EE669: VLSI Technology

Chemical Vapor Deposition and Atomic Layer Deposition

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Outline

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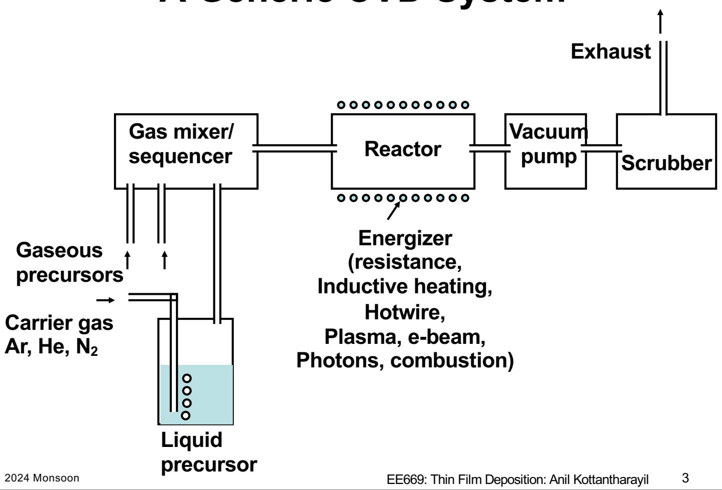
A Generic CVD System



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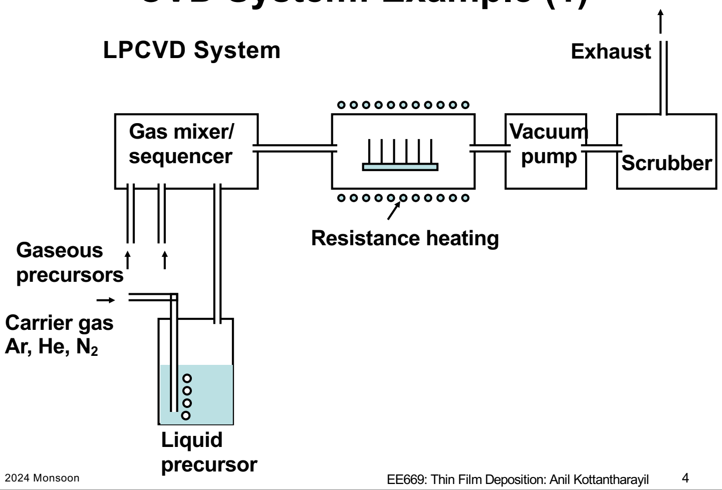
CVD System: Example (1)



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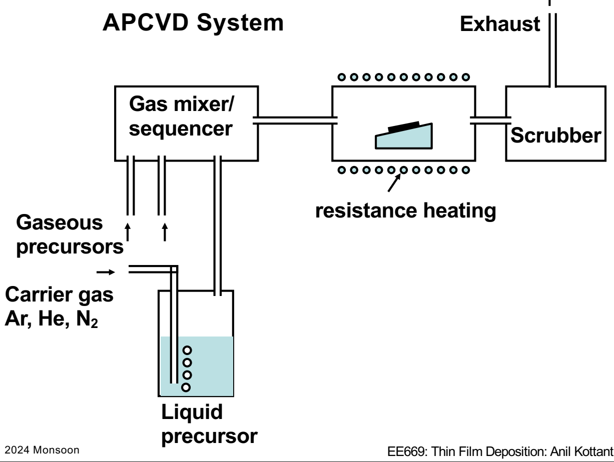
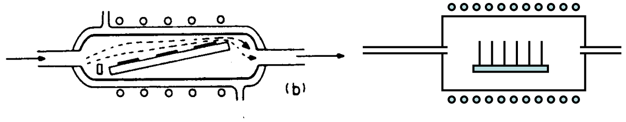
CVD System: Example (2)

APCVD System



Thermal CVD Reactor Designs

Horizontal, hot wall reactors



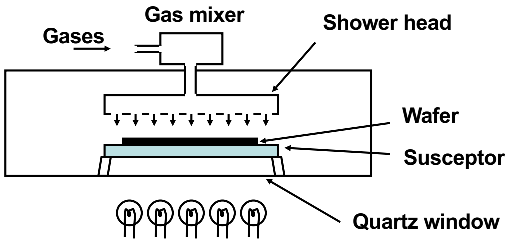
APCVD	LPCVD, RPCVD
EPI Doped oxides (PSG, BPSG)	Dielectrics, poly-Si, a-Si

- **Excellent temperature profiles**
- **Deposition on the walls of the reaction chamber, flaking, …..**
- **Contamination from the reaction chamber**

S. Sivaram, "Chemical Vapor Deposition", Van Nostrand Reinhold, 1995

Thermal CVD Reactor Designs (2)

Single wafer, cold wall Rapid Thermal - CVD reactor



- **Typical of 300mm CVD reactors**
- **In case of non-RTCVD, the heating may be using induction or resistive heating**
- **No deposition on the chamber walls, less particle contamination concerns**

Turbulence in Thermal CVD Reactors

Turbulence
- **Leads to nonuniform film growth**
- **Gas phase reactions**

Laminar flow (smooth layer by layer flow) is desired
Flow regime determined by Reynolds number

$$R_e = \frac{\rho u d}{\mu}$$

ρ : **Volume density of the gas in kg/m³**

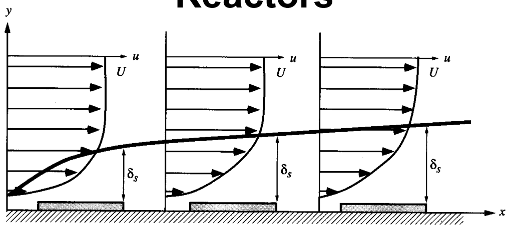
u : **Mean fluid velocity in m/sec**

d : **Tube diameter in m**

μ : **Viscosity in Pa. sec**

When the Reynolds number > 2000: turbulent flow
When the Reynolds number < 1000: laminar flow

Boundary Layer in Thermal CVD Reactors



$$\delta_S(x) \,\square\, \left(\frac{\square x}{\rho U}\right)^{1/2}$$

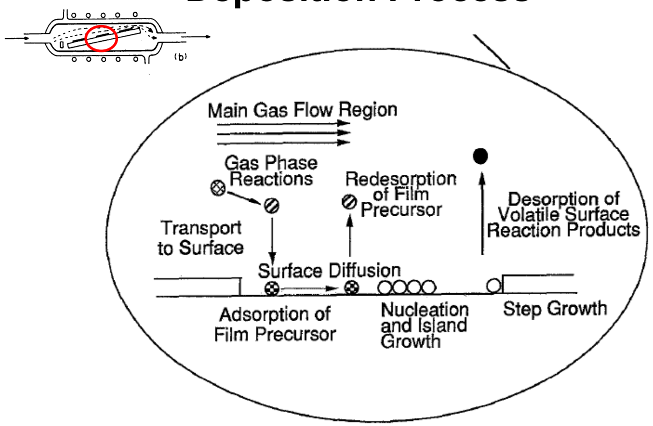
Where all the parameters are as defined on slide 8. U is the velocity of the gas in the main flow above the boundary layer.

Plummer et al., "Silicon VLSI Technology", Prentice Hall, 2000

Boundary Layer in Thermal CVD Reactors (2)

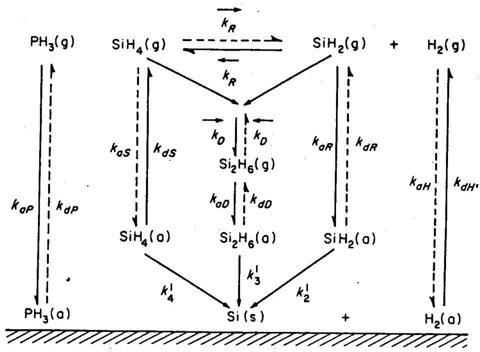
- **The boundary layer plays an important role in determining the layer growth kinetics**
- **In laminar flow regime, the reactants are transported from the main flow by diffusion to the wafer surface through the boundary layer**
- **Reaction byproducts are transported from the wafer surface to the flow through the boundary layer**
- **Thicker the boundary layer, longer it takes for the reactants to diffuse to the wafer surface ➔ lower reactant flux arriving on the wafer surface ➔ slower film growth rate if the growth is limited by availability of reactants**

Deposition Process



D. G. Coronell and K. F. Jensen, J. Computer-Aided Materials Design, 1993, pp. 3-26

Deposition Process: Reaction pathways



Si deposition by thermal decomposition (pyrolysis) of SiH_4

Hitchman and Jensen, Chapter 1 in Chemical Vapor Deposition Principles and Applications, edited by Hitchman and Jensen, Academic Press, 1993

Deposition Process: Reaction pathways (2)

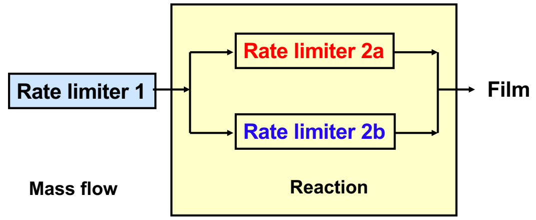
Pyrolysis of SiH_4 is one of the best understood CVD process:
27 contributing reactions out of the 120 possible elementary reactions
➔ Complex to analyze
- Gas phase chemical reactions
- Adsorption rates
- Surface reactions
- Desorption rates

An easier approach for the study of deposition rates is to consider the overall reaction as one of the rate limiting steps.

Such an analysis has its limitations.

Hitchman and Jensen, Chapter 1 in Chemical Vapor Deposition Principles and Applications, edited by Hitchman and Jensen, Academic Press, 1993

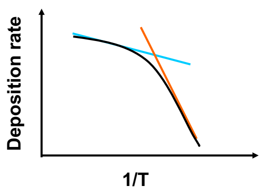
CVD kinetics



Hitchman and Jensen, Chapter 1 in Chemical Vapor Deposition Principles and Applications, edited by Hitchman and Jensen, Academic Press, 1993

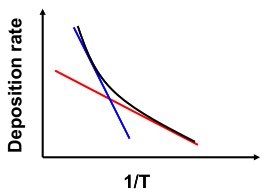
CVD kinetics (2)

Serial rate limiting steps



e. g.: mass transport – surface reaction, SiH_4 => SiH_2 => pyrolysis route for Si dep.

Parallel, competing reactions



e. g.: SiH_4, Si_2H_6, SiH_2 routes to Si deposition from SiH_4 feedgas

CVD kinetics (4)

The deposition process consist of the following:

Mass transport

1. Transport of the reactants through the boundary layer to the wafer surface

Surface reactions

2. Adsorption of the reactants on the wafer surface. Re-emission of the adsorbed species back into the boundary layer.
3. Surface processes, including decomposition, reaction, surface migration and nucleation
4. Desorption of by-products from the surface to the boundary layer

Not rate limiting

5. Transport of the by-products across the boundary layer into the main flow

CVD Kinetics (5)

- The rate of deposition in cm/sec can be obtained as

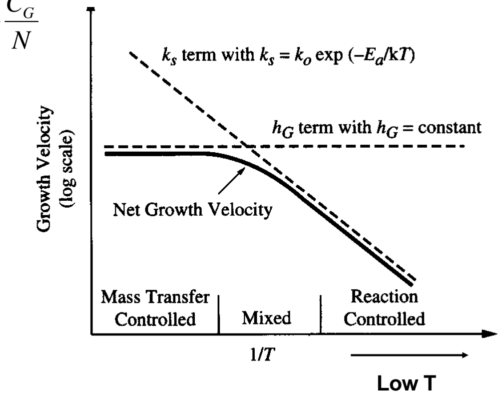
$$t'_{film} = \frac{1}{\frac{1}{k_S} + \frac{1}{h_G}} \frac{C_G}{N}$$

- Where,
  - k_S is the surface reaction rate in cm/sec
  - h_G is the mass transfer coefficient in cm/sec, = D/δ_S
  - C_G is the concentration of the precursor in the main flow, in molecules per cm^3
  - N is the number density of the product atoms in the growing film. Example: N = 5 x 10^{22} atoms per cm^3 for Silicon

For derivation, see the Plummer 2023

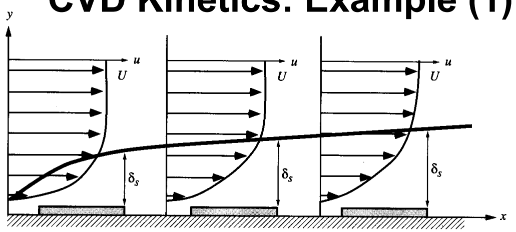
CVD Kinetics (6)

$$t'_{film} = \frac{1}{\frac{1}{k_S} + \frac{1}{h_G}} \frac{C_G}{N}$$



Silicon VLSI Technology, J. D. Plummer, M. D. Deal, P. B. Griffin

CVD Kinetics: Example (1)



- In mass transport limited regime, growth rate decreases with x
- It takes more time for reactants to diffuse through the thicker boundary layer

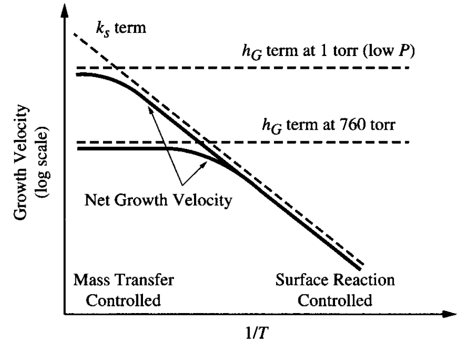
CVD Kinetics: Example (2)

$$t' = \frac{1}{\frac{1}{k_S} + \frac{1}{h_G}} \frac{C_G}{N} = \frac{1}{\frac{1}{k_S} + \frac{\delta_S}{D}} \frac{C_G}{N}$$

- In a gas, diffusivity is inversely proportional to pressure
- As pressure is reduced ➔ D increases ➔ h_G increases
- Even though the boundary layer thickness also increases, the increase is significantly less than the increase in D

CVD Kinetics: Example (2a)

Low Pressure Chemical vapor deposition (LPCVD)



Higher temperature deposition in reaction controlled regime.

Silicon VLSI Technology, J. D. Plummer, M. D. Deal, P. B. Griffin

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- **Langmuir,"The vapor pressure of metallic Tungsten", Physical Review, November 1913.**
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- **J. D. Plummer, M. D. Deal, and P. B. Griffin, "Silicon VLSI technology : fundamentals, practice and modeling", Prentice-Hall, 2000.**

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- **R. L. Puurunen, Journal of Applied Physics 2005.**
- **R. L. Puurunen, Journal of Applied Physics 2004.**
- **R. L. Puurunen, Ph. D. thesis, University of Helsinki, available at http://lib.tkk.fi/Diss/2002/isbn9512261421/isbn9512261421.pdf**