MATS 251A/MAE 265A: Electronic and Photonic Properties of Materials

FINAL EXAM

Due December 5, 2006 by 5 pm in Room 258, Engineering 2

To note:

(1) Answer all questions
(2) No collaboration of ANY kind is permitted
(3) Any assumptions must be plainly stated
(4) Brief answers are always preferred

1. Explain why electronic conduction occurs at all, considering electron motion in an ambient of large, massive nuclei. (In other words, how do those tiny electrons overcome those large obstacles?)

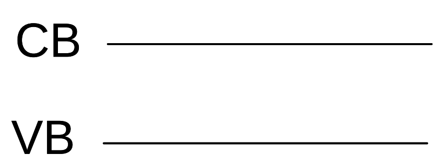
2. Show that the electronic, vibrational, and rotational energies in a solid are approximately in the ratio $\frac{M}{m} : \sqrt{\frac{M}{m}} : 1$, where **M** is the average ionic mass and **m** is the electronic mass. Give approximate values (in eV) of the respective energies for a typical metal.

3. For a one-dimensional Kronig-Penny model (in the limit of P>>1) show that the effective mass of the states at the edge of the first Brillouin zone is equal to $\left| \frac{P}{n^2 \pi^2} \right|$, where n denotes the band number. From this proof, and your understanding, can you explain why the effective mass of carriers in the valence band is larger than the effective mass of carriers in the conduction band?

4. Consider a two-dimensional material composed of chains of Lithium (Atomic number, Z=3) atoms. The inter-atomic distance along the chains (say, ***a***) is smaller than the perpendicular distance (say, ***b***), between the chains. Make a qualitative plot of the density of states (DOS) as a function of energy.

5. Explain how the effective mass of an electron/hole could be negative? Give two instances where the effective mass approximation fails?

6. When we drew “toy” band diagrams for semiconductors in class, we assumed “perfectly pure” materials and “perfectly straight” conduction (CB) and valence (VB) energy *band*s/ levels as below:



(a) Now consider, as is more typically the case, an inhomogeneous distribution of impurities (both neutral and charged) in the material. Draw, how the CB and the VB would be modified?

(b) Draw the Density of States (DOS) vs. Energy (E) distribution for both the pure material and the material containing the impurities. Can you discuss the implications of this diagram for amorphous silicon and devices based on it?

7. Consider a junction of p- and n-type semiconductors fabricated by overlaying, say p-GaAs film on top of a n-GaAs substrate (this arrangement is typically referred to as a p-n junction and is the basis for transistors, lasers, light emitting diodes etc.) Analyze this junction (when an external bias voltage, V, is applied) and derive the drift-diffusion equation: $\mu = \frac{eD}{k_B T}$, where μ is the carrier mobility, D; the diffusion coefficient, k_B is the Boltzmann constant and T is the temperature.

Hint: You should look at both the diffusion and drift of the carriers (e.g., there is a diffusion of electrons from the n-region to the p-region, while there is a *reverse* drift, due to the *resultant* electric field from the p- to the n-region. The following equations hold for the diffusion flux (J_D) = -D$\frac{\partial C_i}{\partial x}$, where C_i refers to the carrier concentration & $C_i = C_o$ $\mathbf{exp}(-\frac{E}{k_B T})$.

8. Is the electron-phonon coupling larger in Sodium (Na) or Lead (Pb)? Why? Illustrate how the electron-phonon coupling could be invoked to distinguish conducting and insulating poly-acetylene?

9. Consider a GaAs /$Al_{0.3}Ga_{0.7}As$ superlattice composed of 50 periods (each period consists of a layer of GaAs of thickness 10 nm and $Al_{0.3}Ga_{0.7}As$ of thickness 10 nm).
Assume the following constants: GaAs: E_g ~ 1.4 eV, electron affinity ~ 4.1 eV
$Al_{0.3}Ga_{0.7}As$: E_g: 1.8 eV, electron affinity ~ 3.7 eV

(a) Draw the electronic band structure of the superlattice and indicate all the possible optical transitions. What is the purpose, from a photonics point of view, of such a structure (what devices could this structure be used in?)
(b) It is generally seen that the luminescence from a lower-dimensional structure (say in the superlattice structure, above) is more intense than a bulk solid. Why?
(c) Compare the absorption *vs*. energy spectra of the superlattice structure with bulk GaAs. (Plot both the absorption-energy curves on the same graph). How does the absorption spectra change as the thickness of the $Al_{0.3}Ga_{0.7}As$ is gradually reduced from 10 nm to 0 nm?
(d) It is generally found that there is a decrease in absorption (α) for photon energies slightly above the bandgap when the semiconductors are heavily doped. Can you explain why?

10.
(a) Draw the band structure of NaCl (E_g ~ 8.8 eV). Would you expect NaF to have a larger/smaller band gap. Why? What can you say about the bandgap of NaBr?
(b) Can stoichiometric NaCl be used as an electrolyte? Why / Why not?
(c) A sample of NaCl appears yellowish brown when seen under visible radiation. What can be said about the purity of the sample? What is the origin of the coloration?
(d) Estimate the concentration of ionic vacancies in $Fe_{0.9}O$.
(e) It is seen that the when $CdBr_2$ is added as a dopant to AgBr the conductivity at first decreases, passes through a minimum, and then increases. Explain this behavior.