Semiconductor Devices

Final Exam
12/12/2023

Name: ____________________________________

ID # : _____________________________________

- There are 4 problems in this exam.
- In taking the examination, you agree that all work recorded herein is your own. A student caught in the act of cheating will be given a grade of F on this examination.

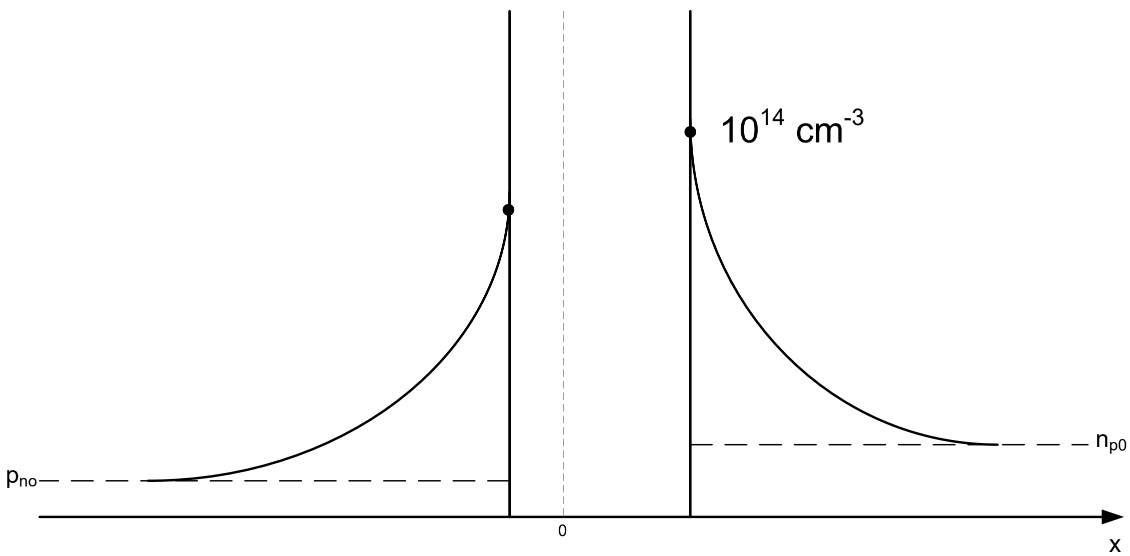
Problem	Points
1	
2	
3	
4	
Total	

Problem 1 (25 points)

The steady state minority carrier densities in a pn junction are shown below. $p_{n0} = 1x10^3$ cm^{-3}, $n_{p0} = 1x10^4$ cm^{-3} , the electron minority carrier density at the edge of the depletion region is $1x10^{14}$ cm^{-3} as indicated in the figure. Assume

$$\tau_n = 0.01\ \mu s,\ \tau_p = 0.01\ \mu s,\ \mu_n = 1000\ cm^2/V.s,\ \mu_p = 500\ cm^2/V.s.$$

$$n_i = 1.5x10^{10} cm^{-3},\ \frac{kT}{e} = 0.026V,\ E_g = 1.12eV, T = 300K$$



a) (5 points) Is the pn junction at equilibrium, forward biased, or reverse biased? Explain.
b) (5 points) Indicate on the graph the p-region and the n-region and the doping level in each.
c) (5 points) Determine the applied voltage.
d) (5 points) Do low-level injection conditions prevail in the bulk regions?
e) (5 points) Draw the energy band diagram and determine the energy barrier height in the conduction band.

Problem 2 (25 points)

Consider a Si pnp transistor with $N_E = 5\text{x}10^{17}$ cm^{-3}, $N_B = 5\text{x}10^{16}$ cm^{-3}, $N_C = 5\text{x}10^{15}$ cm^{-3}, a metallurgical base width of 0.3 μm, and a cross section area of $1\text{x}10^{-4}$ cm^2. Assume the critical electric field to be equal to $4\text{x}10^5$ V/cm.

$\tau_n = 0.01$ μs, $\tau_p = 0.01$ μs, $\mu_n = 1000$ cm^2/V.s, $\mu_p = 500$ cm^2/V.s.

$n_i = 1.5\times10^{10}\ cm^{-3}$, $\varepsilon_s = 11.7\times8.854\times10^{-14}\ F/cm$

a) (5 points) Determine the operating region and draw the excess minority carrier densities across the emitter, base, and collector bulk regions for $V_{EB} = 0.7$V, $V_{EC} = 2.0$V.
b) (5 points) Draw the energy band diagram corresponding to the part a).
c) (5 points) Describe the procedure for estimating the total number of excess holes in the base (You don't need to find the actual value).
d) (5 points) Determine the common-base breakdown voltage.
e) (5 points) Determine V_{EC} at punch-through (neglect the E-B depletion region).

Problem 3 (25 points)

A MOS capacitor has an aluminum gate and a p-type semiconductor with doping $N_A = 10^{16}$ cm^{-3}. The silicon dioxide gate has a thickness of 400 $\mathring{A}$. The oxide charge density is $Q'_{ss} = 3\times10^{11}$ cm^{-2}. For the aluminum-silicon dioxide junction, assume $\phi'_m = 3.4V$ and for the silicon-silicon dioxide junction, $\chi' = 3.25V$

$$\varepsilon_{ox} = 3.9\varepsilon_o, \varepsilon_s = 11.7\varepsilon_0,\ \varepsilon_0 = 8.85\times10^{-14}\frac{F}{cm},\ E_g = 1.12eV$$

$$\frac{kT}{e} = 0.026V,\ n_i = 1.5\times10^{10}\ cm^{-2}$$

Q'_{SS} is the number of electronic charges per unit area in the oxide

a) (5 points) Calculate the flat-band voltage.
b) (5 points) Calculate the threshold voltage.
c) (5 points) Is this enhancement or depletion type?
d) (5 points) Sketch the charge density along the MOS capacitor at the onset of inversion.
e) (5 points) Sketch the energy band diagram in the semiconductor region at the onset of inversion.

Problem 4 (25 points)

Consider an n-channel MOSFET biased as shown in the figure below. Assume the following parameters: p^+ poly gate such that $E_F = E_V$,

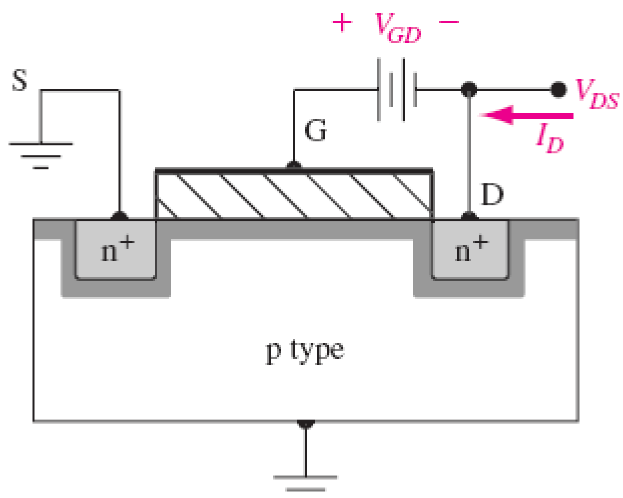
$t_{ox} = 100\overset{o}{A}, Q'_{SS} = 10^{11} cm^{-2}, N_A = 10^{16} cm^{-3}, n_i = 1.5 \times 10^{10} cm^{-3}$

$\frac{kT}{e} = 0.026V$

$\varepsilon_s = 11.7 \times \varepsilon_o, \varepsilon_{ox} = 3.9 \times \varepsilon_o, \varepsilon_o = 8.854x10^{-14} F/cm$

Q'_{SS} is the number of electronic charges per unit area in the oxide

$W = 10\mu m, L = 2\mu m, \mu_n = 700 \frac{cm^2}{V.s}$



a) (5 points) Determine the threshold voltage V_{TN}.
b) (10 points) Plot $\sqrt{I_D}$ versus V_{DS} for $V_{GD} = 0$ and $0 \le V_{DS} \le 5V$
c) (10 points) Plot $\sqrt{I_D}$ versus V_{DS} for $V_{GD} = V_{TN}$ and $0 \le V_{DS} \le 5V$