Solid State Devices I - Purdue ECE-606

Homework No. 4

Student name: ______________________

Student ID: ______________________

I solved the homework assignment myself without copying a solution from someone else or from the web. Student Initials here: _______

Problem 3. [34 points total]

This question makes use of the Band Structure Lab. It is designed to give you more practice with band structure concepts.

Launch Band Structure Lab: Choose Si as the material. As you did in HW #3, simulate the band structure of bulk Si.

a) From the plot measure the band gap and record your answer for Bulk Silicon. (2 points)

b) Clear out your previous results before you start the next calculation. Now perform a similar calculation, but instead of bulk choose the structure as rectangular nanowire. Under the dimensions tab, set the height and width to be 3nm. Choose Option "Both Bands" to enable the computation of conduction and valence bands to display on the plot.

   Obtain the band gap from the plot and note it down - Also copy in the bandstructure picture into your answer. (4 points)

c) Repeat the above sub question but with the dimensions now set to 4nm. Also copy in the bandstructure picture into your answer. What difference do you observe in the band gap? (6 points)

d) Give a physical argument as to why the band gap changes when the dimensions of the wire is altered. (4 points)

e) What physical parameters would you expect to change from the values you computed for the bulk material and why? List at least three of them. (6 points)

f) Can you reconcile your answers with simple expressions for energy states for particle in a box that you have learnt earlier? (4 points)

g) Repeat the calculation for a 3nm square nanowire but choose the wire orientation in [111] and the lateral confinement orientation as [1 -1 0]. Compare the two different 3nm bandstructures. Interpret the results and speculate on consequences for electron transport in the two crystal directions. (8 points)

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Problem 2. (20 points total)

Determine the equilibrium electron and hole concentrations inside a uniformly doped sample of Si under the following conditions:

(a) T=300 K, $N_A \ll N_D$, $N_D=10^{14}$/ cm^3.

(b) T=300 K, $N_A = 10^{15}$/ cm^3, $N_D \ll N_A$.

(c) T=300 K, $N_A = 9\times10^{15}$/ cm^3, $N_D = 10^{16}$/ cm^3.

(d) T=470 K, $N_A = 0$, $N_D = 10^{14}$/cm^3.

(e) T=645 K, $N_A = 0$, $N_D = 10^{14}$/ cm^3.

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Problem 3 - (25 points total).

(a) A set of five Si samples with decade values of donor doping ranging from $10^{13}/cm^3$ to $10^{17}/cm^3$ are maintained at T=545 K. In all cases, $N_D \gg N_A$. What are the electron and hole concentrations inside the five Si samples?

(b) Determine the position of E_i, compute $E_F - E_i$, and draw a carefully dimensioned energy band diagram for each of the Si samples.

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Problem 4 - (25 points total).

Below shows the structure of a heterojunction bipolar transistor (https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200912le1.html). Use the information provided in the table to draw the band diagram along the red line from InGaAs cap to InGaAs/InP subcollector. Show Fermi level, valence band, conduction band, vacuum level, and any junction discontinuity. Assume T=300K, and that the intrinsic Fermi level of all material is at the midgap.

Layer	**Bandgap (eV)**	**Electron affinity (eV)**	**$\lvert E_{Fermi}-E_i \rvert$ (eV)**	**Doping (cm^{-3})**
InGaAs cap	0.78	4.50	0	0
n-InP emitter	1.34	4.38	0.6	1.5E17
p-InGaAs base	0.78	4.50	0.47	5E19
InGaAs collector	0.78	4.50	0	0
InGaAs/InP subcollector	1.10	4.45	0	0