PHL 727: Quantum Heterostructures

Time: 2 Hour — *Major Test: November 22, 2008* — Max. Marks 45

1. Briefly explain, how
   (i) high electron mobility is achieved in heterostructure HEMT ?
   (ii) application of electric field to an isotropic crystal changes its refractive index ?
   (iii) strong reverse bias in a photodiode improves both efficiency and response time ?
   (iv) mini-bands are formed in a superlattice?

   [4x2]

2. Plot following curves
   (i) Responsivity of an ideal silicon photodiode (quantum efficiency ~100%) as a function of wavelength.
   (ii) Exciton broadening and binding energy with quantum well width.

   [2x2]

3. Describe *qualitatively* the quantum mechanical effect of a uniform dc magnetic field on 3D electron system. What are the changes expected in 2D electron system?

   [4]

4. What is quantum confined Stark effect? Explain, how this effect can be used in quantum well based optical modulator?

   [3]

5 (i) Sketch structure of a quantum well infrared photodetector (QWIP) and describe its operation and underlying physics. How QWIP can be used for detection of short and far infrared radiation *simultaneously*? Discuss its advantages and disadvantages.
  (ii) Design a QW infrared detector made of n-type GaAs/AlGaAs (Al mole fraction x is 0.30) for detection of 3.1 μm radiation. Assume that AlGaAs conduction band varies with mole fraction as 1.253+1.097x.

   [5+3]

6 (i) Explain single electron tunneling in a tunnel junction. How this phenomenon can be used in a single electron transistor (SET)?
  (ii) Estimate the capacitance required of a tunnel junction with an area of 0.001 μm^2 and insulting film of thickness 1 nm operating at 1K for a single electron tunneling.

   [4+3]

7. Draw structure of a resonant tunneling diode (RTD) and define the role and thickness of each layer. Explain I-V characteristics of the RTD structures and describe on what parameters the *peak-to-valley current ratio* would depend.

   [4]

8. (i) Describe *structure* and *output characteristics* of a surface emitting quantum well laser?
   (ii) Calculate the threshold gain in a surface emitting GaAs QW laser if the top mirror and bottom mirror reflectivities are 95% and 99%, respectively. The cavity length is 1 μm and there are no other losses in the cavity.

   [4+3]

Useful physical constants:

Electron charge $e = 1.602 \times 10^{-19}$ C
Mass of electron $m_o = 9.109 \times 10^{-31}$ kg
Boltzman constant $k_B = 8.617 \times 10^{-5}$ eV/K
Planck's constant $h = 6.626 \times 10^{-34}$ J-s

GaAs $E_g = 1.43$ eV,
$m_e = 0.068\ m_o$, $m_h = 0.56\ m_o$
Refractive index = 3.6