Final Exam, Fall 2004

ECSE-6960, Physical Foundations of Solid-State Devices

1. (a) Calculate the ionization energy for hydrogenic donors in InAs, E_d.
   (b) Calculate the ionization energy for hydrogenic acceptors in InAs, E_a.
   (c) What is the temperature at which the acceptor activation energy is equal to kT?
   (d) Calculate the percentage of acceptors ($N_A = 10^{17}$ cm^{-3}) that are ionized at that temperature.
   (e) Explain the result obtained under (d).

2. Consider a bulk semiconductor with two scattering mechanisms, ionized impurity scattering with mobility μ_{II}, and phonon scattering with mobility μ_{Ph}. It is $\mu_{II} = 500\ \text{cm}^2/(\text{Vs})\ (T/300\ \text{K})^{3/2}$ and $\mu_{Ph} = 250\ \text{cm}^2/(\text{Vs})\ (T/300\ \text{K})^{-3/2}$
   (a) Which of the two scattering mechanisms dominates at room temperature?
   (b) Which of the two scattering mechanisms dominates at very low temperature (< 50 K)?
   (c) At which temperature are carriers scattered equally strongly by both scattering mechanisms?
   (d) What are the mobilities: (i) μ, (ii) μ_{II} and (iii) μ_{Ph} at this temperature?
   (e) What is the mobility of carriers at room temperature?
   (f) What would be the mobility if the bulk material discussed above would be made into a modulation-doped semiconductor?
   (g) Explain the temperature dependence of μ_{II}.
   (h) Explain the temperature dependence of μ_{Ph}.

3. Discuss the advantages and disadvantages of three different methods that are used to calculate the energy levels in a semiconductor quantum well.

4. Consider and electron in a one-dimensional periodic structure along the x direction with lattice constant (period) $a = 5$ Å $= 0.5$ nm. Consider further that the electron occupies the lowest band of the periodic structure. The lowest band has a width of $2\Delta E_0 = 20$ meV.
   (a) What is the group velocity of the electron at $k = 0$, $k = \pi/(2a)$, and $k = \pi/a$.
   (b) Consider that the electron has a k value of $k = \pi/(2a)$ and that the electron is subjected to an electric field pointing along the *positive x* direction with magnitude 1000 V/cm. How much time passes until the electron has the group velocity zero?
   (c) Consider that the electron has a k value of $k = \pi/(2a)$ and that the electron is subjected to an electric field pointing along the *negative x* direction with magnitude 1000 V/cm. How much time passes until the electron has the group velocity zero?

5. In the mid infrared spectral region, intersubband transitions are used in quantum-well infrared photodetectors or "QWIP" detectors. In n-type detectors, the lowest state in a conduction band quantum well is populated with electrons. Upon illumination, electrons are lifted to the first excited state of the quantum well from where they tunnel out of the quantum well, driven by an electric field. These electrons constitute the photocurrent.
   (a) Calculate the detection wavelength of an n-type GaAs quantum-well photo-detector with a well width of 100 Å. The infinite well approximation can be used in the calculation.
   (b) Assume that the tunneling probability from the first excited state out of the well was determined to be $T = 10^{-4}$. What is the time it takes the electron to tunnel out of the well?
   (c) Suggest an application for detectors in this spectral region.
   (d) Calculate the detection wavelength if the structure is p-type doped.
   (e) Is it possible to use intersubband transitions in semiconductor quantum wells for the visible spectral range? Explain your answer.