Final Exam, Fall 2006

ECSE-6968 – 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. The composition x of an $Al_xGa_{1-x}As$ layer is graded from $x = 0$ to 0.30 over a distance of 500 nm. Assume that the bandgap energy varies with composition according to $E_g = 1.424$ eV + 1.247 x eV and that 2/3 of the band discontinuity occur in the conduction band.
   (a) What is the quasi-electric field in the composition-graded region?
   (b) How long would it take an electron with mobility of 2000 cm^2/Vs to traverse the graded region?
   (c) What is the diffusion constant of the electrons at 300 K?
   (d) What is the time needed for carriers to diffuse over the thickness of the graded region?

2. The measured electron mobility in a selectively doped $Al_xGa_{1-x}N$/GaN heterostructure at room temperature is 1800 cm^2/Vs. An equivalent uniformly doped GaN sample has a mobility of 600 cm^2/Vs. Answer the following questions; explain your conclusions.
   (a) What is the ionized impurity scattering mobility in the two structures?
   (b) Which scattering mechanism dominates for the two structures?
   (c) Assuming $T \rightarrow \infty$, which scattering mechanism will dominate for the two structures?
   (d) Assuming $T \rightarrow 0$, which scattering mechanism will dominate for the two structures?

3. How would the electron density, n_{2DEG}, in a selectively doped $Al_xGa_{1-x}N$/GaN heterostructure change when …
   (a) … increasing the Al content in $Al_xGa_{1-x}N$?
   (b) … increasing the doping concentration?
   (c) … increasing the spacer layer thickness?
   (d) … increasing ΔE_C?

4. An electron with effective mass $m^* = 0.45\ m_0$ tunnels through a barrier that is $U_0 = 50$ meV high. Due to a design requirement, the tunneling probability must be 10^{-6} or less.
   (a) Calculate the minimum barrier thickness L_B (give numerical value).
   (b) Give a formula that describes the tunneling probability through a rectangular barrier.
   (c) Write the formula in the following form: $T = \exp\,(-L_B / L_e)$.
   (d) Can you explain the physical meaning of L_e?
   (e) Calculate L_e (give mathematical formula and numerical value).

5. Consider electrons and holes in a quantum well (QW) structure. The Hamiltonian operator of an optical transition has the form $H'(x) = e\,\mathcal{E}x$.
   (a) What is the symmetry of p-orbital-like valence band states and s-orbital-like conduction band states?
   (b) Which of the QW electron states, E_{0e}, E_{1e}, E_{2e}, E_{3e}, has even symmetry?
   (c) Which of the QW hole states, E_{0h}, E_{1h}, E_{2h}, E_{3h}, has even symmetry?
   (d) What is the symmetry (even or odd symmetry) of the hamiltonian operator of an optical transition?
   (e) Which interband (conduction-to-valence-band) transitions are possible for an electron in the E_{0e} state?
   (f) Which intraband (within conduction band) transitions are possible for an electron in the E_{0e} state?
   (g) Do the answers to (e) and (f) change in the presence of a static electric field? Explain your answer.