Department of Electrical and Computer Engineering, Cornell University

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ECE 5330: Semiconductor Optoelectronics

Fall 2014

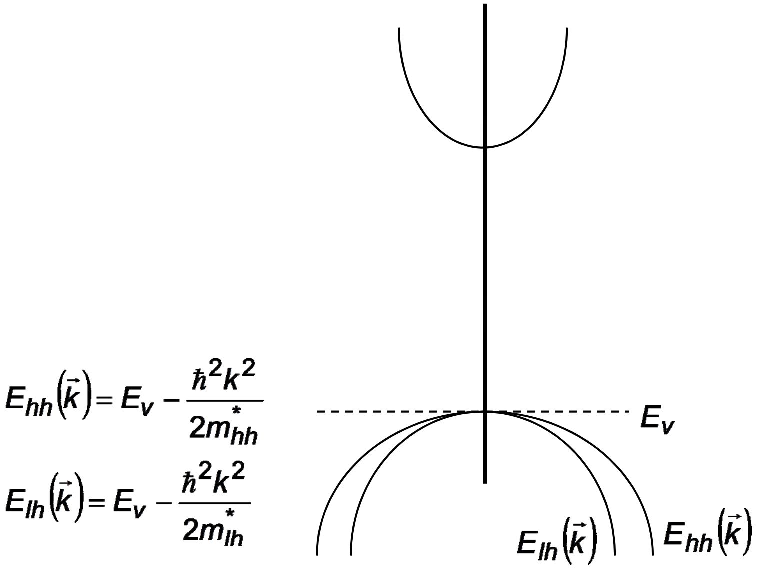
Homework 1 **Due on Sep. 04, 2014 by 5:00 PM**

Suggested Readings:

a) Chapter 2 of "Physics of Optoelectronic Devices" for basic device physics review. Notation used in the book is slightly different than in the lecture notes and their definition of the Fermi function (or Fermi integral) is also slightly different. But it does cover many useful topics.
b) Chapter 3 of "Physics of Optoelectronic Devices" for basic quantum mechanics review. Leave out sections 3.5 and 3.6.
c) You may also want to brush up your basic solid state.

Problem 1.1: (Semiconductor review problem)

GaAs and InP both have two valence bands (the heavy hole band and the light hole band) that are degenerate at the Γ-point. The bands are described by the energy dispersion relations shown in the figure.



a) Find the density of states function for the valence band that would include contributions from both the valence bands. Show that it has the form,

$$g_V(E) = \begin{cases} \dfrac{\sqrt{2}}{\pi}\left(\dfrac{m_{dh}^*}{\hbar^2}\right)^{\frac{3}{2}}\sqrt{E_V - E} & E_V \geq E \\ 0 & E_V \leq E \end{cases}$$

b) What is the hole density of states effective mass m_{dh}^*?

Problem 1.2: (Semiconductor review problem)

The conduction band of a semiconductor is described by the parabolic (but not isotropic) dispersion relation,

$$E(\vec{k}) = E_c + \frac{\hbar^2}{2}\,\vec{k} \bullet M_e^{-1} \bullet \vec{k}$$

The effective mass matrix is,

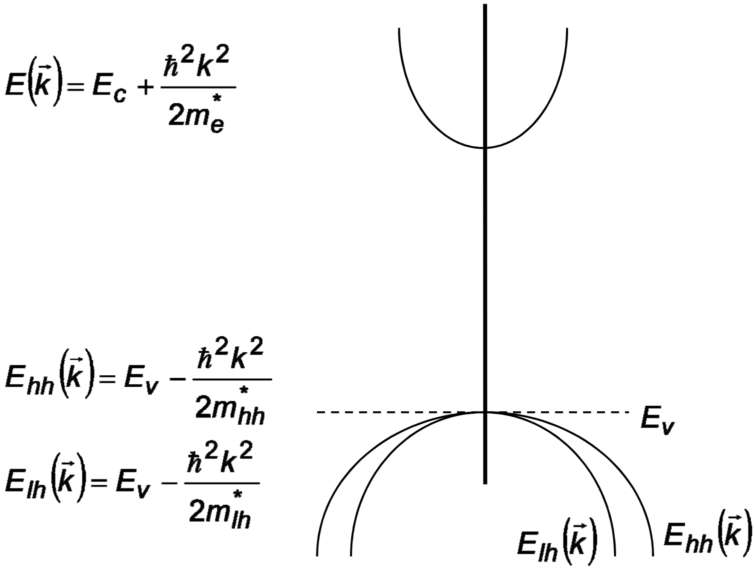
$$M_e = \begin{bmatrix} 0.3750 & 0.0217 & 0.0375 \\ 0.0217 & 0.2313 & 0.0541 \\ 0.0375 & 0.0541 & 0.2938 \end{bmatrix} m_o$$

where m_o is the free space electron mass.

a) Find the density of states function $g_c(E)$ for the conduction band.

Problem 1.3: (Semiconductor review problem)

Consider a n-doped GaAs crystal with the bandstructure shown in the figure below.



For part (a), use the following parameter values:

$E_g = 1.42\text{ eV}$ $\quad$ $N_d = 0$

$m_e^* = .067\, m_o$

$m_{hh}^* = 0.5\, m_o$

$m_{lh}^* = 0.08\, m_o$

a) Calculate the intrinsic carrier concentration n_i for GaAs at room temperature (300K).

For the following parts assume:

$N_d = 10^{17}\text{cm}^{-3}$

$E_c - E_d = 10\text{ meV}$ (typically Si or Sn atoms are used to n - dope GaAs and InP)

b) Where exactly is the Fermi level position (in energy) at $T = 0\text{K}$?

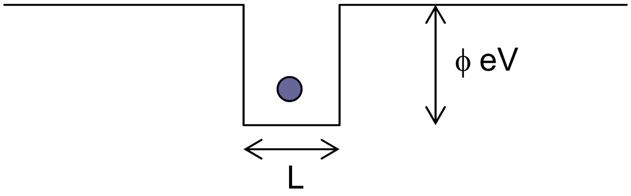
c) What happens to the Fermi level position as $T \to \infty$?

d) At what doping density N_d does the Fermi level go above the conduction band edge. Assume $T = 300\text{K}$.

Hint: You will have to use Fermi statistics. Maxwell-Boltzman statistics do not apply when the Fermi level approaches the conduction band edge. You will need to calculate the Fermi function (or the Fermi integral) $F_{1/2}(x)$ numerically.

Problem 1.4: (Quantum mechanics review problem)

You might want to consult your favorite undergraduate quantum mechanics book for this problem. It's a 1-D particle in a finite potential well problem. Consider an electron (of mass 0.1 m_o) confined in a potential well of depth ϕ eV. The width of the potential well is L.



a) Find the condition (that ϕ and L must satisfy) so that the well supports **only** a single confined energy state.

b) Find the condition that the well supports **only** two confined energy states.

c) If ϕ=100 meV, and L=10 nm, find the energies (in eV) of all the confined states and sketch their wavefunctions (sketch - not plot).