ECE 255 ELECTRONIC ANALYSIS AND DESIGN Fall 2009

Homework 1 Solutions

Problem 1 (Text 2.12)

(a) A voltage of 5 V is applied across a 10 μm long region of silicon.

What is the electric field? $|\mathrm{E}| = \frac{Voltage}{Distance} = \frac{5\,\mathrm{V}}{10\,\mu\mathrm{m}} = 5000\ \frac{\mathrm{V}}{\mathrm{cm}}$

(b) Suppose the maximum field allowed in silicon is 10^5 V/cm. How large a voltage can be applied to a 10 μm long region of silicon? $\mathrm{V} = |\mathrm{E}| \times Distance = \left(10^5\,\frac{\mathrm{V}}{\mathrm{cm}}\right)(10\,\mu\mathrm{m}) = 100\ \mathrm{V}$

Problem 2 (Text 2.27)

Silicon is doped with $6\text{x}10^{18}$ boron atoms/cm^3.

(a) Is this *n*- or *p*- type silicon? Since boron is in group III of the periodic table, it is an acceptor $\Rightarrow$ $\mathrm{N_A} = 6\times10^{18}/\mathrm{cm}^3$

Assume $\mathrm{N_D} = 0$, since it is not specified. Therefore, the material is p-type.

(b) What are the electron and hole concentrations at room temperature?

At room temperature, $n_i \approx 10^{10}\,/\,\mathrm{cm}^3$ (text page 47) and $\mathrm{N_A} = 6\times10^{18}/\mathrm{cm}^3 \gg n_i$

Therefore, $p \approx 6\times10^{18}/\mathrm{cm}^3$ and $n \approx \frac{n_i^2}{p} = \frac{10^{20}/\mathrm{cm}^6}{6\times10^{18}/\mathrm{cm}^3} = 16.7/\mathrm{cm}^3$

(c) What are the electron and hole concentrations at 200°K?

At 200°K, $n_i^2 = B\mathrm{T}^3 e^{\frac{-\mathrm{E_G}}{k\mathrm{T}}} = 1.08x10^{31}(200)^3 e^{\left(\frac{-1.12}{8.62x10^{-5}(200)}\right)} = 5.28\times10^9/\mathrm{cm}^6$

Therefore, $p \approx 6\times10^{18}/\mathrm{cm}^3$ and $n \approx \frac{n_i^2}{p} = \frac{5.28\times10^9/\mathrm{cm}^6}{6\times10^{18}/\mathrm{cm}^3} = 8.80\times10^{-10}/\mathrm{cm}^3$

Problem 3 (Text 2.30)

Silicon is doped with $5\text{x}10^{17}$ boron atoms/cm^3 and $2\text{x}10^{17}$ phosphorus atoms/cm^3.

(a) Is this *n*- or *p*- type silicon? Boron is in group III and therefore an acceptor, while phosphorus is in group V and therefore a donor. $\mathrm{N_A} = 5\times10^{17}/\mathrm{cm}^3$ and $\mathrm{N_D} = 2\times10^{17}/\mathrm{cm}^3$

Since $\mathrm{N_A} > \mathrm{N_D}$, the material is p-type.

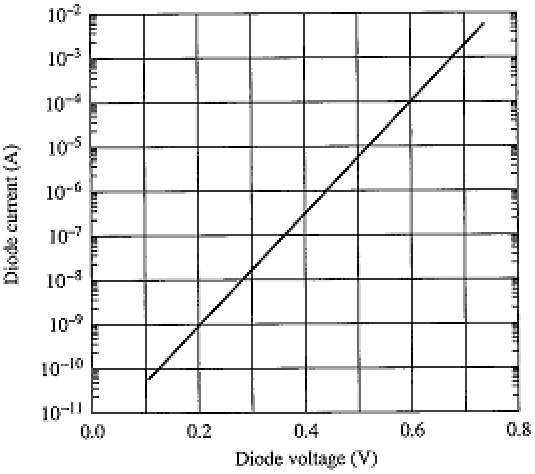
(b) What are the electron and hole concentrations at room temperature?

At room temperature, $n_i \approx 10^{10}/\mathrm{cm}^3$ and $\mathrm{N_A} - \mathrm{N_D} = 3\times10^{17}\,/\,\mathrm{cm}^3 >> 2n_i$

Consequently, $p \approx 3\times10^{17}/\mathrm{cm}^3$ and $n = \frac{n_i^2}{p} = \frac{10^{20}/\mathrm{cm}^6}{3\times10^{17}/\mathrm{cm}^3} = 333/\mathrm{cm}^3$

Problem 4 (Text 3.21)

What are the values of I_S and n for the diode in the graph below? Assume $V_T = 0.025$ V.



Since $I_D = I_S\left[e^{\left(\frac{V_D}{nV_T}\right)} - 1\right]$, pick two points; then you will have two equations in two unknowns.

The simultaneous solution to the two equations yields $n = 1.39$ and $I_S = 3.17 \times 10^{-12}$ A = 3.17 pA.

Problem 5

Based on the information in plot above, develop a D.C. diode model which will be exact at 100 μA and very accurate in the neighborhood of 100 μA. Show your method of solution (including calculations) and the resulting values for V_0 and R_0.

The slope at 100 μA is $\left.\frac{dI_D}{dV_D}\right|_Q = \left(\frac{1}{nV_T}\right) I_S e^{\left(\frac{V_D}{nV_T}\right)} = \left(\frac{1}{nV_T}\right)(I_D + I_S) \approx \frac{1}{1.39 \times 0.025\,\text{V}}(100\,\mu\text{A})$

Therefore, $R_0 = \frac{34.75\,\text{mV}}{100\,\mu\text{A}} = 348\,\Omega$ and

$$V_D = R_0 I_D + V_0 = 0.60\,\text{V} = 348\,\Omega \times 0.1\,\text{mA} + V_0 \Rightarrow V_0 = 0.565\,\text{V}$$

Problem 6 (Text 3.52)

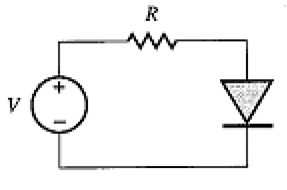
A *pn* diode has a resistivity 2 Ω-cm on the *p*-type side and 0.01 Ω-cm on the *n*-type side. What is the value of R_S for the diode if the cross-sectional area of the diode is 0.01 cm^2 and the length of the *p*- and *n*- sides of the diode are each 250 μm?

The series resistance R_S is the sum of the bulk resistance on the *n*-side, R_n, and *p*-side, R_p, of the junction. $R_n = \rho_n \frac{L_n}{A_n} = (0.01\,\Omega\text{-cm})\frac{0.025\,\text{cm}}{0.01\,\text{cm}^2} = 0.025\,\Omega$ and

$R_p = \rho_p \frac{L_p}{A_p} = (2\,\Omega\text{-cm})\frac{0.025\,\text{cm}}{0.01\,\text{cm}^2} = 5.0\,\Omega$ Therefore, $R_S = R_p + R_n = 5.03\,\Omega$

Problem 7 (Text 3.56)

(a) Plot the load line and find the *Q*-point for the diode circuit shown if V = 5 V and R = 10 kΩ. Use the *i-v* characteristic in Figure P3.41.



From KVL, $5\text{ V} = (10\text{ k}\Omega)\, I_D + V_D$

Load line axis intercepts are: $V_D = 0,\ I_D = 0.5\text{ mA}$

and $V_D = 5\text{V},\ I_D = 0$

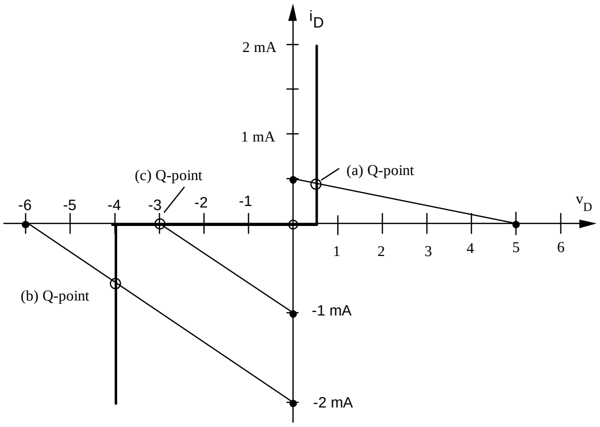
Q: $\{V_D = 0.5\text{ V},\ I_D = 0.45\text{ mA}\}$

(b) Repeat for $V = -6$ V and $R = 3$ kΩ

Q: $\{V_D = -4\text{ V},\ I_D = -0.667\text{ mA}\}$

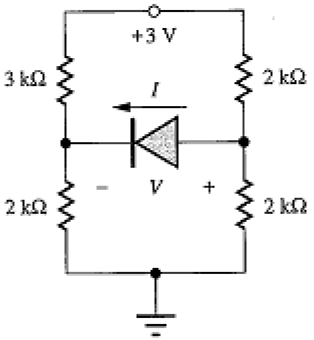
(c) Repeat for $V = -3$ V and $R = 3$ kΩ

Q: $\{V_D = -3\text{ V},\ I_D = 0\text{ mA}\}$



Problem 8 (Text 3.66)

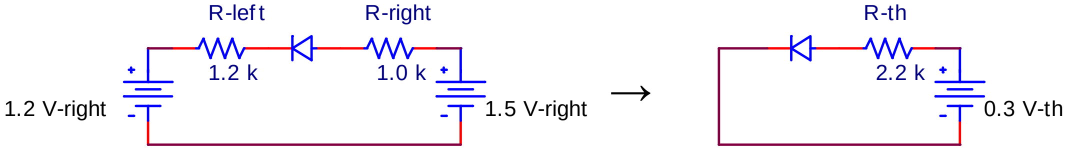
Find the *Q*-point for the diode in the circuit shown using:



(a) the ideal diode

The diode is clearly forward biased and therefore is modeled as a short circuit.

Using Thévenin equivalent circuits we can redraw the circuit as:



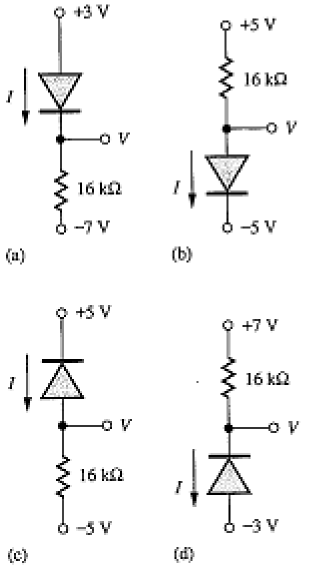
Therefore, *Q*: $\{V_D = 0,\ I_D = 0.136\text{ mA}\}$

(b) the constant voltage model with $V_{on} = 0.6$ V.

If we simply plug in the constant voltage model with $V_{on} = 0.6$ V, we find that $I_D = -0.136$ mA which inconsistent with our assumption that the diode is "on". Thus the diode model must be "off". Consequently, *Q*: $\{V_D = 0.3\text{ V},\ I_D = 0\}$

(c) Which answer do you feel is most correct? Neither are very good! The second estimate is a bit better since 0.3 V is not sufficient to forward bias the diode into significant conduction.

Problem 9 (Text 3.69)



(a) Find I and V in the four circuits shown using the ideal diode model.

(a) Diode forward biased, *Q*: $\{V_D = 0\text{ V},\ I_D = ?\}$

$$I_D = \frac{10\text{ V}}{16\text{ k}\Omega} = .625\text{ mA} \quad \therefore \quad V = 3\text{ V} \qquad \text{and} \qquad I = 0.625\text{ mA}$$

(b) Diode forward biased $\therefore$ $V = -5$ V and $I = 0.625$ mA

(c) Diode reverse biased $\therefore$ $V = -5$ V and $I = 0$

(d) Diode reverse biased $\therefore$ $V = 7$ V and $I = 0$

(b) Repeat using the constant voltage model with $V_{on} = 0.7$ V.

(a) Diode forward biased, so $I_D = \dfrac{(10-0.7)\,\text{V}}{16\,\text{k}\Omega} = .581\,\text{mA}$

∴ V = 2.3 V and I = 0.581 mA

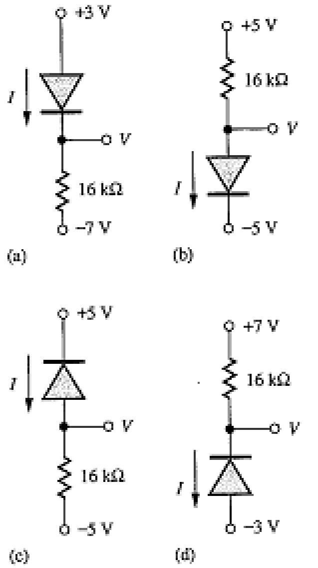
(b) Diode forward biased ∴ V = –4.3 V and I = 0.581 mA

(c) Diode reverse biased ∴ V = –5 V and I = 0

(d) Diode reverse biased ∴ V = 7 V and I = 0

Problem 10

Continue the previous using a diode model with $V_0 = 0.6$ V and $R_0 = 200\ \Omega$.



(a) Diode forward biased, *Q*: {V_D = ?, I_D = ?}

$$I_D = \frac{(10-0.6)\,\text{V}}{(16+0.2)\,\text{k}\Omega} = 0.580\,\text{mA}$$

and $V_D = 0.6\,\text{V} + 200\,\Omega \times I_D = 0.716\,\text{V}$

so *Q*: {V_D = 0.716 V, I_D = 0.580 mA}

Therefore: V = 2.284 V and I = 0.580 mA

(b) Diode forward biased ∴ V = –4.284 V and I = 0.580 mA

(c) Diode reverse biased ∴ V = –5 V and I = 0

(d) Diode forward biased ∴ V = 7 V and I = 0