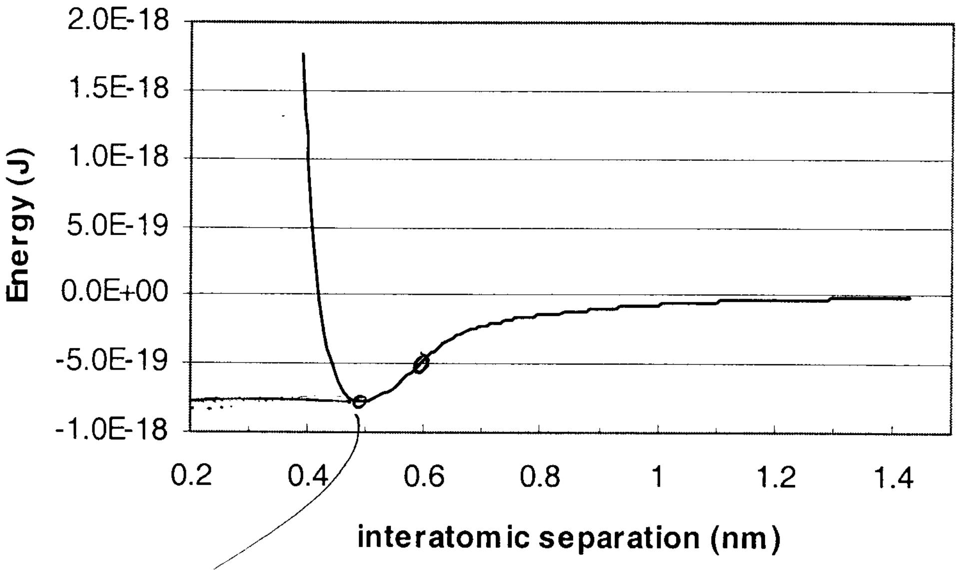
Spring 2001

Name: ______________________

ENGR 240 Science of Materials – Exam 1

Point values are in brackets. 100 points total.

1. Shown below is an interatomic energy vs. separation curve for two atoms.



a. Determine as precisely as possible (let's say two significant figures), the bond energy in kJ/(mole of bonds). [4]

$$\rightarrow E_0 \approx 0.75 \times 10^{-18}\ J \left(\frac{kJ}{1000\,J}\right)\left(\frac{6.02 \times 10^{23}}{mol}\right) = \boxed{450\ kJ/mol}$$

b. Determine, again to two significant figures, the separation distance (nm) at which the net interatomic force (F) is at a maximum (highest attractive force). [2]

$$F = \frac{dE}{dr}$$

highest net F is where slope of curve (above) is highest

$$\boxed{@ \approx 0.60\ nm}$$

2. The following statements describe a material property or characteristic, and two separate cases, 1 and 2. For each statement, indicate whether the material property or characteristic is higher in case 1, higher in case 2, or the same in both cases. Then provide a brief written explanation for your answer. [15 points total – 3 points each]

   a. Melting temperature of:

      i. bromine (Br_2)
      [✓ ii.] PET plastic (a polymer composed of C, H, and O)

      Br_2 : small covalent molecule

      polymer : very large covalent molecule ← more secondary (van der Waals) bonding between molecules

   b. Steady-state diffusion flux of helium through a thin copper sheet exhibiting:

      i. a coarse (large) grain structure
      [✓ ii.] a very fine (small) grain structure

      Small grains = more grain boundaries which are fast diffusion pathways

   c. In an alloy containing 50 wt% magnesium (Mg) and 50 wt% vanadium (V), the:

      [✓ i.] atom% Mg
      ii. atom% V

      In 100 g of mix :

      $$50\text{ g Mg}\left(\frac{\text{mol}}{24.3\text{ g}}\right) = 2.1\text{ mol Mg}$$ ← MORE ATOMS!

      $$50\text{ g V}\left(\frac{\text{mol}}{50.9\text{ g}}\right) = 0.98\text{ mol V}$$

   d. Electrical resistance of a cylindrical silver wire:

      i. 10 cm long with a diameter of 0.2 cm
      [✓ ii.] 20 cm long with a diameter of 0.1 cm

      ρ (resistivity is constant)

      $$R = \frac{\rho l}{A}$$

      ↑ wire (ii) has bigger l and smaller A (πr^2) – both lead to bigger R

   e. Bond energy of a:

      [✓ i.] metallic bond
      ii. hydrogen bond

      PRIMARY bond – ~~[illegible]~~ free e⁻ shared by atoms

      Secondary bond : weaker electrostatic interaction between molecules

3. Steady-state diffusion of oxygen through plastic food packaging can lead to food spoilage. The diffusion coefficient for oxygen in low density polyethylene (LDPE) is 1.38 x 10^{-6} cm^2/s at 35 °C, and the activation energy for diffusion in this system is 42,200 J/mol.

   What is the diffusion coefficient for oxygen in LDPE at a refrigerated temperature of 5 °C? [15]

$$D = D_0 \exp\left(\frac{-Q_d}{RT}\right)$$

1: Find constant D_0:

At 35 °C

$$1.36 \times 10^{-6} \frac{cm^2}{s} = D_0 \exp\left(\frac{-42{,}000 \text{ J/mol}}{(8.314 \text{ J/mol}\cdot\text{K})(308 \text{ K})}\right)$$

$$D_0 = 19.5 \text{ cm}^2/\text{s}$$

2: At 5 °C,

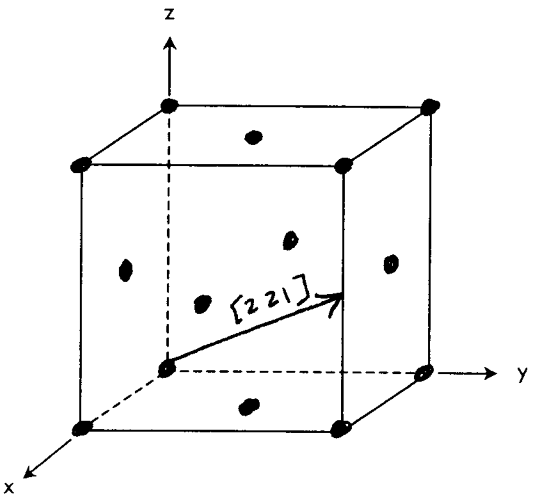
$$D = 19.5 \text{ cm}^2/\text{s} \exp\left(\frac{-42{,}000}{(8.314)(278)}\right)$$

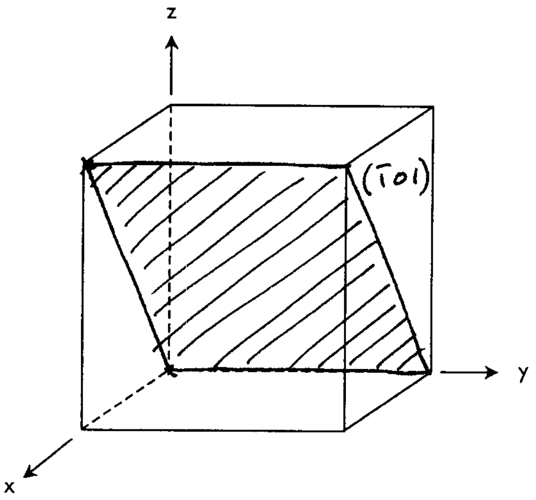
$$= 2.2 \times 10^{-7} \text{ cm}^2/\text{s}$$

4. a. In the unit cell on the left, show the atom positions for the fcc structure. [2]

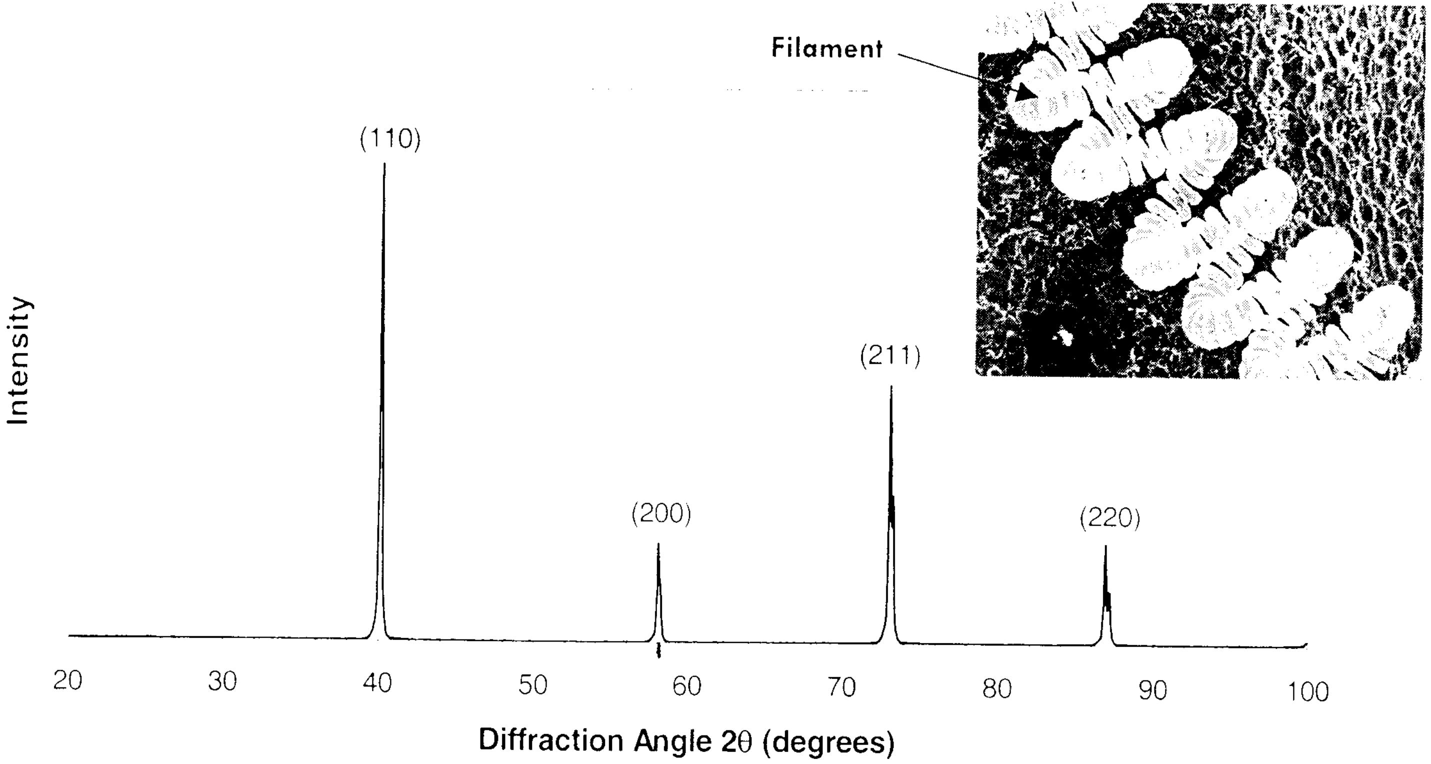
   b. Show the [2 2 1] within the unit cell on the left. [4]

   c. Show the ($\bar{1}$ 0 1) within the unit cell on the right. [4]





5. Light bulb filaments are made from tungsten, a high temperature metal with the bcc crystal structure and an x-ray diffraction pattern shown below. Copper radiation (0.1542 nm wavelength) was used in the x-ray diffraction analysis.



a. Calculate the interplanar spacing (in nanometers) for the (200) in tungsten. [4]

$2\theta = 58^\circ$

$\theta = 29^\circ$

$n\lambda = 2d\sin\theta$

$$d = \frac{n\lambda}{2\sin\theta} = \frac{(1)(0.1542\,\text{nm})}{2\sin\left(\frac{58}{2}\right)} = \underline{\underline{0.159\ \text{nm}}}$$

b. Calculate the lattice parameter a (in nanometers) for the tungsten filament. [4]

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}} \Rightarrow a = d\sqrt{h^2+k^2+l^2}$$

$$= 0.159\,\text{nm}\left(\sqrt{2^2+0^2+0^2}\right) = \underline{\underline{0.318\ \text{nm}}}$$

c. Calculate the atomic radius R (in nanometers) for the tungsten filament. [4]

$a = \frac{4R}{\sqrt{3}}$ FOR bcc

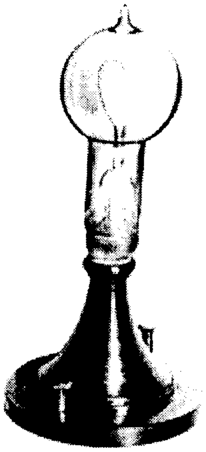
$$R = \frac{a\sqrt{3}}{4} = \frac{0.225\,\text{nm}\sqrt{3}}{4}$$

$a = 4$

$$R = \frac{0.318\overset{\text{nm}}{}\sqrt{3}}{4} = \underline{\underline{0.138\ \text{nm}}}$$

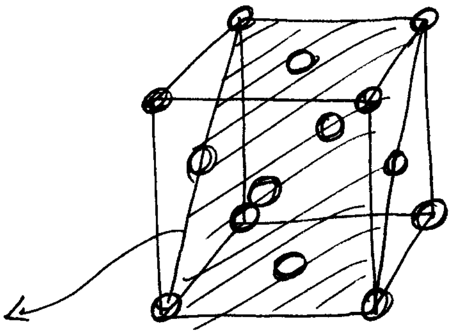
6. Edison's first commercial light bulb, shown below, had a beautiful base made of α-brass. α-brass has the fcc structure, a lattice parameter a of 0.368 nm, and an atomic weight of about 63.8 g/mole.

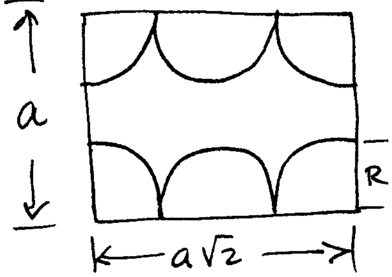
    a. Calculate the planar density of atoms on the (101). [8]
    b. Estimate the density of the brass in g/cm³. [7]



(a.) $PD = \dfrac{A_{atoms}}{A_{plane}}$

$a = 2R\sqrt{2}$





$$PD = \frac{2 \text{ ATOMS} (\pi R^2)}{a(a\sqrt{2})} = \frac{2\pi R^2}{8R^2\sqrt{2}}$$

$$= \frac{2\pi}{8\sqrt{2}} = \underline{\underline{0.555}}$$

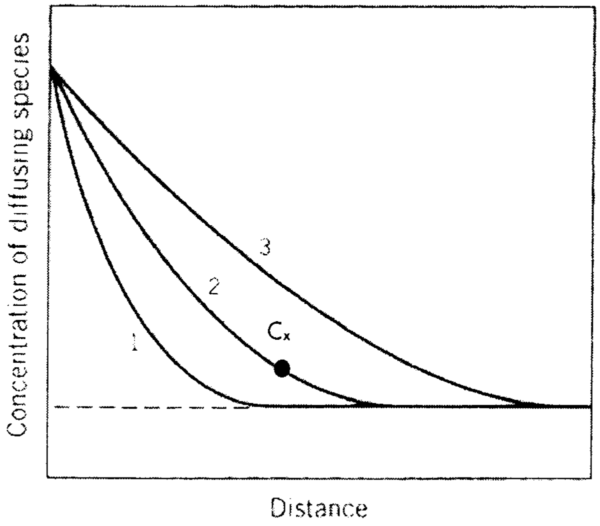
(b) $\rho = \dfrac{nA}{V_c N_A} = \dfrac{nA}{a^3 N_A}$ $n = 4$ ATOMS / CELL

$$= \frac{63.54 \text{ g/mole} \cdot 4}{(0.368\text{nm})^3(6.023\times10^{23}/\text{mole})} = 8.47\times10^{-21} \text{ g/nm}^3$$

$$\rho = 8.47\times10^{-21} \frac{g}{nm^3} \cdot \frac{(10^7 nm)^3}{(1 cm)^3}$$

$$\underline{\underline{\rho = 8.47 \text{ g/cm}^3}}$$

7. The plot below shows the concentration profiles for nonsteady-state diffusion of carbon in iron. Assume Curve 2 is the concentration profile of C in Fe after nonsteady-state diffusion for 1 hour at 700 °C. The left end of each curve indicates the surface concentration of carbon, and the right end of the curves shows the initial concentration of carbon in iron at time = 0.



a. Which curve would best describe the concentration profile of C in Fe after nonsteady-state diffusion for 2 hours at the same temperature (700 °C)? [3]

CURVE 3 . MORE TIME → HIGHER CONCENTRATION FOR ANY DISTANCE OR HIGHER DISTANCE FOR ANY CONC.

b. Consider the concentration C_x on Curve 2. What would happen to the concentration C_x if the diffusion temperature were changed from 700 °C to 600 °C? Assume no other variables are changed. [3]

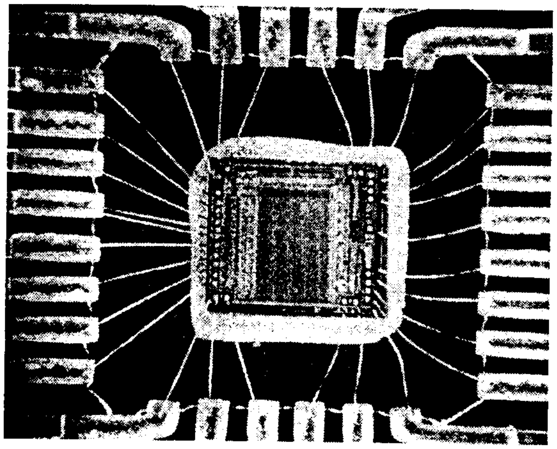
i. Concentration C_x would increase.

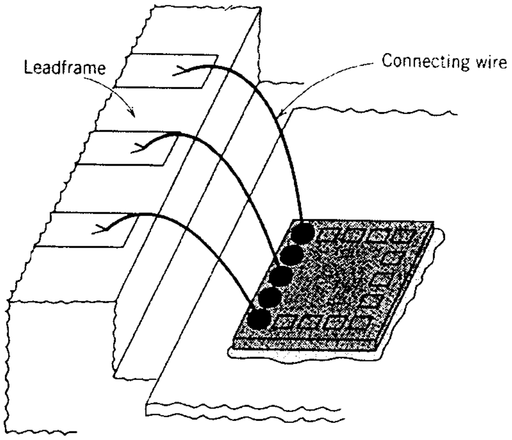
[✓ ii.] Concentration C_x would decrease.

iii. Concentration C_x would remain the same.

iv. Concentration C_x would be equal to the surface concentration.

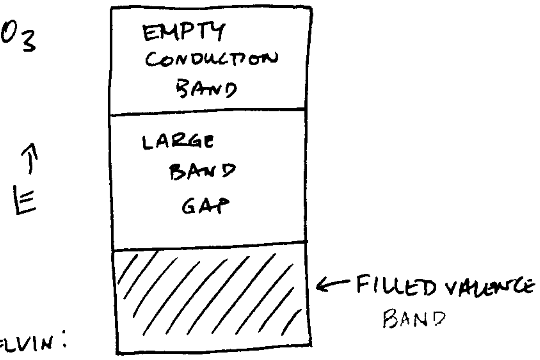
8. An integrated circuit (IC) chip photo and schematic drawing are shown below. In order to connect the chip to the larger leadframe wires of the chip package, small gold ($\sigma = 4.26 \times 10^7\ (\Omega \cdot m)^{-1}$) wires are often used. The chip package is made of aluminum oxide, an insulating ceramic material.





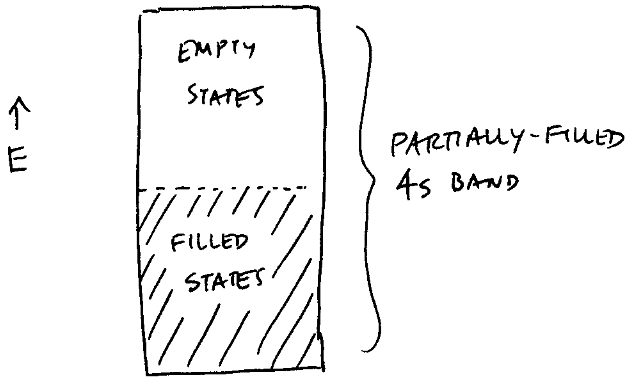
a. Sketch a schematic energy band diagram for (i) the aluminum oxide chip package and (ii) the pure gold connecting wires. Be sure to label all important features of your sketches. Gold (Au) has an electronic configuration of [Xe]$5d^{10}4s^1$. [8]

(i) Al_2O_3



AT 0 KELVIN:

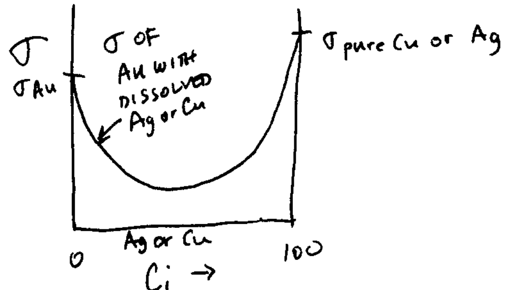
(ii) Au - PARTIALLY-FILLED S BAND



b. Sometimes alloying elements such as silver and copper are added to pure gold to enhance mechanical properties. If all of the alloying elements form a solid solution with the gold, how would addition of the alloying elements affect the conductivity of the gold wires? Briefly explain your answer. [4]

IF Cu & Ag FORM A SOLID SOLUTION WITH Au, RESISTIVITY WILL DECREASE ACCORDING TO: $\rho_i = A c_i(1-c_i)$ DUE TO ADDITIONAL ELECTRON SCATTERING BY THE ATOMS IN SOLID SOLUTION (THE DISSOLVED IMPURITIES).

CONDUCTIVITY = $\frac{1}{\text{RESISTIVITY}}$, SO σ WOULD LOOK LIKE THIS ⟶ AS A FUNCTION OF IMPURITY CONCENTRATION.



9. What effect does adding a small amount of a Group VA element to pure silicon have on the electrical conductivity of silicon? [3]

   a. The conductivity of silicon will decrease due to creation of electron donor states.
   [✓ b.] The conductivity of silicon will increase due to creation of electron donor states.
   c. The conductivity of silicon will increase due to creation of electron acceptor states.
   d. The conductivity of silicon will remain the same.

10. The addition of some elements to pure silicon will result in the creation of holes in silicon's valence band. Which of the following statements about holes is FALSE? [3]

   a. Hole creation is due to excitation of valence electrons to acceptor states.
   [✓ b.] Holes act as a point defect and lower the conductivity of the pure silicon.
   c. Holes have a positive charge that is the same in magnitude as electron charge.
   d. Holes will move in an applied electric field.

11. What effect does increasing temperature have on the electrical conductivity of pure silicon? [3]

   a. Temperature has no effect on the conductivity of pure silicon.
   b. Conductivity will decrease due to phonon scattering.
   [✓ c.] Conductivity will increase due to promotion of more electrons to the conduction band.
   d. Conductivity will increase due to ionic conduction.