EMTR 1030 – Electronics

Assignment 2 reference solution

Problem 3.11

3.11 Holes are being steadily injected into a region of n-type silicon (connected to other devices, the details of which are not important for this question). In the steady state, the excess-hole concentration profile shown in Fig. P3.11 is established in the n-type silicon region at room temperature. Here "excess" means over and above the thermal-equilibrium concentration (in the absence of hole injection), denoted p_{n0}. If $N_D = 10^{16}/\text{cm}^3$, $n_i = 1.5 \times 10^{10}/\text{cm}^3$, $D_p = 12\ \text{cm}^2/\text{s}$, and $W = 50$ nm, find the density of the current that will flow in the x direction.

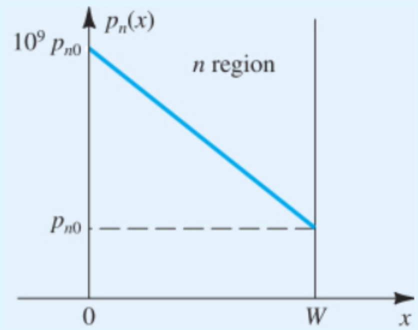


Figure P3.11

3.11

$$p_{n0} = \frac{n_i^2}{N_D} = \frac{(1.5 \times 10^{10})^2}{10^{16}} = 2.25 \times 10^4/\text{cm}^3$$

From Fig. P3.10,

$$\frac{dp}{dx} = -\frac{10^8 p_{n0} - p_{n0}}{W} \simeq -\frac{10^8 p_{n0}}{50 \times 10^{-7}}$$

since 1 nm $= 10^{-7}$ cm

$$\frac{dp}{dx} = -\frac{10^8 \times 2.25 \times 10^4}{50 \times 10^{-7}}$$

$$= -4.5 \times 10^{17}$$

Hence

$$J_p = -qD_p \frac{dp}{dx}$$

$$= -1.6 \times 10^{-19} \times 12 \times (-4.5 \times 10^{17})$$

$$= 0.864\ \text{A/cm}^2$$

Problem 3.14

(just calculate the junction built-in voltage)

3.14 If, for a particular junction, the acceptor concentration is $10^{17}/\text{cm}^3$ and the donor concentration is $10^{16}/\text{cm}^3$, find the junction built-in voltage. Assume $n_i = 1.5 \times 10^{10}/\text{cm}^3$. Also, find the width of the depletion region (W) and its extent in each of the p and n regions when the junction terminals are left open. Calculate the magnitude of the charge stored on either side of the junction. Assume that the junction area is 10 μm^2.

3.14 From Table 3.1,

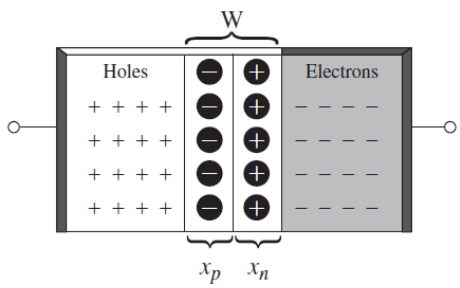
V_T at 300 K = 25.9 mV

Using Eq. (3.21), built-in voltage V_0 is obtained:

$$V_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) = 25.9 \times 10^{-3} \times$$

$$\ln\left(\frac{10^{17} \times 10^{16}}{(1.5 \times 10^{10})^2}\right)$$

$= 0.754$ V



Depletion width

$$W = \sqrt{\frac{2\epsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)V_0} \leftarrow \text{Eq. (3.25)}$$

$W =$

$$\sqrt{\frac{2 \times 1.04 \times 10^{-12}}{1.6 \times 10^{-19}}\left(\frac{1}{10^{17}} + \frac{1}{10^{16}}\right) \times 0.754}$$

$= 0.328 \times 10^{-4}$ cm $= 0.328\ \mu$m

Use Eqs. (3.26) and (3.27) to find x_n and x_p:

$$x_n = W\frac{N_A}{N_A + N_D} = 0.328 \times \frac{10^{17}}{10^{17} + 10^{16}}$$

$= 0.298\ \mu$m

$$x_p = W\frac{N_D}{N_A + N_D} = 0.328 \times \frac{10^{16}}{10^{17} + 10^{16}}$$

$= 0.03\ \mu$m

Use Eq. (3.28) to calculate charge stored on either side:

$$Q_J = Aq\left(\frac{N_A N_D}{N_A + N_D}\right)W, \text{ where junction area}$$

$A = 10\ \mu\text{m}^2 = 10 \times 10^{-8}\ \text{cm}^2$

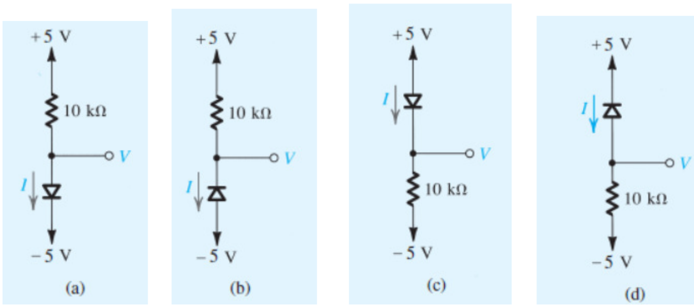
$$Q_J = 10 \times 10^{-8} \times 1.6 \times 10^{-19}\left(\frac{10^{17} \cdot 10^{16}}{10^{17} + 10^{16}}\right)$$

$$\times\ 0.328 \times 10^{-4}$$

Hence, $Q_J = 4.8 \times 10^{-13}$ C

<u>Problem 4.2</u>

4.2 For the circuits shown in Fig. P4.2(a), (b), (c), and (d) using ideal diodes, find the values of the voltages and currents indicated.



4.2 Refer to Fig. P4.2.

(a) Diode is conducting, thus

$V = -5$ V

$$I = \frac{+5-(-5)}{10\text{ k}\Omega} = 1.0\text{ mA}$$

(b) Diode is reverse biased, thus

$I = 0$

$V = +5$ V

(c) Diode is conducting, thus

$V = +5$ V

$$I = \frac{+5-(-5)}{10\text{ k}\Omega} = 1.0\text{ mA}$$

(d) Diode is reverse biased, thus

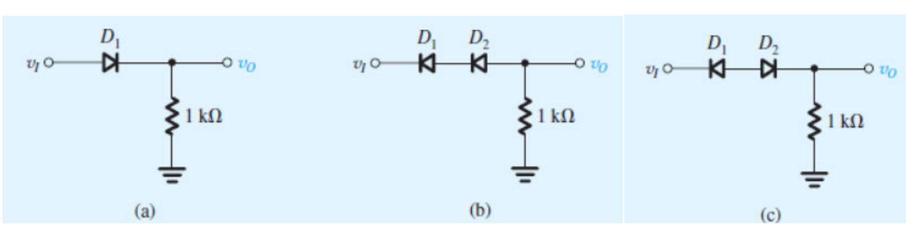
$I = 0$

$V = -5$ V

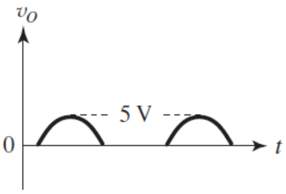
<u>Problem 4.4</u>

Questions (a), (b), (c) only.

4.4 In each of the ideal-diode circuits shown in Fig. P4.4(a), (b), (c), (d), (e), (f), (g), (h), (i), (j), and (k), v_I is a 1-kHz, 5-V peak sine wave. Sketch the waveform resulting at v_O. What are its positive and negative peak values?

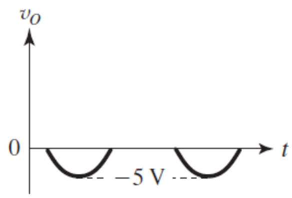


(a)



$V_{p+} = 5\text{ V} \quad V_{p-} = 0\text{ V} \quad f = 1\text{ kHz}$

(b)



$V_{p+} = 0\text{ V} \quad V_{p-} = -5\text{ V} \quad f = 1\text{ kHz}$

(c)

$v_O = 0\text{ V}$

Neither D_1 nor D_2 conducts, so there is no output.

Problem 4.20

4.20 A diode for which the forward voltage drop is 0.7 V at 1.0 mA is operated at 0.6 V. What is the value of the current?

4.20 $I_1 = I_S\, e^{0.7/V_T} = 10^{-3}$

$i_2 = I_S e^{0.6/V_T}$

$$\frac{i_2}{i_1} = \frac{i_2}{10^{-3}} = e^{\frac{0.6-0.7}{0.025}}$$

$i_2 = 18.3\ \mu\text{A}$

Problem 4.38

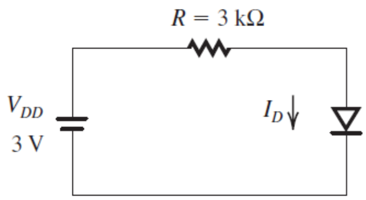
Questions (a), (b) only.

4.38 Consider the circuit in Fig. 4.10 with $V_{DD} = 3$ V and $R = 3$ kΩ.

(a) Find the current using a constant-voltage-drop model.

(b) What value of I_S is required to make this solution exact?

(c) Approximately how much will the current change from this value if I_S increases by a factor of 100?



a) $I_D = \frac{3 - 0.7}{3} = 0.767$ mA

b) $I_D = I_S e^{V_D/V_T} \Rightarrow I_S = I_D e^{-V_D/V_T}$

$I_S = 0.767 \times e^{-700/25} = 5.3 \times 10^{-16}$ A

c) I_S increases by a factor of 100

$$\Rightarrow \Delta V_D = V_T \left[\ln\left(\frac{I_D}{100 I_S}\right) - \ln\left(\frac{I_D}{I_S}\right) \right]$$
$$= -V_T \ln 100 = -115 \text{ mV}$$

$$\Rightarrow I_D = \frac{3 - (0.7 - 0.115)}{3} = \frac{3 - 0.585}{3}$$
$$= 0.805 \text{ mA}$$

We can iterate the anlysis to improve the accuracy. With $I_D = 0.805$ mA,

$$V_D = V_T \ln\left(\frac{I_D}{100 I_S}\right) =$$
$$25 \times \ln\left(\frac{0.805 \times 10^{-3}}{5.3 \times 10^{-14}}\right) = 586 \text{ mV}$$

This is almost identical to the value computed above. Thus, the current increases by $0.805 - 0.767 = 0.038$ mA $= 38$ μA.