Name: ***Key***

CHEMICAL ENGINEERING 179
Exam 1
Wednesday, March 18, 2008
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. What is ‘high k gate dielectric?’

These are materials used to replace SiO2 with high dielectric constant. This allows the gate dielectric to be thicker, avoiding tunneling, while maintaining the necessary electrical properties (capacitance).

2. What is considered the most likely limitation to future semiconductor device scaling?

Heat must be dissipated from currents/resistances in devices, including leakage currents.

Not mention heat dissipation : -1

3. What is the mathematical form for solid state diffusivity? Is this an 'activated process?'

$$D = D_0 \exp(\frac{-E_d}{kT})$$

+3

This is an activated process. +2

4. Write the expression for radiative heat flux, defining each term.

$j_{rad} = \varepsilon \sigma T^4$, ***where***

ε ***is emissivity,*** σ ***is Stefan-Boltzmann constant, T is absolute temperature.***

5. What is the key dimensionless quantity in the Deal-Grove model?

$\frac{k\delta}{D}$***, where k is oxidation rate coefficient,*** δ ***is film thickness and D is diffusivity.***

6. What happens when the quantity is (a) small compared to 1 and (b) large compared to 1? Sketch the O-species concentration profiles in each case.

(a) Reaction is rate-limiting step; diffusion is fast compared to reaction: O profile flat and nearly equal to O concentration at surface of SiO2. **+2.5**

(b) Diffusion or mass transfer is rate-limiting; diffusion is slow compared to reaction; O profile linear with O concentration near 0 at Si-SiO2 interface. **+2.5**

7. Write the equation for mean speed in terms of the speed distribution function (hint: the integral form).

$$\langle v \rangle = (\frac{m}{2\pi kT})^{3/2} \int_0^\infty 4\pi v^2 \exp(\frac{-mv^2}{2kT}) dv \bullet v$$

8. What is the difference between mean thermal speed of a gas and the average gas velocity?

Mean thermal speed is the average random speed (a scalar), whereas the average gas velocity is the mean speed in a particular direction (a vector).

9. What is a 'chemically amplified resist?'

Chemically amplified resists contain a photoacid group that is released when struck by a photon. This acid diffuses and releases other acid sites, thereby 'amplifying' the effect of the original photon. The resist is developed by rinsing in an aqueous base, resulting is dissolution of the exposed region. Unexposed regions are not affected.

10. Describe 2 optical lithography 'tricks' that are used to allow smaller features to be printed on photoresist. **+2.5/each**

Optical proximity correction - mask features that exploit additional structures on the mask to allow printed feature to be closer to desired shape.

Phase shift masks - masks that employ adjacent regions with different refractive indexes to promote desired constructive and destructive interference in order to print desired feature shape.

Etch trim of photoresist - after printing larger features, use etch to trim or reduce the size of the printed resist.

Spacer etch - uses conformal film deposition over line, followed by anisotropic etch and isotropic, selective etch to create hard mask that is much smaller than can be made by direct printing.

Immersion lithography - uses a high index liquid to expose the feature, reducing the 'effective' wavelength of the light, thereby promoting a reduced diffraction effect.

Double exposure - use multiple exposures at adjacent regions to print features closer to each other than would be possible in a single exposure.

11. Describe Moore's law.

Moore's law (in various forms) essentially states that number of transistors per chip increases by about a factor of 2 every 18 months to two years. Equivalently, the 'law' can be interpreted to mean a steady rate of improvement in some critical metric over some period of time, usually related to semiconductor device manufacturing costs and value.

12. List 3 applications of rapid thermal processing.

1. Annealing and activating dopants after ion implantation.
2. Rapid thermal chemical vapor deposition.
3. Rapid thermal oxidation.
4. Rapid thermal silicidation.

13. What is the distribution of free paths for an ideal gas? Show how to solve for the mean free path.

$f_{fp}(x) = n\sigma \exp(-xn\sigma)$; ***where*** σ ***is cross section, n is number density and x is distance;***
Mean free path is obtained by integrating over the distribution to form the first moment:

$$\lambda_{mfp} = \int_0^\infty x f_{fp}(x)dx = \int_0^\infty xn\sigma \exp(-xn\sigma)dx = \frac{1}{n\sigma}$$

Not mention 1/nσ : -1

14. Estimate the kinematic viscosity ($\upsilon = \frac{\mu}{\rho}$) of Ar at 1 Torr and 300K if its diffusivity at 1 atm (760 Torr) and 300K is 0.1 cm^2/s.

$$\mathrm{D} = \frac{<v>\lambda}{3} \quad \underline{+1}$$

$$\mu = \frac{\mathrm{mn}<v>\lambda}{3}$$

$$\upsilon = \frac{\mu}{\rho} = \frac{\mathrm{mn}<v>\lambda}{3} * \frac{\mathrm{RT}}{\mathrm{Pm}} = \frac{<v>\lambda}{3} = \mathrm{D} \sim \frac{1}{\mathrm{P}} \quad \underline{+2}$$

$\mathrm{D}^1(0.1\ \mathrm{cm}^2/\mathrm{s})*\mathrm{P}_1(760\ \mathrm{Tor}) = \mathrm{D}_2*\mathrm{P}_2\ (1\ \mathrm{Torr})$

$\mathbf{D_2 = 76\ cm^2/s}$ $\underline{+2}$

Problem.

(30) 1. A new dopant has been developed and is tested using drive-in diffusion into a silicon wafer. The diffusivity (D) of the dopant in Si is 3 x 10^{-13} cm^2/s. How long does it take for the dopant concentration to reach 1% of the surface concentration at a depth of 1 micron below the surface?

Recall that for drive-in diffusion, the concentration profile at depth z and time t, is given by,

$$C(z,t) = \frac{Q_T}{\sqrt{\pi D t}} \exp\left(-\frac{z^2}{4Dt}\right)$$

<sol>

$$\mathrm{Cs} = \frac{\mathrm{QT}}{\sqrt{\pi \mathrm{Dt}}}$$

$$\mathrm{C} = \mathrm{C}\ (0.0001\ \mathrm{cm}, \mathrm{t}) = \frac{\mathrm{QT}}{\sqrt{\pi \mathrm{Dt}}} \exp\left(-\frac{10^{-8}}{4*3*10^{-13}*\mathrm{t}}\right) = 0.01\ \mathrm{Cs}$$

Misusing QT: -2

Take Eqn. 1 into Eqn. 2

t = 1809 sec **Wrong unit conversion or answer with correct step: -5**