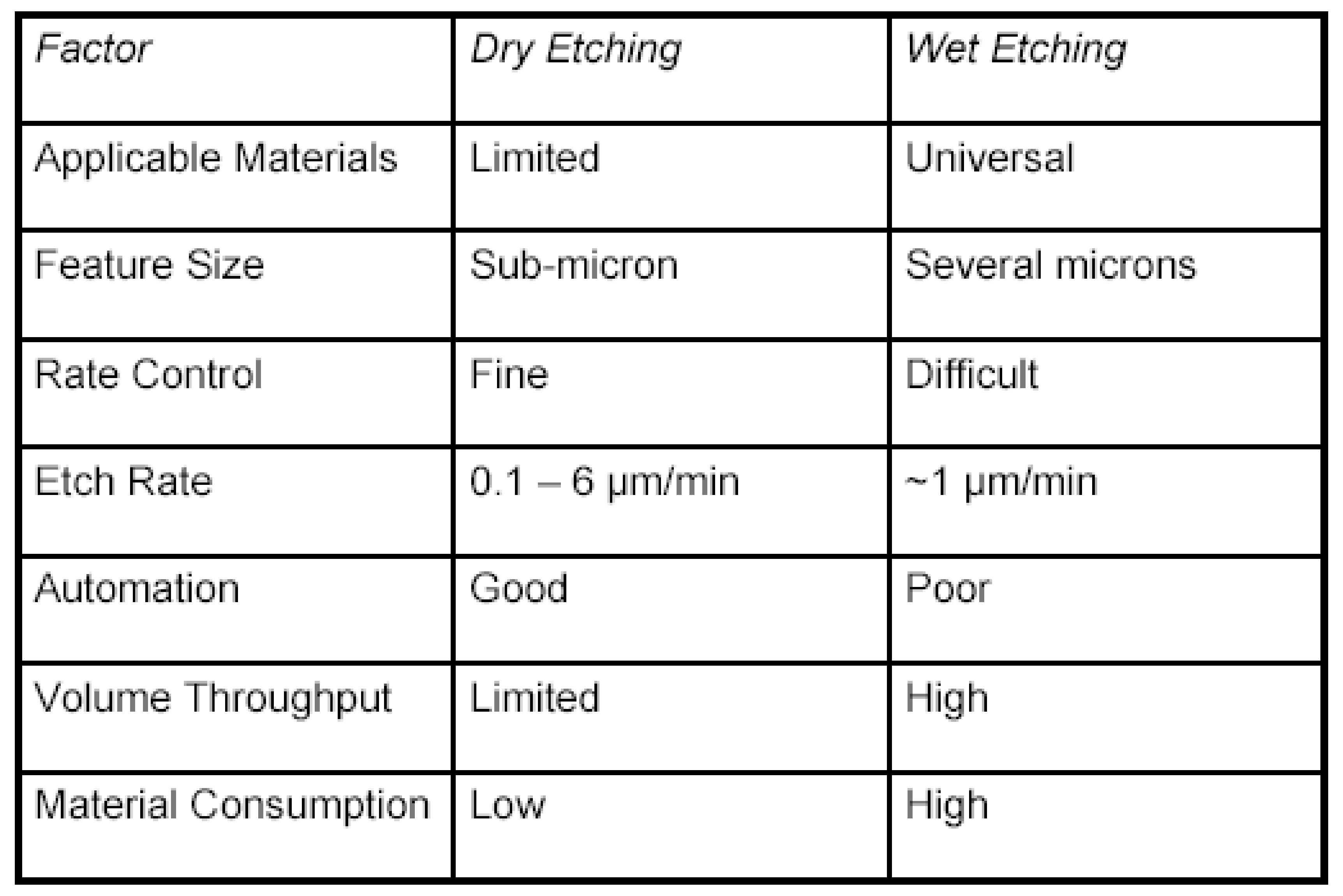
- Wide variety of materials
- No crystal alignment required
- May be very fast
- Sometimes less demand for mask resilience

ANISOTROPIC

- Predictable profile
- Better depth control
- No mask undercutting
- Possibility of close feature arrangement

Multiple layers are common

Dry and Wet Etching: Comparison



Factor	*Dry Etching*	*Wet Etching*
Applicable Materials	Limited	Universal
Feature Size	Sub-micron	Several microns
Rate Control	Fine	Difficult
Etch Rate	0.1 – 6 µm/min	~1 µm/min
Automation	Good	Poor
Volume Throughput	Limited	High
Material Consumption	Low	High