Homework Set # 6

Assigned Monday, October 12, 2009 **Due Monday, October 26, 2009**

1. CdTe is a semiconductor, with each atom bonding to four neighbors, just like in silicon. In terms of covalent bonding and the positions of Cd and Te in the Periodic Table, explain how this is possible. Would you expect the bonding in CdTe to have more ionic character than that in III-V semiconductors?

2. The density of states in a semiconductor is given by the following relationships:

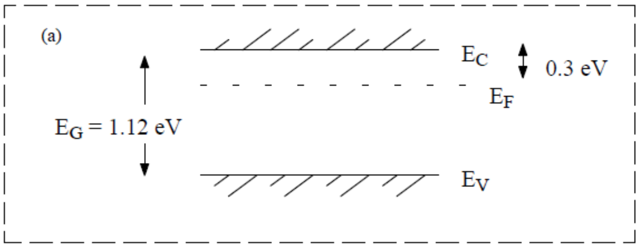
$$g_c(E) = A \exp[-\alpha(E-E_c)] \qquad \text{for } E > E_c$$

$$g_v(E) = (A/2) \exp[-\alpha(E_v-E)] \qquad \text{for } E < E_v$$

where A and α are constants. Assume the semiconductor is lightly doped (i.e. non-degenerate) and is maintained at room temperature (T = 300K) under equilibrium conditions. **(a)** Sketch the electron distribution in the conduction band and the hole distribution in the valence band as functions of energy. **(b)** Derive expressions for n and p, the electron and hole concentrations per unit volume, respectively.

3. The Fermi energy of electrons in copper at room temperature is 7.0 eV. The electron drift mobility in copper, from Hall effect measurements, is 33 $cm^2\ V^{-1}\ s^{-1}$. **(a)** What is the speed v_F of conduction electrons with energies around E_F in copper? By how many times is this larger than the average thermal speed $v_{thermal}$ of electrons, if they behaved like an ideal gas (Maxwell-Boltzmann statistics)? Why is v_F much larger than $v_{thermal}$? **(b)** What is the De Broglie wavelength of these electrons? Will the electrons get diffracted by the lattice planes in copper, given that interplanar separation in Cu = 2.09 Å? (Solution guide: Diffraction of waves occurs when $2d \sin\theta = \lambda$, which is the Bragg condition. Find the relationship between λ and d that results in $\sin\theta > 1$ and hence no diffraction.) **(c)** Calculate the mean free path of electrons at E_F and comment.

4. Consider the energy gap and band edges as shown for Si. **(a)** If $E_C - E_F = 0.3$ eV, determine the probability that an energy state at $E = E_C$ is occupied by an electron, and **(b)** the probability that a state at $E = E_V$ is empty. For the case when the gap energy is 1.43 eV (as in the case of GaAs), repeat the question (a) and (b).



5. Consider what happens when a metal such as Al is bombarded with high energy electrons. The inner atomic energy levels are not distributed in the solid so these inner levels remain as distinct single levels, each one localized to the parent atom. When an energetic electron hits an electron in one of the inner atomic energy levels, it knocks out this electron from the metal leaving behind a vacancy in the inner core as depicted in Figure 1(a). An electron in the energy band of the solid can then fall down to occupy this empty state and emit a photon in the process. The energy difference between the energies in the band and the inner atomic level is in the X-ray range so that the emitted photon is an X-ray photon. Since electrons occupy the band from the bottom, E_B, to the Fermi level, E_F, the emitted X-ray photons have a range of energies corresponding to transitions from E_B and E_F to the inner atomic level. These energies are in the soft X-ray spectrum. We assumed that the levels above E_F are almost empty though, undoubtedly, there is no sharp transition from full to empty levels at E_F. Further, since the density of states increases from E_B towards E_F, there are more and more electrons that can fall down to the atomic level as we move from E_B toward E_F. Therefore, the intensity of the emitted X-ray radiation increases with energy until the energy reaches the Fermi level, beyond which there are only a small number if electrons available for the transit. **(a)** Based on Figure 1 (b), what is the Fermi energy of the electrons in Al? **(b)** Taking the valence of Al to be 3, what is the expected Fermi energy? **(c)** What should be the emission spectrum from a semiconductor?

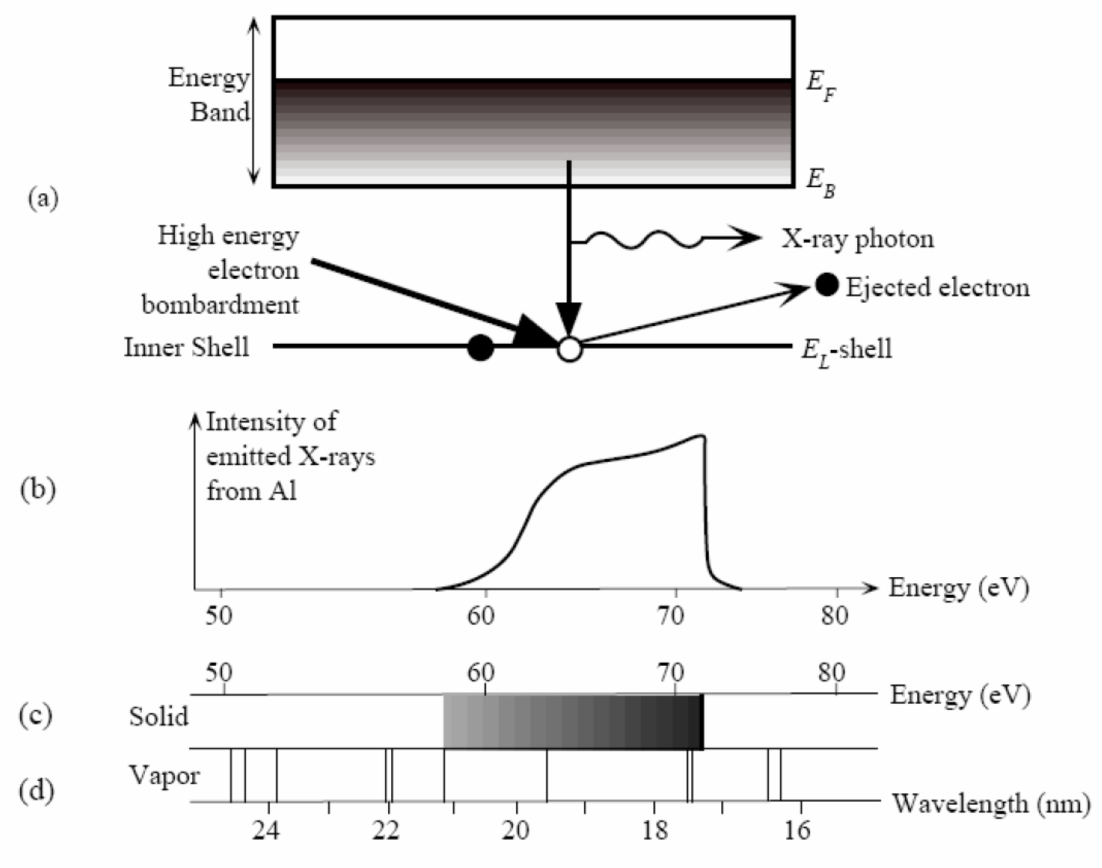

Energy
Band
E_F
E_B
(a)
High energy
electron
bombardment
X-ray photon
Ejected electron
Inner Shell
E_L-shell
Intensity of
emitted X-rays
from Al
(b)
Energy (eV)
50
60
70
80
(c)
Solid
Energy (eV)
(d)
Vapor
Wavelength (nm)
24
22
20
18
16

Fig 1