Name **PUID.**

EE 606: Solid State Devices … Exam No. 1

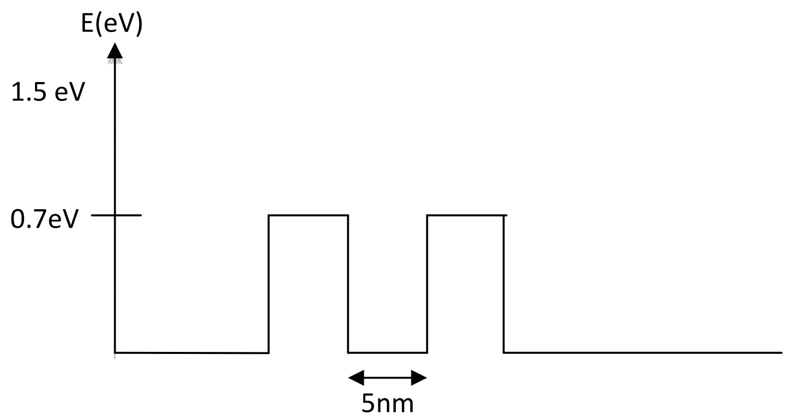
Instructions: Open Text and Notes. Be sure that there are 5 pages in total. Show all your work and write neatly, this exam is worth 100 points. You have 70 minutes to complete the exam.

Problem 1 (37 points)

This question deals with quantum mechanics.

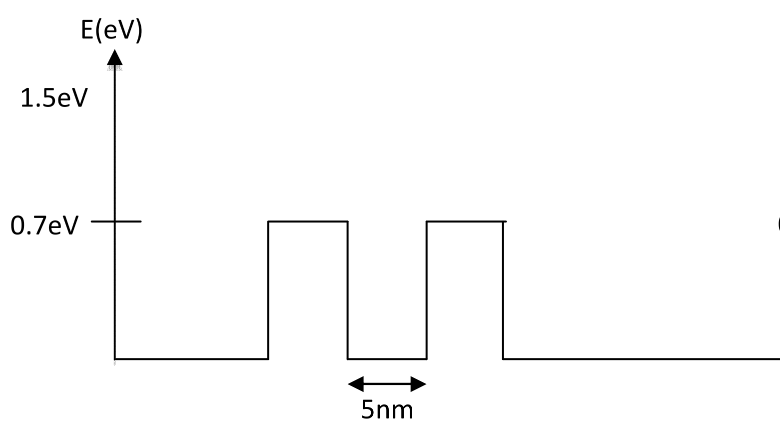
A. Compute the lowest three eigenenergies in units of eV for a particle in an infinite potential well, where the well width is 5nm. Assume the effective mass of the particle to be $0.1m_0$. (**5 points**)

B. Consider a double barrier structure as follows,

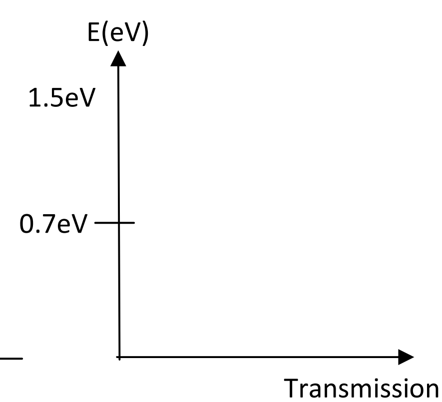


Sketch the eigenenergies levels of this structure (using solid line) and that of part A (using dashed line). Explain the relative position of the new energies compared to the ones computed in part A). (**7 points**)

C. Sketch the transmission through the quantum structure in B as a function of energy. Clearly identify the key features. Indicate the resonance energies as a function of energy and occurrence. (**5 points**)

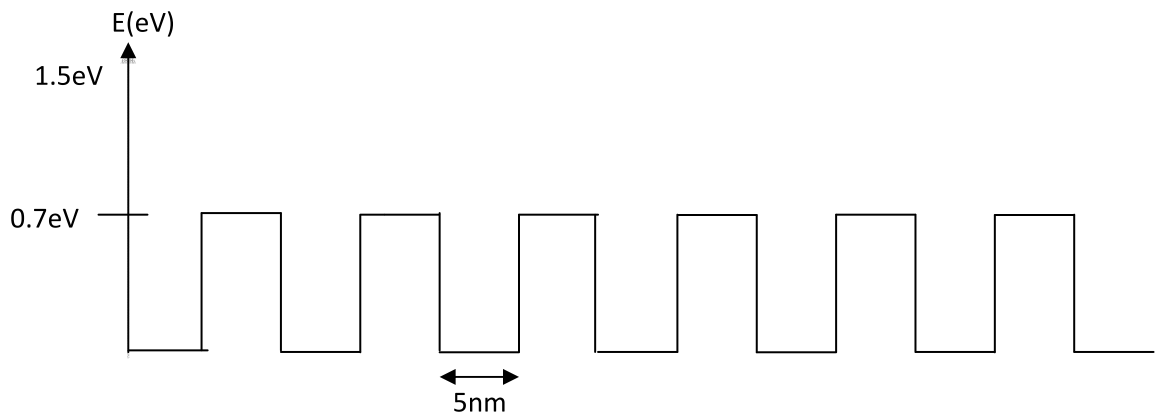


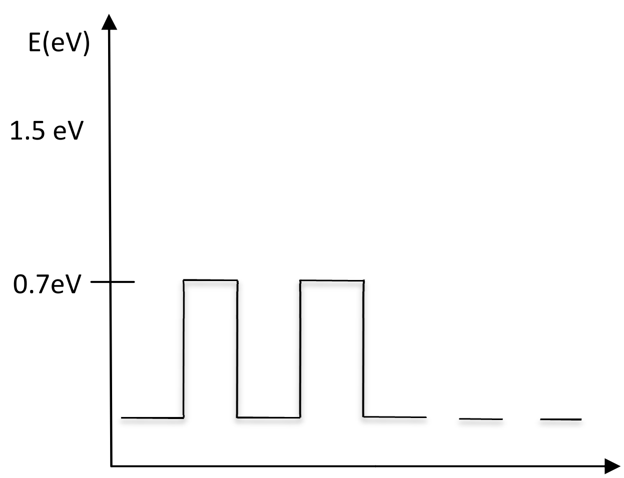
Sketch your answer for part B
on the figure above

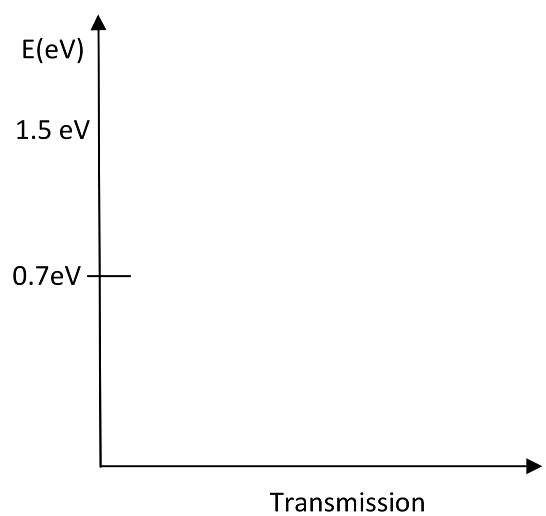


Sketch your answer for part C
on empty graph above

D. Consider now a similar quantum structure like B, but now with 6 barriers instead. How many resonance energies are we expecting to get in this case? Sketch also its transmission as a function of energy. Transmission is along x-axis. (**10 points**)







E. Explain how the structure in D would change as one make a Kronig Penney model out of these series of quantum well. (**5 points**)

F. Explain how would the bandstructure in a Kronig Penney model change if the barrier were made thicker? (**5 points**)

Problem 2 (15 points)

Si is n-doped with N_D=1x10^{17} cm^{-3} of Phosphorus. Assume T=300K and bandgap 1.12eV

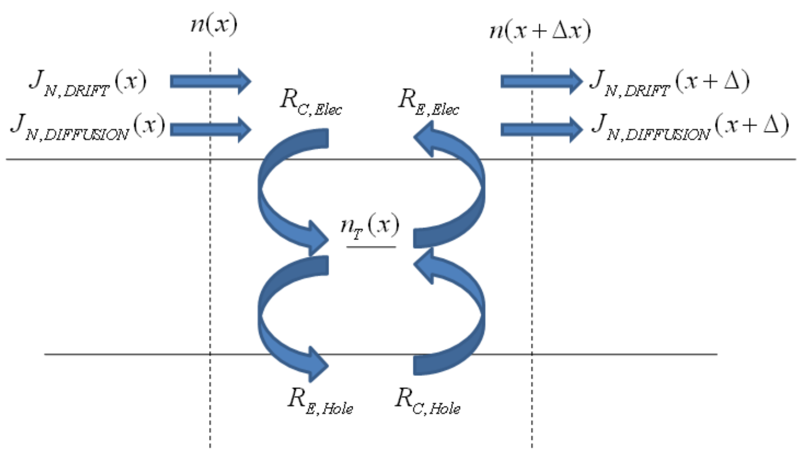
A. Compute the equilibrium electron and hole density assuming complete ionization and non-degenerate carrier statistics. (**5 points**)

B. You were tasked to performed an experiment to measure the majority carrier density n, briefly describes this experiment (**5 points**)

C. You found experimentally that the electron carrier density was only 95.8% of N_D, suggesting incomplete ionization. Determine the donor energy level assuming standard value for the degeneracy factor (**5 points**)

Problem 3 (13 points)

Consider the physical processes illustrated on the band diagram below, where the subscripts C/E denotes capture and emission respectively.



A. If the sample is in **equilibrium**, circle one choice for each statement below. (**4 points**)

n_T(x) must be 0...	True	False
$R_{C,Hole}$ must be equal $R_{C,Elec}$..............................	True	False
$J_{N,DRIFT}(x) = -J_{N,DIFFUSION}(x)$........................	True	False
$J_{N,DRIFT}(x) = J_{N,DRIFT}(x+\Delta x)$...........................	True	False

B. If the sample is in **non-equilibrium steady state**, write down an equation governing the quantities related to electrons shown in the figure. (**4 points**)

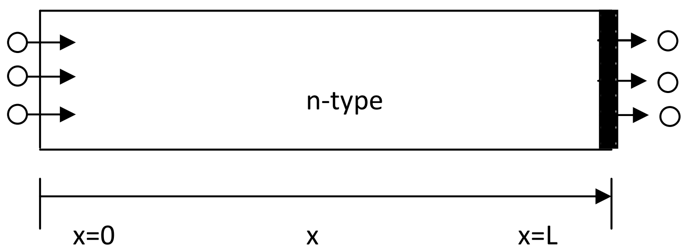
C. Si is unintentionally doped with impurities that creates traps level at (i) E_1 = 0.3eV above mid-gap, (ii) E_2 = 0.3eV below mid-gap and (iii) E_3 = mid-gap level. Compute the ratio of the steady state recombination rate R (E_1)/R (E_3) and R (E_2)/R (E_3) for depletion region. Assume the following:

- Depletion condition
- Trap densities for each energy level are the same
- Electron/hole capture coefficients are the same and the degeneracy factor is one

Which trap level dominates the process?

(**5 points**)

Problem 4 (35 points)



Holes are injected and extracted into an n-doped semiconductor at x=0 as shown in above figure. However, the doping is not perfectly uniform such that there is a small internal electric field E. Assume that the semiconductor is maintained in the dark and with low level recombination and the right end is contacted with a metal.

A. Obtain an expression for the excess hole density Δp in terms of $\Delta p(x=0)$ and at steady state condition. (**15 points**)
   Hint: The solution of a homogeneous differential equation of the following
   $$a\frac{\partial^2 \Delta p}{\partial x^2} + b\frac{\partial \Delta p}{\partial x} + c\Delta p = 0$$
   Can be expressed as
   $$\Delta p(x) = c_1 \exp(r_1 x) + c_2 \exp(r_2 x)$$
   Where r_1 and r_2 are roots to the quadratic equation
   $$ar^2 + br + c = 0$$

B. Assuming that the minority carrier lifetime is τ_p = 100ns and the hole mobility is 400 cm^2/Vs, compute the drift and diffusion current assuming that L=10μm, $\Delta p(0)=1x10^{15}cm^{-3}$ and E=10V/cm at x=0. (**8 points**)

C. Supposed one did the calculation by assuming E=0V/cm. What is the fraction of error introduced in the diffusion current calculation? (**4 points**)

D. Answer the following questions on basic concepts

(i) Hall measurement of carrier density requires high magnetic field so that electron forms cyclotron orbits
True/False (**2 points**)

(ii) Excitons flow does not contribute to a net electrical current
True/False (**2 points**)

(iii) Graphene has six valleys in the first Brillouin zone
True/False (**2 points**)

(iv) Boltzmann Maxwell distribution is a good approximation to Fermi Dirac distribution when the temperature is low
True/False (**2 points**)