Exam #1 — EE 531 Winter 2007

Due Tuesday, Feb. 20 at start of lecture

The test is a take-home exam. Show all work. Be sure to state all assumptions made and **check** them when possible. Please limit your time working on the exam to 8 hours. Do not talk to anyone else about the exam until after the due date. Any questions should utilize EPost (also look there for updates/corrections).

1. A thick silicon sample is uniformly doped with $N_a = 10^{16}\text{cm}^{-3}$ to a depth of 1μm, with doping of $N_a = 10^{19}\text{cm}^{-3}$ below that point. At the top surface ($x = 0$), carriers are generated at a rate of $10^{18}\text{cm}^{-2}\text{sec}^{-1}$ (note: this is surface generation and is per unit area). There is no bulk generation. The top surface also has a recombination velocity of $s = 10^4$cm/s. Take values of diffusivity and recombination lifetime from plots in notes.

   (a) Determine the excess electron concentration as a function of position. Note that there is a potential step at the interface between doping concentrations.

   (b) Calculate the two components of current density for holes near $x = 0$.

2. A semiconductor has eight conduction band minima given by $E = E_c + A(k - k_i)^2$, where A is a positive constant and $k_i = (\pm k_0, \pm k_0, \pm k_0)$.

   (a) Give expression for the conduction band effective density of states (N_c).

   (b) If the scattering rate is $S(k, k') = S_0\delta[E(k)-E(k')]$, what would be the momentum relaxation time as function of E?

3. Consider scattering dominated by acoustic phonon scattering for which $\tau_m \propto {T_e}^{-1/2}$ and $\tau_e \propto {T_e}^{1/2}$. Using energy balance equations, calculate an expression for the electron velocity as a function of the applied field.

4. An MOS capacitor has a substrate doped with $N_a = 5 \times 10^{17}\text{cm}^{-3}$, an oxide of thickness 1.5nm and an n+ poly gate ($\phi_s = \chi_s$). There is an n+ channel contact biased at +1V relative to the substrate.

   (a) What is the value of V_{GB} required to make $\psi_s = V_{CB} - 2\psi_B + 0.1$V? Sketch the charge density, electric field and band diagram (energy band extrema versus distance) for these conditions.

   (b) What would be the gate capacitance calculated under these conditions?

   (c) When the device is biased in inversion, there is a confining potential that keeps the inversion charge near the surface, forming a 2D electron gas. Assume that this potential can be considered a triangular potential well, with slope equal to the surface electric field, then the sub-band energies are

   $$E_j = \left[\frac{3hq\mathcal{E}_s}{4\sqrt{2m_\perp}}\left(j + \frac{3}{4}\right)\right]^{2/3},$$

   where $m_\perp$ is the effective mass perpendicular to the interface. Calculate the inversion electron charge considering quantum confinement for V_{GB} as in (a).

   (d) Calculate the average effective mass in the plane of the channel for the inversion electron population considering quantum confinement (note anisotropic effective mass in any single minimum).