FYS3410 Spring 2016

Module IV

Practical assignments:

1. Metals are characterized with a partially filled upper band that is called the conduction band. In contrast, an insulator has an empty conduction band and a completely filled valance band. To classify a solid to be a metal or an insulator, one should (i) correlate the number of orbitals in a band with the number of electrons available to fill the orbitals and (ii) account for possible band overlap(s).
   (a) Consider 1D crystals having a lattice constant *a* and composed of either mono- or divalent atoms. Classify these crystals as metals or insulators.
   (b) Consider 3D crystals (e.g. in form of a simple cubic lattice) composed of either mono- or divalent atoms. Would the classification made in 1D always hold for 3D crystals? Motivate your answer.

2. Introduce the idea of using "effective mass" by comparing the dispersion relations for FEFG and an arbitrary $E(k)$ as expanded in Taylor series in the vicinity of minima/maxima points. Plot such $E(k)$, its first and second derivatives, as well as the effective mass as a function of k within the the 1^{st} Brillouin zone (BZ) for a 1D crystal.
   (a) Why the effective mass is different from that of the electron rest mass?
   (b) Can the effective mass be negative? What does it mean? Introduce the concept of holes.
   (c) Assume the energy of electrons in the vicinity of the conduction band edge to be $E(k)=Ak^2$, with A=5e-37 $J{\cdot}m^2$. Compute the effective mass of electrons at the conduction band edge.

3. GaAs is a semiconductor with a direct band gap of ~1.42 eV at room temperature. The experimental values for the effective masses (in unit of the free electron mass) are: 0.067, 0.082, and 0.45 for electrons in the conduction band as well as light and heavy holes at the top of the valence bands, respectively. Compute the corresponding energy dispersion relations and sketch the band structure of GaAs in the vicinity of Γ point. What is the origin to have "light" and "heavy" holes?

4. Consider P donors in Si in terms of hydrogen-like model in the effective mass approximation.

(a) Calculate the value of the ionization level for electrons to be excited to the conduction band;
(b) calculate the Borh orbit for these electrons and estimate the doping concentration to transform localized states into an impurity band.

5. Consider the carrier concentration evolution as a function of temperature in 10^{17} P/cm^3 homogeneously doped Si. Choose several characteristic temperature limits, specifically low, intermediate, and high – corresponding to the donor freezing out, full donor activation, and overtaking by intrinsic carriers, respectively. For these limits, compute
(a) the equilibrium concentration for electrons and holes;
(b) the E_F position relative to E_i;

Plot the electron concentration and E_F position as a function of temperature (1/T).