Name:____________________

CHEMICAL ENGINEERING 179
Exam 2
Wednesday, April 11 2012
Closed Book with 3x5 Card

$k_B = 1.381 \times 10^{-23}$ J K^{-1}; R = 8.314 J (mole K)$^{-1}$ = 1.987 cal (mole K)$^{-1}$; $N_A = 6.022 \times 10^{23}$ (mole)$^{-1}$; e = 1.602 x 10^{-19} C; $m_p = 1.673 \times 10^{-27}$ kg = 1.007 amu ; 1 liter = 1000 cm^3 ; STP = 273 K, 760 torr (1 atm); 1 atm = 1.013 x 10^5 Pa; 1 Pa = 1 J/m^3; 1 eV = 1.602 x 10^{-19} J

Short Answer. 5 pts. each.

1.What is the chief advantage of plasma etching over wet liquid etching in semiconductor manufacturing?

Anisotropy is possible in the etch profile.

2. A measurement of Si etch rate is made with F atoms only hitting the surface, then F atoms plus Ar^+ (500 eV), then only Ar^+ (500eV). Sketch the expected etch rate vs. time for this experiment, labeling the different regions.

Low etch rate, followed by a high etch rate, followed by a low rate again.

3. Chemical vapor deposition (CVD) reactor design calculations usually require chemical kinetics rather than chemical thermodynamics. Why is this?

The chemical processes are not at equilibrium, which is required to use chemical thermodynamics.

4. In semiconductor manufacturing, CVD processes are usually conducted at reduced pressure. List 2 reasons why low pressure is preferred to atmospheric pressure for CVD.

- higher diffusivity leads to better film deposition uniformity; lower pressure reduces particle formation;

5. For cylindrical, isothermal LPCVD (low pressure CVD) reactors with multiple wafers and flow in the annular region, what is the expected axial profile (that is, along the length of the reactor) in reactant concentration?

The expected profile will be an exponential decline in concentration.

6. What is the definition of the effectiveness factor (in terms of a ratio of reaction rates)?

Ratio of actual rate divided by maximum possible rate in absence of mass transfer limitations.

7. For best growth rate uniformity results, should the LPCVD reactor be operated in the reaction rate limited or mass transfer limited regimes? Why?

Reaction rate limited regime implies no mass transfer limitations, leading to film deposition rate uniformity.

8. How do 'magnetron' plasma sputtering systems work?

They use magnets above the target electrode to intensify the plasma, reducing electron losses and allowing higher deposition rates at lower pressure than conventional sputtering systems.

9. What is the source of light emitted by 'glow discharge plasma?'

Electron impact excitation leads to emission of photons and light emission.

10. List 3 ways that plasmas are used in thin film processing.

Etching; deposition, photoresist stripping; surface cleaning

Problem.

(50) 1. Consider a rectangular-shaped atmospheric pressure CVD reactor. The reaction occurs only on the bottom interior surface of the reactor and the reaction is controlled by the rate of mass transfer through the boundary layer.

The gas enters at 273K, 1 atmosphere pressure, and the reacting (lower) surface is maintained at a high temperature. Assume the gas diffusivity is 1 cm^2/s in the boundary layer.

Ignore pressure drop in the reactor and any effects of gas temperature on properties.

The reactor length is 20 cm, the height is 5 cm and the width is 10 cm. The flowrate of the gas entering is 50 standard liters per minute and the inlet mole fraction of reactive component is 0.001. Assume the flow remains laminar down the length of the reactor, and the boundary layer above the reactive surface increases down the length (x) as $\delta(x) = 1.5\sqrt{\frac{x\upsilon}{U_{gas}}}Sc^{-\frac{1}{3}}$, where the symbols have their normal meaning (as in the HW).

Solve for and plot the **relative rate of reaction** (rate divided by some scaling rate) as a function of length down the reactor.

Solution.

The rate of film deposition in the limit of mass transfer control is $r(x) = \frac{D_{AB}}{\delta(x)}(C_A - 0)$.

Since we want relative rate of deposition, we only need to plot a normalized function. So all we need is to get the gas velocity U_{gas} *and the minor* S_c *correction, recognizing that* $S_c \sim 1$*. This comes from the inlet volumetric flow (we are at standard conditions) and the cross sectional area of the inlet rectangle.*

The gas velocity does not change down the length and we are ignoring the effects of gas temperature changes, so it is fairly straightforward.

(+10)

$r(x) = \frac{D_{AB}}{\delta(x)}(C_A - 0)$, as from HW5

$D_{AB} = \underline{\underline{1\ \text{cm}^2/\text{s}}}$

(+5)

$C_A = X_A \frac{P}{RT} = 0.001\left(\frac{101325\ \text{Pa}}{8.314\ \frac{\text{J}}{\text{mol K}} \cdot 273\ \text{K}}\right) = 0.044\ \text{mol}/\text{m}^3 = \underline{\underline{4.4 \times 10^{-8}\ \text{mol}/\text{cm}^3}}$

$\delta(x) = 1.5\sqrt{\frac{x\nu}{U_{gas}}}\ Sc^{-1/3}$

$= 1.5\sqrt{\frac{x\nu}{U_{gas}}}\left(\frac{\nu}{D}\right)^{-1/3}$

(+5)

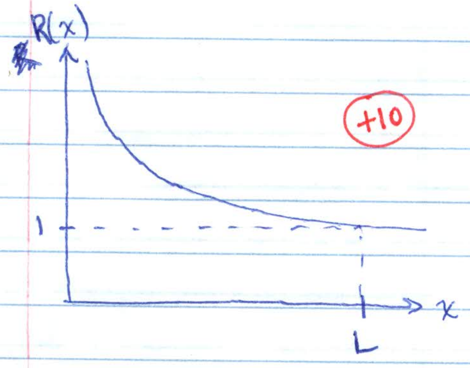
Recall that for a gas, $\nu \sim D$ (kinetic theory), so $Sc \sim 1$ and $\underline{\underline{\nu \approx 1\ \text{cm}^2/\text{s}}}$

$U_{gas} = \frac{Q}{A} = \frac{50\ \text{L/min}}{(5\ \text{cm})(10\ \text{cm})} = 0.167\ \text{m/s} = \underline{\underline{16.67\ \text{cm/s}}}$ (+5)

$\Longrightarrow \delta(x) = 1.5\sqrt{\frac{1\ \frac{\text{cm}^2}{\text{s}} \cdot x}{16.67\ \text{cm/s}}}\ \cancel{(1)^{-1/3}}^{\,1} = \underline{\underline{0.367\sqrt{x}\ \text{cm}}}$ (+5)

(+10)

$\Rightarrow r(x) = \frac{D_{AB}}{\delta(x)} C_A = \frac{(1\ \text{cm}^2/\text{s})(4.4 \times 10^{-8}\ \text{mol}/\text{cm}^3)}{0.367\sqrt{x}\ \text{cm}} = \cancel{\frac{1.199}{\sqrt{x}}}\ \boxed{\frac{1.2}{\sqrt{x}}\ \frac{\text{mol}}{\text{cm}^2 \cdot \text{s}}}$



$R(x) = \frac{r(x)}{r(L)}$

$R(x) = \frac{1.2/\sqrt{x}}{1.2/\sqrt{L}} = \boxed{\sqrt{\frac{L}{x}}}$

(+10)

Didn't need to solve for C_A, U, ν, etc. if they came out in your normalization.