CDEEP
IIT Bombay

EE 669 Slide 01
L-24

In an Integrated Circuit Fabrication, many films of different materials are deposited.

These films are of either Metals, Metal-Silicides, and Dielectrics like SiO_2, Si_3N_4.

Requirements of Deposition

i Desired Composition, Low Contaminates

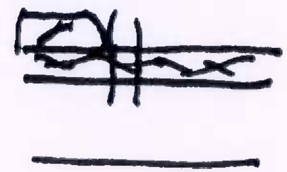
ii Good Electrical properties of films (Desired)

iii Mechanical Properties should also be good. Adhesion is one such important Property iv Uniform thickness across Wafer and Run to Run.

v. Most important requirement is Good Step Coverage

vi If 'Interconnect' is desired from metal films, then they should give very low Resistance/length.

vii Better Electromigration resistance



$J_c \geq 10^5 Am/$

viii Non-Corrosive

ix Economical

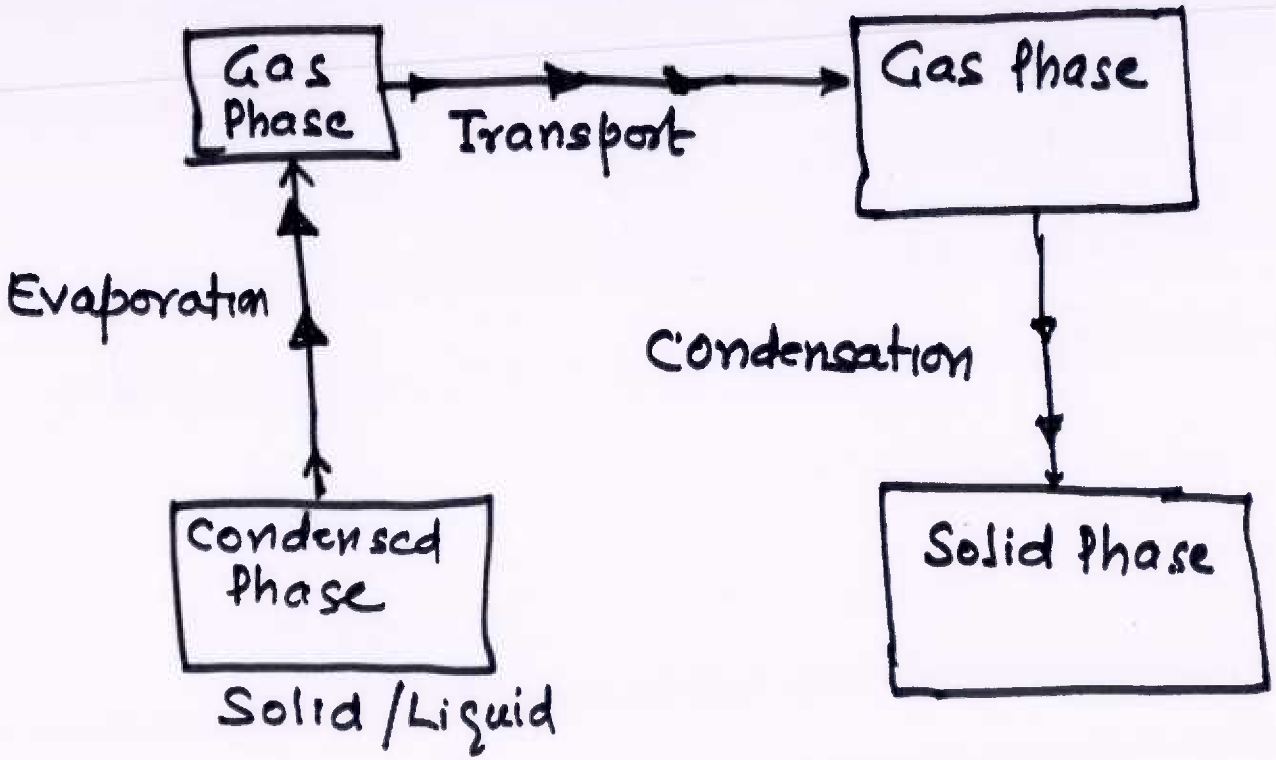
x Compatible to other processes in IC fabrication.

Two Major Deposition Techniques :

1. Physical Vapour Deposition (PVD)
   (a) Evaporation
   (b) Sputtering

2. Chemical Vapour Deposition (CVD)
   a. At. Pressure CVD (APCVD)
   b. Low Pressure CVD (LPCVD)
   c. Plasma Enhanced CVD (PECVD)
   d. Hot-Wire CVD (HWCVD)

Typical PVD process looks like a <u>Four Step Process</u>



Evaporation System Requirement

1. Vacuum :
   - Need 10^{-6} torr or better vacuum for better quality films.
   - Better vaccum be Ultra High Vacuum which could be around 10^{-9} torr.

2. Heating System
   - Thermal Heating
   - Electron-Beam related

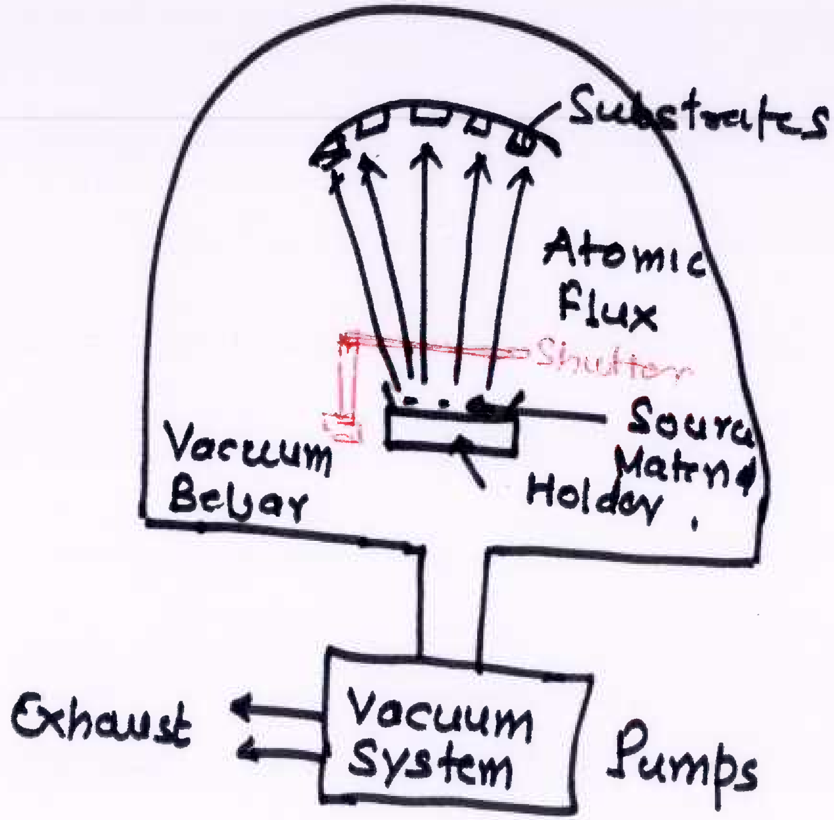
   ] 1-10 kW Power

3. A Bell-Jar to keep vaccum.

4 Thickness Monitor

5. Mechanical Shutter System

Control on evaporating flux reaching substrate



Modeling of Evaporation:

(i) We define p^* as Partial Pressure of a gas in equilibrium with it's Condensed Phase at a given Temperature T.

Generally p^* is only function of Temperature (T).

(ii) p is defined as ambient hydrostatic pressure acting upon evaporant in Condensed State

According to Hertz principle, the evaporation rate is $\propto (p^* - p)$

In vacuum, p is closed to zero

(iii) V_g and V_c are volume of evaporant in Gas Phase and Condensed Phase respectively.

(iv) If we define ΔH_e as enthalpy-change from one phase going to the other, then according to Clausius Clapeyron Equation

$$\frac{dp^*}{dT} \propto \frac{\Delta H_e}{T(V_g - V_c)} \cong \frac{\Delta H_e}{T\,V_g}$$

(Normally $V_g >> V_c$)

By Ideal Gas Laws $p^* V_g = RT$ where R is Universal Gas Constant

Clausius Clapeyron Equation

$$\therefore \quad \frac{dp^*}{p^*} = \frac{\Delta H_e}{RT^2}\, dT$$

$$\text{or} \quad \ln p^* = -\frac{\Delta H_e}{RT} + c^*$$

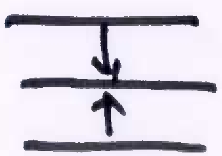
Let $c^* = \ln C_1$

$$\therefore \quad p^* = C_1\, e^{-\Delta H_e / RT}$$

Clearly p^* is only function of Temperature T

(v) Evaporation Rate R_{ev}

We have two Fluxes:



Evaporant's Vapour Pressure → P [redacted] dependent

condensed evaporation Rate → P^* dependant

If A is cross-section area of flux coming out of evaporator, then

$$\frac{1}{A}\frac{dN_e}{dt} = \frac{1}{(2\pi m k T)^{1/2}}(p^* - p)$$

where $\frac{1}{A}\frac{dN_e}{dt}$ represents net Evaporation Rate

$$\text{or} \quad R_{ev} = \frac{1}{A}\frac{dN_e}{dt} = \frac{1}{(2\pi m k T)^{1/2}}(p^* - p)$$

Hertz-Knudson equation for R_{ev} also takes care of return flux which is decided by α_v called Sticking Coeff for vapour molecules on the surface and thus is written as

$$R_{ev} = \frac{1}{A}\frac{dN_e}{dt} = \alpha_v (2\pi mkT)^{-1/2}(p^* - p)$$

In vacuum, two things are affected

(i) p the pressure due to return flux could be closed to → 0 (zero). Knudsen cell can esure this.

& (ii) The mean free path of evaporant atoms increases i.e.

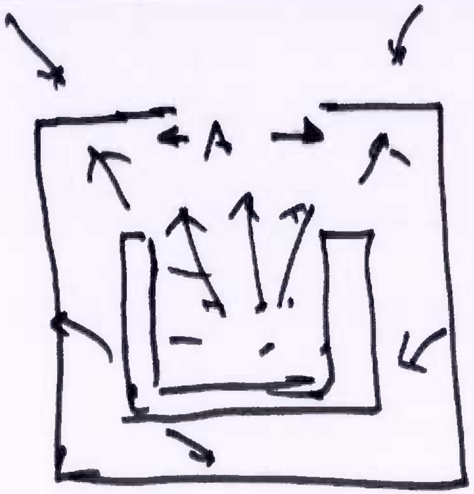
$$\lambda = \frac{kT}{\sqrt{2}\,\pi \sigma^2 p}$$

Clearly better vaccum means higher mean free path.

Higher Mean Free Path means, unlikely events of collision between evaporant atoms → Unidirection Flow.

$$\therefore \quad R_{ev} = \frac{\alpha_v \, p^*}{\sqrt{2\pi m k T}}$$

In Knudsen Cell, we can make $\alpha_v = 1$



Then $R_{ev} = \dfrac{p^*}{\sqrt{2\pi m k T}}$

Then the Film Growth Rate

$$F_{GR} = \frac{R_{evp}\, m}{\rho} \qquad \rho \text{ is density}$$

$$= \sqrt{\frac{m}{2\pi k T}} \; \frac{p^*}{\rho} = 5.83 \times 10^{-3} A \left(\frac{m}{T}\right)^{1/2} p^*$$

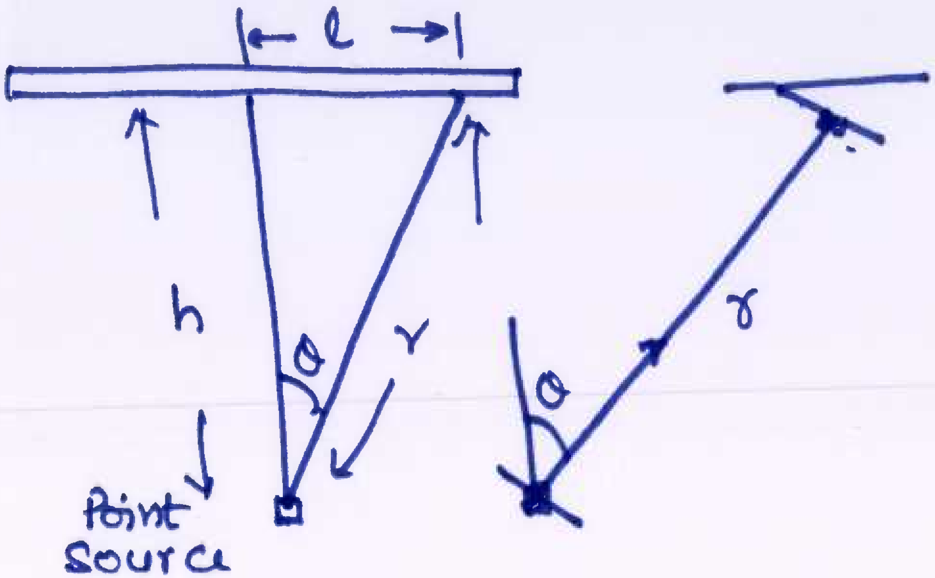
$\Rightarrow$ cm/sec.

Here 'A' is area.

Evaporation process starts from first melting of the evaporant substance and with increase of Temperature, vapour pressure increases, and evaporation of the substance starts.

Source of evaporation could be either a Point Source or a 'small area' source.

Assuming Point source, we wish to find deposition rate along plane of the target (substrate on which evaporated film deposits)



Let Ω is the solid angle over which source emits, ρ is the density of evaporant substance and h, r and l are verticle, radius of curvature (solid∠) and horizontal distance between verticle position on the target to the point which subtends an angle θ at source.

If vaccum is better ($< 10^{-6}$ torr), then mean free path is good no. like 100 cm. Since Distance between Source & target, vertically is around 30 cm (max.) [$h \sim 30$ cm], we can assume flux Transport reaching target with scattering and at low Pressure, return flux from target can also be treated v.v. small.

In this case $\Omega = 2\pi$

Then Flux reaching in verticle case $= F = \dfrac{R_{evp}}{2\pi r^2}$

$\therefore$ Growth rate $= \dfrac{R_{evp}}{2\pi r^2} \dfrac{m}{\rho}$

From geometric Consideration $h^2 + l^2 = r^2$

and $\cos\theta = \dfrac{h}{r}$

Growth rate at point 'l' from vertical point on substrate is

$$= \frac{R_{evp}}{2\pi r^2} \frac{m}{\rho} \cos\theta$$

since $h^2 + l^2 = r^2$ $\therefore r = \sqrt{h^2 + l^2}$

We have $\cos\theta = \frac{h}{r}$ and $\frac{\cos\theta}{r^2} = \frac{h}{r^3}$

$$\therefore \frac{\cos\theta}{r^2} = \frac{h}{(h^2 + l^2)^{3/2}}$$

$$\text{Film Growth rate} = \frac{R_{evp} \cdot m}{2\pi \rho} \frac{h}{(h^2 + l^2)^{3/2}}$$

Evaporation Sources :

i Resistance Heated

ii E-beam heated

(i) Usually heating source is made out of wires filaments of Tungsten, Tantalum or Molybdom filaments.

Current needed to reach 1800°c temperature in filament is generally of order of 200 - 300 Amp

Typical deposition rate around 1-25 Å / sec.

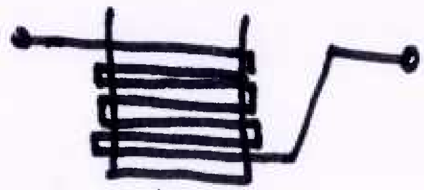
Materials which can be evaporated by this technique are : Al, Sn, Cr, Sb, Ge, In, Au, Ag, Mg etc and CdS, PbS, CdSe, NaCl, KCl, MgF_2, CaF_2 etc

Typical Resistance Heated filaments

Hairpin

Wire helix

Basket



BN Crucible