CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
www.lithoguru.com/scientist/CHE323

Lecture 24 Chemical Vapor Deposition, part 1

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Reading:
Chapter 13, *Fabrication Engineering at the Micro- and Nanoscale*, 4th edition, Campbell

Chemical Vapor Deposition

- CVD is used to deposit most dielectrics and silicon, but also for some metals
- Performed in furnaces, like oxidation and diffusion, and in newer single-wafer reactors
- Chemical reactions produce the desired species being deposited

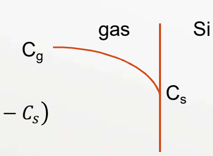
Chemical Vapor Deposition

- Gas-phase (homogeneous) reactions
  - Reactions occur in the gas phase
  - Solid is produced, that then lands on the wafer
  - Poor uniformity, many particles
- Solid surface (heterogeneous) reactions
  - Reaction occurs on the wafer surface
  - Solid formed is the deposited film
  - This is what we try to achieve

Simplified CVD Mechanism

- Transport of reactants to wafer surface (diffusion)
- Adsorption of reactants on surface
- Reaction
  - Assumed to be rate-limiting step
- Desorption of by-products
- Transport of by-products into gas stream

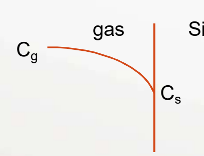
CVD Mechanism, Step 1



$$J_1 = D\frac{dC}{dx} \approx \frac{D_g}{\delta}(C_g - C_s) = h_g(C_g - C_s)$$

J_1 = flux of reactant to wafer surface
D_g = diffusivity of reactant in gas
C_g = bulk reactant concentration = $\frac{n}{V} = \frac{P_g}{kT}$
C_s = surface gas concentration
δ = boundary layer thickness
$h_g = D_g/\delta$ = mass transfer coefficient

CVD Mechanism, Step 2



$$J_2 = k_s C_S$$

J_2 = flux of reactant as it reacts
k_s = reaction rate constant
C_S = reactant concentration at wafer surface

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Steady State

- Assume that the surface reaction is the rate-limiting step
- Steady state is reached where all fluxes are equal

$$J_1 = J_2 = J_{SS}$$

- Solve for the unknown concentration (C_S) and eliminate from equation

$$C_S = \frac{h_g C_g}{h_g + k_S}$$

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Simplified Rate Equation

- Steady State reaction rate

$$J_{SS} = k_T C_g \qquad k_T = \frac{h_g k_S}{h_g + k_S}$$

- For N = # atoms/cm³ in deposited film,

$$deposition\ rate = v = \frac{J_{SS}}{N}$$

- Overall deposition rate

$$v = \frac{k_T}{N} C_g = \frac{k_T}{N}\left(\frac{1}{kT}\right) P_g$$

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Simplified Rate Equation

- Deposition rate

$$v = \frac{k_T}{N}\left(\frac{1}{kT}\right) P_g \qquad k_T = \frac{h_g k_S}{h_g + k_S}$$

- Two regimes,

$$if\ k_S \gg h_g, \quad k_T \approx h_g\ (diffusion - controlled)$$

$$if\ k_S \ll h_g, \quad k_T \approx k_S\ (reaction - controlled)$$

Note: P_g must be kept low to prevent homogeneous reaction

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Effect of Temperature

- In general, $E_{a(reaction)} >> E_{a(gas\ diffusion)}$

$$D_g \propto T^{\frac{3}{2}} \frac{P_g}{P_T}, \qquad \delta \text{ varies slowly with T}$$

- At high temperatures, $k_S >> h_g$
  - Diffusion-limited regime
- At low temperatures, $k_S << h_g$
  - Reaction-limited regime

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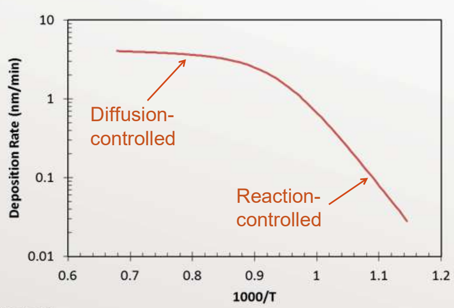
Deposition Rate vs. Temp



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Lecture 24: What have we learned?

- Why is heterogeneous CVD preferred over homogeneous CVD?
- What are the two steps in our very simplified mechanism for CVD?
- Explain diffusion-controlled vs. reaction-controlled regimes for CVD?

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