Homework #1 - EE 531

due 4/6/17

1. In a real semiconductor, trapping centers have a variety of energies within the bandgap. Consider a silicon sample with $N_1 = 10^{12}$ cm^{-3} recombination centers due to metal contamination located at the intrinsic Fermi level, and $N_2 = N_d$ recombination centers due to shallow dopants located 0.05eV below the conduction band. Assume that the electron and hole thermal velocities are 10^7 cm/s and 6×10^6 cm/s, respectively.

   (a) Assuming that recombination via the shallow and deep levels occurs independently, and that capture cross sections for both shallow and deep centers are $\sigma = 10^{-14}$ cm^2, calculate the minority carrier lifetime at 300K under low-level injection for $N_d = 2 \times 10^{18}$ cm^{-3}. Do the shallow or the deep centers dominate the recombination lifetime?

   (b) In reality, the capture cross-section for shallow dopants is much smaller than for deep levels. Assuming that the upper line on the curve in the figure on page 6 of notes is for recombination lifetime limited by shallow donors, calculate the capture cross-section for the shallow donors.

   (c) Assuming that lower line on plot gives lifetime due to Auger recombination, determine K_n for Auger recombination in this material.

   (d) How does the effective lifetime change as the injection level increases into high level injection? Calculate and plot τ versus $\Delta p = \Delta n$ for doping of 10^{16} cm^{-3} and 10^{19} cm^{-3}.

2. A silicon membrane with thickness 5μm has a uniform donor concentration of 5×10^{17} cm^{-3}. One end is irradiated and hole-electron pairs are generated at a rate of 10^{18} cm^{-2}s^{-1} at the surface. At the other surface, the recombination velocity is 10^4 cm/s. Assume D_p = 4 cm^2/s and τ_p = 100 ns. Ignore recombination at the irradiated end.

   (a) Calculate and sketch the concentrations of holes and electrons as a function of distance. Use the Diffusion Approximation (drift current is negligible for minority carriers under low level injection) and the Quasi-Neutrality Approximation ($\Delta n \approx \Delta p$).

   (b) What percentage of the injected carriers recombine at the surface?

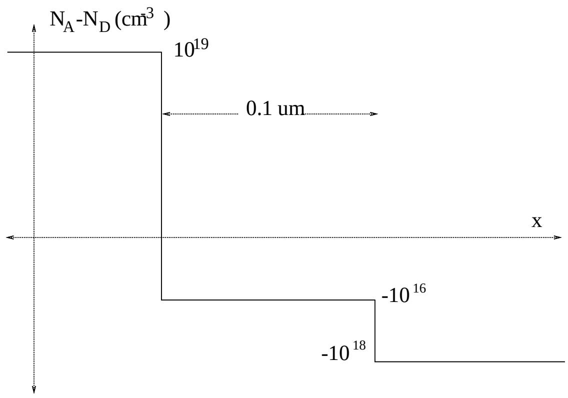
   (c) Based on your solution to (a), calculate the majority carrier diffusion current as function ofposition.

   (d) Since $J_n = J_p$ in steady state (carriers are generated and recombine as pairs) for this system, determine the majority carrier drift current and from this the electric field.

   (e) Use your calculation of the electric field to test the Diffusion Approximation.

   (f) Use your calculation of the electric field and Poisson's equation to determine the charge density and thus test the Quasi-Neutrality Approximation.

3. (a) Find and sketch the built-in field and potential for a silicon *pin* junction with the doping profile shown to the right. Indicate the length of each depletion region. (The symbol *i* represents a lightly doped or intrinsic region. In this case the central region is lightly *p*-doped, also called a *pπn* diode.)



(b) Compare the maximum field in the *pin* diode to that in a *pn* junction without the lightly doped *p* region, but with the same dopant concentrations in the other regions. Why are they different?

(c) Discuss how the depletion capacitance for the *pin* structure varies with voltage, comparing it as in part (b) to the normal *pn* junction with the same doping (but no lightly-doped *p*-region). Sketch capacitance *C* versus applied bias, using a single set of axes for both plots.

4. In an abrupt **silicon** p-n junction at 300K, N_a = 10^{19}cm^{-3}, N_d = 10^{17}cm^{-3}, $\tau_n = \tau_p = 0.02\mu$s in heavily doped *p*-region and $\tau_n = \tau_p = 0.5\mu$s in *n*-region, W_p = 50nm and W_n = 500μm.

(a) If the p-region is biased at +0.7V relative to the n-region, sketch the current densities as functions of position and calculate (neglecting recombination in the depletion region):

i. The hole current density in the n-region at the edge of the depletion region.

ii. The hole current density in the p-region at the edge of the depletion region.

iii. The electron current density at the contact to the p-region.

iv. The electron current density at the contact to the n-region.

(b) If the p-region is biased at +0.4V relative to the n-region, sketch the current densities as functions of position and calculate (including recombination in the depletion region) the same set of current densities as in (a).