Problem 1 (25 points)

Consider a silicon pn junction with a cross section area of $1x10^{-5}$ cm^2, a forward bias V_a = 0.5V, and the following parameters at T = 300K:

$$N_d = 10^{16} cm^{-3}, N_a = 10^{15} cm^{-3}, \tau_p = 10^{-7} s, \tau_n = 10^{-6} s$$

$$\mu_p = 400\ cm^2 / V.s,\ \mu_n = 1000 cm^2 / V.s$$

$$n_i = 1.5x10^{10}\ cm^{-2},\ \varepsilon_s = 11.7 \times 8.854 \times 10^{-14} F / cm; \frac{kT}{e} = 0.025V$$

Assume the critical field to be equal to $3x10^5$ V/cm.

a) (5 points) Compare the hole density at x_n to the electron density at $-x_p$
b) (5 points) Compare the hole current at x_n to the electron current at $-x_p$
c) (5 points) Determine the breakdown voltage.
d) (10 points) Calculate the total number of excess electrons in the p bulk region.

Problem 2 (25 points)

Consider an Si npn transistor with $N_E = 5\text{x}10^{17}$ cm^{-3}, $N_B = 5\text{x}10^{15}$ cm^{-3}, $N_C = 10^{15}$ cm^{-3}. The metallurgical base width is 1 μm and the base cross sectional area is 10 μm^2. $n_i = 1.5\times10^{10}\ cm^{-2}$, $\frac{kT}{e} = 0.025V$

a) (5 points) Draw the energy band diagram under equilibrium.
b) (5 points) Sketch the electric field, charge density, and determine the potential between the emitter and collector.
c) (7.5 points) For V_{BE} = 0.7V, V_{CE} = 0.2V, draw the excess minority carrier densities across the emitter, base, and collector regions.
d) (7.5 points) Describe the steps for estimating the total number of excess electrons in the base.

Problem 3 (25 points)

Consider a MOS capacitor with p$^+$ polysilicon gate and p-type silicon substrate with $N_A = 10^{16}$ cm^{-3}. $E_F = E_V$ in the polysilicon gate. Assume the following parameters:

$$t_{ox} = 200\,\overset{\circ}{\mathrm{A}},\ Q'_{SS} = 0, n_i = 1.5\times 10^{10}\ cm^{-2},\ \varepsilon_o = 3.9\times 8.854x10^{-14}\ F/cm$$

$$\varepsilon_s = 11.7\times\varepsilon_o,\ \varepsilon_{ox} = 3.9\times\varepsilon_o$$

a) (5 points) Calculate the metal-semiconductor work function difference.
b) (5 points) Calculate the surface potential at the threshold inversion.
c) (5 points) Calculate the depletion width (in μm) at the threshold inversion.
d) (5 points) Calculate the flat band voltage.
e) (5 points) Determine the threshold voltage.

Problem 4 (25 points)

Consider an n-channel MOSFET at T=300K with the following parameters:

n+ polysilicon gate, $t_{ox} = 200\,\mathring{A}, N_A = 10^{16} cm^{-3}, Q'_{SS} = 2\times 10^{11} cm^{-2}$,

$$W = 1\mu m, L = 0.2\mu m, \mu_n = 1000\frac{cm^2}{V.s}, \varepsilon_{ox} = 3.9\varepsilon_o, \varepsilon_s = 11.7\varepsilon_0,$$

$$\varepsilon_0 = (8.854)(10^{-14})\frac{F}{cm}$$

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

a) (10 points) Determine the threshold voltage V_{TN}.
b) (5 points) Is the transistor an enhancement or depletion mode? Explain.
c) (5 points) Determine the drain current for V_{GS} = 3V and V_{DS} = 2V.
d) (5 points) What type of implant and dose are required such that V_{TN} = 1V