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Final Exam — EE 482

Winter 2009

The test is open book/open notes. Show all work. Be sure to state all assumptions made and **check** them when possible. The number of points per problem are indicated in parentheses. Total of 160 points in 5 problems on 7 pages. If not otherwise specified, assume $T = 300\text{K}$ and the material is silicon.

1. Two materials have same valence band structure, the same band gap and the same electron conduction effective mass, but material B has 8 equivalent conduction band minima, while material A has just one.

   (a) What is the expected ratio of intrinsic carrier concentration n_i in material B to that in material A? Explain. (10)

   (b) Which material is likely to have the larger hole diffusion length L_p? Explain. (10)

2. A silicon p-n junction has uniform doping of $N_d = N_a = 2 \times 10^{18}\text{cm}^{-3}$. However, there is also a positive sheet of charge (delta function) at the metallurgical junction with a concentration of $5 \times 10^{12}\text{cm}^{-2}$ (note that this is per unit area).

   Calculate the voltage at which this diode will break down if the breakdown field is $\mathcal{E} = 2 \times 10^6$ V/cm. Sketch the electric field versus position at this bias. (22)

3. A silicon p-channel (n-substrate) MOS capacitor with a polysilicon gate heavily doped with boron ($E_f = E_v$) has a substrate doping of $N_d = 2 \times 10^{18}\text{cm}^{-3}$ and an oxide thickness of $x_{ox} = 2\,\text{nm}$. There are no significant interface charges. The device is biased such that the voltage dropped across the oxide is $0.5\,\text{V}$ (more positive toward gate).

   (a) Calculate the charge in the semiconductor and on the gate. What mode is the device operating in? (10)

   (b) What is the applied voltage between the gate and substrate? (12)

4. A silicon n-channel MOS transistor has an oxide thickness of 2 nm, uniform substrate doping of $N_a = 2\times 10^{18}\mathrm{cm}^{-3}$ and $W = 300\mathrm{nm}$ and $L = 100\mathrm{nm}$. $V_T = 0.4\,\mathrm{V}$ with $V_S = V_B = 0\,\mathrm{V}$. Assume $\mu_n' = 150\,\mathrm{cm}^2/\mathrm{Vs}$ in the inversion layer.

(a) If the gate metal work function is 4.0V, what must the oxide interface charges be (assume no charges in bulk of oxide)? (12)

(b) Calculate the change in threshold voltage with the change in channel to substrate bias (δ) for $V_{SB} = 0$. (12)

(c) If $V_S = V_B = 0\mathrm{V}$ and $V_G = 2\mathrm{V}$, what drain voltage would bring the transistor to the edge of saturation. (Use full or linearized model). (8)

(d) For $V_D = 2V$ (and $V_S = V_B = 0$V, $V_G = 2.0$V), determine the operating mode and calculate the drain current. Include channel length modulation if appropriate. (14)

(e) Sketch the band diagram in channel near drain if $V_G = 2.0V$, $V_D = 2V$, and $V_B = V_S = 0V$. What is the voltage dropped across the semiconductor? (12)

5. A silicon *npn* transistor with constant doping in each region, has $A_E = A_C = 10^{-6}\text{cm}^2$, $N_{dE} = 2 \times 10^{19}\text{cm}^{-3}$, $N_{aB} = 5 \times 10^{17}\text{cm}^{-3}$ and $N_{dC} = 2 \times 10^{16}\text{cm}^{-3}$. The width of the undepleted emitter is $x_E = 100\text{nm}$, the width of the undepleted base region is $x_B = 20\text{nm}$ and the width of the undepleted collector region is $x_C = 2\mu\text{m}$. Assume that in all regions the minority carrier lifetimes are $0.1\mu\text{s}$. The diffusion coefficients are $D_n = 3\text{cm}^2/\text{s}$ and $D_p = 1.5\text{cm}^2/\text{s}$ in the emitter regions and $D_n = 12\text{cm}^2/\text{s}$ and $D_p = 5\text{cm}^2/\text{s}$ in the base, and $D_n = 25\text{cm}^2/\text{s}$ and $D_p = 12\text{cm}^2/\text{s}$ in the collector regions

   (a) Calculate I_{ES} and α_F in Ebers-Moll model for moderate current levels (assume recombination in depletion regions is negligible, no high level injection effects). (14)

   (b) If $I_E = -10\mu\text{A}$ (positive currents are into the device) and $V_{BC} = -2\text{V}$, what mode is the transistor operating in (forward active, reverse active, cutoff or saturation)? Calculate V_{BE} and I_C. (12)

(c) Calculate the minority charge in the base, and sketch the minority carrier concentrations in the transistor as a function of position. (12)

End Of Exam