520/530/580.495
Microfabrication Laboratory
and
520.773
Advanced Topics in
Fabrication and Microengineering

Lecture 6

Thin Film Deposition

Deposition Process

- Physical Deposition Process
  - Evaporation
  - Sputtering

- Chemical Deposition Process
  - Chemical Vapor Deposition (CVD)
  - Epitaxy

Physical Evaporation

- Film growth achieved by the accumulation (condensation) of vapor (e.g. Au or Al vapor) onto a cooler substrate.
- In order to control the composition of the deposited material, evaporation is performed under vacuum condition.
  - Mean free path can play a significant role
- Vapor Generation
  - Boiling vapor of a molten metal or dielectric materials using a heater (filament or thermal evaporation)
  - Materials are physically knocked and bombarded using an electron-beam (EB evaporation)
- Deposition rate is proportional to the rate of mass transfer to the surface

Thermal Evaporator

- Pump down to 1 μtorr
  (1 torr = 1 mmHg)
- Place wafers upside down to reduce particles
- Heat sources until white hot
- Low pressure = long mean-free-path (i.e., directional deposition)
- Use shutter for better timing

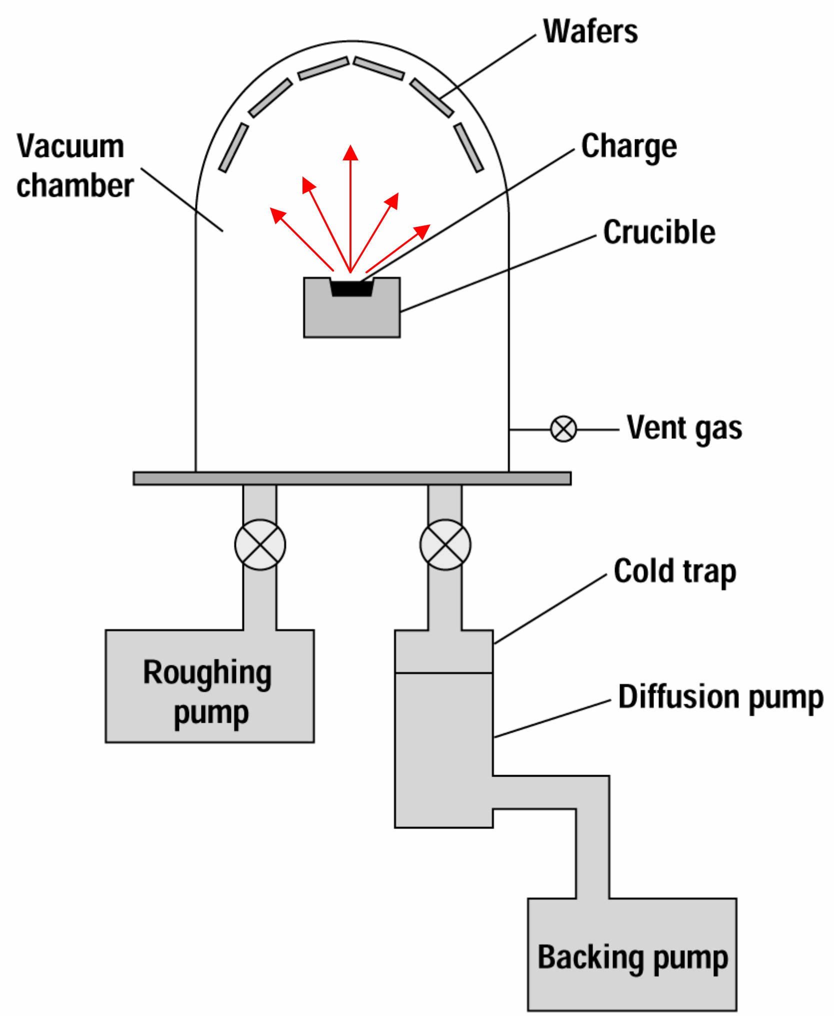
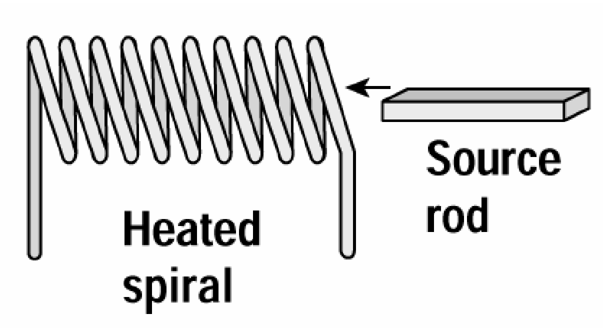


Figure 12.1 A simple diffusion-pumped evaporator showing vacuum plumbing and the location of the charge-containing crucible and the wafers.

Crucible Heating Techniques

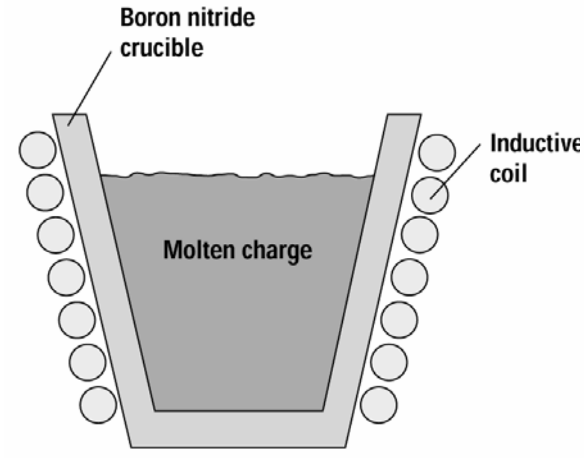
1. Filament coil heating



+ Simple, inexpensive

- Contamination due to outgoing from the wire (occurring when depositing refractory metals)

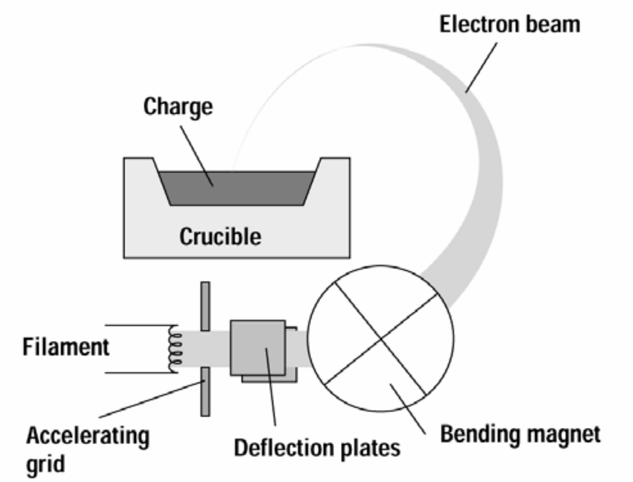
2. Inductive heating



- RF through inductive coils generate eddy current to the charge
- The coil can be water cooled to keep its temperature belwo 100 ^{0}C.

+ Simple, inexpensive
- Contamination from the crucible can still occur)

3. E-beam heating



- Focused beam of electrons are used to locally heat the source
- Can be used to heat/evaporate even high melting point materials

Deposition Rate

- The flux of atoms striking the surface of a vacuum system, which is also be used to describe the loss rate of atoms from an evaporator source

$$J_n = \frac{P}{\sqrt{2\pi mkT}}$$

(molecules/cm^2-sec)

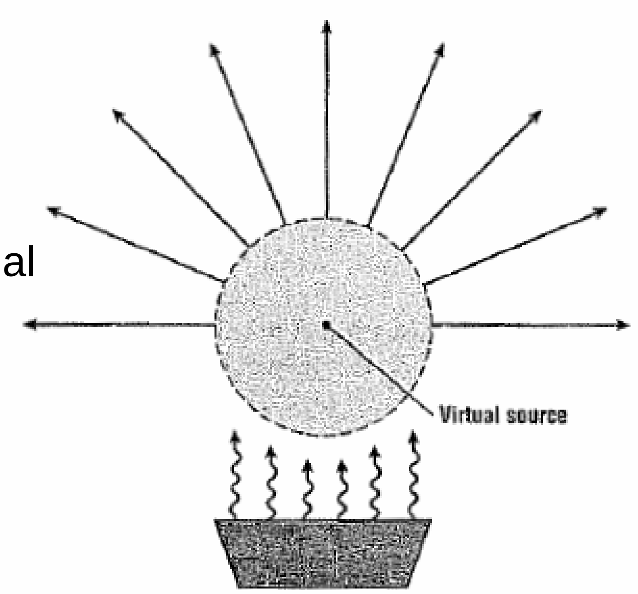
P: pressure in the chamber
m: the mass of the molecule
k: Boltzmann's constant
T: Temperature

- Mass evaporation rate is determined by multiplying the flux by the mass of the molecule

$$R_{ME} = \sqrt{\frac{m}{2\pi kT}} \cdot P_e$$

Unit ?

P_e: the equilibrium vapor pressure of the crucible material

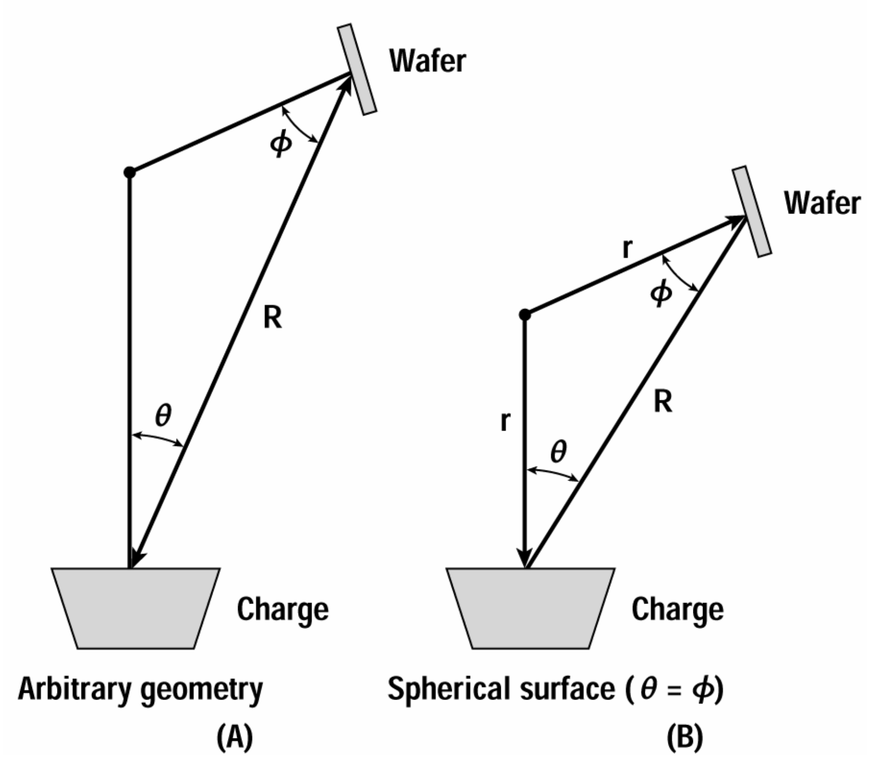


Deposition Rate

- Growth rate

$$R_d = \frac{R_{ME} \cdot A}{\rho} \cdot \frac{\cos\theta \cos\phi}{\pi R^2}$$

(cm/sec)

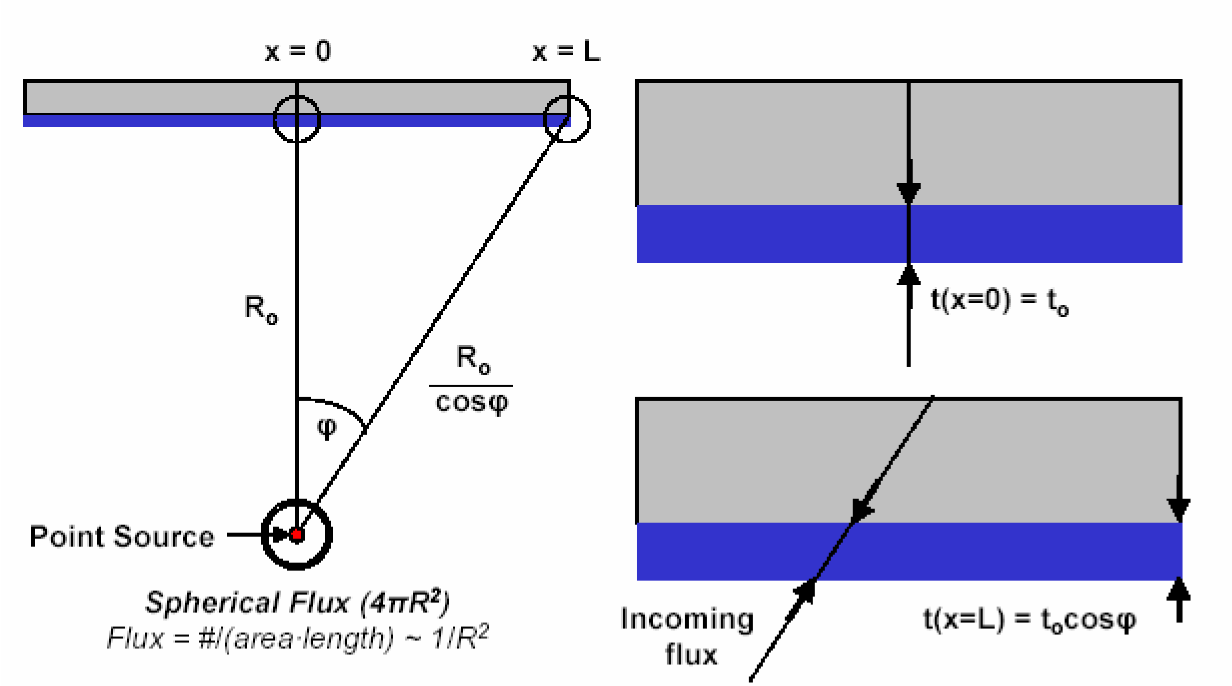


To improve the uniformity, one can place the crucible and wafers on the surface of a sphere

$$\cos\theta = \cos\phi = \frac{R}{2r}$$

$$R_d = \frac{R_{ME} \cdot A}{\rho} \cdot \frac{1}{4\pi r^2}$$

Evaporation Uniformity



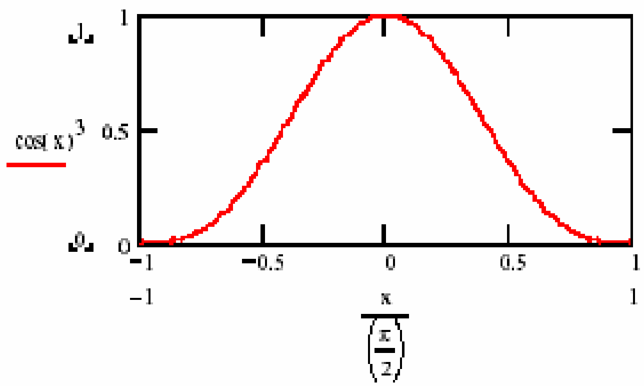
$$t(x=0) \sim 1/R_0^2$$

$$R = R_0 / \cos\varphi$$

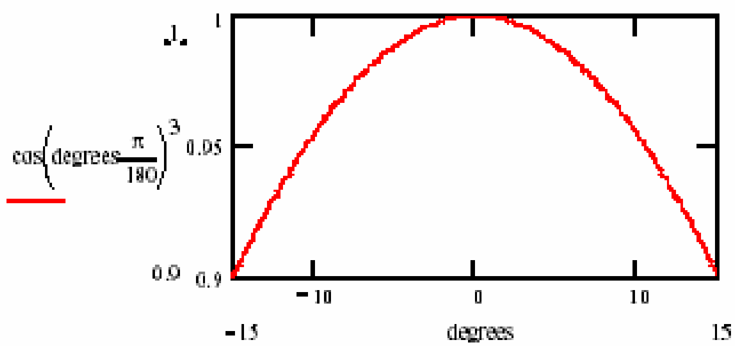
$$t(x=L) \sim \cos^2\varphi / R_0^2$$

$$t(x=L) \sim \cos^3\varphi / R_0^2$$

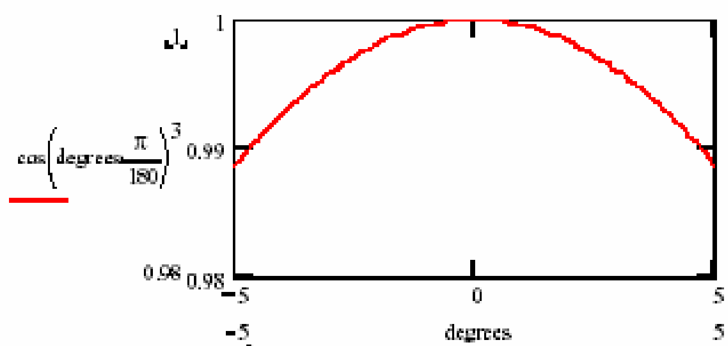
Evaporation Uniformity



Variation across all 180°

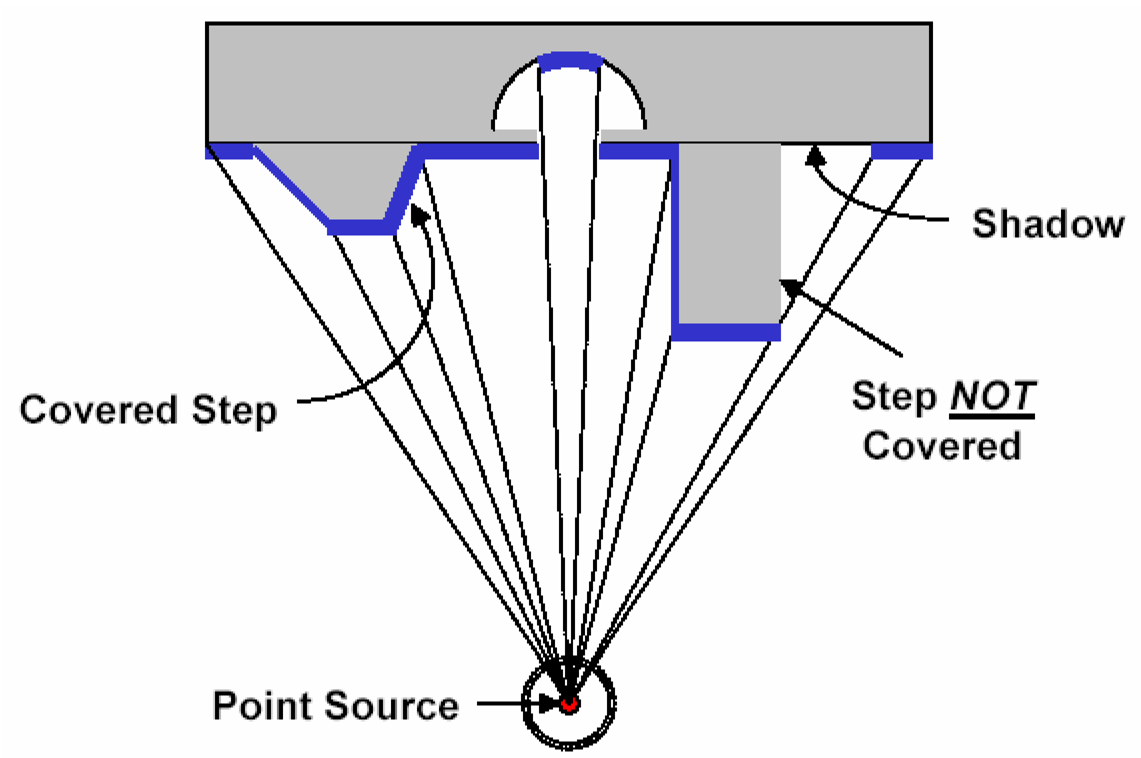


90% uniformity across +/-15°



99% uniformity across +/-5°

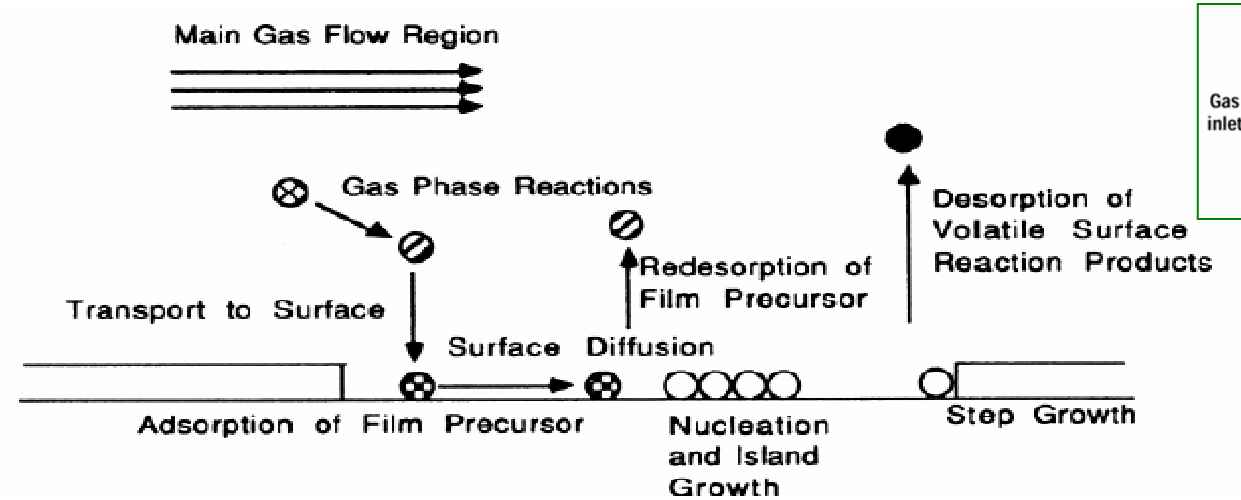
Step Coverage

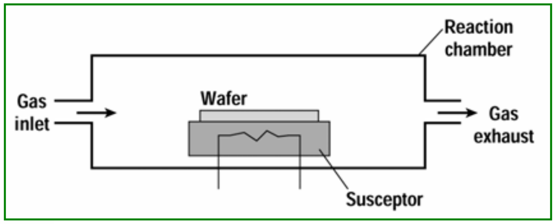


Thickness depends on the angle between the surface and the incoming source flux

Chemical Vapor Deposition (CVD)

Chemical vapor deposition (CVD) forms a thin film on the surface of a substrate by thermal decomposition and/or reaction of precursor molecules (gaseous compounds)





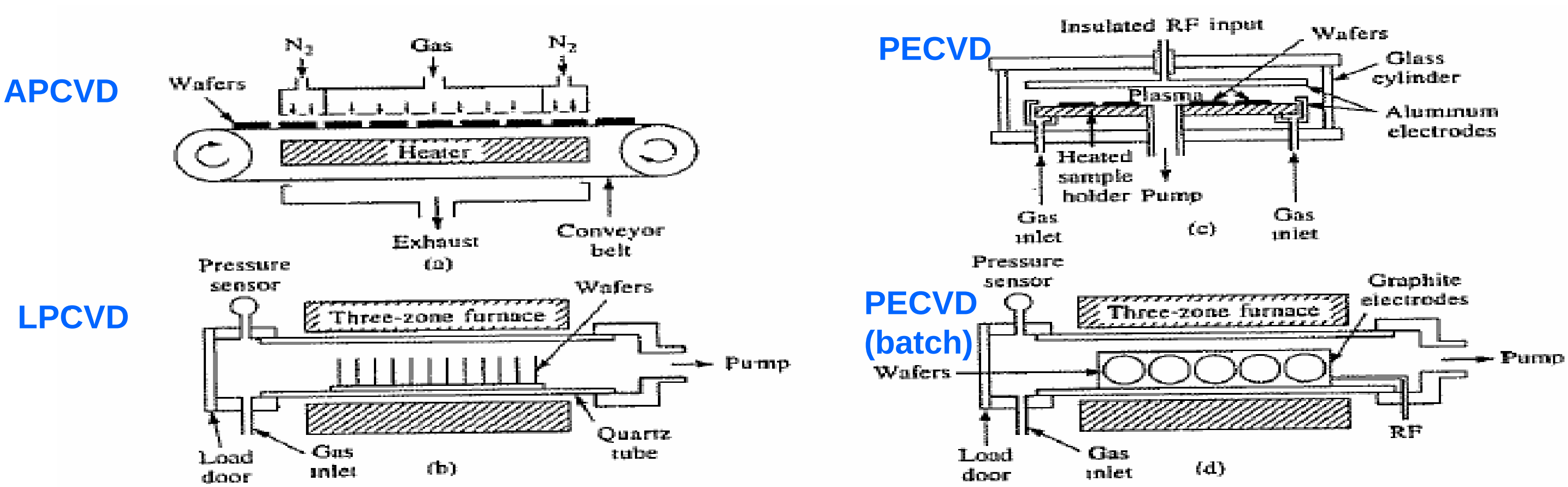
1. Vaporization and transport of precursor molecules into a reactor
2. Diffusion of precursor molecules to the surface of the substrate
3. Adsorption of precursor molecules to the surface and further diffusion across the surface
4. Decomposition of precursor molecules and incorporation into solid films
5. Desorption of volatile byproducts into the gas phase

Silicon :	$SiH_{4(g)} \rightarrow Si_{(s)} + 2H_{2(g)}$
Silicon dioxide:	$SiH_{4(g)} + O_2 \rightarrow SiO_{2(s)} + 2H_2(g)$
Silicon Nitride:	$3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12\ H_2$
Tungsten:	$WF_6 \rightarrow W + 3F_2$

- Slowest Step Dominates
  - Reaction-rate limited process
  - Mass-transport limited process

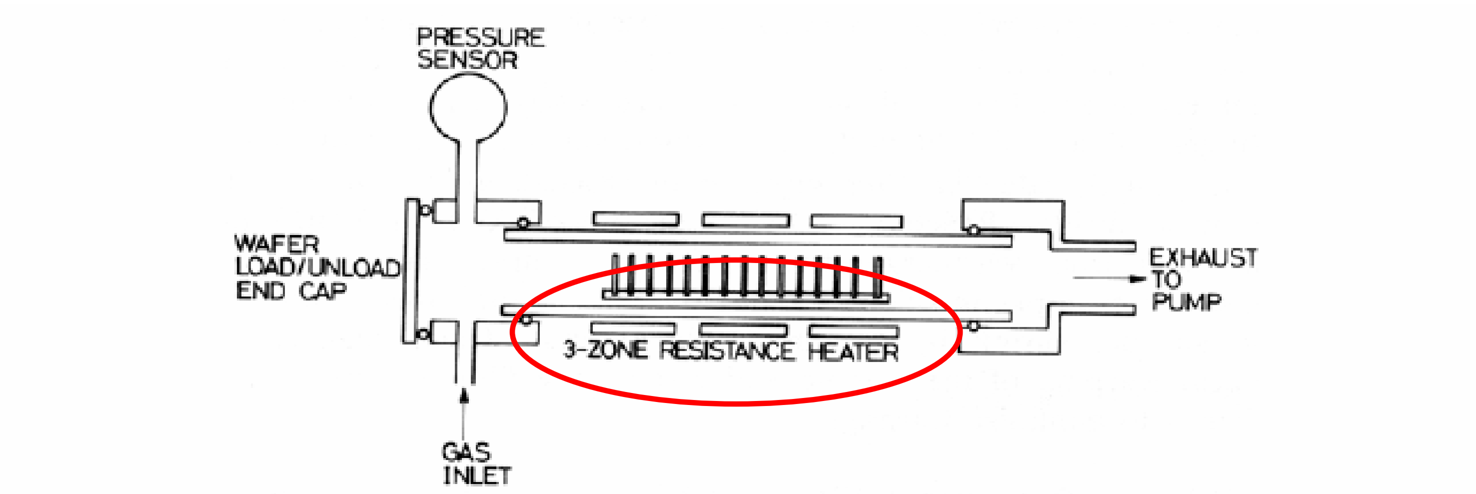
Types of CVD Processes

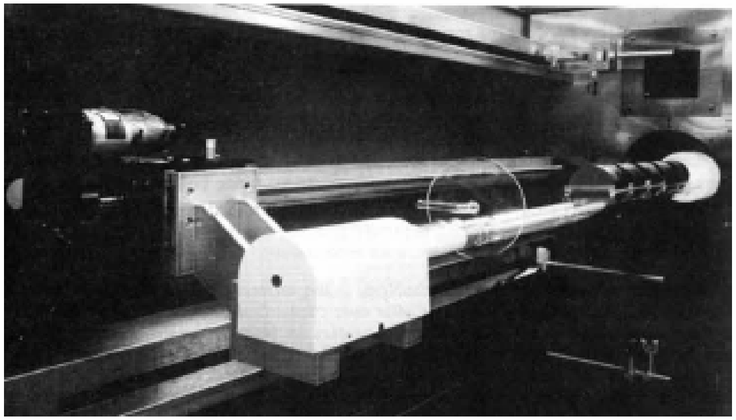
- Atmospheric pressure chemical vapor deposition (APCVD)
  high deposition rate, low uniformity and film quality
- Low-pressure chemical vapor deposition (LPCVD)
  Low pressure (0.1 to 1 torr),
- Plasma-enhanced chemical vapor deposition (PECVD)
  Deposition at low temperature
  APCVD and LPCVD involve elevated temperatures ranging from 500 ^{0}C to 800 ^{0}C. These temperatures are too high for metals with low eutectic temperature with silicon, such as gold (380 ^{0}C) or aluminum (577 ^{0}C). **PECVD** has a part of their energy in the plasma; thus, lower substrate temperature is needed, typically on the order of 100 ^{0}C to 300 ^{0}C.

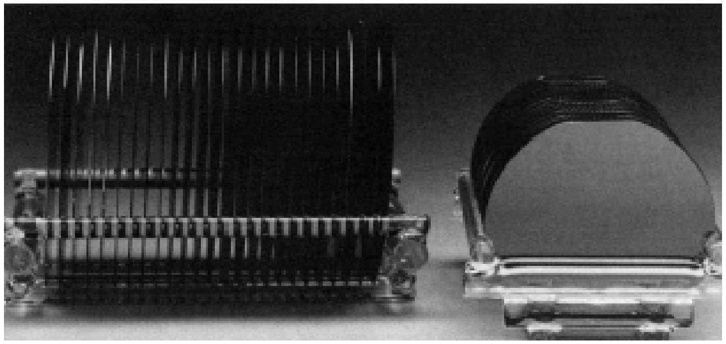


LPCVD Systems

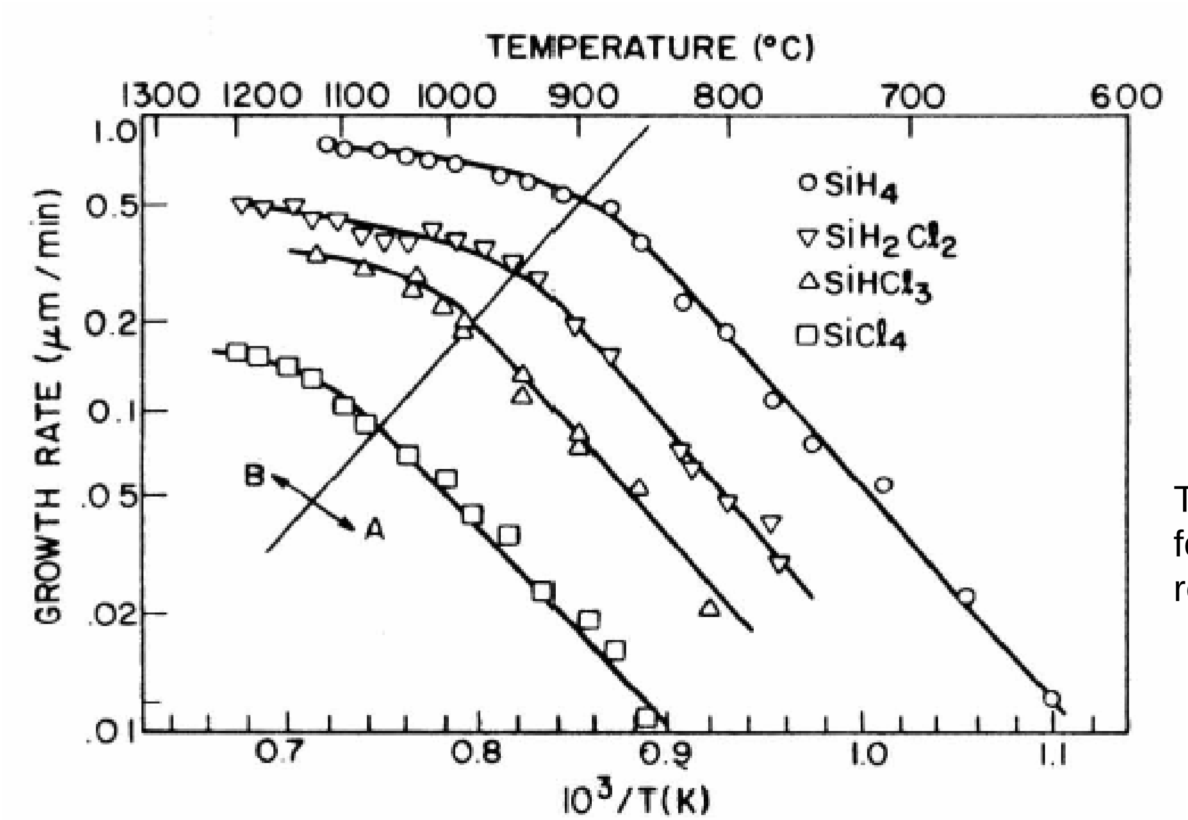
- LPCVD allows chemical deposition of thin film with the best quality. In addition to keeping a low pressure, control the uniformity of temperature distribution is also very important.
- 3-zone heating design is commonly used.







CVD Growth Rate



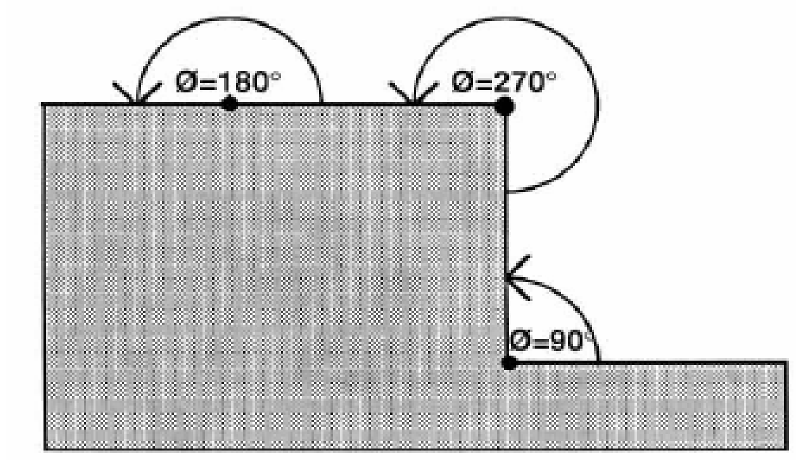
$$R \sim e^{-\left(\frac{E_A}{kT}\right)}$$

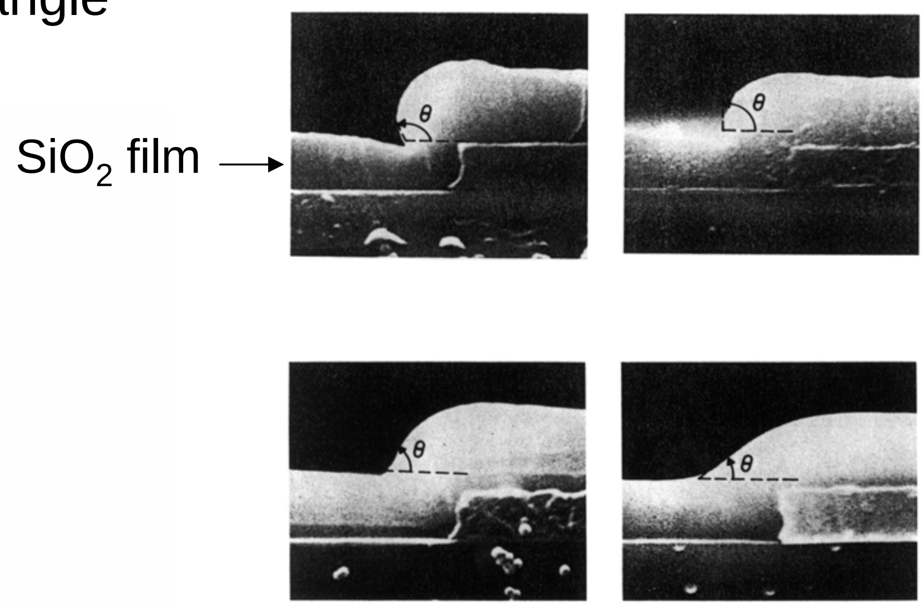
The deposition rate follows Arrhenius relationship

- Slowest Step Dominates
  - Reaction-rate limiting process (A or B ?)
  - Mass-transport limiting process (A or B ?)

Acceptance Angle

- When mass-transport limited (e.g. insignificant diffusion and migration), the grow rate is dependent on the flux density of the gas molecules incident to the surface, which is a function of acceptance angle





Scanning electron micrographs (10,000x) of samples annealed in a steam at 1100°C for 20 minutes for the following weight percent of phosphorus:
(a) 0 wt%, (b) 2.2 wt%,
(c) 4.6 wt%, and (d) 7.2 wt%.