Assignment 6: Transistors

1. Consider a *pnp* BJT that has the following properties. The emitter region acceptor concentration is 2×10^{18} cm^{-3}, the base region donor concentration is 10^{16} cm^{-3}, and the collector region acceptor concentration is 10^{16} cm^{-3}. The hole drift mobility in the base is 400 $cm^2V^{-1}s^{-1}$, and the electron drift mobility in the emitter is 200 $cm^2V^{-1}s^{-1}$. The transistor emitter and base neutral widths are about 2 μm each under common base (CB) mode with normal operation. Device cross section is 0.02 mm^2. Hole lifetime in the base is 400 ns. Assume the emitter has 100% efficiency. Calculate the CB transfer ratio α and the current gain β. What is the emitter-base voltage if the emitter current is 1 mA?

2. Consider an idealized Si *npn* BJT with the properties shown below. Assume uniform doping. The cross sectional area is 10^4 μm^2. The base-emitter forward bias voltage is 0.6 V and the reverse bias base-collector voltage is 18 V.

Emitter width	**Emitter doping**	**Hole lifetime in emitter**	**Base width**	**Base doping**	**Electron lifetime in base**	**Collector doping**
10 μm	10^{18} cm^{-3}	10 ns	4 μm	10^{16} cm^{-3}	400 ns	10^{16} cm^{-3}

   (a) Calculate the depletion layer width between collector-base and emitter-base. What is the width in the neutral base region?

   (b) Calculate α and hence β for this transistor. $\mu_e = 1250$ $cm^2V^{-1}s^{-1}$ in the base, $\mu_h = 100$ $cm^2V^{-1}s^{-1}$ in the collector.

   (c) What are the emitter, collector, and base currents? Take unity emitter injection efficiency for (b) and (c).

3. Consider the n-channel JFET, shown below in figure 1. The width of each depletion region extending into the n-channel is W. The channel depth (thickness) is $2a$. For an abrupt pn junction and with $V_{DS} = 0$,

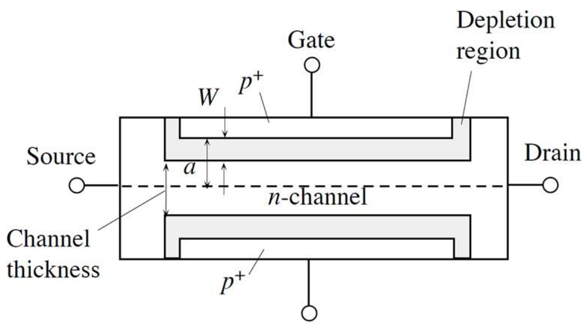

Figure 1: For problem 3. Schematic of a n-channel MOSFET. Adapted from *Principles of Electronic Materials - S.O. Kasap*

show that when the gate to source voltage is V_p, pinch-off occurs when

$$V_p = \frac{a^2 e N_D}{2\epsilon} - V_0$$

where V_0 is the built-in potential and N_D is the donor concentration of the channel. Calculate V_p when acceptor concentration is $10^{19}\ cm^{-3}$, $N_D = 10^{16}\ cm^{-3}$ and channel width ($2a$) is 2 μm.

4. Consider a *npn* Si MOSFET with $N_A = 10^{18}\ cm^{-3}$.

   (a) Determine the position of E_{Fp}.

   (b) Determine applied voltage needed to achieve strong inversion. Calculate depletion width and n-channel width at strong inversion.

   (c) Determine depletion width when applied voltage is 0.5 V.

   (d) Plot the energy bands as a function of distance, starting from the bulk and moving to the surface. The plot should also include the Fermi level.

   Relation between surface potential, ϕ_s, and depletion width, w_D, is given by

$$\phi_s = \frac{e N_A w_D^2}{2\epsilon_0\epsilon_r}$$