Tutorial for Lectures 12-15

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Lecture 12 – Quantum Mechanics I

1. Calculate the energies of the e1→ hh1 and e1→lh1 transitions for a 5nm and 15nm GaAs QW with infinite barriers
2. What thickness of an $In_{0.2}Ga_{0.8}As$ QW with infinite barriers will have a ground state energy matching that of a 10nm wide $In_{0.1}Ga_{0.9}As$ QW? (you may want to create a spreadsheet for this!!)
3. What thickness must an InAs QW with infinite barriers be to match this emission energy? Is this a reasonable number?

GaAs: $E_g = 1.42eV,\ m_e^* = 0.063m_0, m_{hh}^* = 0.51m_0,\ m_{lh}^* = 0.082m_0$

InAs: $E_g = 0.36eV,\ m_e^* = 0.023m_0, m_{hh}^* = 0.41m_0,\ m_{lh}^* = 0.026m_0$

$In_{1-x}Ga_xAs$: $E_g = (0.36 + 0.63x + 0.43x^2)eV$

$$m_e^* = (0.023 + 0.037x + 0.003x^2)m_0$$

$$m_{hh}^* = (0.41 + 0.1x)m_0$$

$$m_{lh}^* = (0.026 + 0.056x)m_0$$

Lecture 13 – Quantum Mechanics II

Go to: http://phet.colorado.edu/en/get-phet/one-at-a-time

"Quantum Tunneling and Wave Packets", PhET Interactive Simulations, University of Colorado Boulder, http://phet.colorado.edu

1. Investigate the potential step using the applet for the three cases of $E < V$, $E = V$, $E > V$. Make sketches of the wavefunctions in all regions for the three cases.
2. Repeat this for a "thick" finite barrier such that the wavefunction does not enter the right hand region.
3. Now make the barrier narrower so that you can tunnel through. Adjust the energy from an initially low level through the entire range and examine closely the transmission and reflection coefficients.
4. Make a double barrier structure where the well is 4x the width of the barriers where the barriers are thin enough to allow tunnelling. Adjust the energy from an initially low level across the entire range and plot the Transmission coefficient vs Energy.
5. Now make the QW 8x the barrier width and repeat.
6. Do you see anything strange?

Lecture 12/13 – Further Problems

1. Review all applications of Schroedinger's equations given in the notes.
2. For an InP/InGaAs quantum well (well width = 10nm and V_{CB} = 0.24 eV, m_e*=0.04m_0, m_h*=0.45m_0, and V_{VB} = 0.36 eV).

a. Calculate the energy of the first electron bound state in the case of an infinite and finite quantum well. <u>(Use the Lecture 13 spreadsheet for the Finite QW)</u>
b. For the same quantum well, using the infinite well approximation, calculate the confinement energy for the first heavy hole state.
c. What is the band-offset for this material system?
d. Why is the band-offset important in engineering a device?
e. Describe how the absorption energy can be calculated from a) and b). What information is missing?

3. Comment on the effect of quantum confinement upon excitonic effects.
4. Discuss the influence of the quantum well width on emission wavelength.
5. Compare qualitatively the difference between quantum confinement in an infinitely deep well and for finite well depth.

Lecture 14 – Optical Transitions and the Density of States

1. Describe, in your own words, using schematic diagrams as necessary;
    a. Absorption
    b. Spontaneous emission
    c. Stimulated emission

2. Define the rates of the transitions above and describe how a change in carrier density can result in optical gain. Define the terms "inversion" and "transparency" in a real material used within a laser.

3. Derive the electronic density of states in three dimensions.

4. At room temperature, a direct band-gap semiconductor has a band-gap of 1.42 eV, and an absorption coefficient of 4×10^6 m^{-1} at 750nm. Stating all assumptions;
    a. Calculate the thickness of semiconductor required to absorb one half of the incident photons at 750nm.
    b. Estimate the absorption coefficient at 650nm
    c. Comment on the effect of increasing temperature on the absorption coefficient at 750nm.
    d. Estimate the effect on the absorption coefficient of replacing the sample with a semiconductor with an effective mass half that of the original.

Lecture 15 – Excitons and Free Carriers

1. Briefly describe, in your own words, what an exciton is. What is the difference between a Wannier-Mott and Frenkel exciton?

2. InP has a relative permittivit ε_r=12.5, effective masses m_e^*= 0.08m_o, m_h^*= 0.6m_o, and a unit cell size of 0.587nm. Calculate;
    a. The exciton Rydberg energy
    b. The exciton Bohr radius

c. The energy difference between the n=1 and n=2 exciton
d. Estimate;
e. The number of unit cells contained within the orbit of the n=1 exciton
f. The temperature range over which you would expect this exciton to be stable
g. The Mott density for excitons in InP

3. Describe in your own words, using figures as necessary, excitonic effects upon the absorption spectrum of a semiconductor.

4. Describe in your own words, using figures as necessary, the effect of an electric field on a bulk semiconductor material.

5. Describe in your own words, using figures as necessary, the reason for an observed shrinkage in the energy gap of a semiconductor under high carrier densities.

Constants you may need -
Rydberg energy of the atom R_H= 13.6 eV
Bohr radius of the hydrogen atom (a_H=5.29 x10^{-11} m)
Boltzman constant =8.617 x10^{-5} eVK^{-1}

Lecture 14/15 – Further Problems

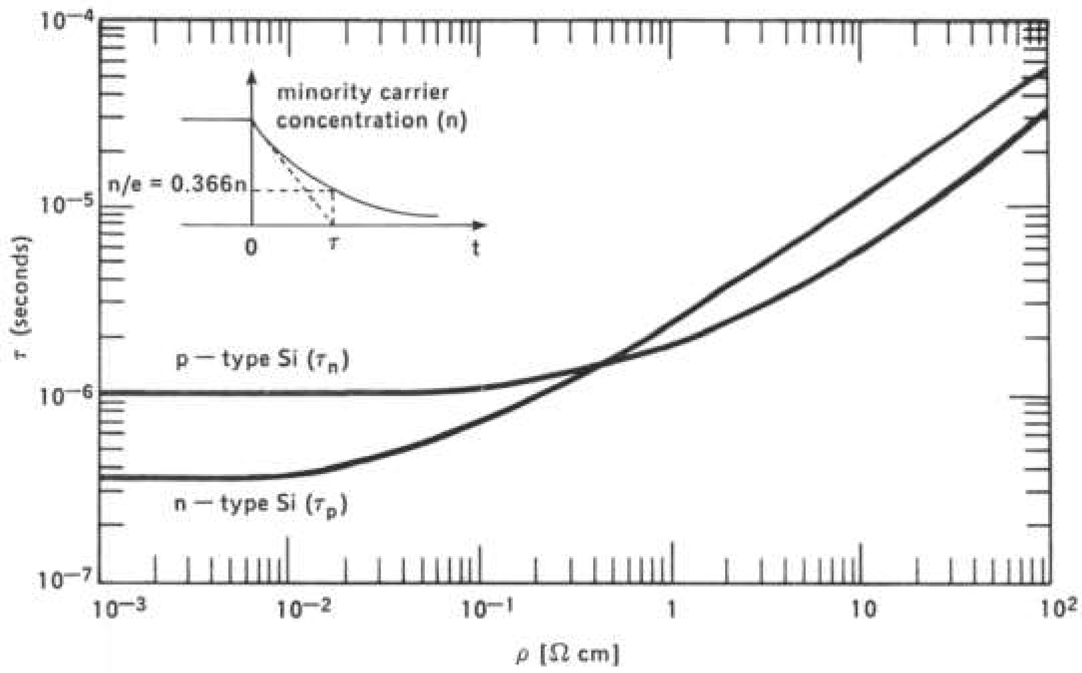
1. Discuss the forms of the densities of states for bulk, thins films, nanowires and quantum dots.
2. How would you define a quantum dot?
3. How would one go about modifying the band-structure of a quantum well laser to enhance gain per unit carrier and reduce threshold current density?

Lecture 16 – LASERs

1. Explain the two basic physical principles every LASER relies on.
2. Why do you need population inversion for stimulated emission?
3. Write down the equations for Stimulated Emission, Spontaneous Emission and Absorption for a two level system stating clearly what all terms in the equation represent.
4. Discuss the influence of the quantum well width on emission wavelength.
5. Compare qualitatively the difference between quantum confinement in an infinitely deep well and for finite well depth.

Lecture 17 – 18 – Conductivity, Conduction and Carrier Lifetime

1. Explain the dependence on the charge carrier density, *n*, of non-radiative and radiative recombination in materials.
2. Write down an equation describing the possible recombination processes in a material as a function of the minority *and* majority carrier densities.
3. In the plot given below, indicate where the purest silicon crystal with the lowest doping is to be found. Explain your answer….



4. A parallel plate capacitor has a spacing 100 µm with air between them. If a dielectric plate of relative permitivity ε_r =10 is placed between the plates what should the new spacing be to leave the capacitance unchanged? For the same capacitor the new dielctric between the plates has a breakdown field of 50 $MVm^{-1.}$ What is the maximum voltage which can be applied across the capacitor?
5. A 2cm long Si rod with cross sectional area of 5mm^2 has a voltage of 10V applied across its length, giving a current of 3 mA. The rod is known to have a uniform density of free electrons and temperature throughout its length. Given that μ=0.12 $m^2V^{-1}s^{-1}$ m^*=0.98m_e
   a. What is the average time between collisions in the material?
   b. What are possible sources of these collisions?
   c. What is the average drift velocity of the electrons in the rod?
   d. What is the concentration of the electrons in the material?
6. Write down the equations for electron (and hole) drift and diffusion currents. Describe in your own words, the role of minority and majority carriers in generating drift and diffusion currents.
7. A semiconductor material with low intrinsic carrier concentration is required for applications in harsh environments (e.g. high temperature). Comment on parameters which will guide you to a suitable material.