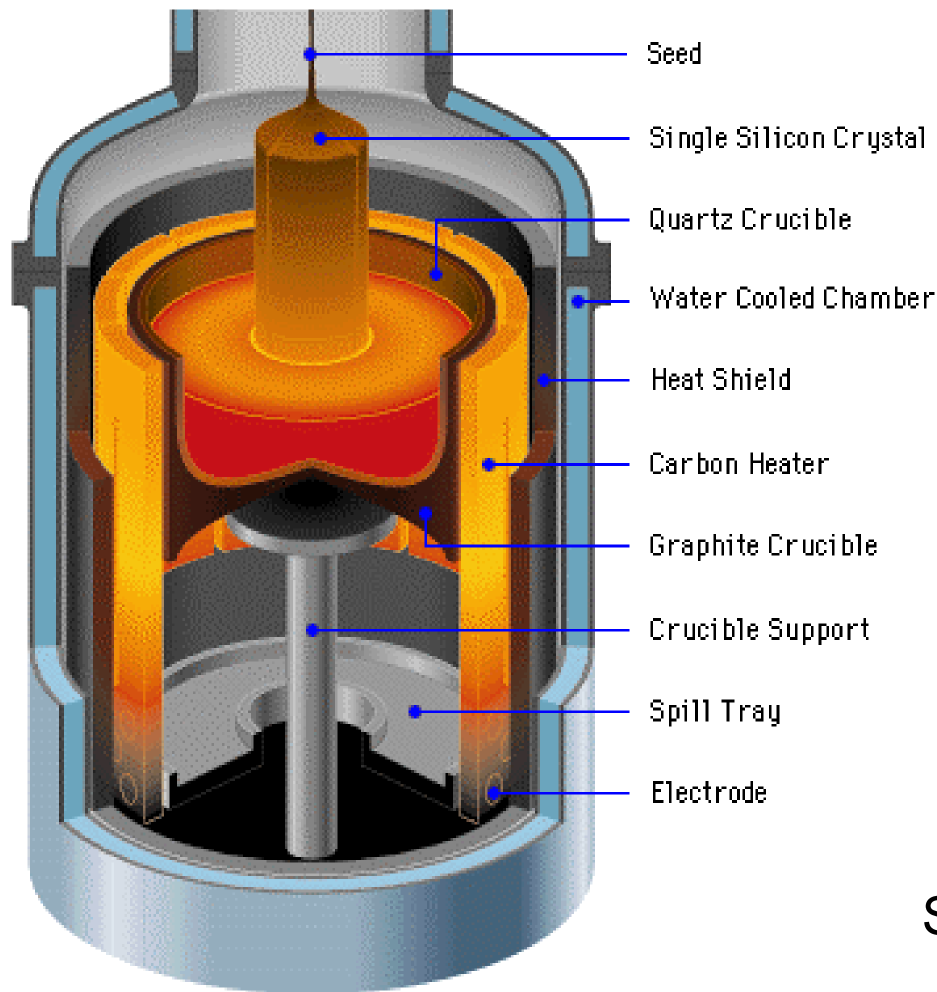
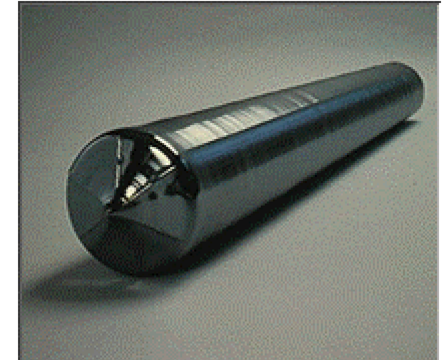
Czochralski Crystal Growth



Crystal Pulling

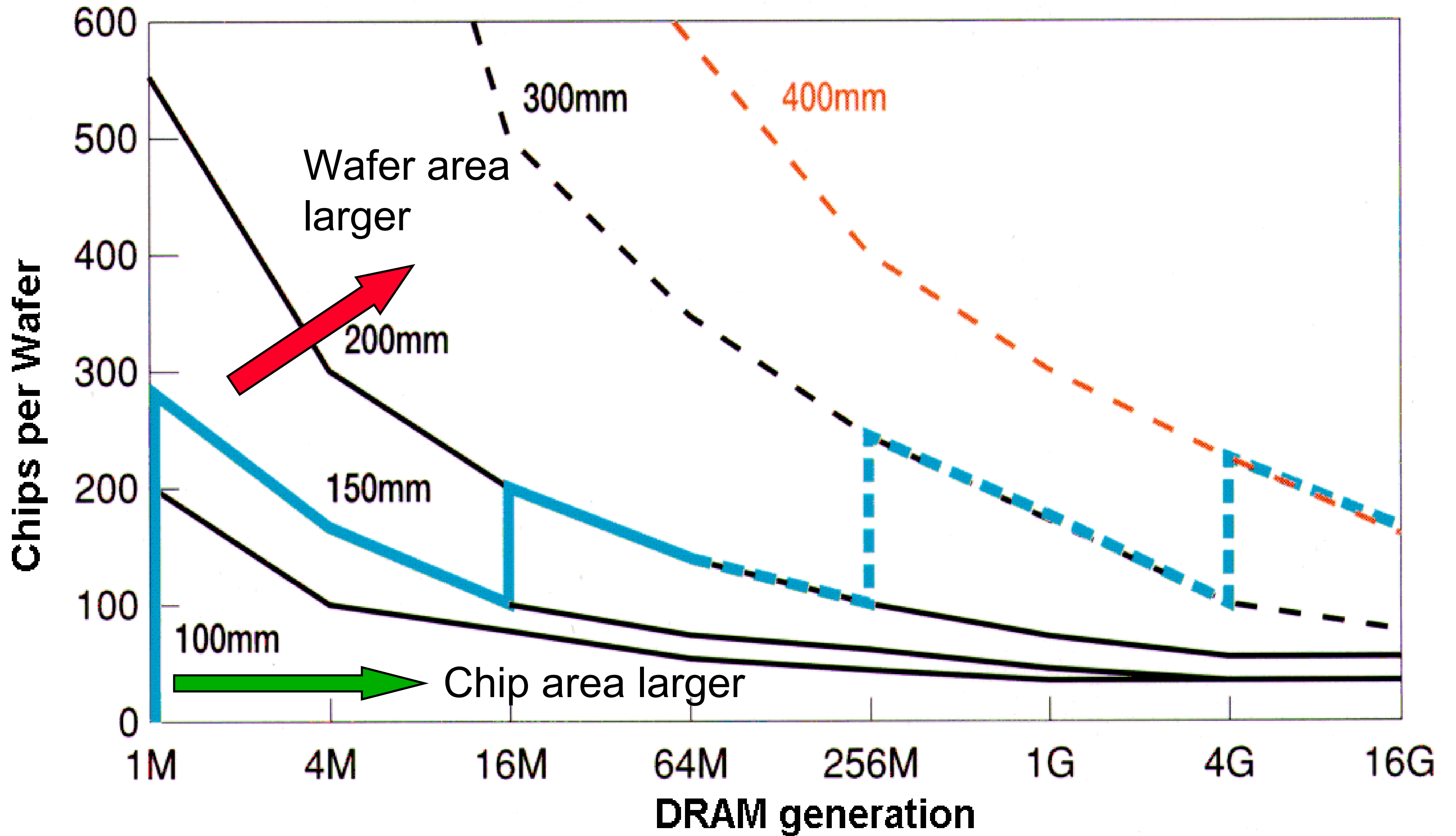
Crystal Ingots



Shaping and Polishing

300 mm wafer

Advantage of larger diameter wafers



Large-Diameter Wafer Handling

La Vals Fab

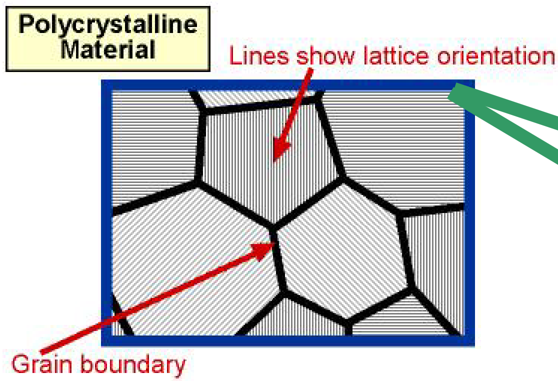
300mm wafer vs pizza

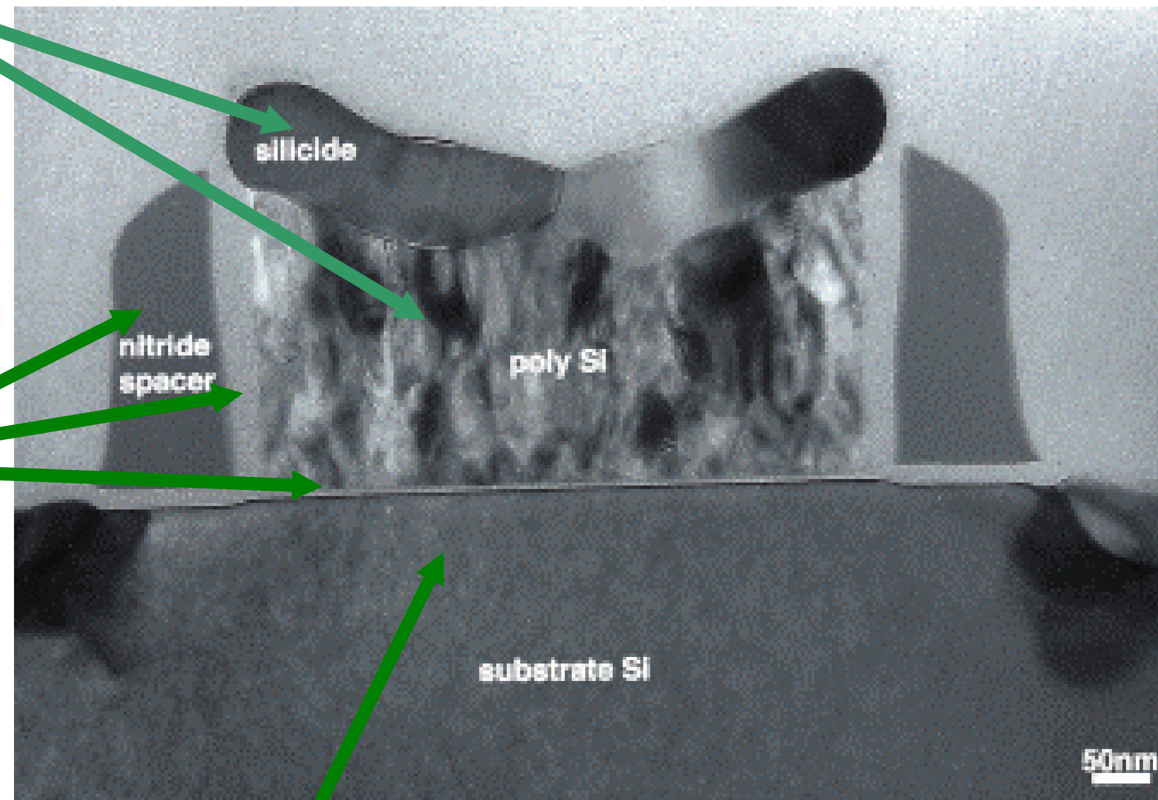
Production Fab

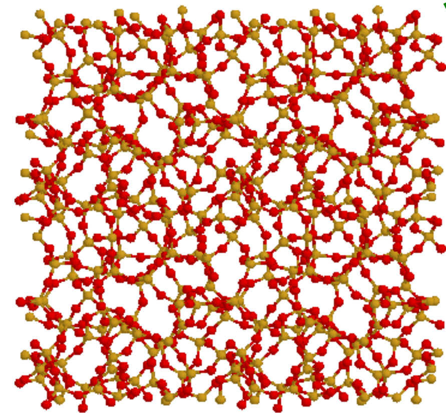
Overhead rail transport of wafer cassette

•Lateral uniformity of processing effects across the WHOLE wafer is key consideration for microfabrication design

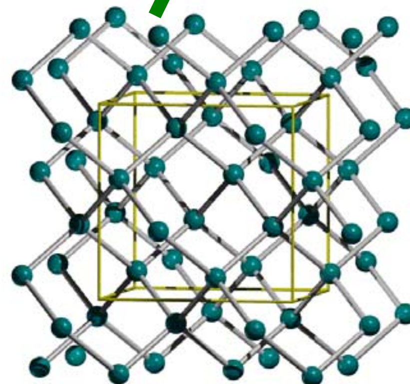
Microstructure of Electronic Materials





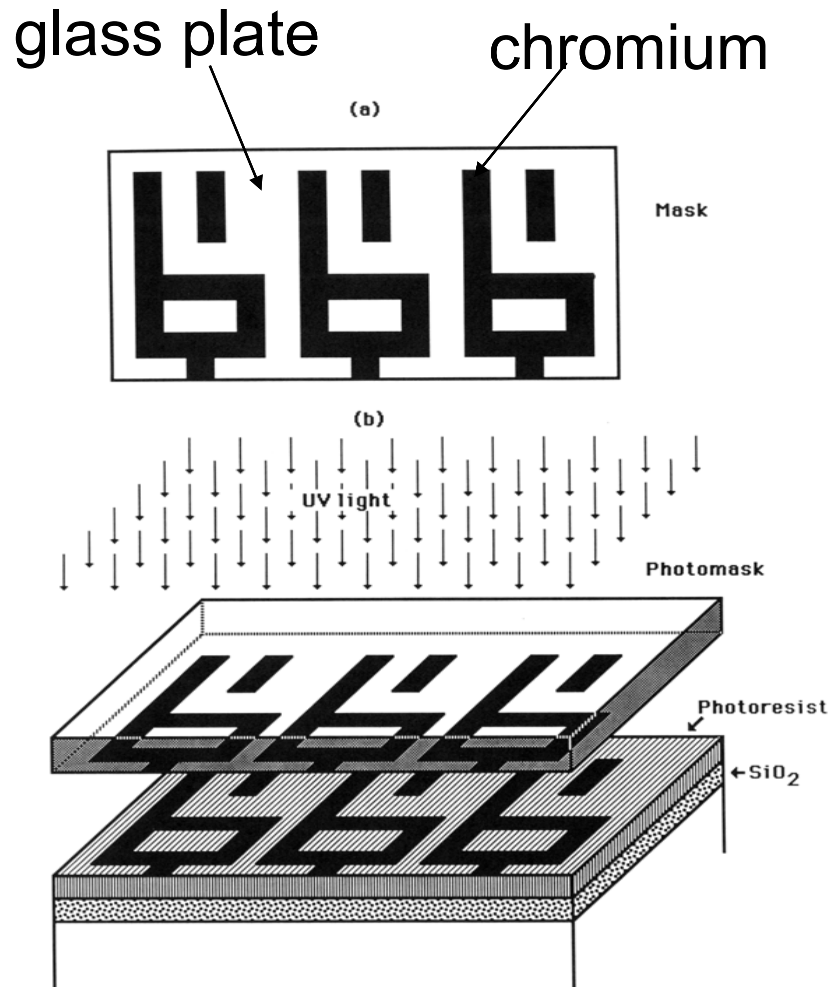


Amorphous materials



Single-Crystal Material

Photolithography



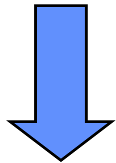
Positive Resist

Part exposed to light will be dissolved in development solution.

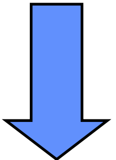
Processing Temperature
Ambient

Etching

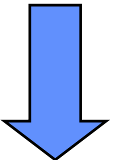
Pattern resist mask



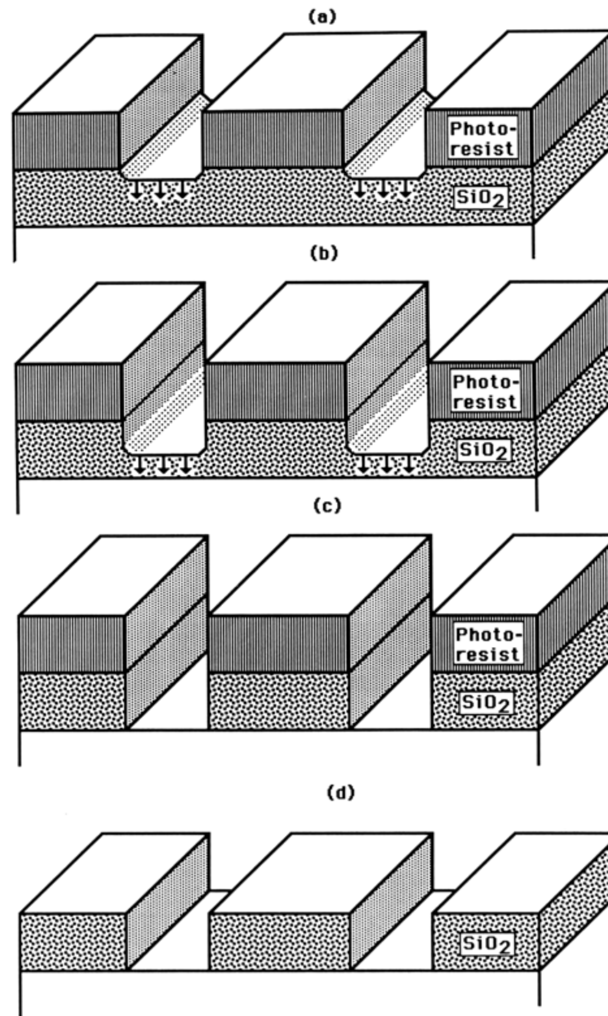
Etching thin film

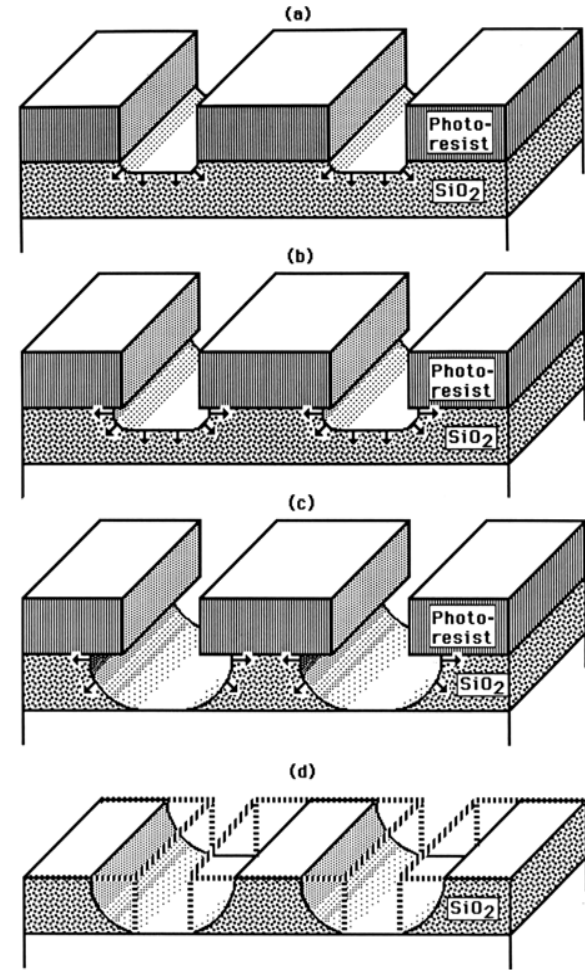


Etching completed



Remove resist mask





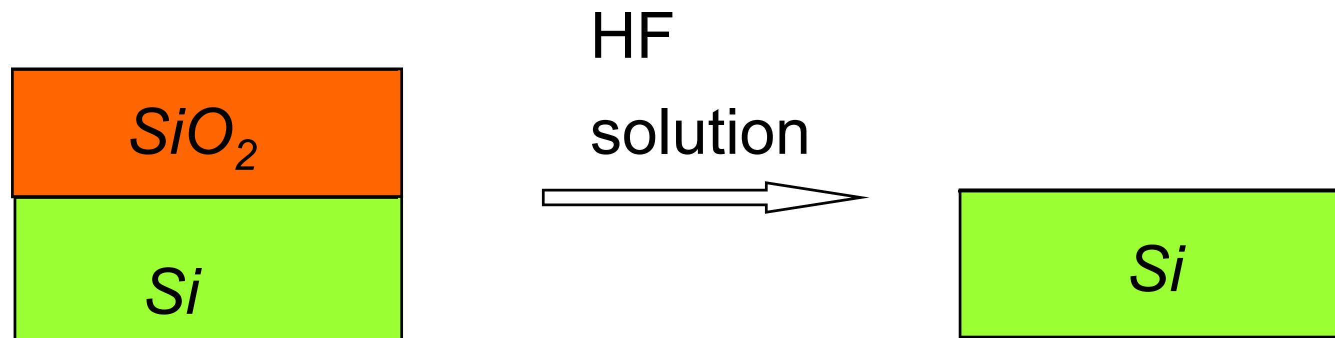
Processing Temperature
Ambient

Anisotropic
(e.g. ***Reactive Ion Etching***)

Isotropic
(e.g. ***Wet Etching***)

Etching Selectivity

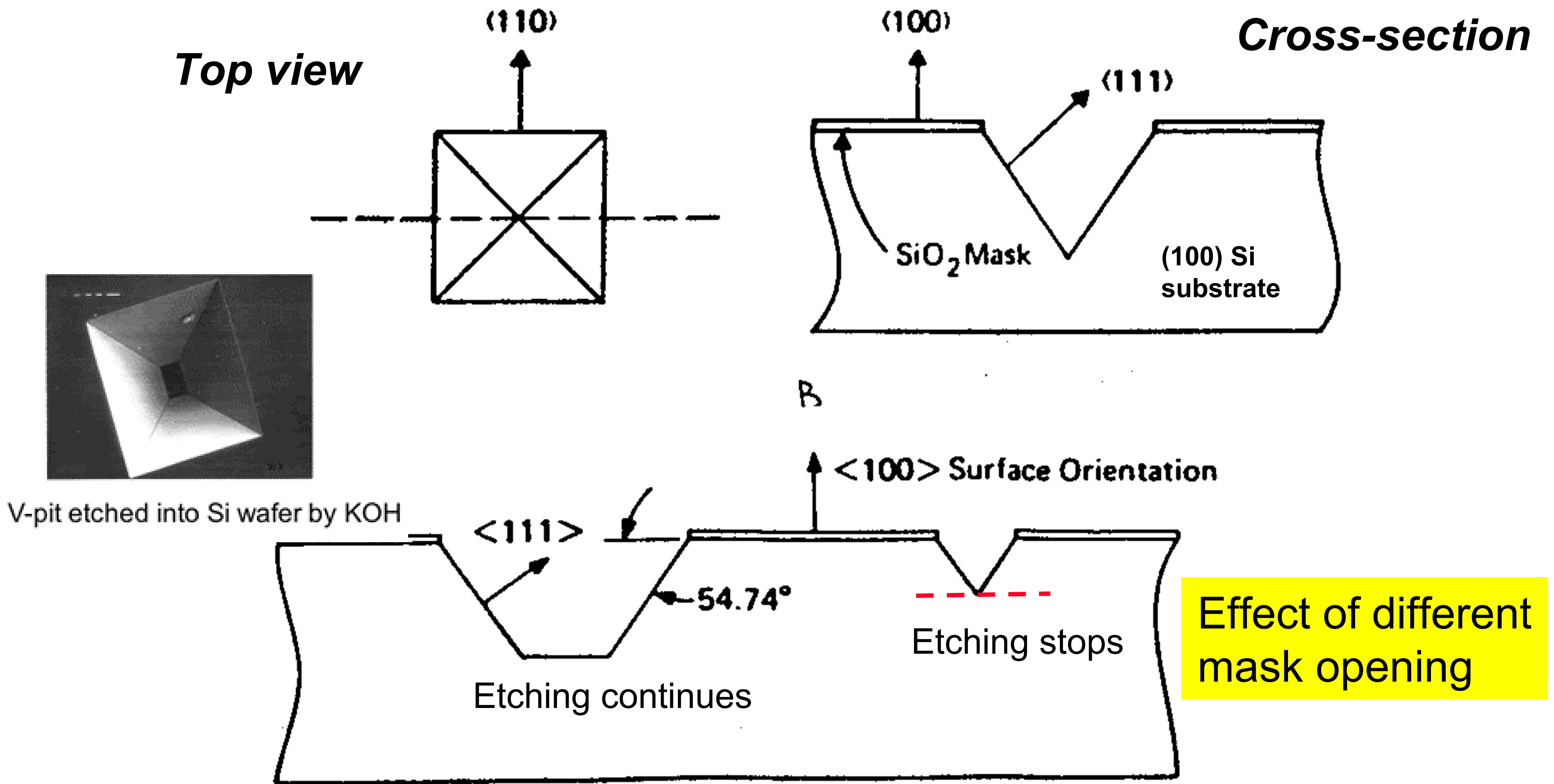
Example: HF solution etches SiO_2 but not Si



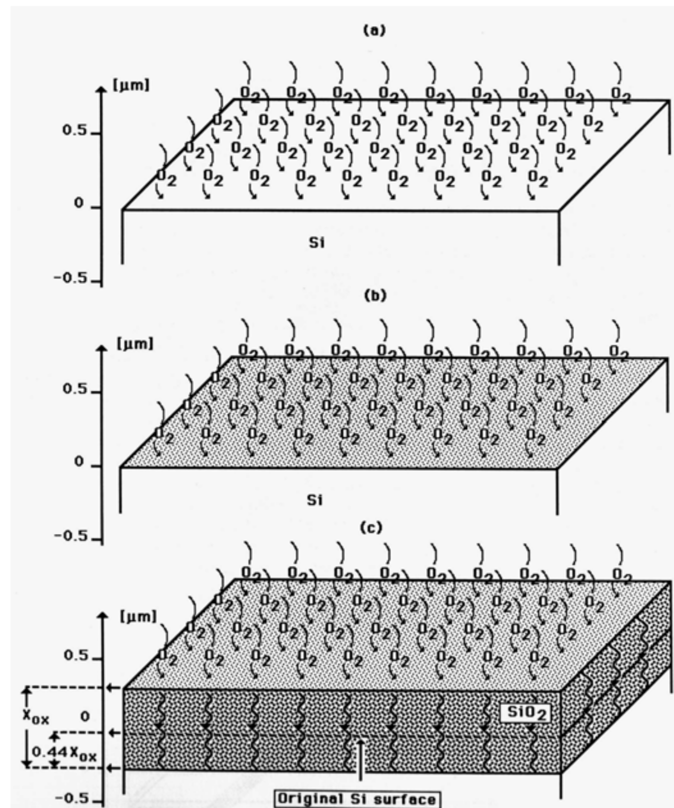
* A high etching selectivity is usually desired

“Anisotropic “ Wet Etching of Si Crystals

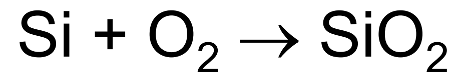
Etchants : KOH or EDP (Ethylene-Diamine_Pyrocatechol)

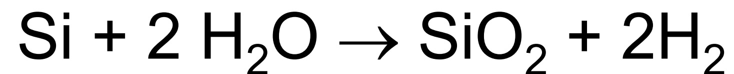


Thermal Oxidation

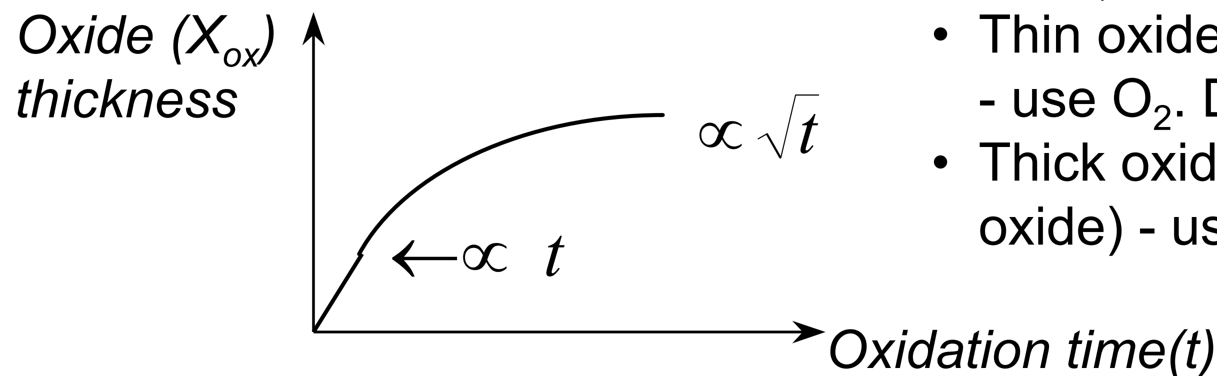


Processing Temperature
900-1100 °C



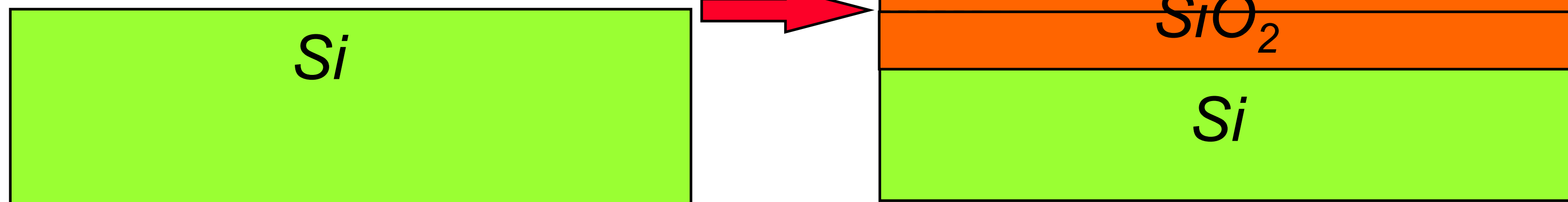


- O_2 (or H_2O) diffuses through SiO_2 and reacts with Si at the interface to form more SiO_2.
- 1μm of SiO_2 formed consumes 0.44 μm of Si substrate.
- Thin oxide growth (e.g. gate oxide) - use O_2. Dry oxidation
- Thick oxide growth (e.g. field oxide) - use H_2O. Wet oxidation



Uneven surface topography with window oxidation

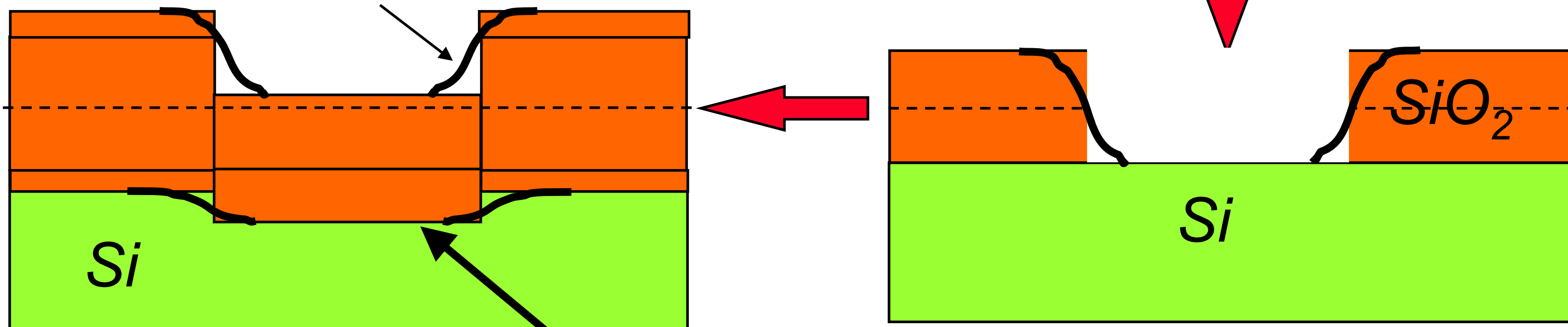
1st oxidation



Realistic topography with 2-dimensional effect

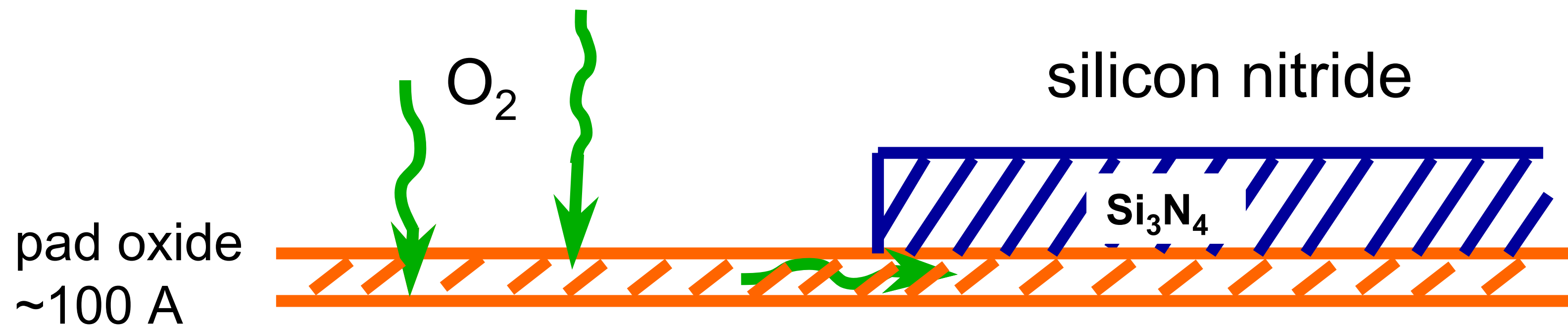
2nd oxidation

Pattern oxide window by litho and etch



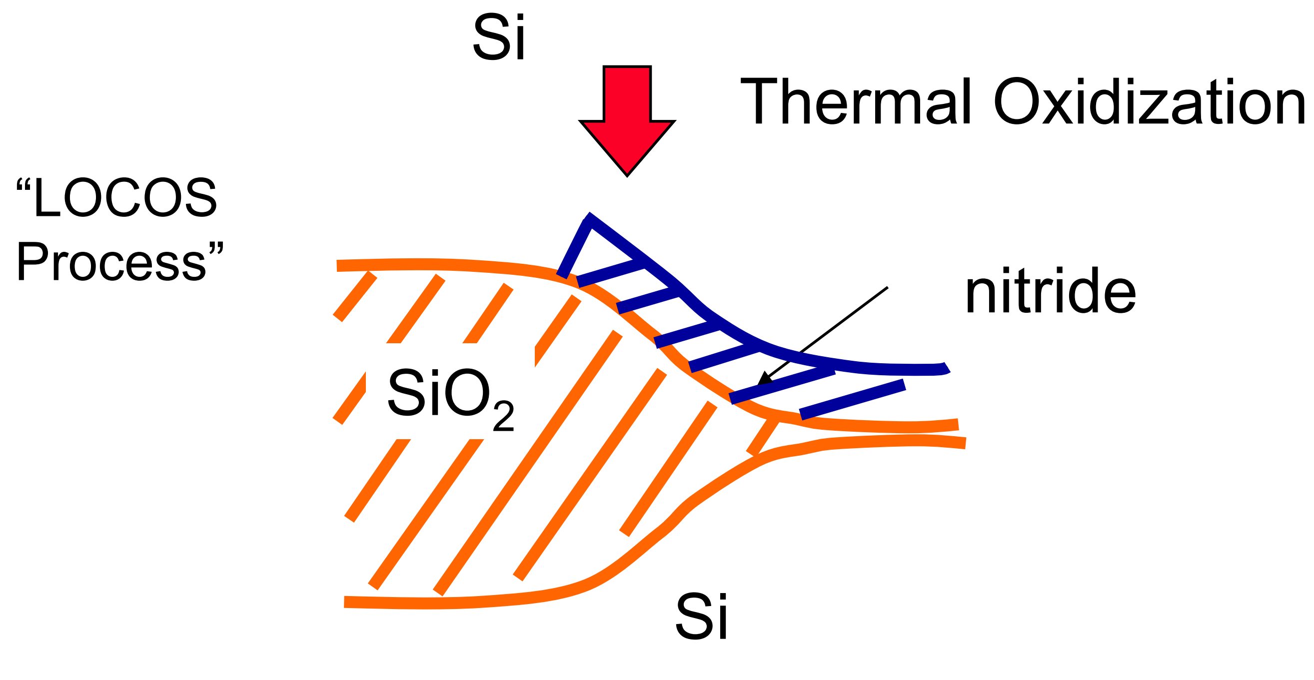
Note uneven Si surface after window oxidation

Local Oxidation



Thermal Oxidization

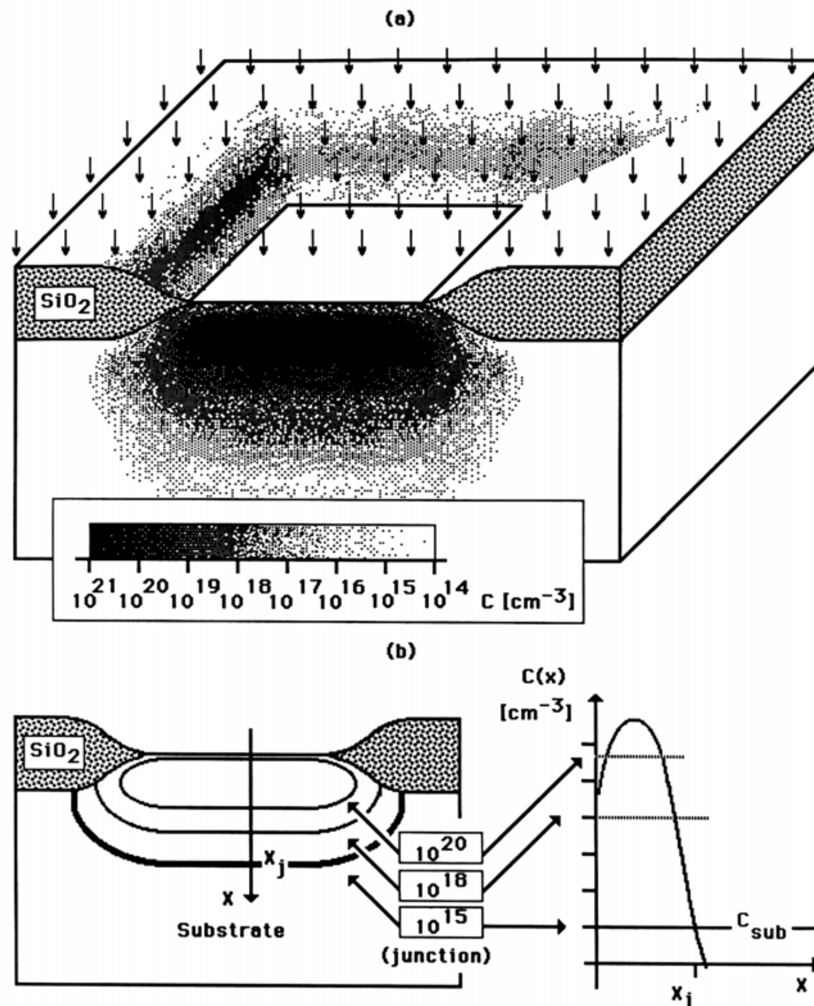
"LOCOS Process"



Ion Implantation

typically used to introduce dopans into semiconductors

Ion Energy
~1 keV to
200 keV



Processing Temperature

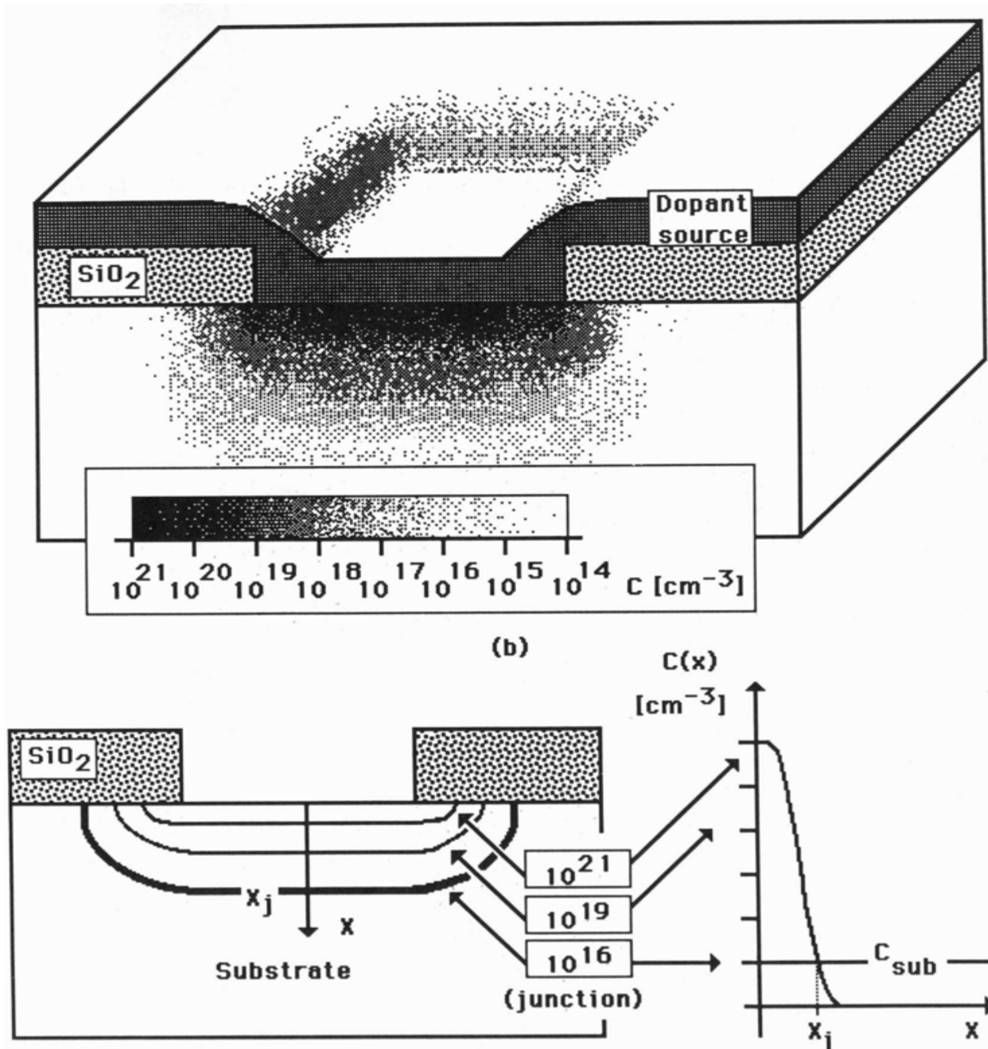
Room temp during implantation.

After implantation, a 900°C-1000°C anneal step is needed to:

1) activate dopants
2) restore Si crystallinity

Diffusion

- To introduce dopants into semiconductors [Predeposition]
- To spread out the dopant profile [Drive-in]



$$D = D_0 \cdot e^{-Q/kT}$$

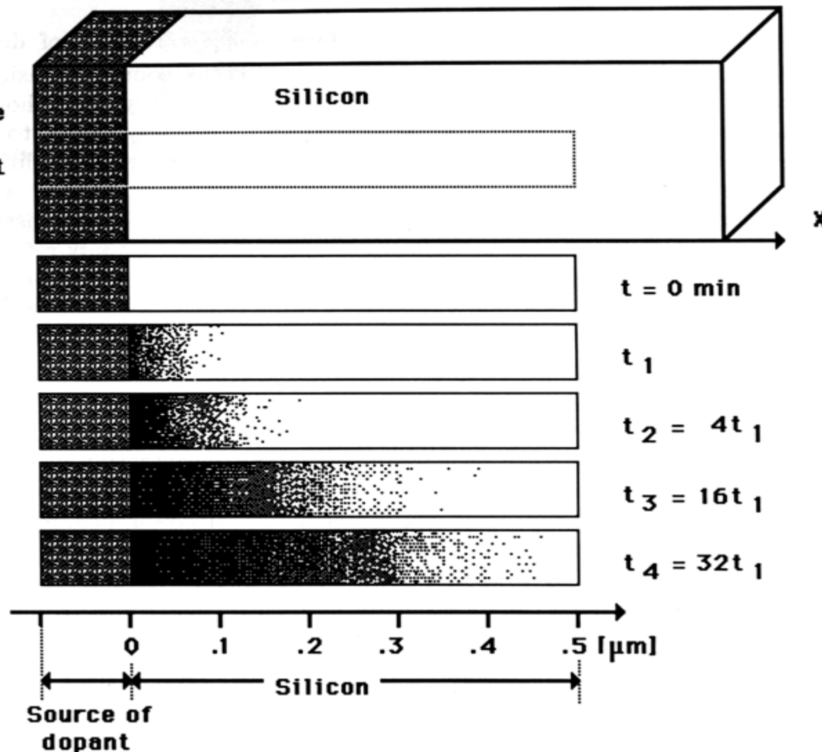
$$D = Diffusion\ \ Constant$$

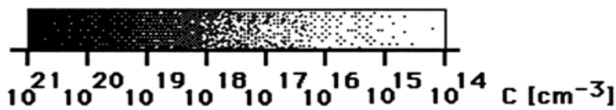
$$Q = \ Activation\ \ Energy$$

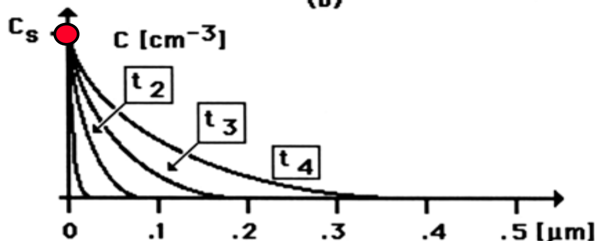
$$T = Temp\ in\ K\left(D \uparrow as\ T \uparrow\right)$$

Processing Temperature
950-1200 ^oC

Predeposition







- Si surface concentration maintained at constant C_s (solid-solubility) during predep.

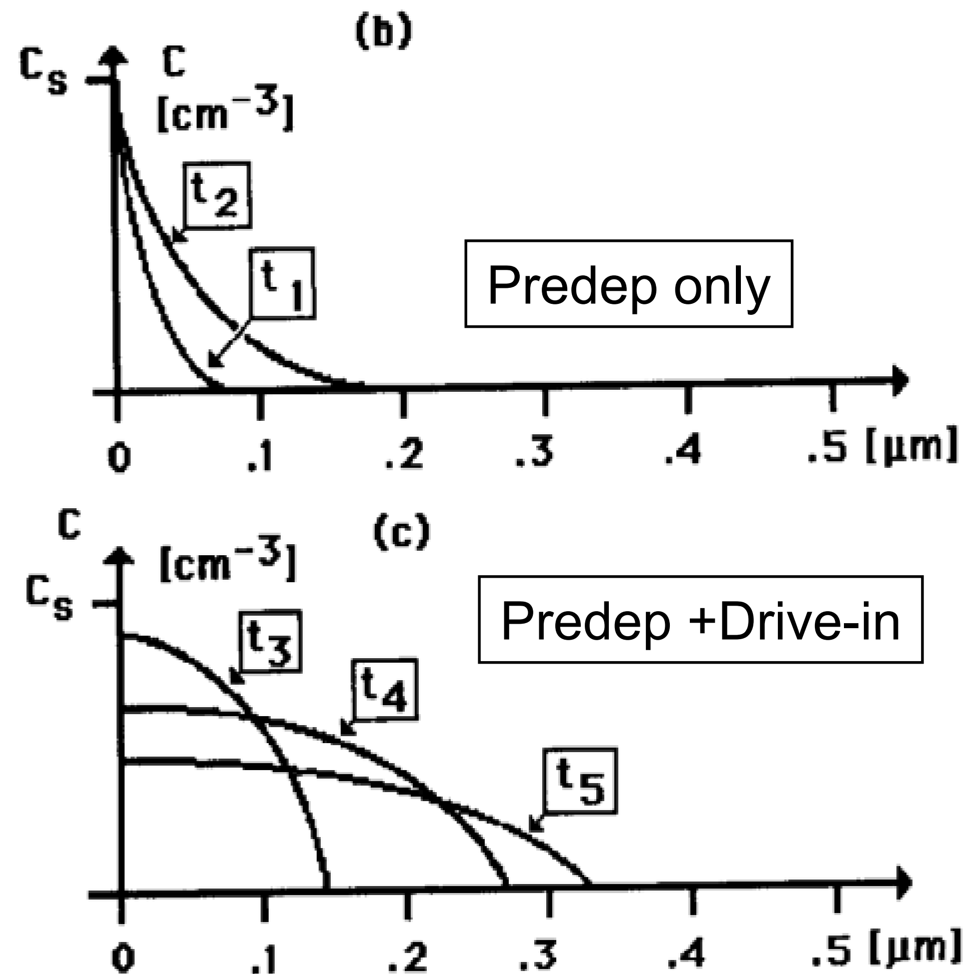
- Dose of dopant incorporation

$$= \frac{C_s \cdot 2\sqrt{Dt}}{\sqrt{\pi}}$$

Predeposition and Drive-in

- Half-gaussian depth profile after long drive-in.
- Dopant dose ***conserved*** during drive-in.
- Diffusion distance

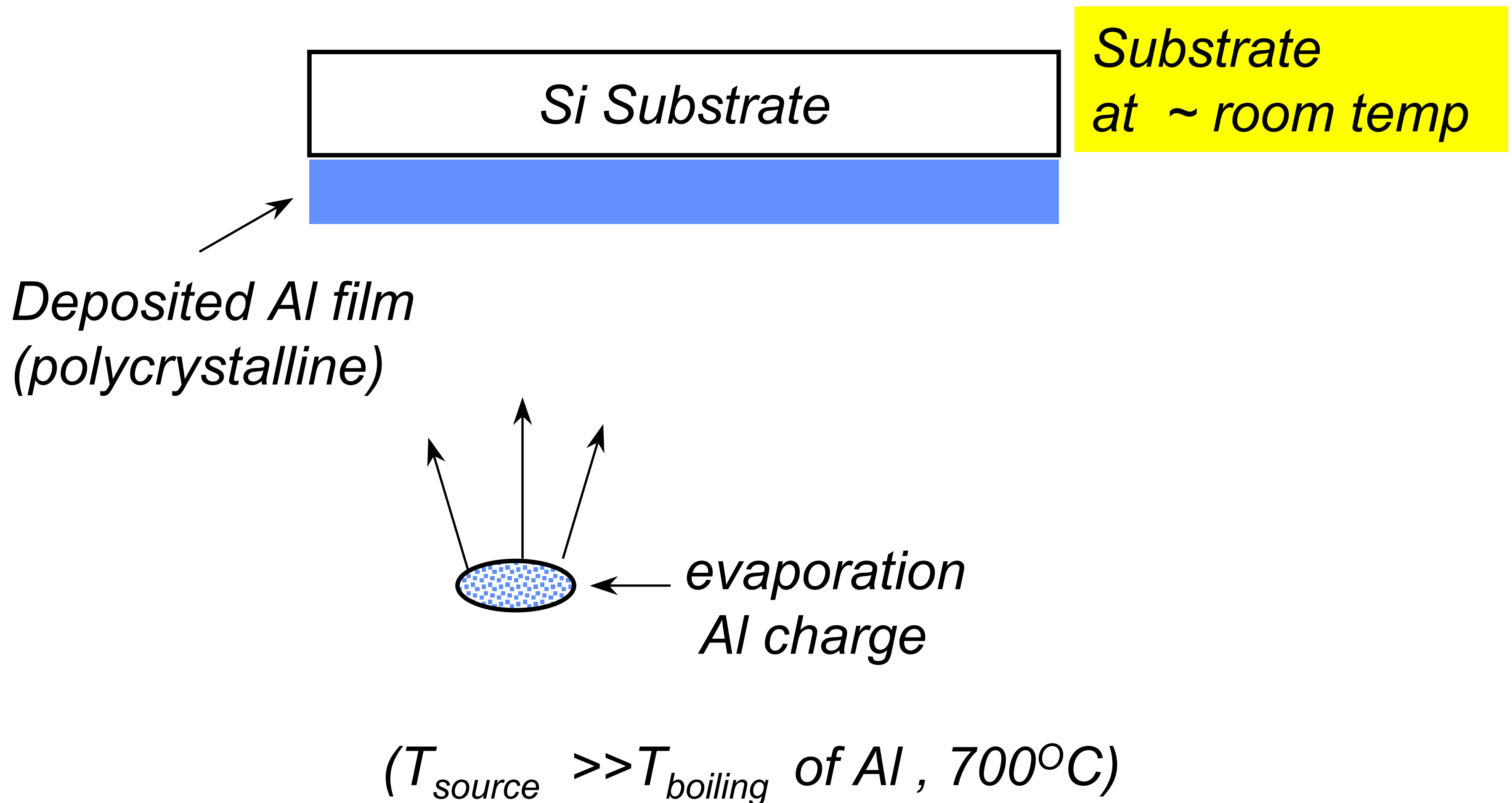
$$\left(\cong \sqrt{Dt}\right)$$



Concentration versus Depth

Physical Vapor Deposition (1)

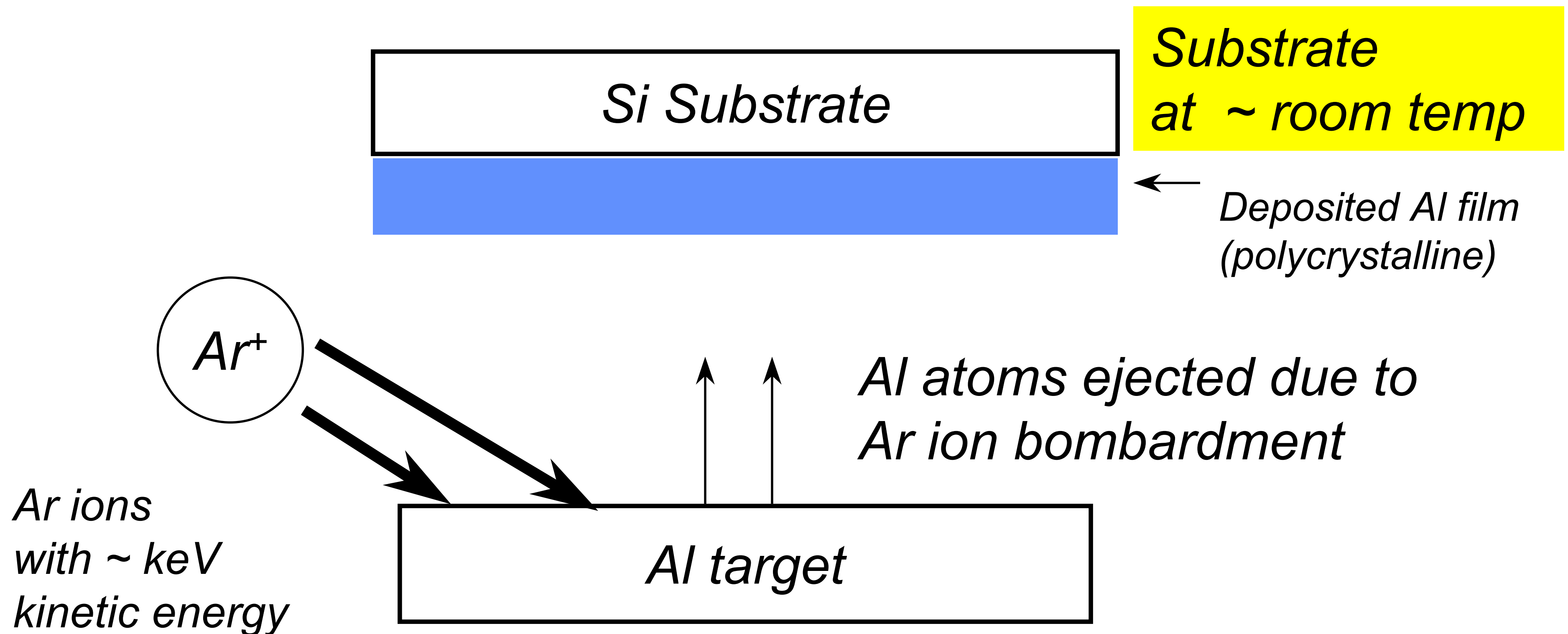
Evaporation Deposition



(T_{source} >> $T_{boiling}$ of Al , 700°C)

Physical Vapor Deposition (2)

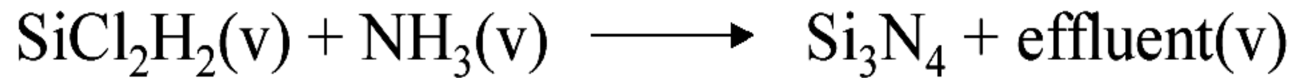
Sputtering Deposition

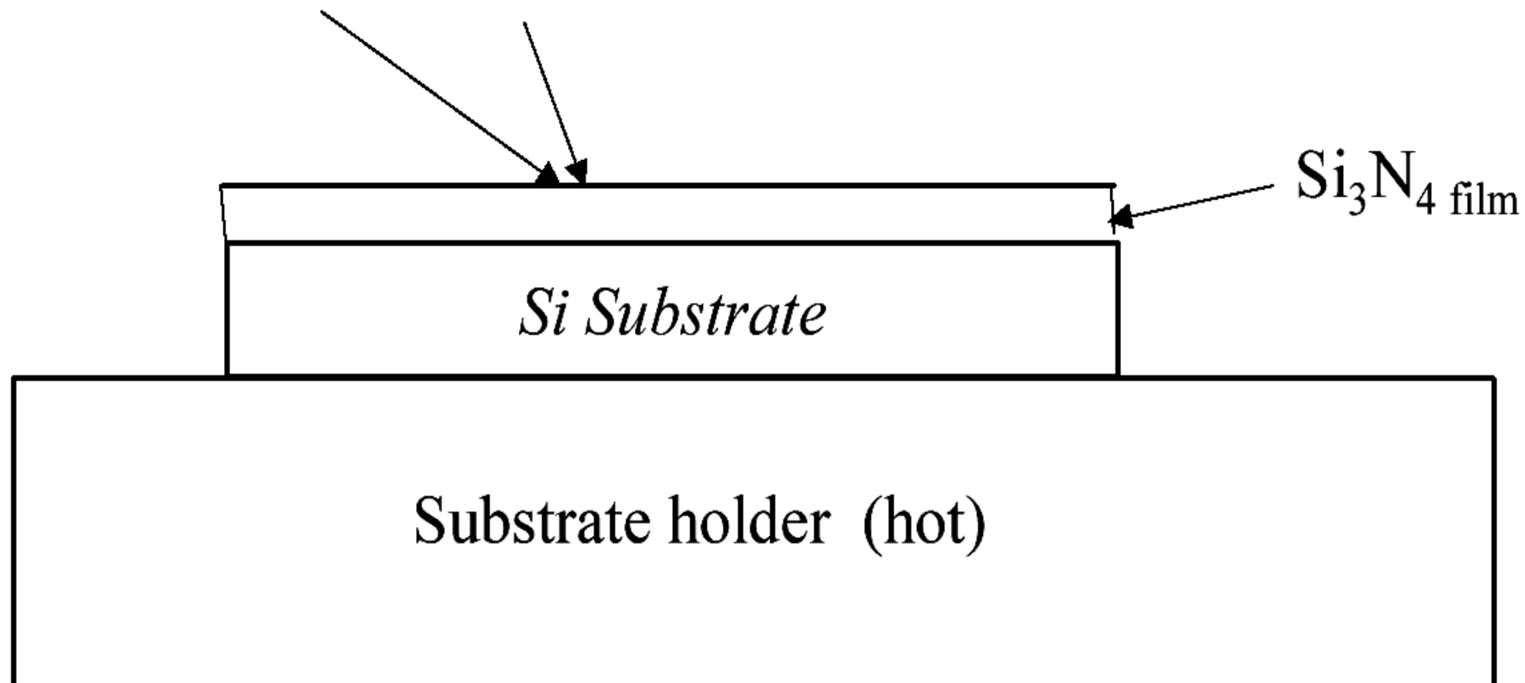


Chemical Vapor Deposition (CVD)

CVD, eg. of Si_3N_4

Processing Temperature 300-600°C

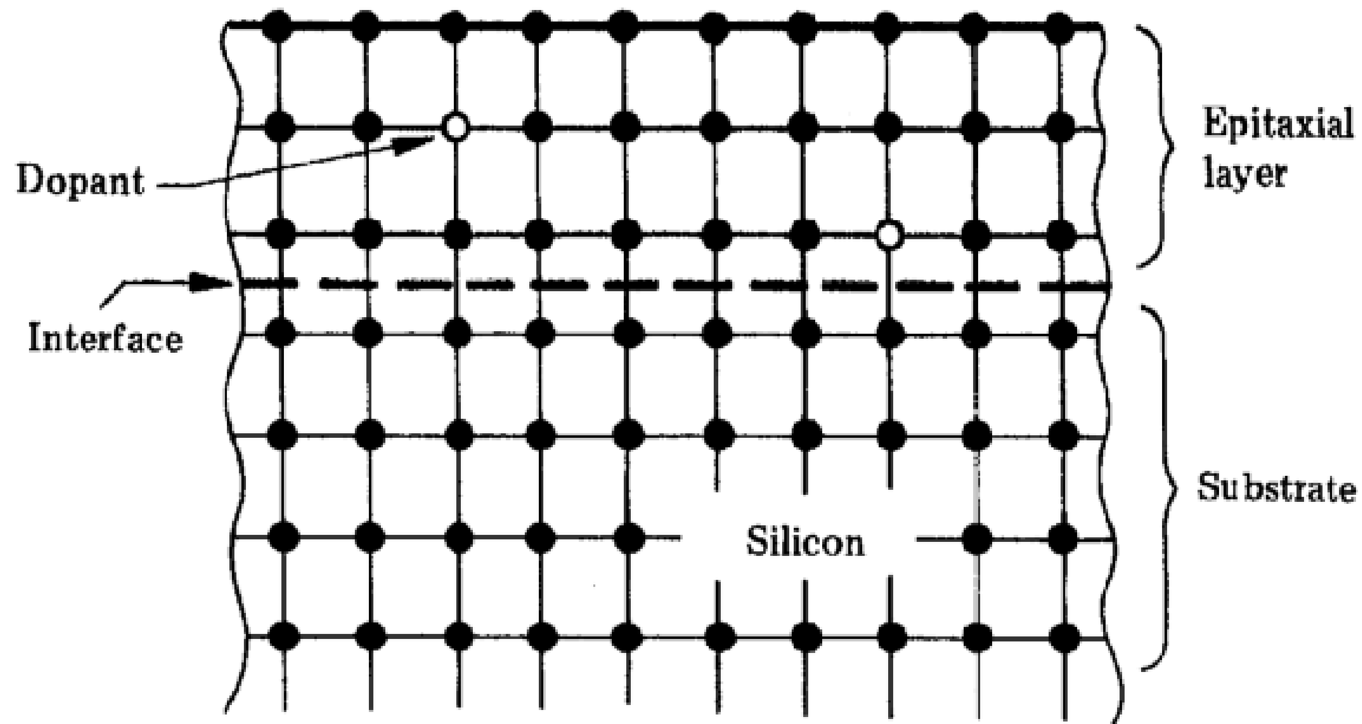




Solid films are formed by chemical reactions taking place at the surface.

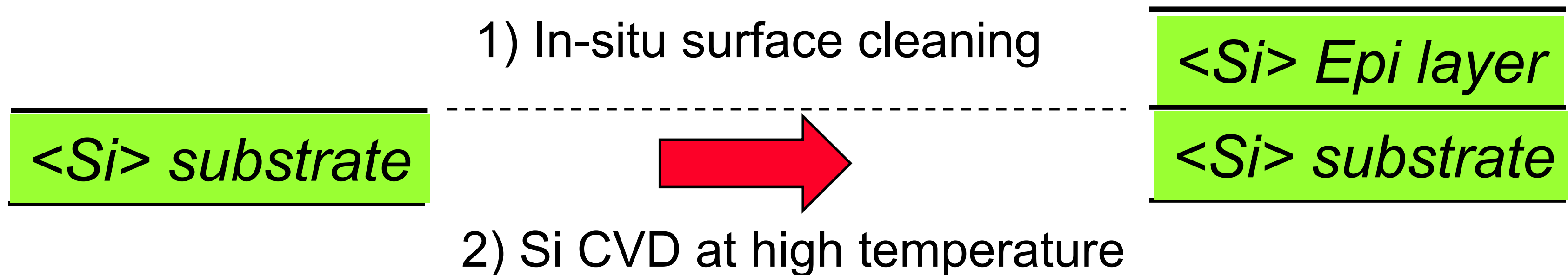
Epitaxial Growth

Processing Temperature 950-1150°C



- Requires an ultra-clean Si surface prior to epi growth.
- Requires deposition of Si at very high temperature for perfect crystallinity.

Epitaxial Growth



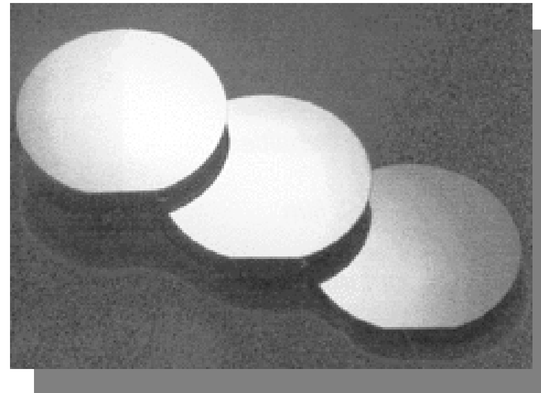
Typically used when we need a lightly doped single-crystal Si layer on top of heavily doped substrate.

Example

n^- <Si> $10^{15}/cm^3$

n^+ <Si> e.g. $10^{20}/cm^3$

Cost of Silicon Real Estate

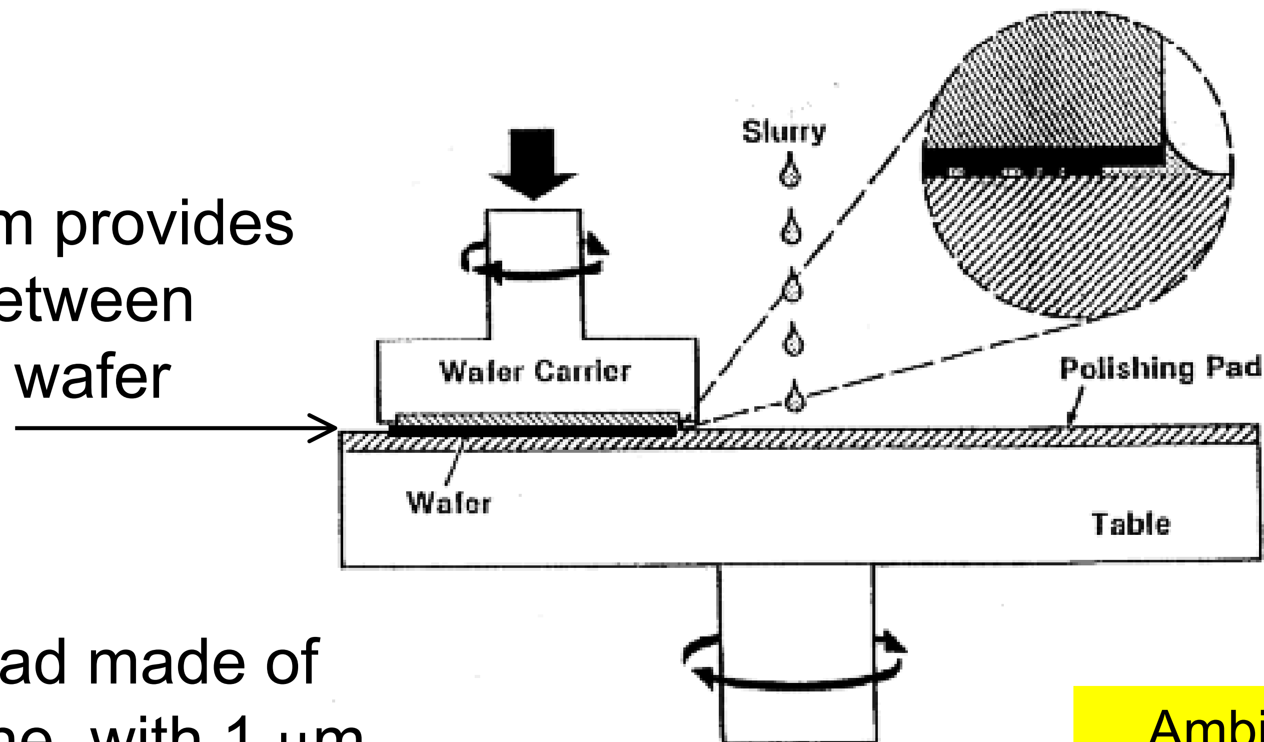
200mm Si wafer	200mm Epi wafer	1812 sq/ft House Menlo Park, CA
		
\$80	\$140	\$944,492
\$0.25 /cm²	*\$ 0.44 /cm²*	*\$0.56 /cm²*

Chemical Mechanical Polishing (CMP)

Wafer is polished using a slurry containing

- silica abrasives (10-90 nm particle size)
- etching agents (e.g. dilute HF)

- Backing film provides elasticity between carrier and wafer



- Polishing pad made of polyurethane, with 1 μm perforations
  - rough surface to hold slurry

Ambient Temperature

Metal Plating

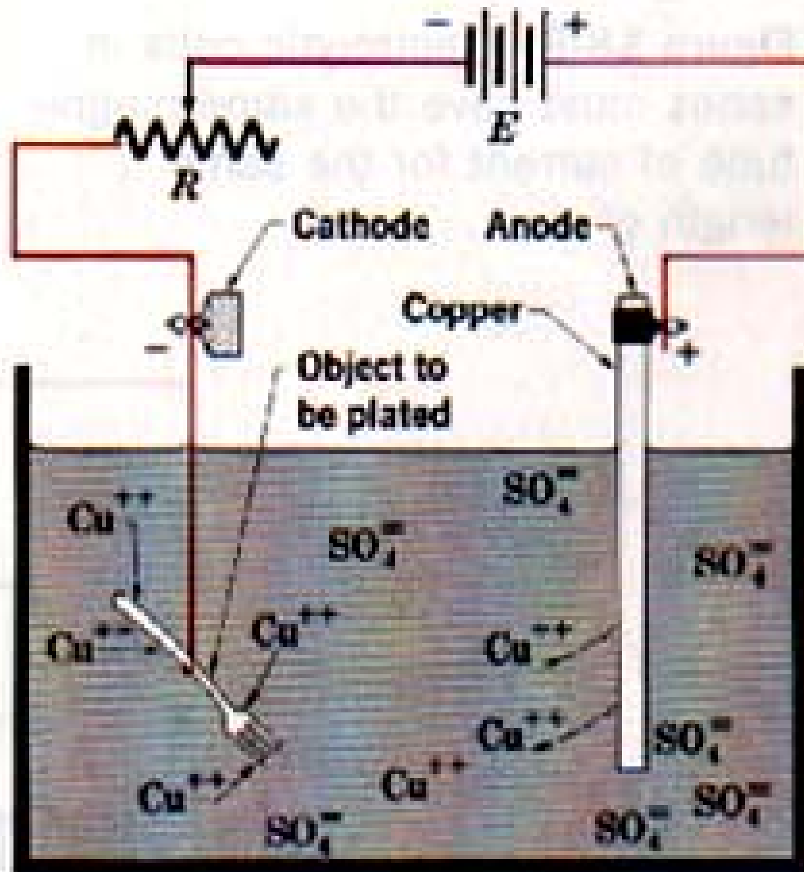
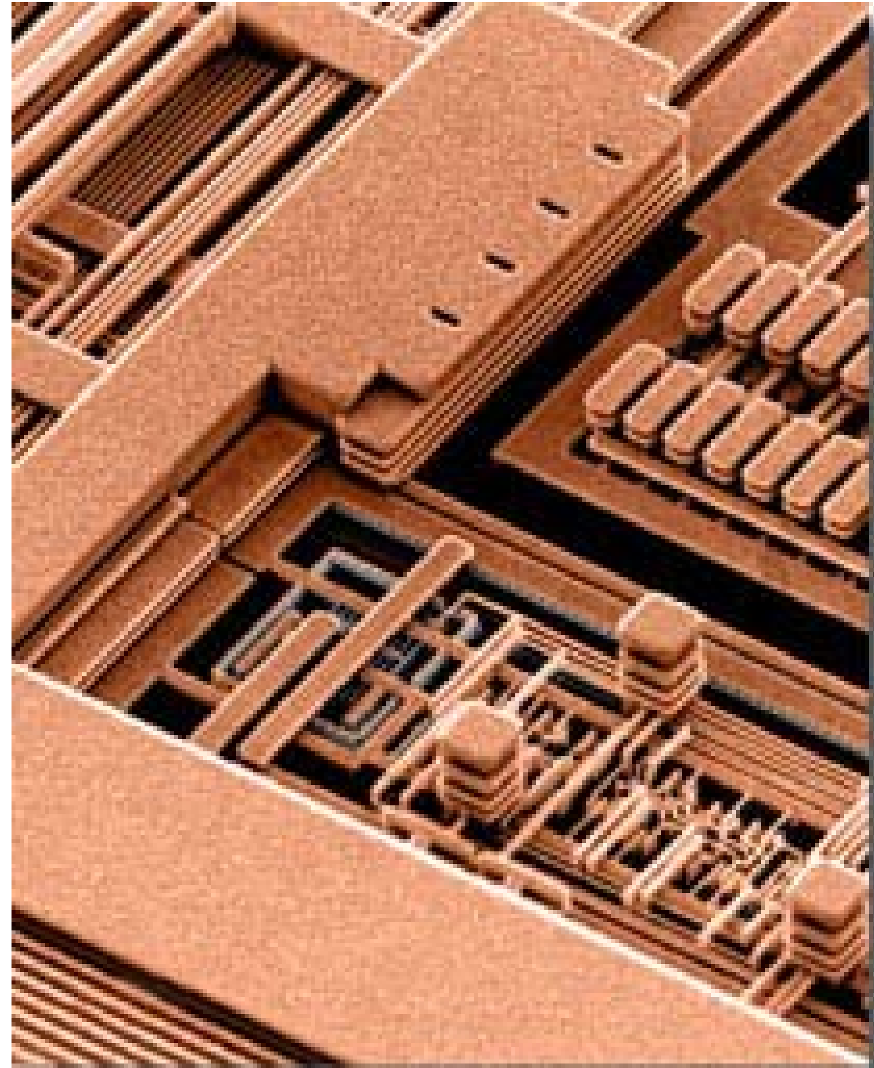


Figure 18-7. An electrolytic cell used for copper plating.

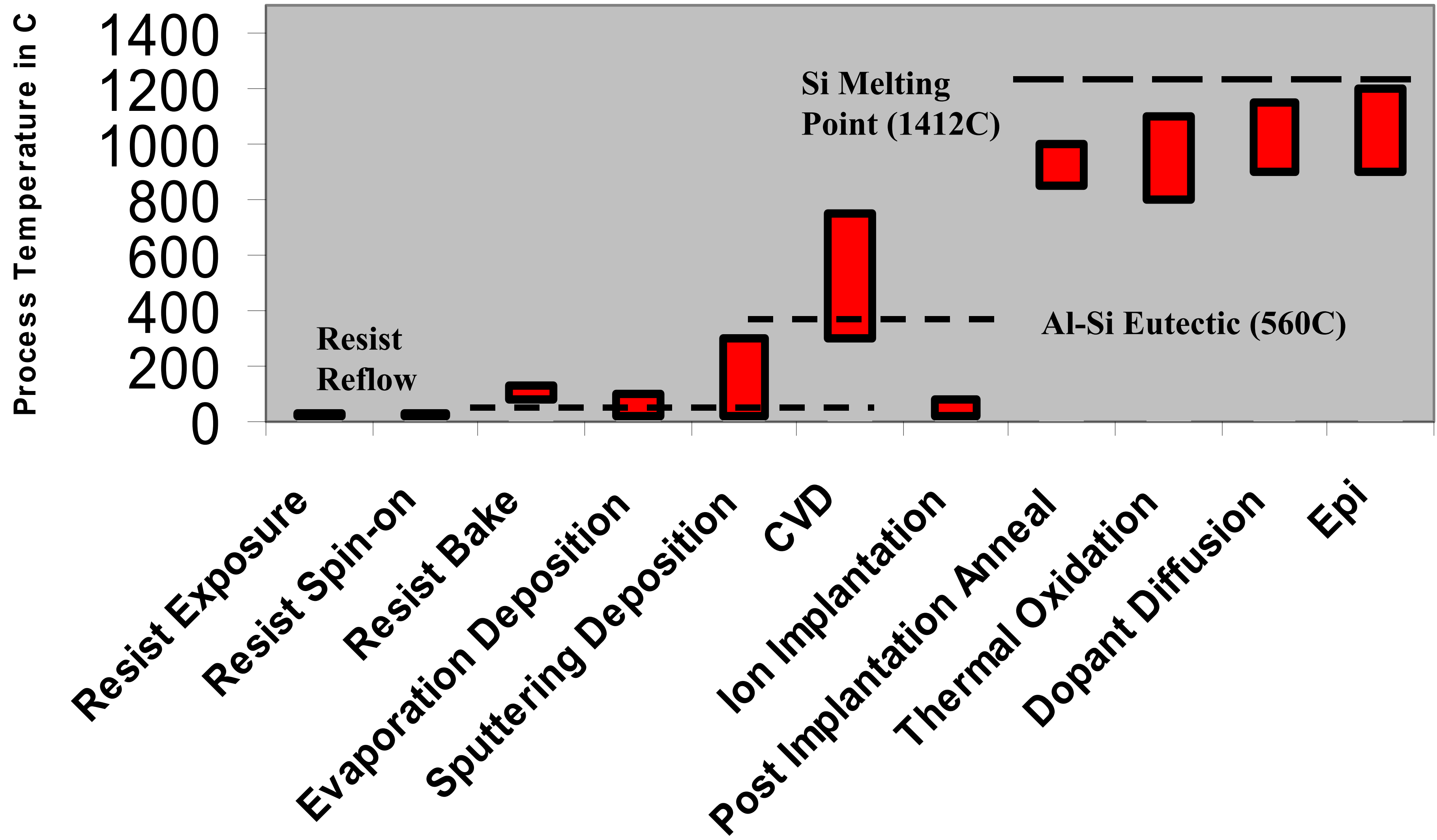


~ ambient temp

List of Conventional Microfabrication Modules

- Lithography
- Thermal Oxidation
- Etching (Chemical , Plasma)
- Ion Implantation
- Diffusion
- Physical Vapor Deposition PVD
- Chemical Vapor Deposition CVD and Epitaxial Growth
- Chemical Mechanical Polishing CMP
- Metal Plating

Processing Temperature and Material Failure Temperature



Interesting Facts about Chip Manufacturing

- **A typical 2-gram silicon chip requires 1.6 kilograms of fossil fuel, 72 grams of chemicals and 32 kilograms of water to manufacture.**
- To make the high-grade silicon needed for the chips requires 160 times the energy used to produce raw silicon. This accounts for about half of the total energy used by the chip. Only a quarter is consumed during its processing life.
- Because a chip's components are so tiny and precisely engineered, far more materials, such as fuels and solvents, are needed for their manufacture than for more traditional goods.
- The mass of these secondary materials outweighs the product by a factor of 600. In contrast, making a typical car requires only about twice its weight in fossil fuels.

Williams, E. D., Ayres, R. U. & Heller, M. The 1-7 kilogram microchip: energy and material use in the production of semiconductor devices. *Environmental Science and Technology*, Published online (2002).