微电子器件第3次测试第1题（共3题）

假设某均匀基区NPN双极管共发射极电流放大系数$\beta \approx I_{NE}/I_{PE}$（不考虑发射结势垒区复合电流），简要证明此时对应的基区输运系数$\beta^*=1$。

$$\beta \approx \frac{I_{nE}}{I_{pE}}$$ 而根据定义有：$\beta = \frac{I_C}{I_B}$

$$\therefore 有：\frac{I_{nE}}{I_{pE}} = \frac{I_C}{I_B} \Rightarrow \frac{I_{nE}}{I_{pE} + I_{nE}} = \frac{I_C}{I_B + I_C}$$

$$即：\frac{I_{nE}}{I_E} = \frac{I_C}{I_E} \Rightarrow I_{nE} = I_C$$

$$\therefore \beta^* = \frac{I_{nE}}{I_C} = 1$$

$$\beta \approx \frac{I_{nE}}{I_{pE}}$$

$$\gamma = \frac{I_{nE}}{I_{nE} + I_{pE}} = \frac{1}{1+\frac{I_{pE}}{I_{nE}}} = \frac{1}{1+\frac{1}{\beta}} = \frac{\beta}{1+\beta} = \alpha$$

$$\because \alpha = \gamma \bullet \beta^*$$

$$\therefore \beta^* = 1$$

$$\beta \approx \frac{I_{nE}}{I_{PE}}$$

$$\beta = \frac{I_C}{I_B} = \frac{I_{nc}}{I_{pE} + I_{pr}} = \frac{I_{nE} - I_{nr}}{I_{pE} + I_{pr}} = \frac{I_{nE} - I_{nr}}{I_{pE} + I_{nr}}$$

$$\therefore \frac{I_{nE}}{I_{pE}} = \frac{I_{nE} - I_{nr}}{I_{pE} + I_{nr}}$$

$$\Rightarrow \frac{I_{nE} + I_{pE}}{I_{pE}} = \frac{I_{nE} + I_{pE}}{I_{pE} + I_{nr}}$$

$$\Rightarrow I_{nr} = 0 \Rightarrow I_{nE} = I_{nc} \Rightarrow \beta^* = 1$$

$$\beta \approx \frac{I_{nE}}{I_{pE}}$$

$$\beta = \frac{I_{nC}}{I_B}$$

$$\therefore 有 \frac{I_{nE}}{I_{pE}} = \frac{I_{nC}}{I_B} = \frac{I_{nE} \bullet \beta^*}{I_{pE} + I_{pr}} = \frac{I_{nE} \bullet \beta^*}{I_{pE} + I_{nE} \bullet (1 - \beta^*)}$$

$$\Rightarrow \frac{1}{I_{pE}} = \frac{\beta^*}{I_{pE} + I_{nE} \bullet (1 - \beta^*)}$$

$$\therefore I_{pE} + I_{nE} \bullet (1 - \beta^*) = I_{pE} \bullet \beta^*$$

$$\Rightarrow I_{pE} \bullet (1 - \beta^*) + I_{nE} \bullet (1 - \beta^*) = 0$$

$$\Rightarrow I_E \bullet (1 - \beta^*) = 0 \Rightarrow \beta^* = 1$$

$$\beta \approx \frac{I_{nE}}{I_{pE}} \qquad \beta = \frac{\alpha}{1-\alpha} = \frac{\beta^* \gamma}{1-\beta^* \gamma}$$

$$\gamma = \frac{I_{nE}}{I_{nE} + I_{pE}}$$

代入有：$\dfrac{I_{nE}}{I_{pE}} = \dfrac{\dfrac{\beta^* I_{nE}}{I_{nE}+I_{pE}}}{\left(1-\dfrac{\beta^* I_{nE}}{I_{nE}+I_{pE}}\right)}$

$\therefore$整理有：$\beta^* \dfrac{I_{pE}}{I_{nE}+I_{pE}} = 1 - \beta^* \dfrac{I_{nE}}{I_{nE}+I_{pE}}$

$$\Rightarrow \beta^* \left(\frac{I_{nE}+I_{pE}}{I_{nE}+I_{pE}}\right) = 1 \Rightarrow \beta^* = 1$$

微电子器件第3次测试第2题（共3题）

在某偏置于放大区的 **NPN** 晶体管中，从基区注入发射区的空穴电流为 **20μA**，基区中的复合电流为 **10μA**，共发射极电流放大系数 β 为 **200**。试求该晶体管的基极电流 I_B、发射极电流 I_E、集电极电流 I_C、发射结注入效率 γ 和基区输运系数 β^*。

NPN管有 $\begin{cases} I_{pE} = 20\mu A \\ I_{pr} = 10\mu A \end{cases}$

则有 $I_B = I_{pE} + I_{pr} = 30\mu A$

$I_C = \beta I_B = 200 \times 30 = 6000\mu A$

$I_E = I_B + I_C = 6030\mu A$

$I_{nE} = I_E - I_{pE} = 6030 - 20 = 6010\mu A$

$\gamma = \dfrac{I_{nE}}{I_E} = \dfrac{6010}{6030} = 0.9967$

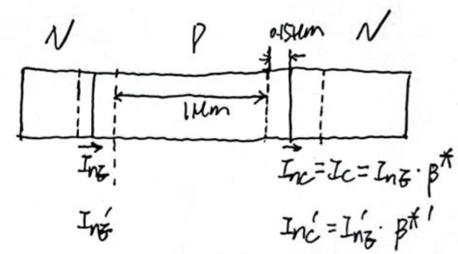
$\beta^* = \dfrac{I_C}{I_{nE}} = \dfrac{6000}{6010} = 0.9983$

微电子器件第3次测试第3题（共3题）

现有一NPN双极管工作于正向放大区，V_{BC}在-1v的时候基区中性区宽度1μm，集电结势垒区在基区一侧宽度为0.15μm，此时注入效率0.998，输运系数0.996，集电极电流1A，假设集电结内建电势为0.7v，发射结偏压不变。问当V_{BC}为-10v时，集电极电流为多少？

第3次测试第2题解答

解：经分析，此题与 r 无关.



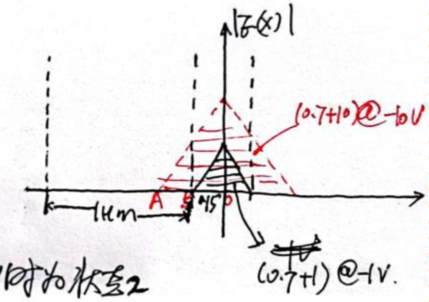
基本思路：

V_{BC}变化 → W_B变化 → $\left\{\begin{array}{l} I_{nE}\text{变化} \\ \beta^*\text{变化} \end{array}\right.$

设基区中性区复合占的权值为A.

有 $A = 1-\beta^* = \frac{1}{2}\frac{W_B^2}{L_B^2} \propto W_B^2$

而 $I_{nE} = \frac{qD_B}{W_B} A n_B(0) \propto \frac{1}{W_B}$



设 $V_{BC} = -1V$ 时为状态1，$V_{BC} = -10V$ 时为状态2

有 $W_{B1} = 1\mu m$，$W_{B2} = 1-|AB| = 1-(|AO|-|BO|)$

$= 1-\left(|BO|\cdot\left(\frac{0.7+10}{0.7+1}\right)^{\frac{1}{2}} - |BO|\right)$

$= 1- 0.15(2.5088-1)$

$= 1-(0.3763-0.15)$

$= 1-0.2263$

$= \boxed{0.7737\,\mu m}$

$\therefore \frac{A_2}{A_1} = \frac{W_{B2}^2}{W_{B1}^2} = \left(\frac{0.7737}{1}\right)^2 \Rightarrow A_2 = 0.7737^2 \times A_1 = 0.7737^2 \times (1-\beta_1^*)$

$= 0.5986 \times (1-0.996) = 0.00239445$

有 $\beta_2^* = 1-A_2 = 0.99761$

$\frac{I_{C2}}{I_{C1}} = \frac{I_{nE2}}{I_{nE1}}\cdot\frac{\beta_2^*}{\beta_1^*} = \frac{W_{B1}}{W_{B2}}\cdot\frac{\beta_2^*}{\beta_1^*} = \frac{1}{0.7737}\cdot\frac{0.99761}{0.996} = \boxed{1.2946}$

$\therefore \boxed{I_{C2} = 1.2946 \times 1 = 1.2946A}$

第二种方法：(最好不用这种方法)

$r \approx 1 - \frac{D_E W_B N_B}{D_B W_E N_E}$，假设对应损失占比重为B，有

$B = 1 - r = \frac{D_E W_B N_B}{D_B W_E N_E} \propto W_B$

$\therefore \frac{B_2}{B_1} = \frac{W_{B2}}{W_{B1}} \Rightarrow B_2 = B_1 \cdot \frac{W_{B2}}{W_{B1}} = (1-0.998) \times \frac{0.7737}{1} = 0.0015474$

$\therefore r_2 = 1 - B_2 = 0.9984526$

由 $r = \frac{I_{nE}}{I_E} = \frac{I_E - I_{pE}}{I_E} = 1 - \frac{I_{pE}}{I_E} \Rightarrow I_E = \frac{I_{pE}}{1-r}$

即由于 V_{BE} 恒定，W_E 也不变，$\therefore I_{pE}$ 恒定

$I_C = I_E \cdot \alpha = I_E \cdot \beta^* r = \frac{I_{pE}}{1-r} \cdot \beta^* \cdot r = I_{pE} \cdot \frac{r}{1-r} \cdot \beta^*$ ①

$\therefore$ 有 $\frac{I_{C2}}{I_{C1}} = \frac{I_{pE2} \cdot \frac{r_2}{1-r_2} \cdot \beta_2^*}{I_{pE1} \cdot \frac{r_1}{1-r_1} \cdot \beta_1^*}$ ② $= \frac{1 \cdot \frac{0.9984526}{1-0.9984526} \cdot 0.99761}{1 \cdot \frac{0.998}{1-0.998} \cdot 0.996}$

$= 1.29517 \Rightarrow \boxed{I_{C2} = 1.29517A}$

如果用精确的r公式，有 $r = \frac{1}{1 + \frac{D_E W_B N_B}{D_B W_E N_E}} = \frac{1}{1+C}$，其中 $C = \frac{D_E W_B N_B}{D_B W_E N_E}$

$r_1 = 0.998 = \frac{1}{1+C_1} \Rightarrow C_1 = \frac{1}{0.998} - 1 = 0.002004$

$\frac{C_2}{C_1} = \frac{W_{B2}}{W_{B1}} = 0.7737 \Rightarrow C_2 = 0.0015505$

$\Rightarrow r_2 = \frac{1}{1+C_2} = 0.998452$

代入②式有 $\frac{I_{C2}}{I_{C1}} = \frac{0.998452}{1-0.998452} \cdot 0.99761 \Big/ \frac{0.998}{1-0.998} \cdot 0.996 = 1.29466$

$\Rightarrow \boxed{I_{C2} = 1.29466A}$