Name:_____KEY_________

CHEMICAL ENGINEERING 179
Exam 1
Friday, March 2, 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 = 1.602×10^{-19} C; $m_p = 1.673 \times 10^{-27}$ kg ; 1 liter = 1000 cm^3 ; STP = 273 K, 760 torr (1 atm); 1 atm = 1.013×10^5 Pa; 1 Pa = 1 J/m^3.

Short Answer. 5 pts. each.

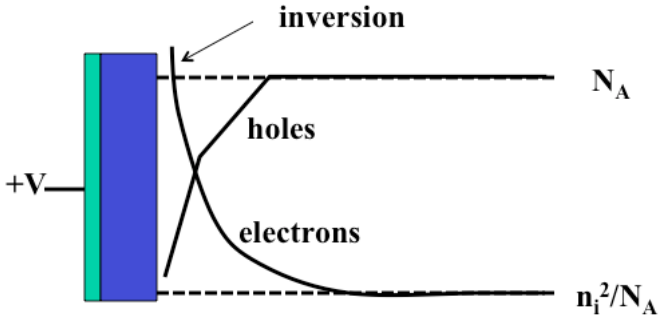
1. In current generation field effect transistor devices, what factor in device operation limits further reduction in size (or 'scaling')?

Power dissipation heats devices, limiting scaling.

2. Briefly describe how dopants affect semiconductor conductivity.

N-type dopants donate electrons to conduction band; P-type dopants accept electrons, creating free holes. In both cases, mobile charge carrier concentration increases, leading to higher conductivity.

3. Sketch the profile of electron and hole density for p-type silicon next to an insulator with a positively biased electrode on the other side. Identify the region of inversion.



4. Why are IC device manufacturers trying to find good gate dielectric materials with a HIGH value of dielectric constant?

So they can increase gate dielectric film thickness (d) without decreasing capacitance.

5. Describe in a few sentences how a phase shift mask works and why it is needed in lithography.

PSM work by altering the phase of light electric fields in adjacent features so as to create interference effects that reduce diffraction limitations. This is needed to print features much smaller than the wavelength of the light.

6. What is the typical dependence of solid-state diffusion coefficient in temperature and why?

D varies as exp (-E/kT); Arrhenius form for an activated process; activation energy needed to overcome diffusion barriers in lattice.

7. List 2 current problems with EUV lithography.

Masks; source intensity; photoresists; defect.

8. A reaction at an interface is first order and irreversible. In what units do we express the rate and what are the units of the rate coefficient?

Rate is expressed as number (or moles) per area per time; rate coefficient units of velocity – distance/time.

9. What is the key dimensionless group in silicon oxidation? Define the terms.

kX/D – rate coefficient for reaction at interface tomes film thickness divided by oxidant diffusivity.

10. In silicon oxidation in the linear regime (following the Deal-Grove model), is the interfacial reaction faster or slower than the rate of diffusion to the interface? Explain your answer.

Rates of reaction and diffusion are always equal in this model – oxidant cannot build up at the interface.

10. In silicon oxidation in the linear regime (following the Deal-Grove model), is the interfacial reaction faster or slower than the rate of diffusion to the interface? Explain your answer.

Problems.

(20) 1. In the Deal-Grove model, we assumed that we could ignore the problem that the film thickness boundary is moving and we solved the steady state equation for oxidant diffusion and reaction at the Si-SiO2 interface. What (approximate) value of oxidant diffusivity would be necessary for this assumption to NOT be correct if a 1 micron thick film is grown in about one hour?

In Deal-Grove, we assume:

+5 diffusion velocity >> film growth velocity

$$\frac{D}{X} \gg \frac{X}{t}$$

But if $^{+10}$ $\frac{D}{X} \le \frac{X}{t}$, this becomes a bad assumption.

$$\Rightarrow D \le \frac{X^2}{t} \quad +5$$

$$\boxed{D \le \frac{1\,\mu m^2}{hr}} = 2.78 \times 10^{-16}\ m^2/s$$

$$= 2.78 \times 10^{-12}\ cm^2/s$$

(30) 2. Consider a gas with the molecular mass of N2 (28 amu). This gas reacts <u>and sticks</u> at the walls of a cylindrical chamber 10 cm in diameter and 10 cm high with a reaction probability that has an activation energy of 0.1 eV. If the gas initially has a pressure of 1 torr, how long would it take for the gas pressure (300K) to reach 1 millitorr? The gas and walls remain at 300K for the entire process.

Transient mass balance:

V = chamber volume
A = wall surf. area

+5 $\frac{dN}{dt} =$ [redacted] $V\frac{dn}{dt} = -rA = -\frac{1}{4}n\bar{v}\gamma A$

$\Rightarrow \frac{dn}{n} = -\frac{1}{4}$ [redacted] $\bar{v}\gamma\frac{A}{V}dt$

A could include top & bottom or just [redacted] cylindrical wall:

ⓐ $\frac{A}{V} = \frac{2\cancel{\pi}r^{\cancel{2}} + 2\cancel{\pi}rh}{\cancel{\pi}r^{\cancel{2}}h} = \frac{2(r+h)}{rh} = 0.6\ \text{cm}^{-1} = 60\ \text{m}^{-1}$

ⓑ +5 OR

$\frac{A}{V} = \frac{2\cancel{\pi r h}}{\cancel{\pi}r^{\cancel{2}}\cancel{h}} = \frac{2}{r} = 0.4\ \text{cm}^{-1} = 40\ \text{m}^{-1}$

+3 $\bar{v} = \sqrt{\frac{8kT}{\pi m}}$

+2 $\bar{v} = 4.76\times10^{2}\ \text{m/s}$

+3 $\gamma = e^{-E_a/kT}$

$\gamma = e^{-0.1/0.03}$

+2 $\gamma =$ [redacted] 2.1×10^{-2}

[redacted] $P = nkT$; since T const., $\frac{P}{P_0} = \frac{n}{n_0}$

$$\int_{n_0}^{n}\frac{dn'}{n'} = -\frac{1}{4}\bar{v}\gamma\frac{A}{V}\int_{0}^{t}dt'$$

+5 $\ln\left(\frac{n}{n_0}\right) = \ln\left(\frac{P}{P_0}\right) = -\frac{1}{4}\bar{v}\gamma\frac{A}{V}t$

$t = \frac{-4\ln\left(\frac{P}{P_0}\right)}{\bar{v}\gamma\frac{A}{V}} =$ [redacted]

+5 [redacted] for ⓐ: 0.05 s

[redacted] for ⓑ: 0.07 s