Midterm Exam, Fall 2004

ECSE-6960, Physical Foundations of Solid-State Devices

Note: (***i***) Put your name on paper, show your work, underline results, and always show units.
(***ii***) Textbook, manuscript, excerpts, and calculators are allowed.

1. Consider an $Al_xGa_{1-x}As / GaAs / Al_xGa_{1-x}As$ quantum well (QW) structure. The thickness of the GaAs well layer is denoted as L_{QW}. Describe the changes in optical emission energy for an intra-well transition from the 2nd excited state to the ground state if
   (a) m^* decreases
   (b) m^* increases
   (c) Give asymptotic value of question (b) for $m^* \to \infty$
   (d) x decreases
   (e) Give asymptotic value of question (d) for $x \to 0$
   (f) x increases

2. Consider a symmetric QW semiconductor structure. The bandgap energy of the semiconductor forming the well is 1.42 eV. Assume that the barriers are infinitely high ($U_{barrier} = \infty$ eV). Assume further that electrons in the conduction-band well and holes in the valence-band well have effective masses of $m_e^* = 0.067\ m_e$ and $m_h^* = 0.45\ m_e$, where m_e is the free electron mass.
   (a) Calculate the optical transition energy of the structure for a QW thickness of $L_{QW} = 100$ Å.
   (b) Assume that the barrier height is now reduced to a *finite* barrier height. Is the optical transition energy going up or down as compared to (a)? Explain your answer.
   (c) Does the *infinite* well approximation work better for
   - a heavy or light carrier mass?
   - a thick or thin QW?

3. Assume that an electron is propagating in a periodic potential under the influence of a constant electric field of 100 V/cm. Assume that the dispersion relation of the electron is given by $E = E_0 - \Delta E_0 \cos(ka)$ where $\Delta E_0 = 20$ meV and $a = 20$ Å. Consider an electron having an initial k value of 0.
   (a) What is the acceleration of the electron at $t = 0$?
   (b) Give an estimate as to how long a time (after $t = 0$) the acceleration of the electron is a constant.
   (c) At which point(s) of the $E(k)$ relation does the group velocity change linearly with time?

4. Assume that a finite quantum well problem is to be solved by the variational method.
   (a) Suggest a suitable trial wave function for the first excited state of the potential well (including formula).
   (b) Sketch your trial function for different trial parameters.
   (c) Explain all parameters of your trial wave function.

5. (a) What is the dimension (the units) of the 2D density of states?
   (b) What is the density-of-states in the lowest subband of an n-type GaAs quantum well?
   (c) What is the total number of states in a 1 cm^2 large sample within the first 100 meV of the lowest subband (E_0)?