

# Physical Vapour Deposition: Sputtering

- 1 DC Sputtering
- 2 RF Sputtering



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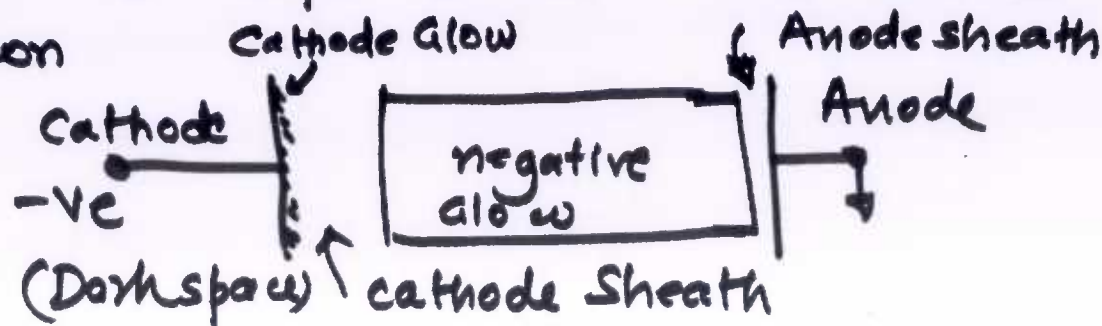
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- (i) Sputtering uses Neutral (Sometimes Active) gas plasma to sputter the Target (Material to be deposited), essentially which displaces the atoms and deposits on the Substrates
- (ii) It normally requires moderate vacuum 1-100 mtorr.
- (iii) It is useful in deposition of metals, alloys, compounds and even insulators.

(iv) The neutral gas (Inactive or Inert) generally used is Argon.

When ionised creates,  $Ar^+$  ions and equal no. of Electrons. Some Argon atoms are not ionised and hence are neutral. Thus we have Argon Plasma available for Sputtering

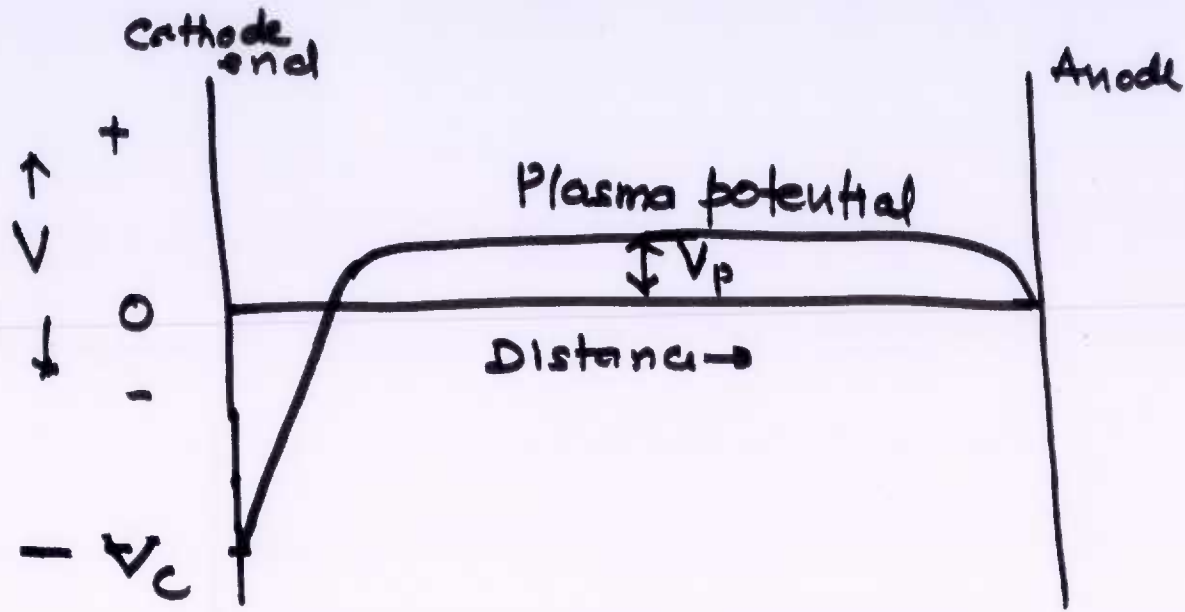
(v) As discussed typical Plasma system used has cathode and Anode and distance between them is kept small. This allows a system as shown



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The corresponding Potential profile is



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At cathode we have -ve Bias of  $-V_c$ . Then we have cathode Dark space which has Voltage increasing from  $-V_c$  towards '0'. Voltage in the Argon Plasma,  $V_p$ , is +tive with reference to both Cathode and Anode

(vi)  $Ar^+$  ions accelerates towards cathode crossing (Cathode) sheath towards  $-V_c$  potential.

$Ar^+$  ions have sufficient K.E. now as they bombard cathode. In our case



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Cathode is the Target plate and Anode is the Substrate.

Target atoms are displaced from cathode and due to process of reversal of momentum, move towards substrate (Anode) and deposits there.

(vii) We define a term Sputtering Yield  $S$  as

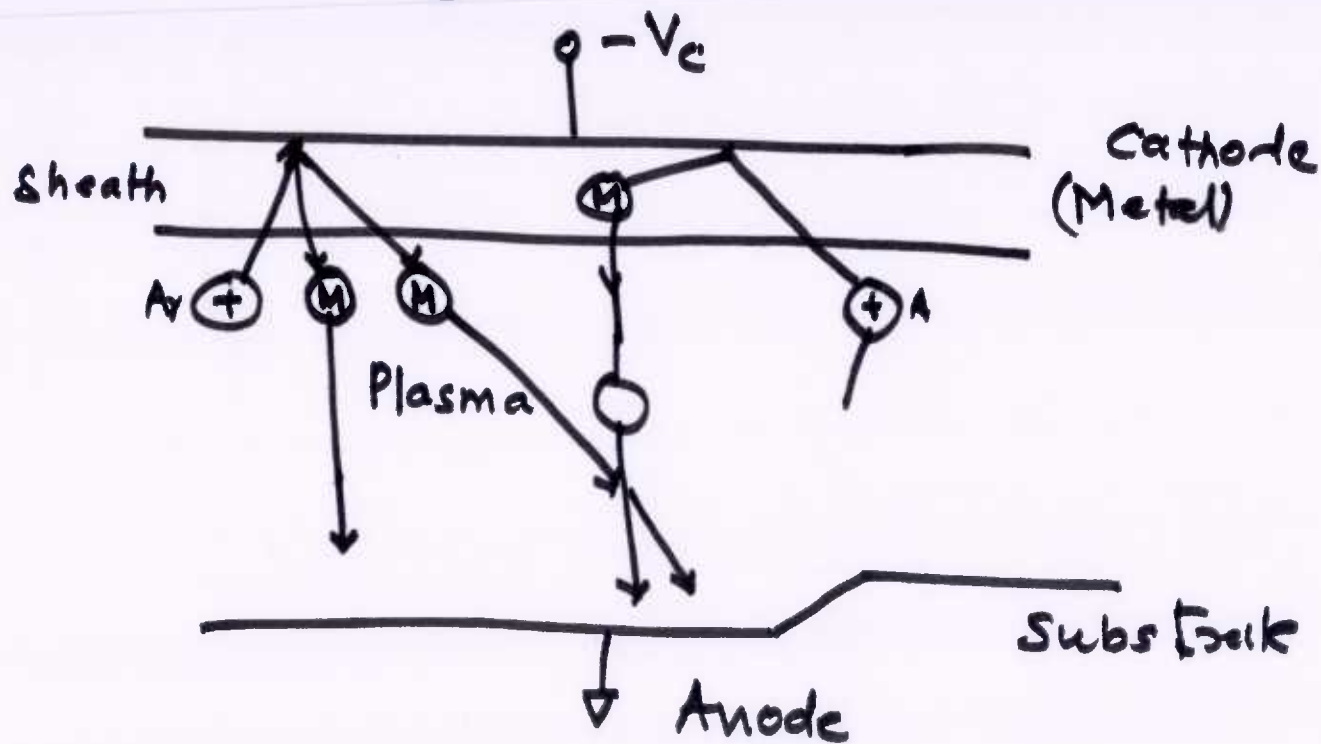
$$S = \frac{\text{No of atoms (molecules) ejected from Target}}{\text{Incident Ion}}$$

The sputtering Yield does depend upon the mass of ions incidenting on target as well as energy they have when they hit the Target.



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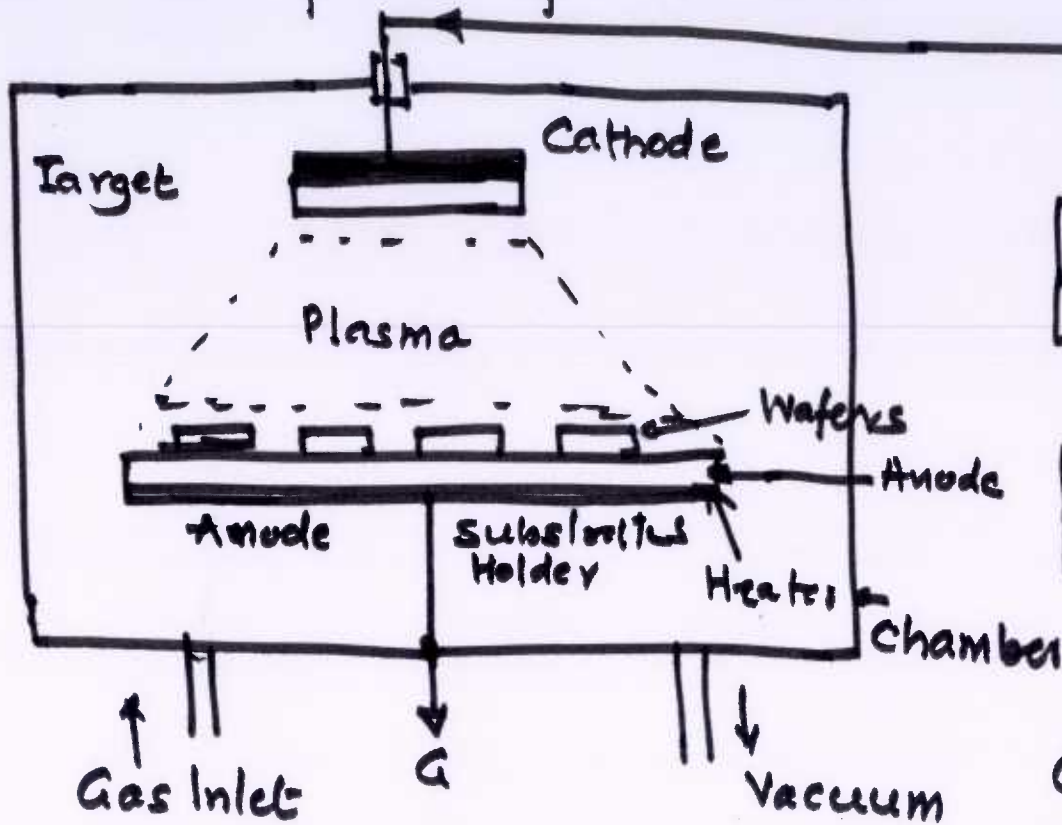
In case of DC Sputtering, Target is Conducting

# (2) RF Sputtering System



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Matching Network

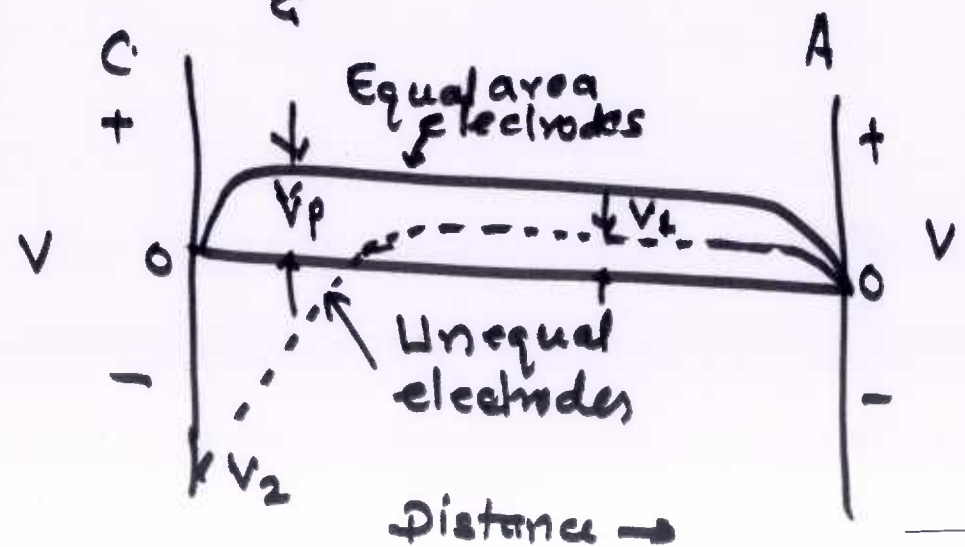
RF Generator

Cathode area =  $A_1$   
Anode area =  $A_2$

- ①  $A_1 = A_2$
- ②  $A_1 < A_2$

$$\frac{V_1}{V_2} = \left( \frac{A_1}{A_2} \right)^{-m}$$

$$m \approx 2 \quad (1-2)$$



## Advantages of RF System

- ① Conformal Deposition
- ② Even Dielectrics can be Sputtered.



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## Basic Modeling of Sputtering

Most important parameter in Sputtering is Sputter Yield  $S$ , which can be given as

$$S = \alpha [E^{1/2} - E_{th}^{1/2}]$$

where  $E$  is incident ion energy and has mass  $m$  &  $M$

$E_{th}$  is the threshold energy required for dislodging target atoms and giving momentum reversal.

$\alpha$  = Proportionality coefficient =  $f(z_t, z_x \& U)$

$z_t$  = Target atom At. no.;  $z_x$  = Atomic no. of Gas atoms

$\Delta U$  is called Sublimation energy or SBE.



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If  $M_2$  is the atomic mass of Target, then max. energy transferred to it by incident energetic ion ( $E$  with Mass  $M_1$ ) is

$$E_{\max} = \frac{4 M_1 M_2}{(M_1 + M_2)^2} E$$

Typically  $E_d$  is defined energy received by stationary atom for dislodging it. Then we can say  $E_{th} = E_d$

Generally  $E_d$  lies between 10 - 35 eV

Please note that if incident ion have higher Energy, than mean energy of stationary atom, then it's gets implanted.



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The proportionality Coefficient  $\alpha$  is given by

$$\alpha = \frac{5.2}{U} \cdot \frac{Z_t}{[Z_t^{2/3} + Z_x^{2/3}]^{3/4}} \left[ \frac{Z_x}{Z_x + Z_t} \right]^{0.67}$$

All <sup>Internal</sup> energies are used in units of eV/mol

Conversion : 1 Kcal/mol. = 0.0434 eV/mol

The incident ion energy and  $E_{th}$  are used in KeV

Thus Cathode Voltage of (-100V) will give incident-ions of energy = 0.1 keV

For a case of Tungsten (W) deposition with cathode bias of 100V, we get  $S \approx 0.2$  atoms/ion



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The rate of Sputtering  $R_{sp} = \frac{S \cdot j_{ion}}{q}$

Units of  $R_{sp}$  are no. of atoms sputtered per unit area per unit time

$R_{sp}$  is related to Growth rate  $G$  by

$$R_{deposition} = \frac{G \times \rho \times Av. No}{(A + Wt) M}$$

atoms / area . sec



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# Chemical Vapour Deposition

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## Types :

1. Atmospheric Pressure CVD : APCVD
2. Low Pressure CVD : LPCVD
3. At. Pressure Low Temperature CVD
4. Plasma Enhanced CVD : PECVD
5. Atomic Layer Deposition : ALD
6. MBE : Molecular Beam CVD



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In VLSI, we need to deposit

1. Dielectric Films :  $\text{SiO}_2$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{HfO}_2$   
etc

2. Polysilicon Films : Self Aligned Gate  
and also for small Interconnect-

3. Metal films of Ti, W, Ta, Mo etc.

Further we also need At. Pressure CVD for  
growing Epitaxial Films.

Thermal Budget and Quality of films desired  
decide the choice of Process.



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# Comparative Performance



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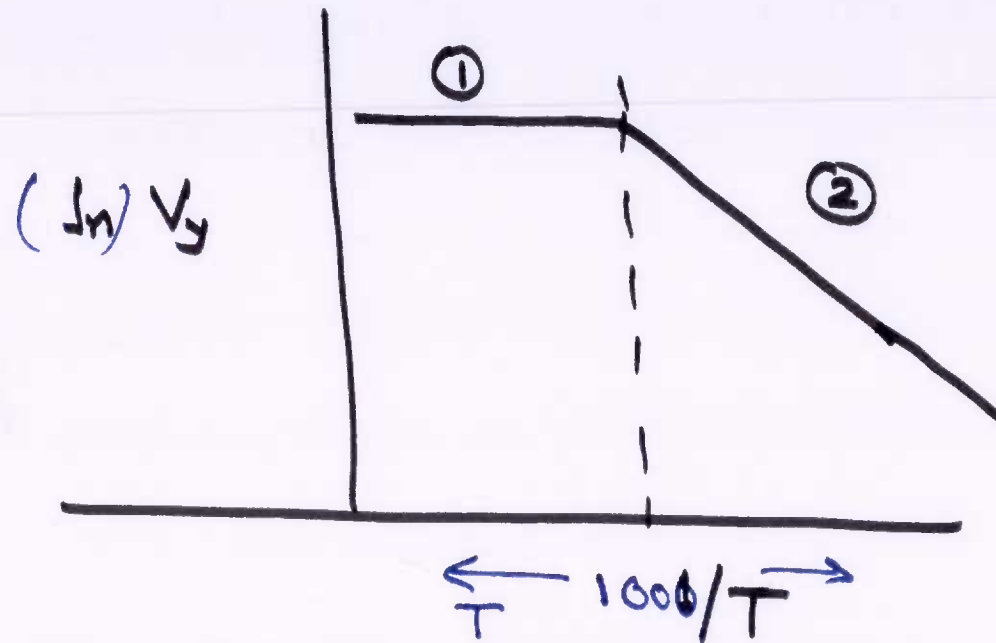
Process	Adv.	Disadv.	Application
1. APCVD	<ul style="list-style-type: none"> <li>i Simple Reactor</li> <li>ii Fast Deposition</li> <li>iii Low Temp.</li> </ul>	<ul style="list-style-type: none"> <li>i Poor Step Coverage</li> <li>ii Particle cont</li> <li>iii Low Throughput</li> </ul>	Doped & Undoped oxides (LTO) / EPITAXIAL Growth
2. LPCVD	Excellent Purity Uniformity Good Step Coverage Large Throughput	<ul style="list-style-type: none"> <li>i High Temp.</li> <li>ii Low Deposition rate</li> </ul>	HTO ; $\text{Si}_3\text{N}_4$ , PolySi W, $\text{WSi}_2$ etc
3. PECVD	Low Temp. Fast Deposition Good Step Coverage	Chemical & Particle Contamination	<ul style="list-style-type: none"> <li>i Low Temp Insulators over Metals</li> <li>ii Passivating Nitride</li> </ul>

Deposition rate  $V_y$  in CVD is a function of Temperature



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① Mass Transfer Limited

② Reaction Rate Limited

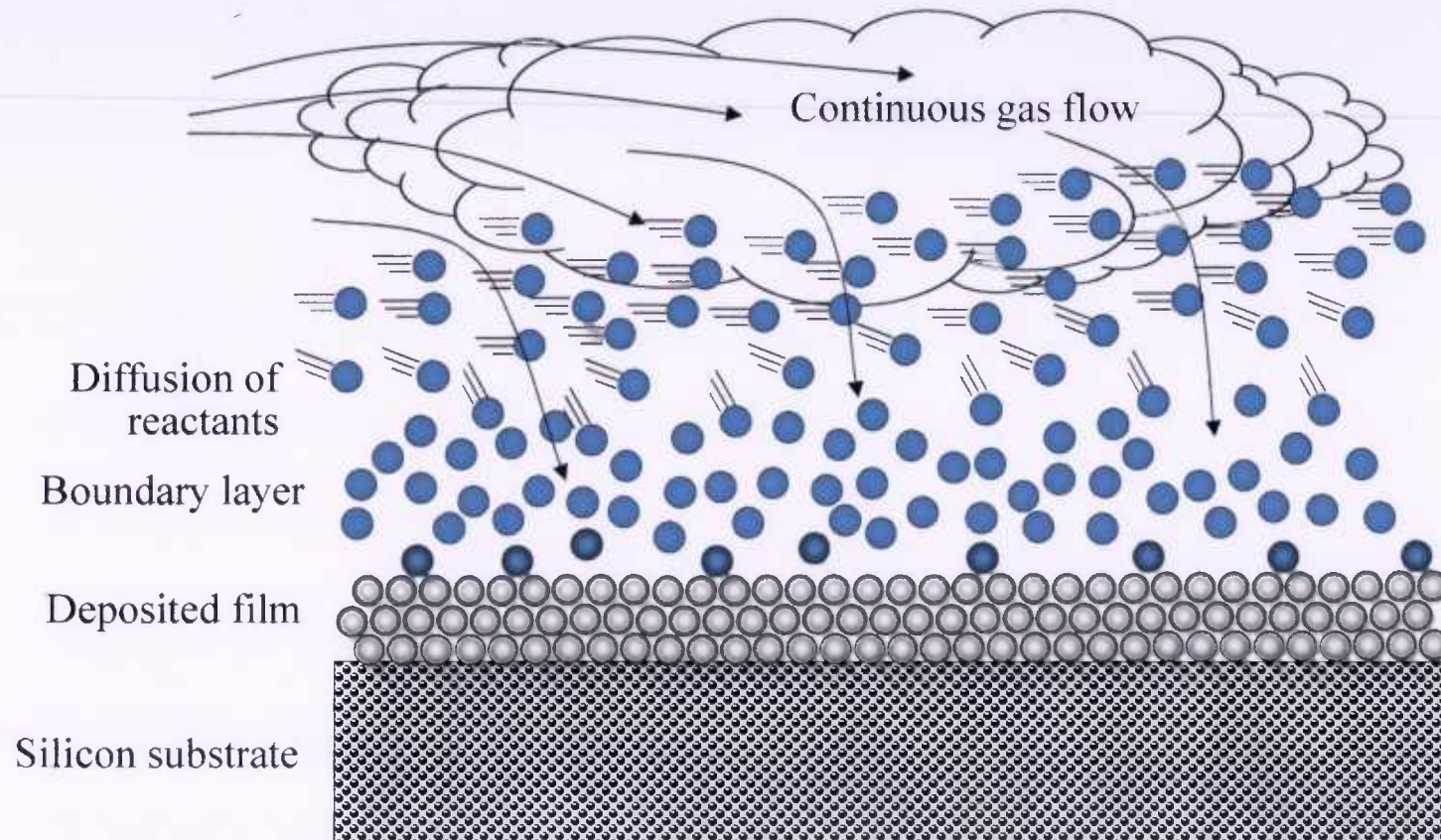


# CVD Chemical Reactions



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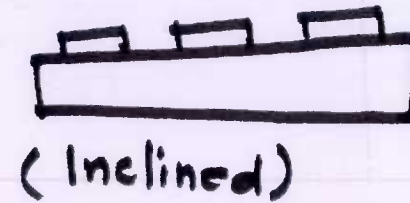
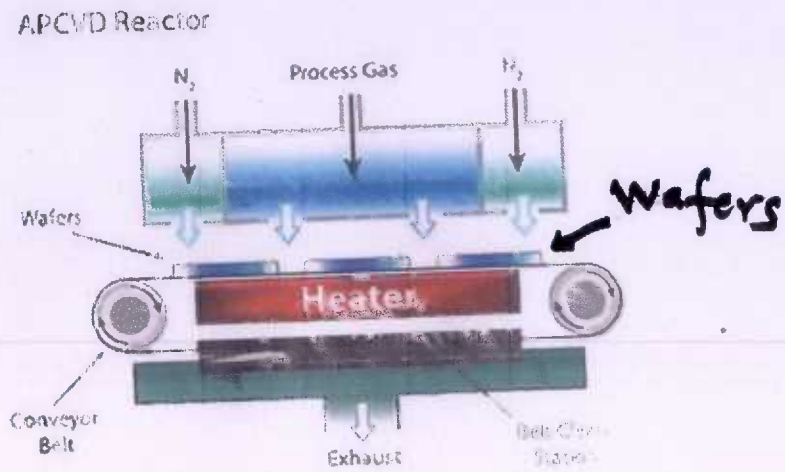
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(copy from Dow Corning)

Steps in APCVD :—

- ① Reactants reaches deposition region where substrates are horizontally kept.
- ② From ambient Gas Stream the reactants diffused through ~~the~~ Boundary Layer (Stagnant layer)



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(c) Reactants are then adsorbed at water surface.

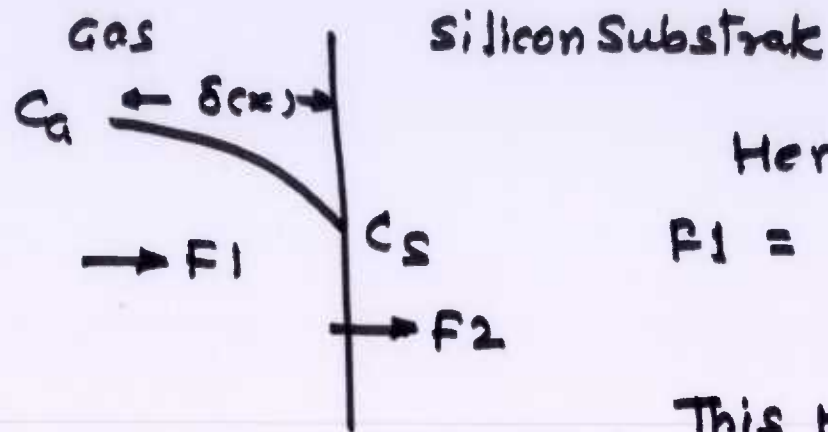
(d) Surface Reactions occur. Here

Chemical reactions take place, and deposition occurs conformally. Simultaneously emission and re-deposition too occurs

(e) Unreacted reactants & Byproducts are desorbed.

They transport through Boundary-Layer and are exhausted out of system.

We can have kinetics of such deposition, similar like Grove-Deal model for oxide growth.



Here

$F_1$  = Diffusion Flux of  
Reactant to the wafer

This process is Mass Transfer process

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$F_2$  = Flux of Reactant consumed by Surface reaction

Thus this process is Reaction rate limited

We have

$$F_1 = h_a (C_a - C_s)$$

$h_a$  is Mass Transfer Coeff.  
(cm/sec)

and 
$$F_2 = k_s C_s$$

In steady state  $F = F_1 = F_2$

$$\text{or } h_a (C_a - C_s) = k_s C_s$$

$$\text{or } h_a C_a = (h_a + k_s) C_s$$

$$\text{or } C_s = \frac{h_a}{h_a + k_s} C_a = \frac{1}{1 + \frac{k_s}{h_a}} C_a$$

$$\text{or } C_s = \left( 1 + \frac{k_s}{h_a} \right)^{-1} C_a$$

The Growth rate  $V_y = \frac{r}{N}$

$N$  is no of atoms incorporated on surface

$$\therefore V_y = k_s \left( 1 + \frac{k_s}{h_a} \right)^{-1} \frac{C_a}{N}$$

If  $C_T$  denotes conc. of all Molecules in Gas Phase, then  $C_a$  is fraction of  $C_T$  or Mole fraction  $Y = C_a / C_T$

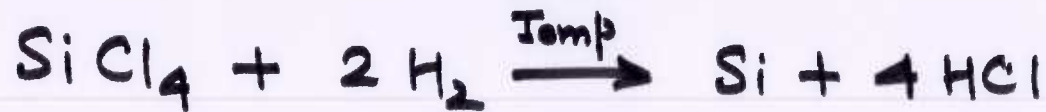


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$$Y = \frac{C_a}{C_T} = \frac{P_a}{P_T} = \frac{P_a \text{ SiCl}_4}{P_a \text{ SiCl}_4 + P_{\text{H}_2}}$$

Reaction used here is



$\Delta G = \Delta H - T \Delta S$  is Thermodynamic statement.

The growth rate  $V_y$  is therefore written as

$$V_y = \frac{k_s h_a}{k_s + h_a} \cdot \frac{C_T}{N} \cdot Y \quad \left( \frac{1}{\frac{1}{k_s} + \frac{1}{h_a}} \right)$$

Two cases :- ①  $k_s \ll h_a$ , then  $V_y = \frac{k_s C_T Y}{N}$  — (A)

② If  ~~$h_a \ll k_s$~~   $h_a \ll k_s$ , then  $V_y = \frac{h_a C_T Y}{N}$  — (B)



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