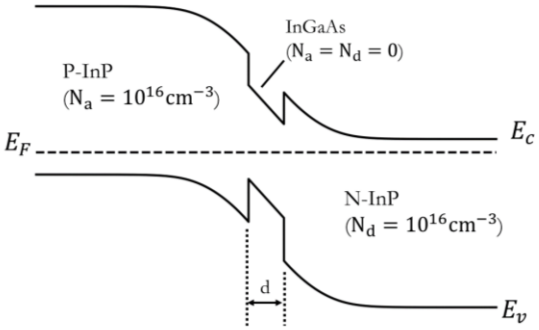
Homework #2
EE 232 – Lightwave devices (Spring 2019)

DUE: 2/21/2019 (Please hand-in homework prior to the beginning of lecture)

(1) Consider a double heterostructure device consisting of low-bandgap InGaAs sandwiched by high-bandgap InP. The InGaAs layer is d = 100 nm thick and is undoped (N_a=N_d=0). The InP layers are doped P-type ($N_a = 10^{16}$ cm^{-3}) and doped N-type ($N_d = 10^{16}$ cm^{-3}). In this problem, we would like to determine how to draw the equilibrium band diagram of this device.



a. Show that the drop in the electric potential across the undoped InGaAs is given by $\Delta\varphi = qN_a x_p d/\varepsilon$ where ε is the DC dielectric permittivity of InGaAs.
Hint: There is a charge $qN_a x_p = qN_d x_n$ on either side of the (essentially) insulating InGaAs layer. What does this resemble? This derivation only requires 1-2 lines of math.

b. Given the results in part a, write down the electric potential (φ) in all layers of the double heterostructure device. To start, set the potential equal to zero in the P-InP, far away from the junction.
Hint: You do not need to do any calculation. You can use the results derived in class for the p-N heterojunction along with the results from part a. Recognize that the depletion region in the P-type InP will be offset to the "left" by d/2 and the depletion region of the N-type InP will be offset to the "right" by d/2.

c. Write an expression for x_n and for x_p in terms of x_w and d where x_w is the total depletion width including the InGaAs thickness.

d. Show that the total depletion width is given by

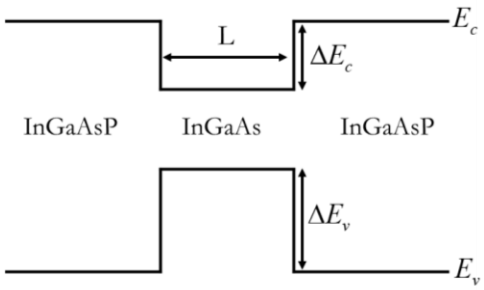
$$x_w = \sqrt{d^2 + \frac{4\epsilon V_0}{qN_d}}$$

Hint: Start by writing an expression for the built-in voltage V_0 as a function of x_n, x_p, and d. Recall that N_a=N_d, therefore x_p=x_n; this will simplify the algebra.

e. Derive an expression for V_0 as a function of known parameters (e.g. bandgap energy and dopant density).
Hint: Start by recognizing qV_0 is equal to the difference of the Fermi level on the N-side and P-side prior to the formation of the junction. The expression for V_0 will be slightly different than what was derived in class for the p-N junction.

f. Using the results from a-e, plot the band diagram of the double heterostructure (E_c, E_v, and E_f) with the plotting software of your choice. Your result should look like the diagram above. Assume the following: DC dielectric permittivity for both materials is $12.7\varepsilon_0$, InP bandgap is 1.344eV, InGaAs bandgap is 0.75eV, the effective density of states for InP is $5.66\times10^{17}cm^{-3}$ and $1.03\times10^{19}cm^{-3}$ for the conduction and valence band respectively. The conduction band offset is $\Delta E_c=0.4\Delta E_g$

(2) Consider the quantum well structure formed by InGaAsP and InGaAs. The InGaAsP bandgap is 1.0eV and the InGaAs bandgap is 0.75eV. We would like to design this quantum well to work in the C-band telecommunications window that is centered at $\lambda=1.55\mu m$ (E=0.8eV). The electron effective mass for InGaAs is $m_e^*=0.04m_0$ and InGaAsP is $m_e^*=0.06m_0$. The heavy hole mass is $m_e^*=0.5m_0$ for both materials. The conduction band offset is $\Delta Ec=0.4\Delta Eg$.



a. Using the finite barrier model, find the width (L) of the quantum well that results in an energy separation of 0.8eV between the first electron and heavy hole subbands. In other words, find L such that $E_{e1} + E_{hh1} = 0.05$ eV. You may find the solution by solving graphically using plotting software. An answer within 10% of the correct answer is suitable.
b. Using the quantum well width determined in part a, calculate $E_{e1} + E_{hh1}$ assuming an infinite barrier potential. Is the infinite well model appropriate for this materials system?