ELE 222E INTRODUCTION TO ELECTRONICS (21604)
Midterm Exam #1 ✎ 19 March 2003 ⌚ 10.00-12.00

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SOLUTIONS w/<u>CORRECTIONS</u>

n	p
$\mu_n = 1350$ cm²/Vs $L_n = 10^{-2}$ cm $N_D = 10^{15}$ 1/cm³	$\mu_p = 480$ cm²/Vs $L_p = 2\ 10^{-3}$ cm

1. A Si diode in the making will have a junction are of 1 mm². n and p type doped areas will have the properties shown on the left.
<u>n_i = 1.5 10^{10} 1/cm³,</u> q = 1.602 10^{-19} C, V_T = 25 mV, ε_r = 12, ε_o = 8.85 10^{-12} F/m.

a. What should N_A be so that <u>$I_o \le 2{,}5$ pA</u> at room temperature? (15 points)

Using Einstein Eq. , i.e., $D_{p/n} = V_T \cdot \mu_{p/n}$, we find D_p = 12 cm²/s and D_n = 33.8 cm²/s. If $I_o = A \cdot q \cdot n_i^2 \cdot \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right] \le 2{,}5$ pA, then for $N_A \ge \dfrac{\frac{D_n}{L_n}}{I_o - Aqn_i^2 \frac{D_p}{L_p N_D}}$ = 10^{16} 1/cm³.

b. What should the widths of n and p type doped areas (d_n and d_p) be for bulk resistances to be R_n = 1 Ω and R_p = 0,25 Ω, respectively? (15 points)

HINT: $R_{n/p} = \rho_{n/p} \dfrac{d_{n/p}}{A} = \dfrac{1}{\sigma_{n/p}} \cdot \dfrac{d_{n/p}}{A}$ ALSO: You may neglect the width of the depletion layer.

We know $\sigma_p = q \cdot \left(\frac{n_i^2}{N_A} \mu_n + N_A \mu_p \right)$; $\sigma_n = q \cdot \left(N_D \mu_n + \frac{n_i^2}{N_D} \mu_p \right)$ Thus σ_p = 0,769 1/(Ω cm) and σ_n = 0,216 1/(Ω cm). Inserting these into the hint equation and reorganizing it we obtain $d_{n/p} = \sigma_{n/p} R_{n/p} A$. Thus d_n = 0,226 cm = 2,26 mm and d_p = 19,2 µm. OBSERVE THE DIFFERENCE IN LENGTHS OF n AND p TYPE DOPED REGIONS!!!!

c. Calculate the total depletion layer thickness and capacitance without any bias voltage applied to this junction. (10 points)

From $V_B = V_T \cdot \ln\left(\frac{N_A \cdot N_D}{n_i^2} \right)$ = 613 mV and $w_{dep} = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot V_B}{q} \left(\frac{1}{N_A} + \frac{1}{N_D} \right)}$ = 94.5 µm.

SEE THAT NEGLECTING THE WIDTH OF THE DEPLETION LAYER IN p TYPED REGION IN PART (a) HAS NOT BEEN A GOOD IDEA!!!!

Inserting the values into $C = \varepsilon_o \cdot \varepsilon_r \dfrac{A}{w}$ we obtain C = 112 pF.

2. Measurements taken on a variety of transistors are incomplete and possibly in error. The submitted data are given on the left. Provide missing data and correct for inconsistent and/or wrong data. (20 points)

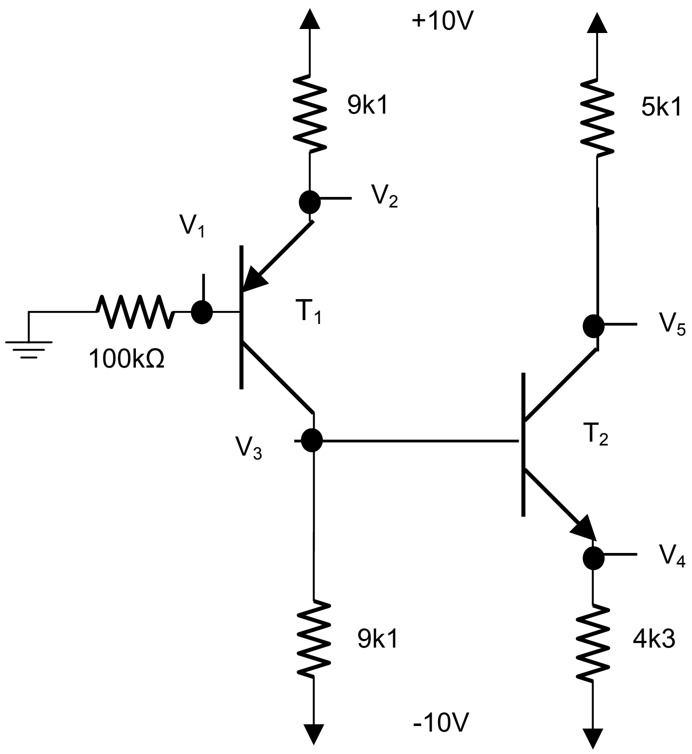
First remember a few definitions:

$I_E = (\beta + 1)\, I_B$
$I_C = \beta\, I_B$
$\alpha = I_C / I_E$

Device	I_C (mA)	I_B (mA)	I_E (mA)	α	β
1	2,0	0	2,0	1	∞
2	1,0	0,01	~~1,4~~ 1,01	0,99	100
3	0,5	0,0025	~~1,2~~ 0,51	0,98	200
4	0,8	~~0,08~~ 0	0,8	1	∞

Now look at the four devices:
1. Assume given data are correct. If $\beta = \infty$ then $I_C = I_E$ and thus $\alpha = 1$ and $I_B = 0$.
2. Assuming $I_C = 1$ mA and $\beta = 100$ are correct.
3. Assuming $I_C = 1$ mA, $\alpha = 0{,}98$ and $\beta = 200$ are correct.
4. Assuming $I_C = 0{,}8$ mA, and $\alpha = 1$ are correct.

3. For the circuits shown on the right, find the collector currents of both transistors ($|V_{BE}| = 0.6$ V), and the labelled node voltages (V_1, V_2, V_3, V_4 and V_5) for



a. $h_{FE} = \beta = \infty$ (20 points)

Automatically, V_1 = 0V and thus $V_2 = 0.6$ V.
$I_{E1} = (V_{CC}-V_2)/9k1 = 1{,}03$ mA.
THUS $I_{C1} = 1{,}03$ mA.
$V_3 = -V_{EE} + I_{C1} * 9k1 = -0{,}6$ V.
Therefore $V_4 = -1{,}2$ V.
$I_{E2} = (V_4 - V_{EE})/4k3 = 2{,}05$ mA.
THUS $I_{C2} = 2{,}05$ mA.
$V_5 = V_{CC} - I_{C2} * 5k1 = -0{,}45$ V.
This last value makes sure that T_2 is still in the active region because CB junction is reverse biased.

b. $h_{FE} = \beta = 100$ (20 points)

Direction 1: From ground over 100k to Vcc.

$I_{C1} = h_{FE} \cdot \dfrac{V_{CC} - (-V_{BE1})}{100k + h_{FE} 9k1}$ = 0,93 mA. $V_1 = I_{B1} * 100k = 0{,}93$ V and $V_2 = 1{,}53$ V.

Loop 2: From $-V_{EE}$ over C_1 to B_2 to E_2 to $-V_{EE}$.

$I_{C2} = h_{FE} \cdot \dfrac{9k1 * I_{C1} - V_{BE2}}{9k1 + (1 + h_{FE})4k3}$ = 1,77 mA. $V_3 = -V_{EE} + 9k1\,(I_{C1} - I_{B2}) = -1{,}70$ V.

Therefore $V_4 = -2{,}30$ V. $V_5 = V_{CC} - 5k1 * I_{C2} = 0{,}95$ V.