Homework #6

Problems 3.12, 3.13, 3.17, 3.21, and 3.24

Problem 3.12

Calculate the built-in voltage of a junction in which the *p* and *n* regions are doped equally with 5×10^{16} atoms/cm^3. Assume $n_i = 1.5 \times 10^{10}$/cm^3 . With the terminals left open, what is the width of the depletion region, and how far does it extend into the *p* and *n* regions? If the cross-sectional area of the junction is 20 μm^2, find the magnitude of the charge stored on either side of the junction.

$$N_A := 5 \cdot 10^{16} \cdot \frac{1}{\text{cm}^3} \qquad N_D := 5 \cdot 10^{16} \cdot \frac{1}{\text{cm}^3} \qquad n_i := 1.5 \cdot 10^{10} \cdot \frac{1}{\text{cm}^3}$$

$$V_T = 25.9\ \text{mV} \qquad V_0 := V_T \cdot \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right) = 0.778 \cdot \text{V}$$

$$\varepsilon_{Si} := 11.7 \cdot \varepsilon_0 \qquad Width := \sqrt{\frac{2 \cdot \varepsilon_{Si}}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right) \cdot V_0} = 200.6 \cdot \text{nm}$$

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$$Width := \sqrt{\frac{2\cdot\varepsilon_{Si}}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\cdot V_0} = 200.6\cdot\text{nm}$$

$$x_n := Width\cdot\frac{N_A}{N_A+N_D} = 100.3\cdot\text{nm} \qquad x_p := Width\cdot\frac{N_D}{N_A+N_D} = 100.3\cdot\text{nm}$$

$$Area := 20\mu m^2 \qquad Q_J := Area\cdot q\cdot\left(\frac{N_A\cdot N_D}{N_A+N_D}\right)\cdot Width = 1.607\times10^{-14}\cdot\text{C}$$

$$Q_J = 16.07\cdot\text{fC}$$

Problem 3.13

If, for a particular junction. the acceptor concentration $10^{17}/\text{cm}^3$ 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 100 μm².

$$N_A := 1\cdot 10^{17}\cdot\frac{1}{\text{cm}^3} \qquad N_D := 1\cdot 10^{16}\cdot\frac{1}{\text{cm}^3} \qquad n_i := 1.5\cdot 10^{10}\cdot\frac{1}{\text{cm}^3}$$

$$V_T = 25.9\ \text{mV} \qquad V_0 := V_T\cdot \ln\left(\frac{N_A\cdot N_D}{n_i^{\,2}}\right) = 754.3\cdot\text{mV}$$

$$\varepsilon_{Si} := 11.7\cdot\varepsilon_0 \qquad Width := \sqrt{\frac{2\cdot\varepsilon_{Si}}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\cdot V_0} = 327.6\cdot\text{nm}$$

Problem 3.13

If, for a particular junction. the acceptor concentration $10^{17}/\text{cm}^3$ 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 $100\ \mu\text{m}^2$.

$$Width := \sqrt{\frac{2\cdot\varepsilon_{Si}}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\cdot V_0} = 327.6\cdot\text{nm}$$

$$x_n := Width\cdot\frac{N_A}{N_A+N_D} = 297.8\cdot\text{nm} \qquad x_p := Width\cdot\frac{N_D}{N_A+N_D} = 29.8\cdot\text{nm}$$

$$Area := 100\mu\text{m}^2 \qquad Q_J := Area\cdot q\cdot\left(\frac{N_A\cdot N_D}{N_A+N_D}\right)\cdot Width = 4.771\times10^{-14}\cdot\text{C}$$

$$Q_J = 47.707\cdot\text{fC}$$

Problem 3.17

If a 3-V reverse-bias voltage is applied across the junction specified in Problem 3.13, find *W* and Q_J.

$$V_R := 3\text{V}$$

$$V_0 := V_T \cdot ln\left(\frac{N_A \cdot N_D}{n_i^{\,2}}\right) = 754.3 \cdot \text{mV}$$

$$Width := \sqrt{\frac{2 \cdot \varepsilon_{Si}}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right) \cdot \left(V_0 + V_R\right)} = 730.8 \cdot \text{nm}$$

$$Q_J := Area \cdot q \cdot \left(\frac{N_A \cdot N_D}{N_A + N_D}\right) \cdot Width = 1.064 \times 10^{-13} \cdot \text{C}$$

$$Q_J := Area \cdot \sqrt{2 \cdot \varepsilon_{Si} \cdot q \cdot \left(\frac{N_A \cdot N_D}{N_A + N_D}\right) \cdot \left(V_0 + V_R\right)} = 1.064 \times 10^{-13} \cdot \text{C}$$

Problem 3.21

Assuming that the temperature dependence of I_s arises mostly because I_s is proportional to n_i^2, use the expression for n_i in Eq. (3.2) to determine the factor by which n_i^2 changes as T changes from 300 K to 305 K. This will be approximately the same factor by which I_s changes for a 5 °C rise in temperature. What is the factor?

$$B := 7.3 \cdot 10^{15} cm^{-3} K^{\frac{-3}{2}} \qquad k_b := 8.62 \cdot 10^{-5} \frac{eV}{K} \qquad E_g := 1.12 \cdot eV$$

$$n_i(Temp) := B \cdot Temp^{\frac{3}{2}} e^{\frac{-E_g}{2 \cdot k_b \cdot Temp}}$$

$$n_i(300\,K) = 1.494 \times 10^{10} \frac{1}{\text{cm}^3}$$

$$\frac{n_i(305K)^2}{n_i(300K)^2} = 2.137$$

$$n_i(305\,K) = 2.184 \times 10^{10} \frac{1}{\text{cm}^3}$$

Problem 3.24

For the *pn* junction specified in Problem 3.13, find C_{j0} and C_j at $V_R = 3$ V.

$$N_A := 1\cdot 10^{17}\cdot\frac{1}{\text{cm}^3} \qquad N_D := 1\cdot 10^{16}\cdot\frac{1}{\text{cm}^3} \qquad V_0 := V_T\cdot ln\left(\frac{N_A\cdot N_D}{n_i^{\,2}}\right) = 754.3\cdot\text{mV}$$

$$C_{j0} := Area\cdot\sqrt{\frac{\varepsilon_{Si}\cdot q}{2}\cdot\left(\frac{N_A\cdot N_D}{N_A+N_D}\right)\cdot\frac{1}{V_0}} = 31.624\cdot\text{fF}$$

$$V_R := 3V \qquad C_j := \frac{C_{j0}}{\sqrt{1+\frac{V_R}{V_0}}} = 14.175\cdot\text{fF}$$