TFE4146 - Semiconductor Devices - Fall 2023

Problem Set 6

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Contents

Problem 1

Consider a p-n-p BJT with $N_E > N_B > N_C$.

a) Sketch the flow of holes and electrons within the transistor. Explain the physical principles behind the different current components.

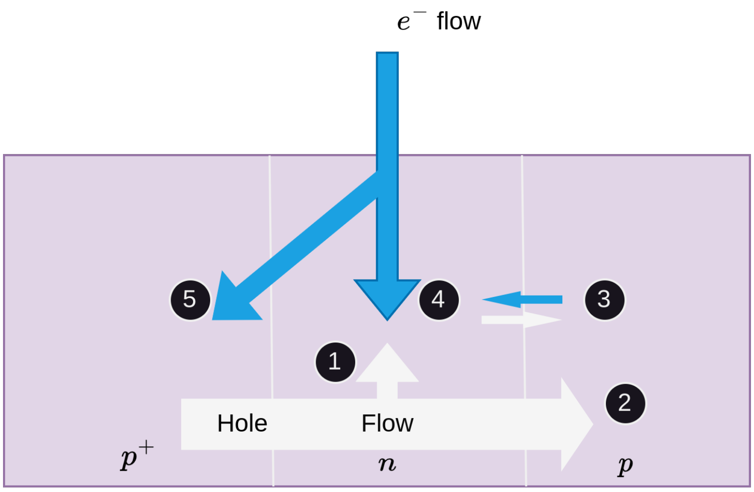

Figure 1: flow of holes and electrons within the transistor.

1. Injected holes lost to recombination in the base.
2. Holes reaching the reverse-biased collector junction.
3. Thermally generated electrons and holes making up the reverse saturation current of the collector junction.
4. Electrons supplied by the base contact for recombination with holes.
5. Electrons injected across the forward-biasedemitter junction.

b) In a good p-n-p transistor, the emitter current is composed almost entirely of holes injected into the base and almost all the holes injected by the emitter is collected at the collector. Explain how the width and the doping level of the base region should be chosen in order to achieve this property.

To achieve this we need the n-type base region to be narrog, and the hole lifetime τ_p to be long. In other words, we can achieve this by specifying $W_b \ll L_p$ where W_p is the length if the neutral n material of the base and L_p is th ediffusion length for holes in the base. We do also require that the current I_E crossing the emitter junction to be composed almost entirely og holes injected into the base, rather than electrons crossing from base to emitter. This can be achieved by doping the base region lightly compared with the emitter.

c) If $I_{Ep} = 10$ mA, $I_{En} = 100\mu$A, $I_{Cp} = 9.8$ mA and $I_{Cn} = 1\mu$A, calculate the base transport factor, emitter injection efficiency, common-base current gain and common-emitter current gain.

The emitter injection efficiency is given by

$$\begin{aligned}\gamma &= \frac{i_{Ep}}{i_{En} + i_{Ep}} \\ &= \frac{10\text{ mA}}{10\text{ mA} + 100\mu\text{A}} \\ &= 0.99009901\end{aligned}$$

as

$$\begin{aligned}i_C &= B i_{Ep} \\ B &= \frac{i_C}{i_{Ep}} \\ &= \frac{9.8\text{ mA}}{10\text{ mA}} \\ &= 0.98\end{aligned}$$

this gives us $\alpha = B\gamma = 0.99009901 \cdot 0.98 = 0.97029703$

and further

$$\begin{aligned}\beta &\equiv \frac{\alpha}{1-\alpha} \\ &\equiv \frac{0.97029703}{1-0.97029703} \\ &\equiv 32.666666997\end{aligned}$$

d) If the minority stored base charge is $4.9 \cdot 10^{-11}$C, estimate the base transit time for holes and the life time for holes in the base.

we have that

$$\frac{\tau_p}{\tau_t} = \beta$$

as $Q_n = i_C \tau_t$

we get

$$\begin{aligned}tau_t &= \frac{Q_n}{i_C} \\ &= g\frac{= 4.9 \cdot 10^{-11}\text{C}}{9.8 \cdot 10^{-3} A} \quad = 5ns\end{aligned}$$

$$\begin{aligned}\tau_p &= \beta \cdot \tau_t \\ &= 32.666666997 \cdot 5 \cdot 10^{-9} s \\ &= 163.33ns\end{aligned}$$

Problem 2

For a p$^+$ – n – p **bipolar junction transistor (BJT) with doping of the emitter, base and collector regions such that** $N_E > N_B > N_C$**.**

a) Sketch the band diagram for this device (qualitative accuracy is sufficient).

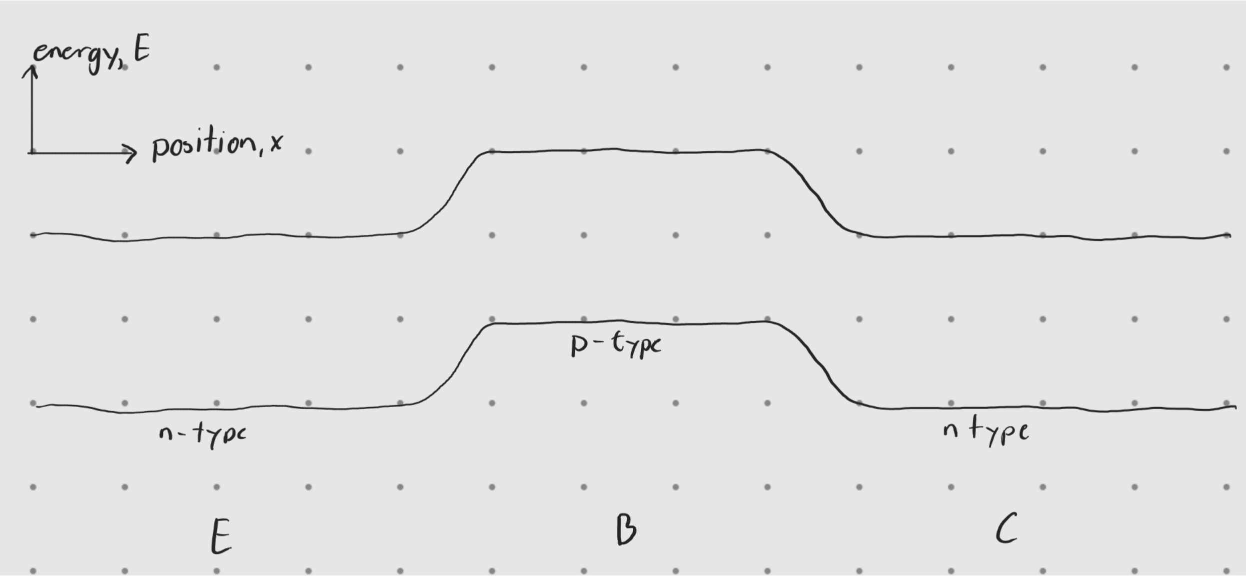

Figure 2: Band diagram

b) Sketch the minority carrier distribution in the emitter, base and collector when the BJT operates in the normal active mode and indicate the space charge regions (qualitative accuracy is sufficient).

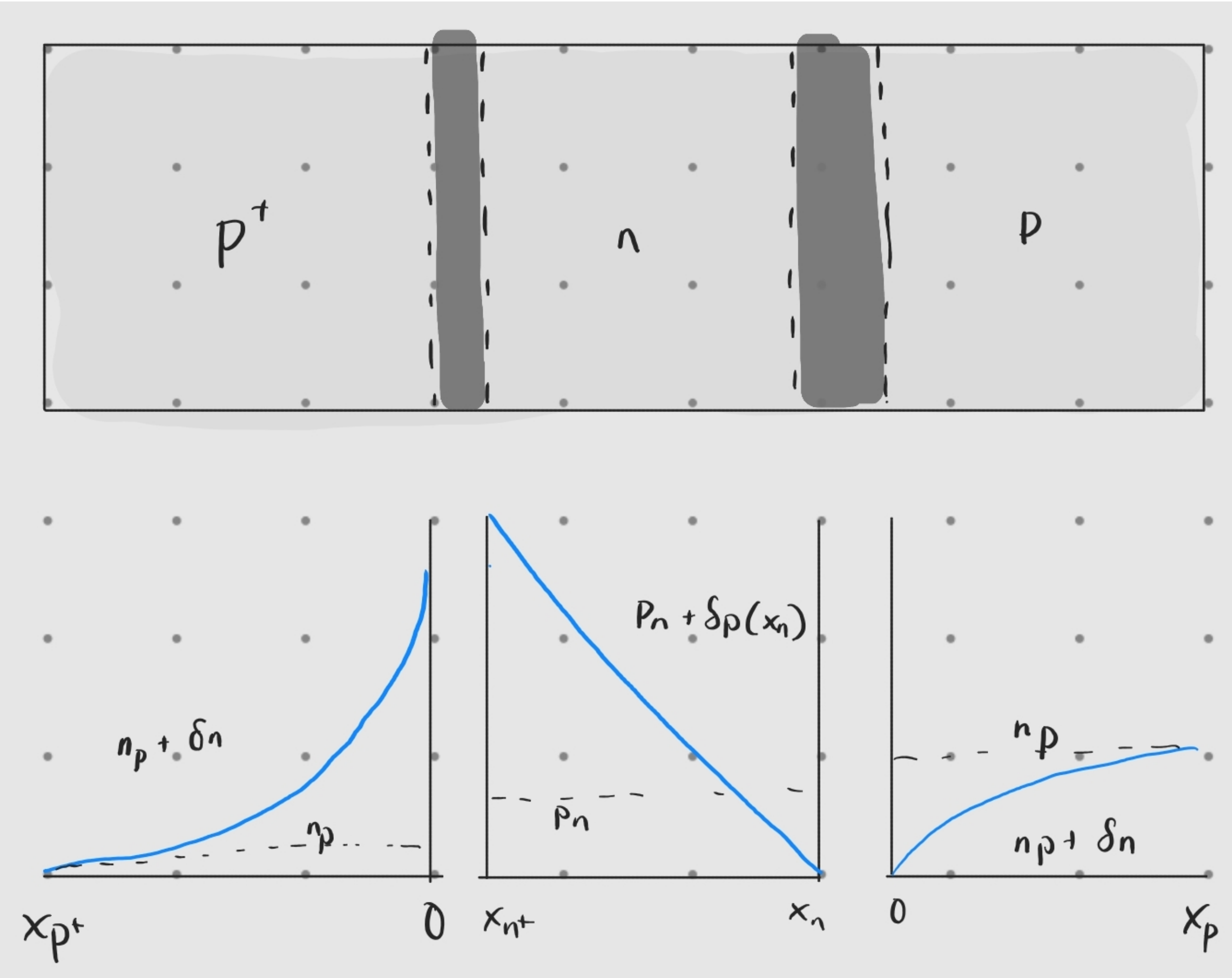

Figure 3: Minority carrier distribution

c) In the following, assume that the base current is mainly due to recombination in the base and that $W_b << L_p$ and $\Delta p_E >> p_n$. Use the charge control approach to find an expression for the base current (explain your reasoning).

The injected hole current at $x_n = 0$ needed to maintain the distribution is simply the total charge divided by the average time of replacement:

$$I_p\left(x_n=0\right)=\frac{Q_p}{\tau_p}=qA\frac{L_p}{\tau_p}\Delta p_n=qA\frac{D_p}{L_p}\Delta p_n$$

As the base current is mainly due to recombination in the base this gives us

d) The exact solution for the base current is

$$I_B=qA\frac{D_p}{L_p}\left[\left(\Delta p_E+\Delta p_C\right)\tanh\frac{W_B}{2L_p}\right] \tag{1}$$

For the same assumptions, show that equation (1) is to a first order approximation equal to the expression from c).