Final Exam — EE 482 Winter 2011

This is a take-home exam, due back by 3pm on Thursday, 3/17. To submit your completed exam, either scan and attach to email or slip under the door of my office.

Please do not discuss the exam with anyone else, in or out of the class. Please limit your active work on the exam to a total of no more than 7 hours. Show all work. Be sure to state all assumptions made and **check** them when possible. If not otherwise specified, assume T = 300K and that the material is silicon.

- 1. In order to create "semi-insulating" GaAs, a 0.5 mm thick wafer ($E_g = 1.42 \,\mathrm{eV}$) is doped with $N_{Cr} = 5 \times 10^{18} \mathrm{cm}^{-3}$ of Cr, which has an acceptor level 0.77eV above the valence band. The Fermi level is located 0.65eV above the valence band.
 - (a) How many Cr atoms are ionized?
 - (b) Assume that there is just one other dopant species which is totally ionized (shallow). What is the type and concentration of that dopant?
 - (c) What would be the resistivity of this wafer?
- 2. A silicon sample is uniformly doped with $N_d = 2 \times 10^{16} \text{cm}^{-3}$. The sample is 100 μ m thick. At one surface (x = 0), carriers are generated by light at a rate of $10^{18} \text{cm}^{-2} \text{s}^{-1}$ (note: this is surface generation and is per unit area). There is negligible bulk generation. At both ends, there is a recombination velocity of $s = 10^3 \text{ cm/s}$. Assume $\tau_n = \tau_p = 40 \,\mu\text{s}$ and T = 300K.
 - (a) Determine the excess hole concentration as a function of position.
 - (b) Calculate the electron current density at $x = 50 \,\mu\text{m}$.
- 3. A silicon MOS capacitor has a polysilicon gate heavily doped with arsenic such that $E_f = E_c + 0.1$ eV and an oxide thickness of $x_{ox} = 2$ nm. The substrate has very light doping up to a depth of 10 nm and then boron doping of $N_a = 10^{19}$ cm⁻³ below that point.
 - (a) Calculate the depletion region depth and associated depletion charge at the edge of strong inversion. Use bulk doping in determining ϕ_F . Hint: Think about the voltage drops in the semiconductor as you would a pn junction with non-uniform doping.
 - (b) If $V_{ox} = 0.8 \text{ V}$, what mode is the device in and what is the applied bias?
- 4. A pMOS silicon transistor has $W = 2L = 0.4 \,\mu\text{m}$, $x_{ox} = 8 \,\text{nm}$, $N_d = 5 \times 10^{17} \text{cm}^{-3}$ and $\Phi_M = 5.1 \,\text{V}$.
 - (a) Calculate the flatband voltage and threshold voltage with $V_{SB} = -2V$.
 - (b) If $V_{DS} = V_{SB} = V_{GS} = -2.0 \text{ V}$, what mode is the transistor operating in?
 - (c) Sketch the charge density, electric field and band diagram in the channel near the source under these bias conditions. Calculate the components of the semiconductor charge (depletion, inversion, accumulation) and electric field in the oxide.
 - (d) Calculate the change in threshold voltage with the change in channel to substrate bias (α) for $V_{CB} = -2$ V.
 - (e) Calculate the drain current using the model based on linearized depletion charge with channel voltage. Use universal channel mobility curves and include channel length modulation under these bias conditions $(V_{DS} = V_{SB} = V_{GS} = -2.0 \text{ V}).$
 - (f) Calculate the output resistance of the transistor.
- 5. A silicon *pnp* transistor with constant doping in each region, has $A_E = A_C = 10^{-6} \text{cm}^2$, $N_{aE} = 10^{19} \text{cm}^{-3}$, $N_{dB} = 10^{17} \text{cm}^{-3}$ and $N_{aC} = 10^{19} \text{cm}^{-3}$. The width of the undepleted emitter is $x_E = 0.5 \,\mu\text{m}$, the width of the undepleted base region is $x_B = 0.2 \,\mu\text{m}$ and the width of the undepleted collector region is $x_C = 0.5 \,\mu\text{m}$. Assume that the minority carrier lifetimes in the base is 5μ s and $0.1 \,\mu\text{s}$ in the emitter and collector.
 - (a) Calculate α_F and α_R at moderate current levels (assume recombination in neutral base and depletion regions can be neglected).
 - (b) If $V_{BE} = -0.7$ V and $V_{CE} = -0.05$ V, what mode is the transistor operating in (forward active, reverse active, cutoff or saturation)? Explain.
 - (c) Calculate the hole current in the base at the edge of the base-emitter depletion region under these bias conditions ($V_{BE} = -0.7$ V and $V_{CE} = -0.05$ V). Consider a current from the emitter to the collector to be positive.
 - (d) Sketch the minority carrier concentrations in the transistor as a function of position. Calculate the excess minority charge storage in the base