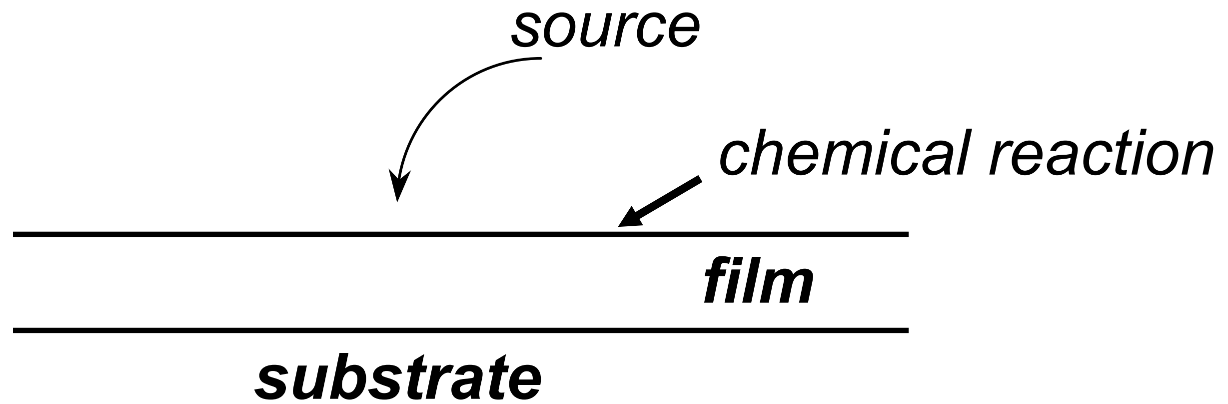
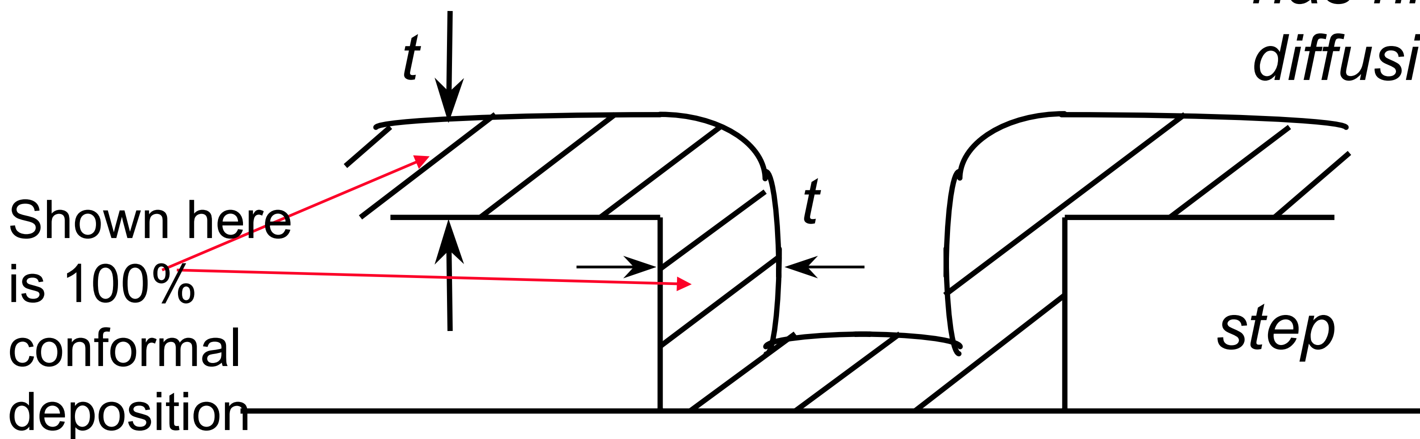
Chemical Vapor Deposition (CVD)

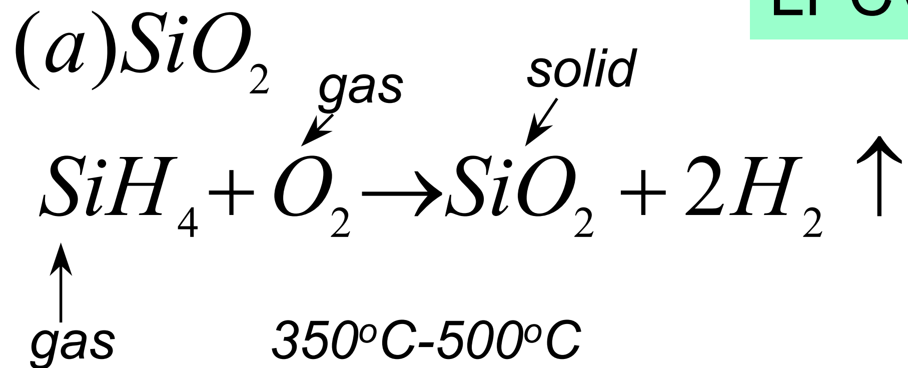


More conformal deposition vs. PVD

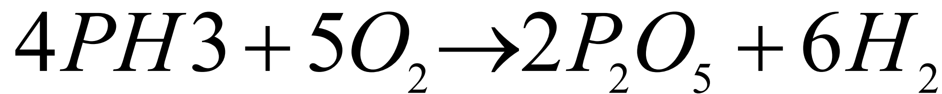
(∵ higher temp has higher surface diffusion)



LPCVD Examples



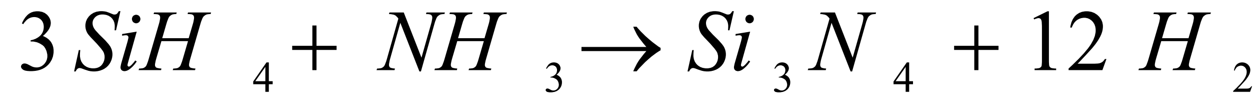
(b) PSG : *phospho silicate glass*. $[P_2O_5 + SiO_2]$



350°C-500°C

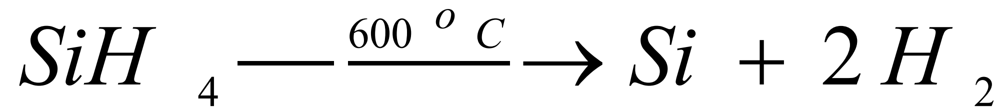
(c) TEOS : *tetraethylene orthosilicate*.

$(d)\,Si_3N_4$



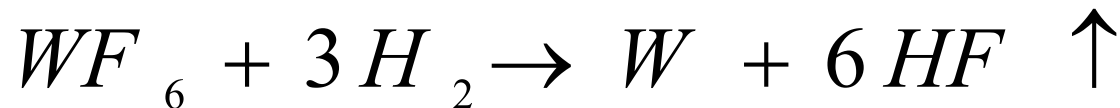
$$3SiH_4 + NH_3 \rightarrow Si_3N_4 + 12H_2$$

$(e)\,Poly - Si$



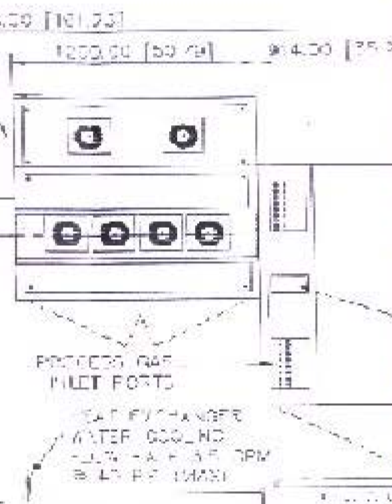
$$SiH_4 \xrightarrow{600^oC} Si + 2H_2$$

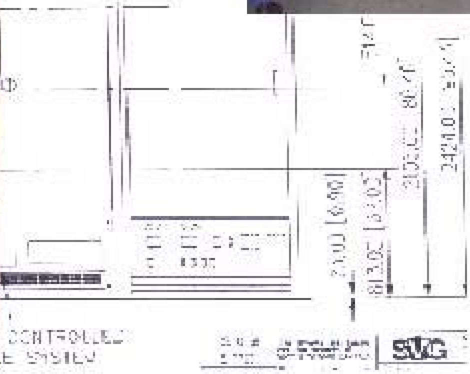
$(f)\,W$



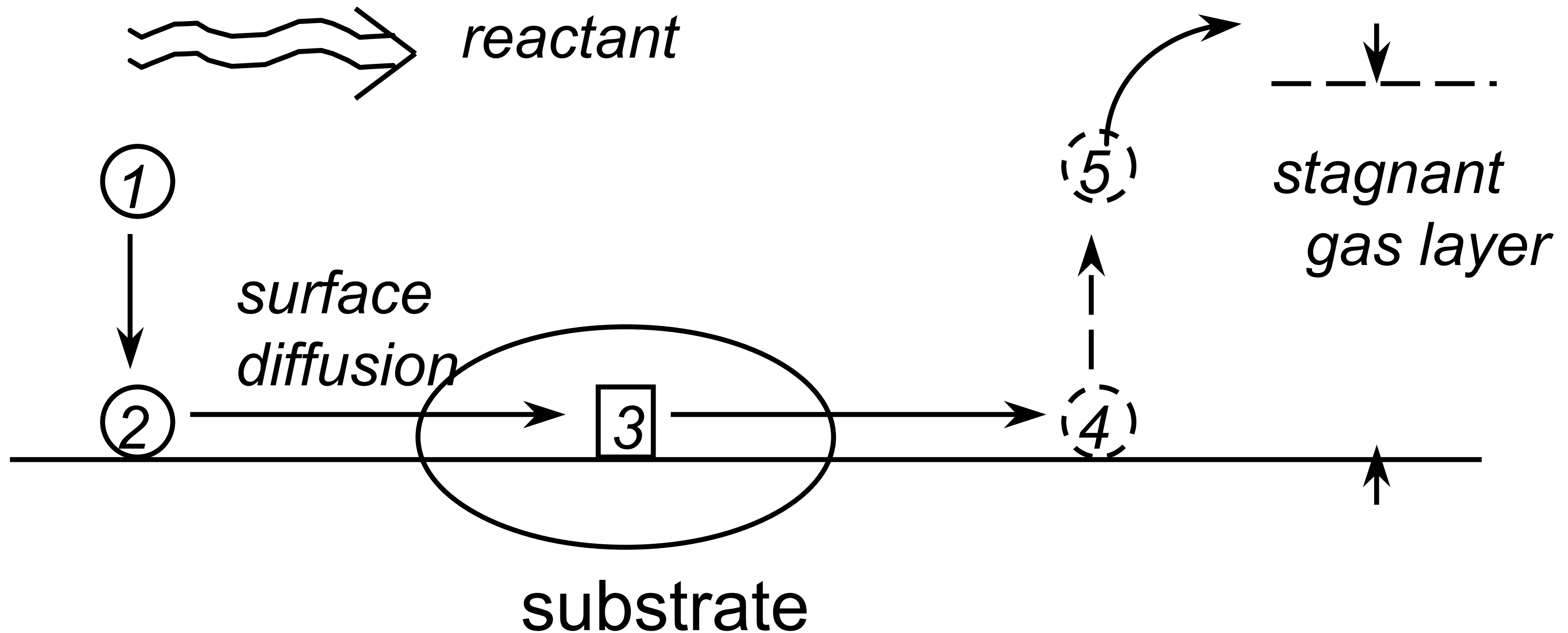
$$WF_6 + 3H_2 \rightarrow W + 6HF \uparrow$$

LPCVD Systems





CVD Mechanisms



1 = Diffusion of reactant to surface
2 = Absorption of reactant to surface
3 = Chemical reaction
4 = Desorption of gas by-products
5 = Outdiffusion of by-product gas

Example Poly-Si Deposition

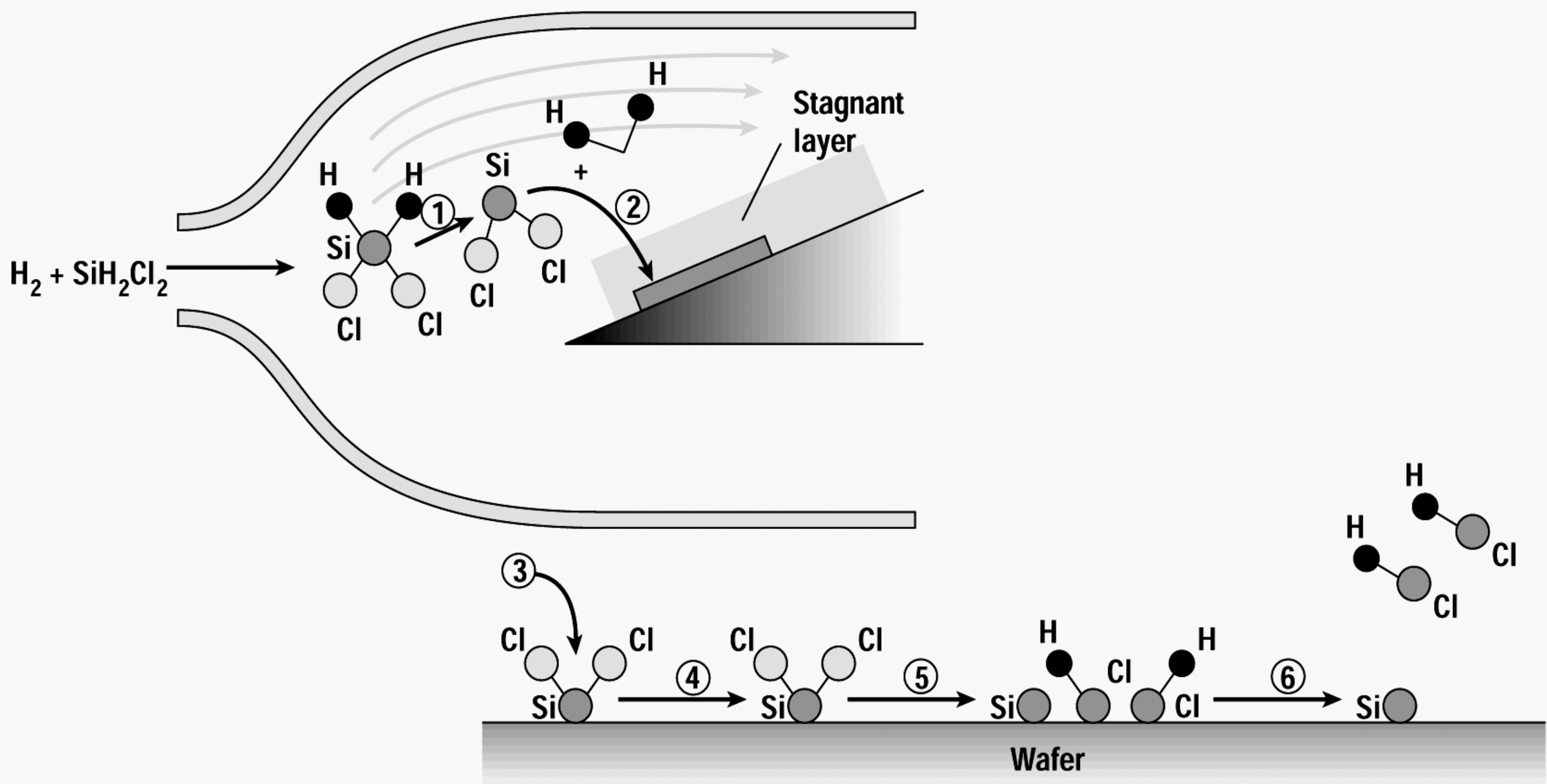
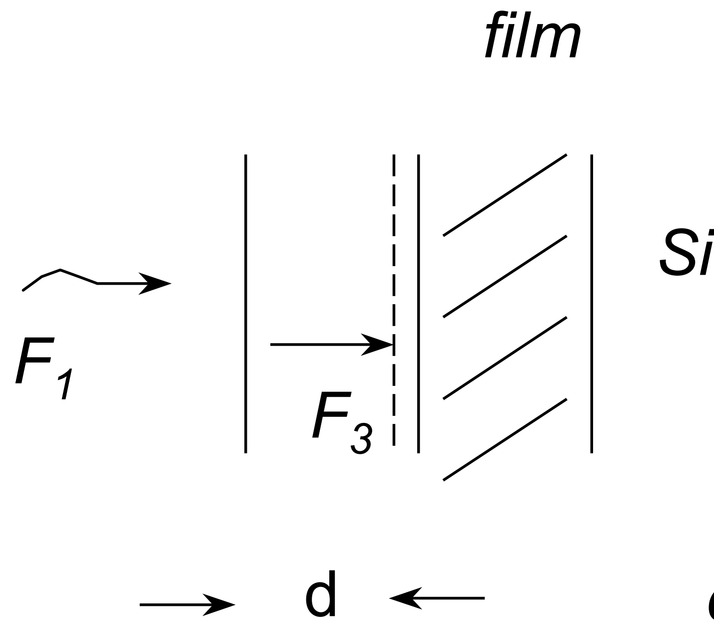


Figure 14.4 VPE steps include (1) gas-phase decomposition and (2) transport to the surface of the wafer. At the surface the growth species must (3) adsorb, (4) diffuse, and (5) decompose, and (6) the reaction by-products desorb.

CVD Deposition Rate [Grove Model]



$$\frac{D}{\delta} = h_G$$

$$k_s = k_o e^{-\Delta E/kT}$$

d = thickness of stagnant layer

F_1 = $D [C_G - C_S] / d$

F_3 = $k_S C_S$

$$F_1 = F_3$$

$$\therefore \boldsymbol{F_3} = \frac{\boldsymbol{k_s h_G}}{\boldsymbol{k_s + h_G}} \cdot \boldsymbol{C_G}$$

Film growth rate = F_3 / N

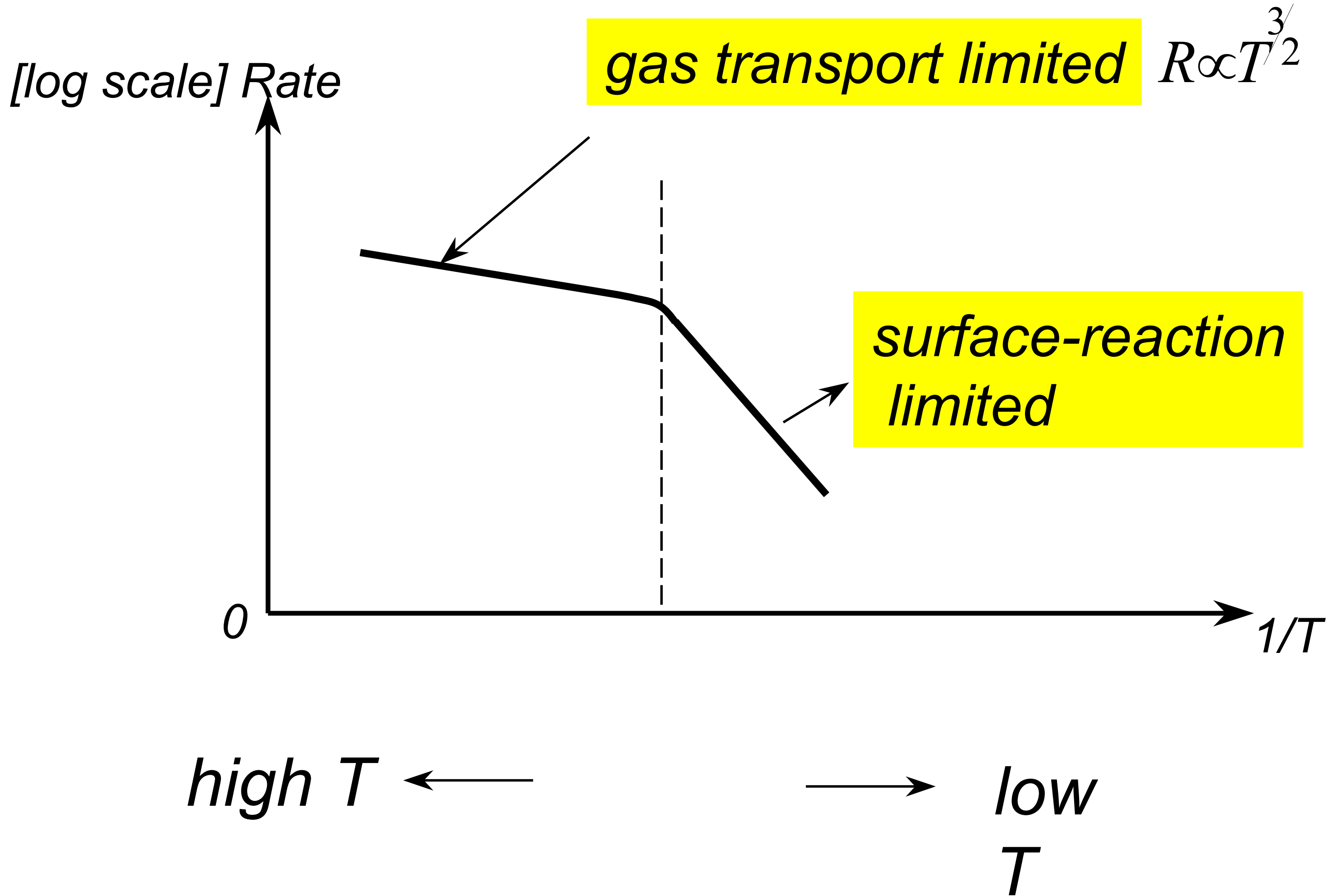
N = atomic density of deposited film

$$\therefore \frac{dx}{dt} = \frac{F_3}{N} = contant\ with\ time$$

$$\left(cm/\mathrm{sec} \right)$$

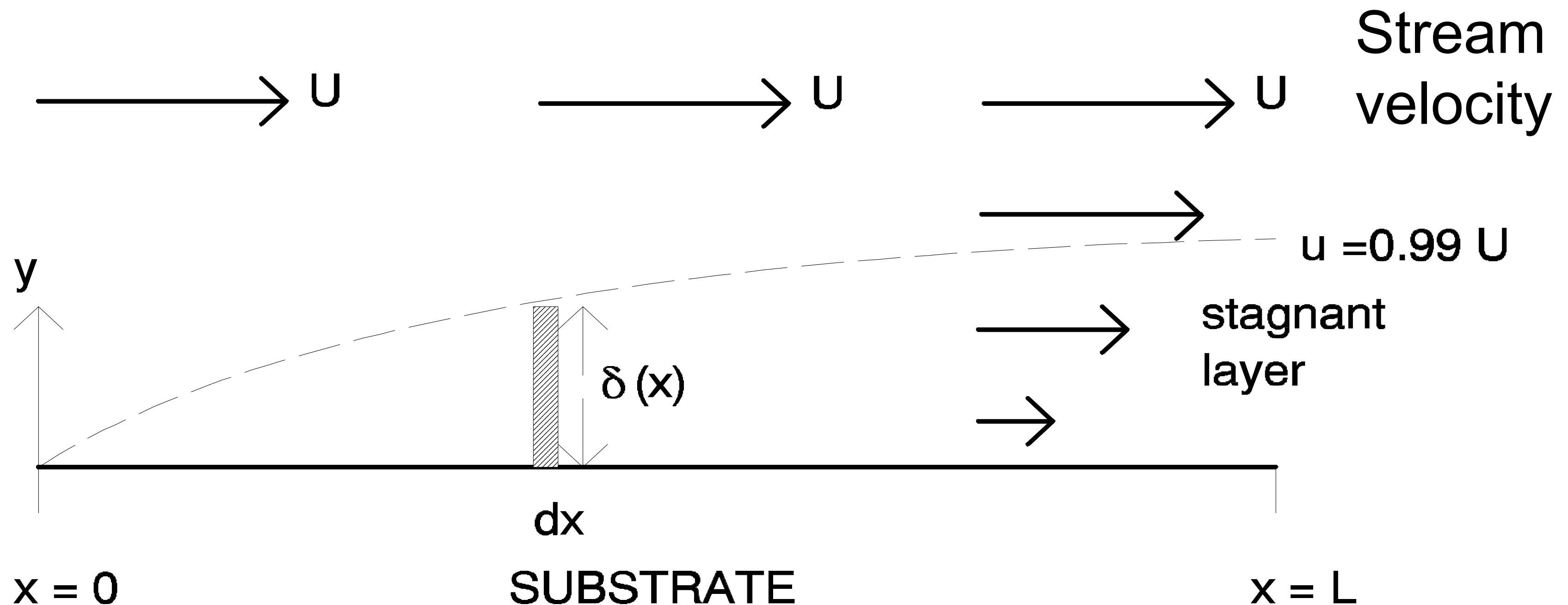
Note: This result is exactly the same as the Deal-Grove model or thermal oxidation with oxide thickness =0

Deposition Rate versus Temp



Boundary Layer Theory for Stagnant Gas Layer

[Planar Geometry]
*See CVD Kinetics Handout for derivation



d(x) boundary layer thickness
L length of the substrate (e.g. substrate or wall of reactor).

For reference only

Derivation of boundary layer continued

The gas velocity u is a function of x and y and is equal to zero at plate's surface and is equal to U in the free gas stream.

Let μ = viscosity of gas. Then frictional force / unit area along the x-direction = $\mu \times \frac{\partial u}{\partial y}$

Let us consider a volume element of unit depth (i.e., into the paper) , height $\delta(x)$ and width dx.

Total friction force on element $= \mu \times \frac{\partial u}{\partial y} \times (1 \times dx) = \mu \frac{\partial u}{\partial y} dx =$ decelerating force

Total accelerating force on element.

$$= \rho \times \delta(x)dx \times \frac{du}{dt} = \rho \times \delta(x)dx \times \frac{du}{dx} \times \frac{dx}{dt} = \rho \times \delta(x)dx \times \frac{du}{dx} \times u$$

where ρ is the gas mass density

Balanced forces : $\mu \frac{\partial u}{\partial y} = \rho \times \delta(x) u \frac{du}{dx}$ and u(x,y) can be solved exactly.

For reference only

Approximate Solutions

Let $\frac{\partial u}{\partial y} \approx \frac{U}{\delta(x)}$; $\frac{\partial u}{\partial y} \approx \frac{U}{x}$

then $\delta(x) \approx A\left(\frac{\mu x}{\rho Y}\right)^{1/2} - B$

"parabolic dependence' where A,B are constants.

The Exact Solution:

The stagnant layer thickness with u= 0.99U is equal to :

$$\delta(x) \approx 5.0\left(\frac{\mu x}{U}\right)^{1/2}$$

See H. Blasius, NACA Tech. Mem., 1949, p. 1217.

For reference only

Average Boundary Layer thickness

∴ The "average" boundary layer thickness $\overline{\delta}$ =

$$\frac{1}{L}\int_0^L \delta(x)\,dx = \frac{2}{3}\frac{L}{\sqrt{\frac{\rho U L}{\mu}}} = \frac{2}{3}\frac{L}{\sqrt{R_{e_L}}}$$

R_{e_L} is called the Reynold Number of the reactor. When R_{e_L} is small ($\leq$ 2000) , viscous flow dominates. When R_{e_L} very large ($\geq$ 2000) , turbulent flow dominates.

In the CVD growth rate model, it was assumed that mass transport across stagnant layer proceeds by diffusion,

then. $F_1 \equiv D_G \cdot \frac{C_G - C_S}{\delta} \Rightarrow h_G = \frac{D_G}{\delta}$ where D_G = diffusivity

For mass-transfer limited deposition, model $\Rightarrow$

$$dx/dt \propto h_G \propto \frac{1}{\delta} \propto \sqrt{U}$$

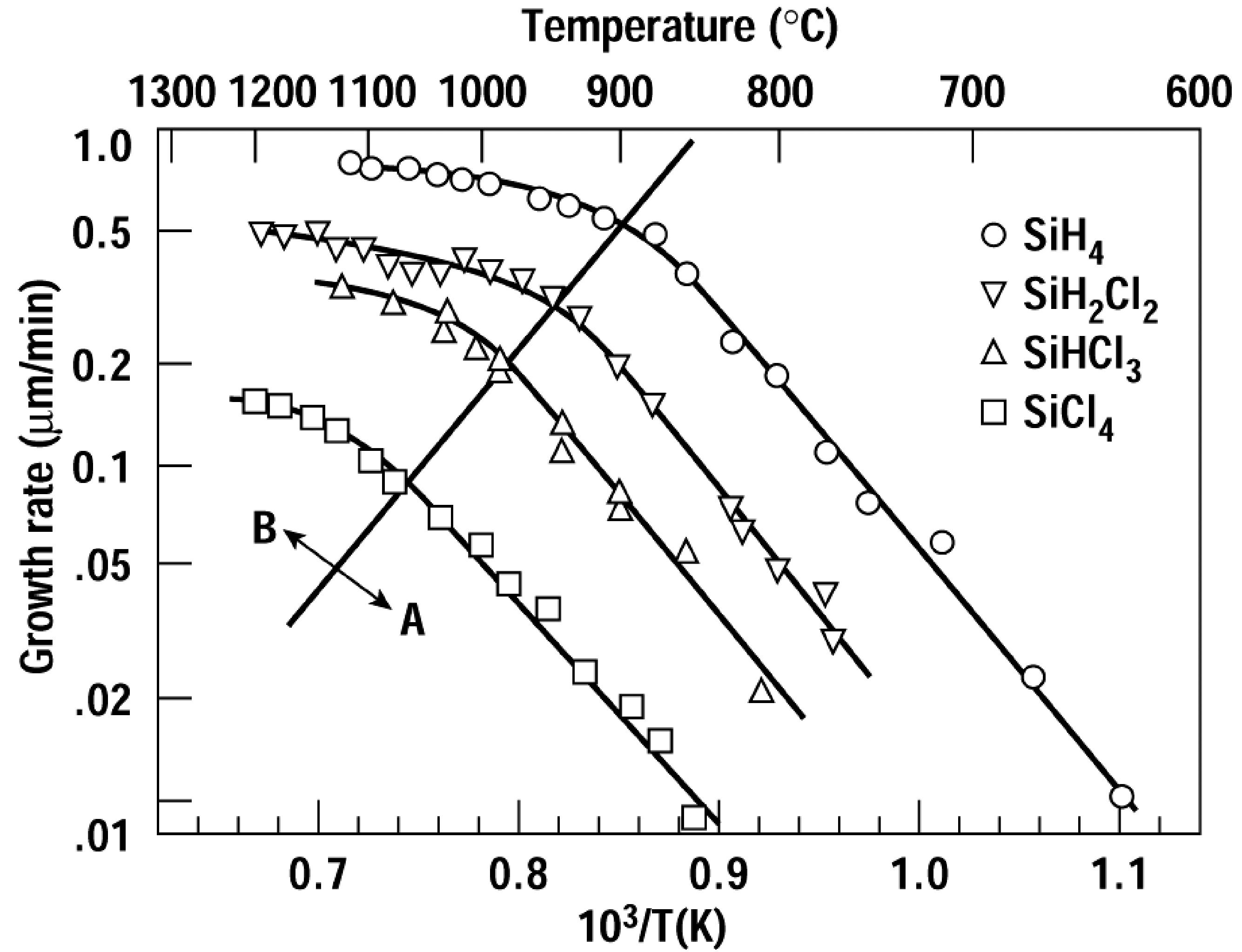
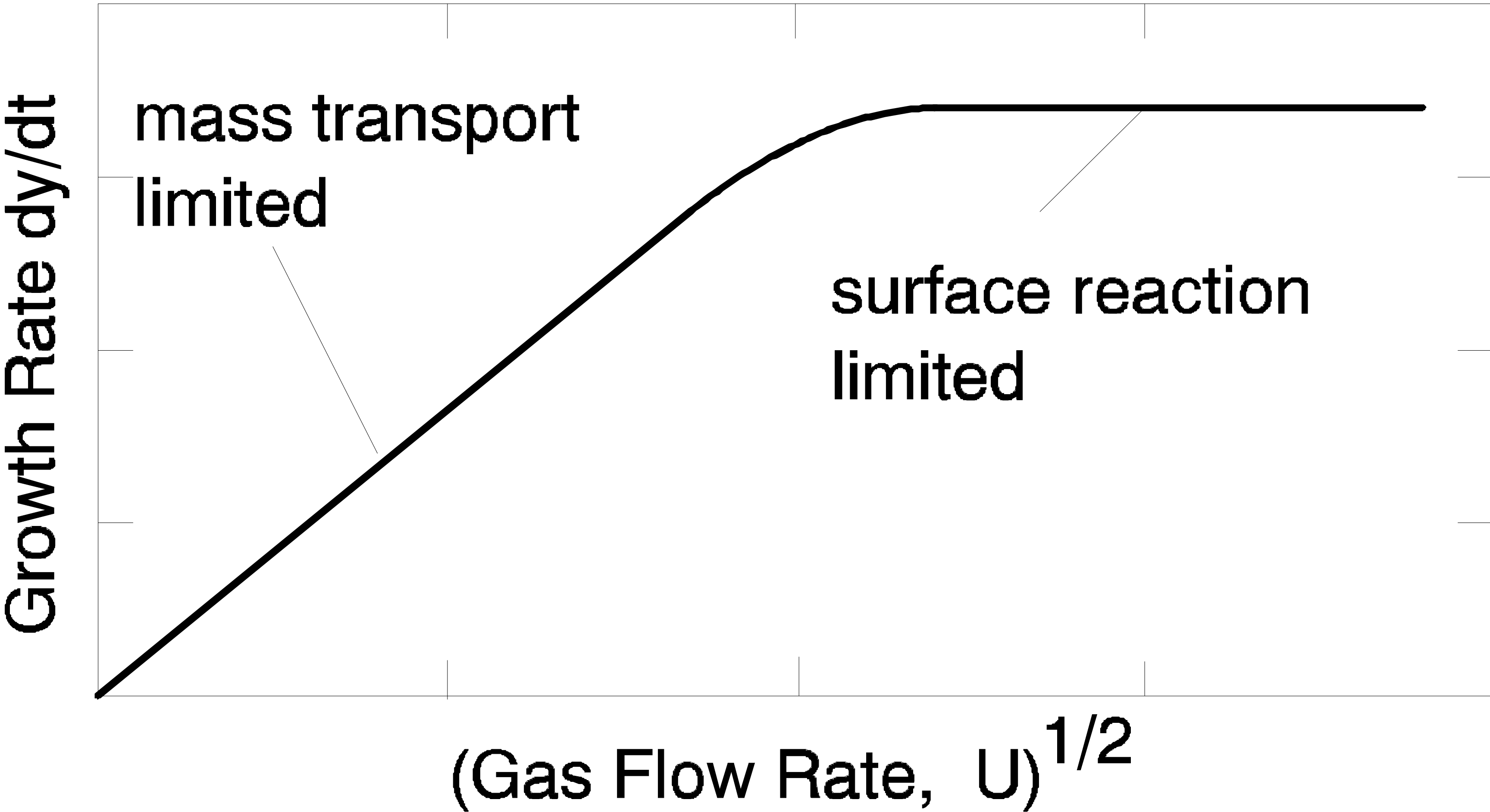


Figure 14.8 Arrhenius behavior of a variety of silicon-containing growth species *(after Eversteyn, reprinted by permission, Philips).*

Growth Rate Dependence on Flow Velocity



LPCVD Reactors

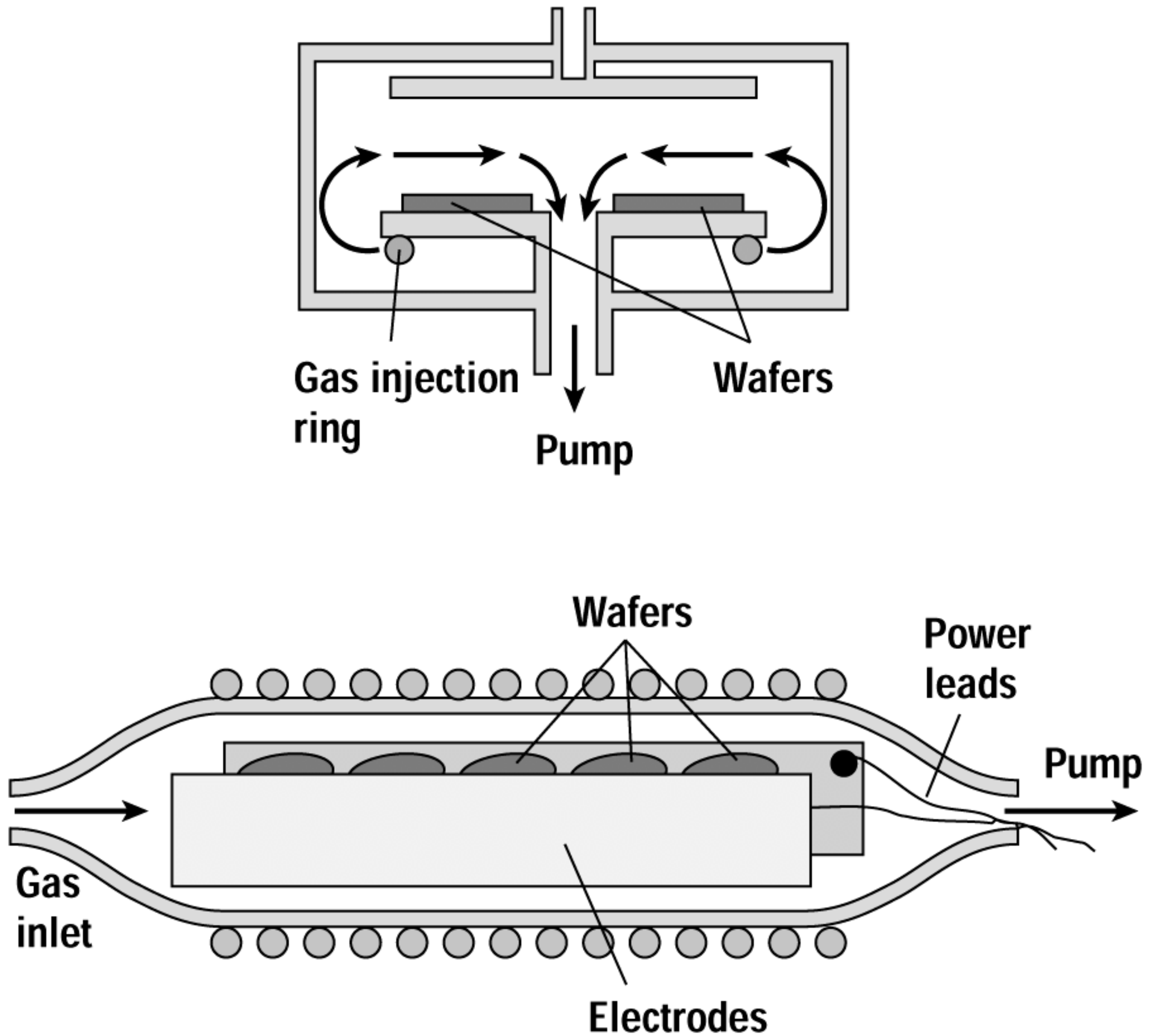


Figure 13.18 Basic PECVD geometries: cold wall parallel plate, hot wall parallel plate, and ECR.

(next page)

LPCVD: Low Pressure and high gas velocity due to pumping $\mathbf{h_G} \uparrow$

Example calculation:

•P reduces ~1000X from 1 atmosphere to ~1 Torr

•Velocity of gas flow U increases ~100X due to pumping

$$D \propto \frac{1}{P} \qquad From\ 760 Torr \rightarrow 1 Torr \quad D \uparrow 1000X$$

$$\delta \propto \sqrt{\frac{\mu}{\rho U}} = \sqrt{\frac{1000}{100}} \sim 3X$$

velocity of gas flow 100X

Gas density $\rho \propto P$

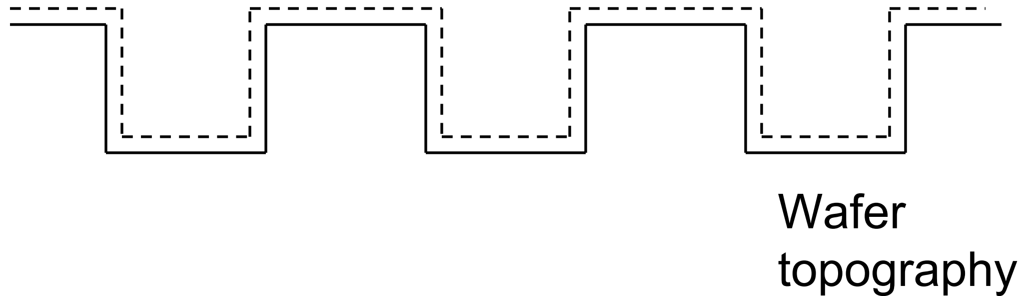
$$h_G \rightarrow \frac{1000}{3} \rightarrow 300X$$

$$h_G = D/\delta$$

Therefore, LPCVD is more likely to be **surface reaction limited**

LPCVD Features

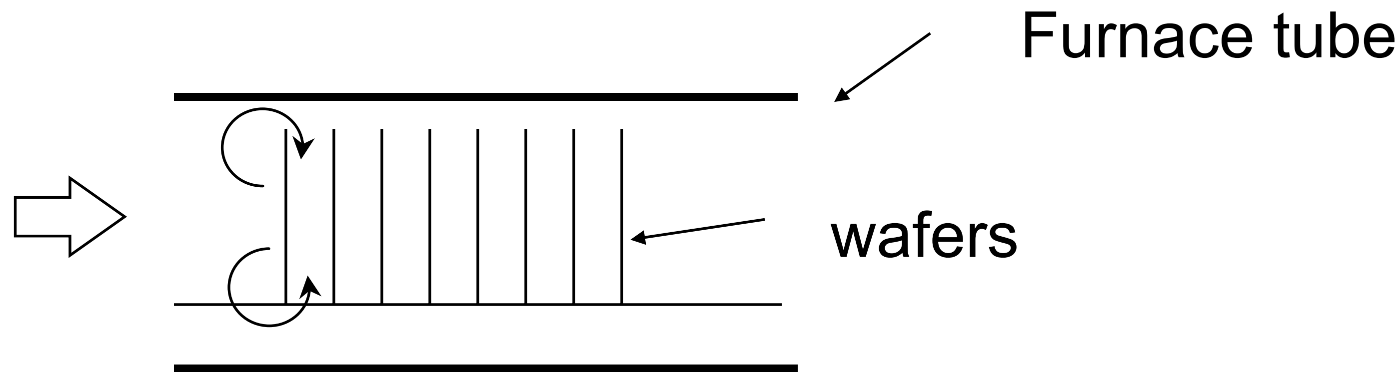
(1) R $\uparrow$, since $h_G \uparrow$
(2) More conformal deposition,
 if T is uniform



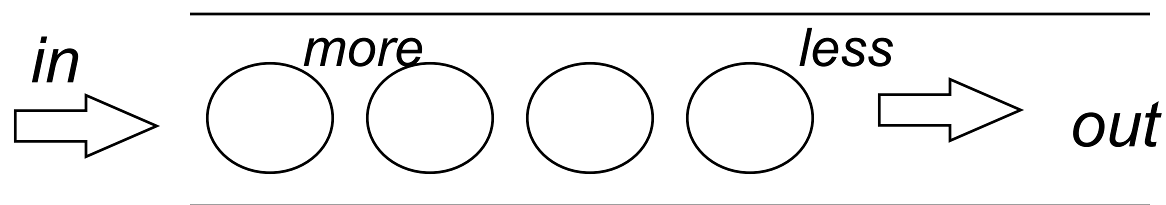
(3) Inter-wafer and intra-wafer thickness uniformity less sensitive to gas flow patterns. (i.e. wafer placement).

Comments

(1) δ depends on gas flow pattern



(2) Mass depletion problem



Solutions

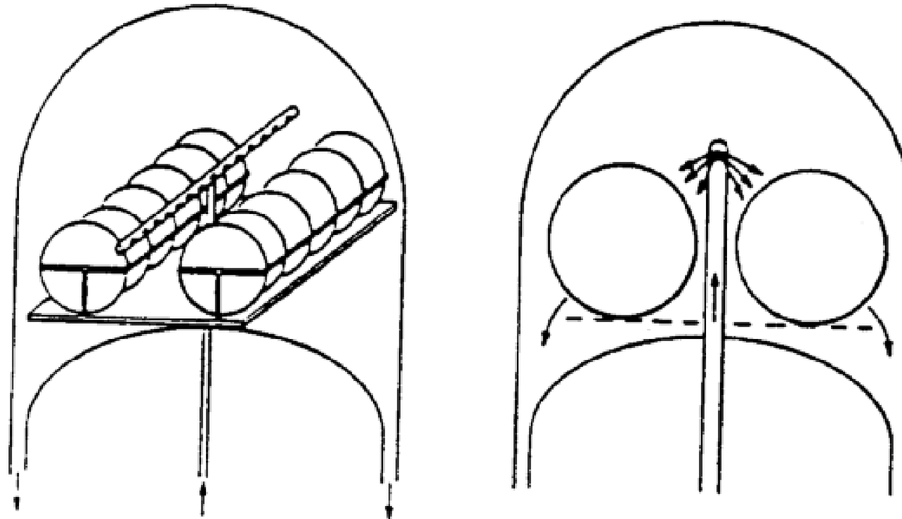
(1) Temperature Ramping along reactor length

For reaction - limited regime:

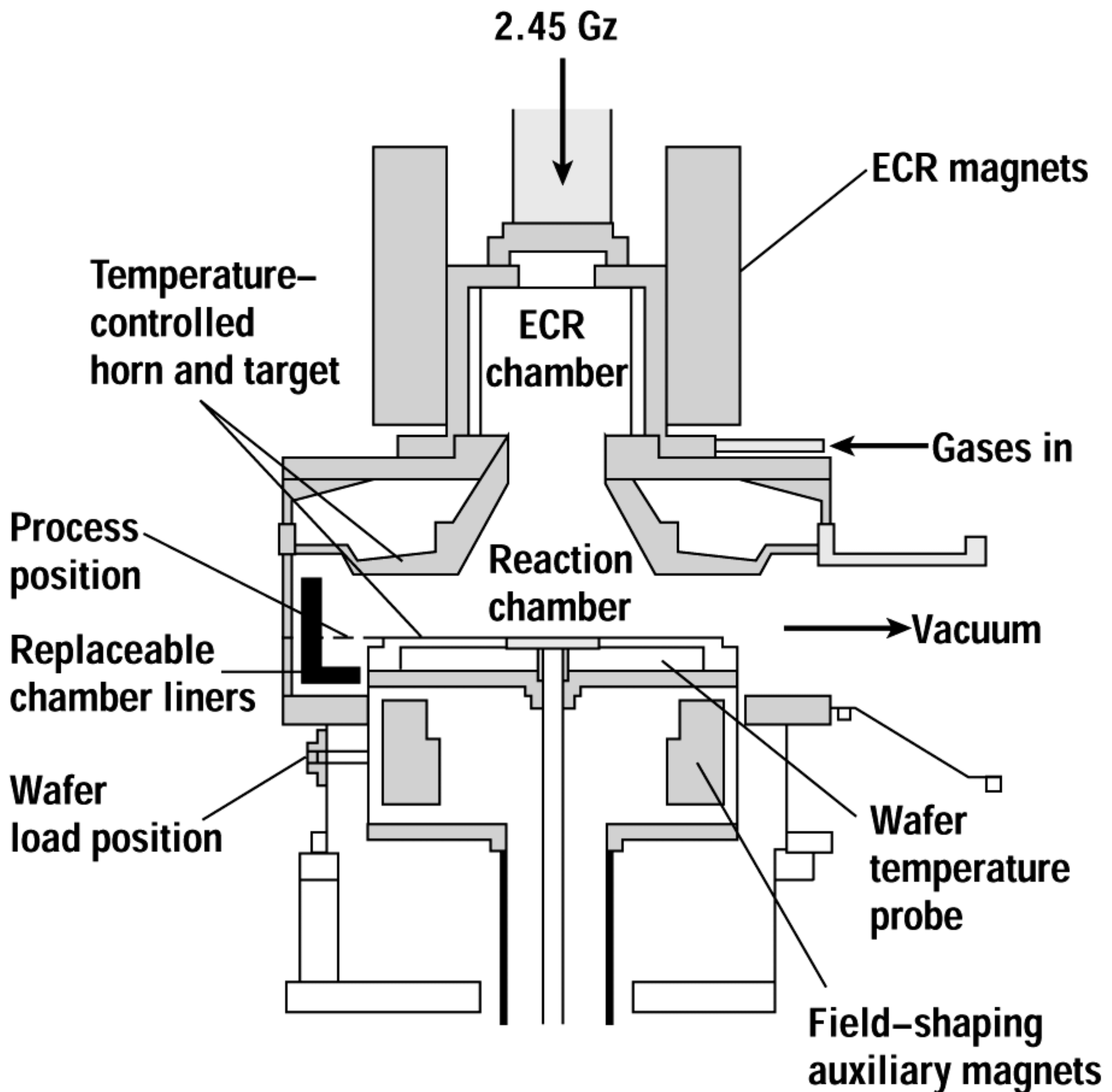
$R(x) = A \exp[-\Delta E/kT] \times C(x)$ [where $C(x) = SiH_4$ Conc.]

∴Creating a temperature gradient of 20 - 40°C along the tube will give better uniformity.

(2) Distributed Feed Reactors



PECVD Reactors



Plasma Enhanced CVD

• Ionized chemical species allows a lower process temperature to be used.

• Film properties (e.g. mechanical stress) can be tailored by controllable ion bombardment with substrate bias voltage.

DIELECTRIC DEPOSITION PROCESSES

	Deposition Temperature	
	LPCVD	PECVD
$SiH_4 + NH_3 \Rightarrow Si_3N_4$	850° C	200-400°C
$SiH_4 + N_2O \Rightarrow SiO_2$	800°C	200-400°C
$TEOS + O_2 \Rightarrow SiO_2$	720°C	350°C
$SiH_4 + O_2 \Rightarrow SiO_2$	400°C	