

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering
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6.977 Semiconductor Optoelectronics – Fall 2002

Problem Set 7 – Material Properties

Problem #1 *This problem applies the relationship between material parameters.* The Coulomb attraction between an electron and hole can result in the formation of a hydrogenic particle called an exciton. This bound electron-hole pair experiences very fast radiative recombination since there is a large spatial overlap between the electron and hole. This problem explores the materials where exciton effects are important in the performance of a laser.

For a hydrogen atom the binding energy is $E_B = -m_o q^4 / 2\hbar^2 (4\pi\epsilon_o)^2 = -13.6eV$. For excitons this binding energy is modified because the electrons move with an effective mass which is smaller than the free electron mass and also because the Coulomb attraction ($V(r) = q^2 / \epsilon_o r$) between charges is screened by the dielectric constant, ϵ : $V(r) = q^2 / 4\pi\epsilon$. Therefore the exciton binding energy is $E_B = -(m^* / \epsilon^2) m_o q^4 / 2\hbar^2 (4\pi\epsilon_o)^2 = -(m^* / \epsilon^2) \times 13.6eV$.

For example the exciton binding energy in GaAs is approximately $E_B = -(0.067/11^2) \times 13.6eV = 7.5 \text{ meV}$. Since the binding energy is less than kT , excitons are not stable at room temperature.

- Determine the lowest energy bandgap of a semiconductor which has stable excitons at room temperature.
- Calculate the color of the luminescence produced by an exciton in the material of part (a).

Problem #2 *This problem explores the properties of the InGaAsP material system.*

- Determine the compositions of *all* ternary compounds containing In, Ga, As, and P that have bandgaps with transitions at 1.55 μm . What are the lattice constants of these 1.55 μm ternary alloys?
- Determine the composition of an aluminum free alloy grown on GaAs that can be used for Er-doped fiber amplifiers. Er can be excited either at pump energies of 1480 nm or 980 nm. Determine the lattice constant and the strain of the active material.
- Consider the design of a 1.55 μm laser with a bulk active region. Since the active region is bulk there can be no strain between the active material and the substrate. Determine the alloy composition if the active region is grown on InP.
- What is the composition of a separate confinement heterostructure grown around the active region if 100 meV of electron confinement is desired? Assume 70% of the bandgap discontinuity is in the conduction band.

Problem #3 This problem explores the design trade-off often encountered in quantum well materials. The goal of this problem is to determine the longest wavelength active region that can be fabricated in the $\text{In}_{1-x}\text{Ga}_x\text{As}/\text{GaAs}$ material system. Consider $\text{In}_{1-x}\text{Ga}_x\text{As}$ quantum wells of varying In mole fraction and GaAs barriers.

The necessary material parameters are: $a_{\text{GaAs}} = 0.565325$, $a_{\text{InAs}} = 0.60584$,
 $E_g(\text{In}_{1-x}\text{Ga}_x\text{As}) = 0.36 + 0.505x + 0.555x^2$ and
 $m^*(\text{In}_{1-x}\text{Ga}_x\text{As}) = (1-x)/m^*_{(\text{InAs})} + x/m^*_{(\text{GaAs})}$

Remember that the growable strain is $< 1.5\%$

- c. Plot the strain and critical thickness for InGaAs on GaAs as a function of In content.
- d. Given the limits on the quantum well thickness set by strain, plot the smallest conduction band-to-heavy hole transition energy as a function of indium content. Use Equation (A1.18) in Coldren & Corzine to approximate the eigenenergies.
- e. What is the longest wavelength transition for InGaAs/GaAs achievable?

Problem #4 This problem applies Harrison Atomic Orbital theory to the determination of various band discontinuities. Using the HAO table of atomic potentials, determine the conduction and valence band discontinuities as well as the type (I, II, or III) of the heterointerface.

- a. InP/InAs.
- b. InP/InSb
- c. InAs/GaSb
- d. Si/Ge