MIT6.772/SMA5111 COMPOUND SEMICONDUCTOR DEVICES

Problem Set No. 2

Issued: March 4, 2003   **Due:** March 11, 2003

NOTE: You should use parameter values from the list of materials properties at the end of this problem set.

Problem 1 -Imagine that you can produce quantum structures with dimensional control of plus or minus one monolayer, or approximately ± 0.25 nm. Calculate the energy above the conduction band edge of the lowest quantum number state in the following structures:

   (a) A quantum well that is 5 nm ± 0.25 nm wide.

   (b) A quantum wire that is 5 nm ± 0.25 nm on a side.

   (c) A quantum box that is 5 nm ± 0.25 nm by 5 nm ± 0.25 nm by 5 nm ± 0.25 nm.

   (d) A quantum wire sized so that the $n = 1$ energy level is the same as that of the quantum well in (a). Also give the dimensions of this quantum wire.

   (e) A quantum box sized so that the $n = 1$ energy level is the same as that of the quantum well in (a). Also give the dimensions of this quantum box.

Assume that the structures are made of GaAs ($m^* = 0.07\ m_o$) and that the barrier height is infinite. State both the nominal value of the energy level, and its possible range of values in light of the dimensional uncertainty.

Problem 2 -Both parts of this problem involve heterojuctions. Part (a) involves a P-n junction, Part (b) an N-p junction:

(a) Sketch and dimension the band diagram through a P-n heterojunction with $N_{AP} = 5 \times 10^{17}$ cm^{-3} and $N_{Dn} = 10^{17}$ cm^{-3}.

(b) Consider at an N-p heterojunction with $N_{DN} = 2 \times 10^{17}$ cm^{-3} and $N_{Ap} = 6 \times 10^{17}$ cm^{-3}.

      (i) How much does the conduction band spike extend above the conduction band edge in the quasineutral region on the p-side (i.e., where $x > x_p$)?

      (ii) How large a reverse bias must be applied to this junction to move the spike below the conduction band edge in the quasineutral region on the p-side?

(iii)   Grade the interface on the N-side over the minimum width needed to eliminate the spike in the conduction band. Over what distance do you have to grade the composition? Let the grading go from E_{gN} to E_{gp}.

Problem 3 -
(a) How large can the sheet electron density be in a 4 nm wide GaAs ($m^* = 0.07m_o$) quantum well be before the $n = 2$ level becomes occupied? (That is, how many states per unit area are there in the $n = 1$ level between $E = E_1$ and $E = E_2$?) Assume absolute zero temperature (i.e., $T = 0$ K) and an infinitely deep well.

(b) Repeat part (a) but this time find out how large the sheet density can be before the $n = 3$ level becomes occupied.

(c) Repeat part (a) but this time for the heavy holes, $m^* = 0.5\ m_o$.

Problem 4 -Suppose one wants to grow GaAs epitaxially at a rate of $1\mu m/hr$ on a 100-oriented substrate.

(a) At what rate must gallium atoms be supplied to the surface?

(b) How long does it take to deposit one monolayer of GaAs on the surface? Define a monolayer as one full layer of gallium atoms and one of arsenic. One can argue about this definition but use it for this problem.)

(c) Assuming that the gallium atoms on the surface have an RMS thermal velocity in the plane of the substrate corresponding to a kinetic energy of kT/2. What is this velocity and what is the average distance a gallium atom with this velocity be able to move on the surface before the gallium layer was be complete and it would be covered by an arsenic layer (and incorporated into the lattice)? Solve the problem for both 800 K and 300 K.

NOTE: In Problems 1 thru 3 concerning heterostructures, use the following parameters values for the two semiconductors:

	Wider bandgap ($Al_{0.4}Ga_{0.6}As$)	Narrower bandgap (GaAs)
Electron Affinity (eV)	3.63	4.07
Energy gap (eV)	1.92	1.42
Conduction band density of states, N_C (cm^{-3})	5.0×10^{17}	4.7×10^{17}
Valence band density of states, N_V (cm^{-3})	8.0×10^{18}	7.0×10^{18}
Relative dielectric constant, ε_r	11.6	12.9