ELECTRONIC DEVICES
ASSIGNMENT 3

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Exercise 1.
A silicon PN junction maintained at $T = 300\,\mathrm{K}$ has doping profile

$$N_D - N_A = N_0 \left(1 - e^{-\alpha x}\right)$$

where N_0 and α are constant.

(1) Sketch the charge density as a function of x.
(2) Establish an expression for the field distribution as a function of position x.

Solution 1.
(1)

$$\begin{aligned}\rho(x) &= q(N_D - N_A) \\ &= qN_0 \left(1 - e^{-\alpha x}\right)\end{aligned}$$

(2)

$$\begin{aligned}\mathcal{E}(x) &= \int \frac{\rho(x)}{\varepsilon\varepsilon_0} \,\mathrm{d}x \\ &= \frac{qN_0}{\varepsilon\varepsilon_0} \int \left(1 - e^{-\alpha x}\right) \mathrm{d}x \\ &= \frac{qN_0}{\varepsilon\varepsilon_0} \left(x + \frac{e^{-\alpha x}}{\alpha} + c\right)\end{aligned}$$

At the boundaries of the depletion region,

$$\begin{aligned}\mathcal{E}(-x_p) &= 0 \\ \mathcal{E}(x_n) &= 0\end{aligned}$$

Therefore,

$$\begin{aligned}0 &= \frac{qN_0}{\varepsilon\varepsilon_0} \left(-x_p + \frac{e^{\alpha x_p}}{\alpha} + c\right) \\ \therefore x &= x_p - \frac{e^{\alpha x_p}}{\alpha}\end{aligned}$$

Therefore,

$$\mathcal{E}(x) = \frac{qN_0}{\varepsilon\varepsilon_0} \left(x + \frac{e^{-\alpha x}}{\alpha} + x_p - \frac{e^{\alpha x_p}}{\alpha}\right)$$

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Exercise 2.
Consider a silicon PN step junction with

$$N_A = 5 \times 10^{15}\text{cm}^{-3}$$
$$N_D = 10^{14}\text{cm}^{-3}$$

maintained at $T = 300\,\text{K}$.

(1) Calculate V_{BI}, x_n, and x_p at zero applied bias.
(2) To increase x_n beyond the equilibrium value found above, what polarity of voltage should be applied? Sketch the PN junction, showing the applied bias, specifically which polarity is applied to each side.
(3) Calculate the required bias for $x_n = 30\text{µm}$.
(4) Sketch the energy band diagram for the above bias.
(5) Calculate x_n for the magnitude of applied voltage calculated above divided by 200 with the opposite polarity.
(6) Sketch the energy band diagram for the above bias.
(7) On the same plot above, sketch the electric field across the device for all three cases: $V = 0$, $V > 0$, and $V < 0$. On the plot, indicate the areas under the electric field curve that correspond to V_{BI}, V_{forward}, and V_{reverse}.

Solution 2.
(1) As the junction is a step junction,

$$\begin{aligned} V_{BI} &= \frac{kT}{q} \ln\left(\frac{N_A N_D}{{n_i}^2}\right) \\ &= \frac{kT}{q} \ln\left(\frac{5 \times 10^{29}}{10^{20}}\right) \\ &= \frac{kT}{q} \ln\left(5 \times 10^{9}\right) \\ &= (0.0257)(22.33270375) \\ &= 0.5739504864\,\text{V} \end{aligned}$$

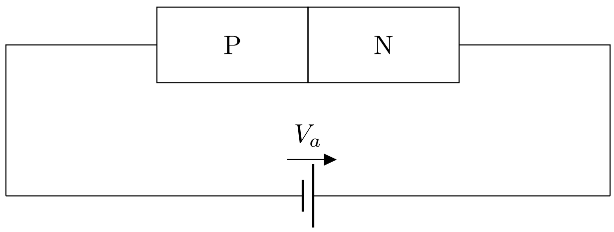
Therefore,

$$\begin{aligned} W &= \sqrt{\frac{2\varepsilon\varepsilon_0 V_{\text{BI}}}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)} \\ &= \sqrt{\frac{(2)(11.8)\left(8.85 \times 10^{-14}\right)(0.574)}{q}\left(\frac{51 \times 10^{14}}{5 \times 10^{29}}\right)} \\ &= 2.76455 \times 10^{-4}\text{cm} \\ &= 2.76455\text{µm} \end{aligned}$$

Therefore,

$$\begin{aligned}
x_p &= W\frac{N_D}{N_A+N_D} \\
&= 2.76455\frac{10^{14}}{51\times 10^{14}} \\
&= 5.42068\times 10^{-6}\text{cm} \\
&= 0.0542068\text{µm} \\
x_n &= W\frac{N_A}{N_A+N_D} \\
&= 2.76455\frac{50\times 10^{14}}{51\times 10^{14}} \\
&= 2.71034\times 10^{-4}\text{cm} \\
&= 2.71034\text{µm}
\end{aligned}$$

(2) The width of the depletion region increases if the PN junction is in reverse bias. Therefore, the voltage should connected as shown.



(3)

$$\begin{aligned}
\frac{x_p}{x_n} &= \frac{N_D}{N_A} \\
&= \frac{10^{14}}{5\times 10^{15}} \\
&= \frac{1}{50} \\
&= 0.02 \\
\therefore x_p &= 0.02x_n
\end{aligned}$$

Therefore,

$$\begin{aligned}
W &= x_p + x_n \\
&= 1.02x_n
\end{aligned}$$

Therefore, for $x_n = 30\text{µm}$,

$$\begin{aligned}
W &= (1.02)(30) \\
&= 30.6\text{µm}
\end{aligned}$$

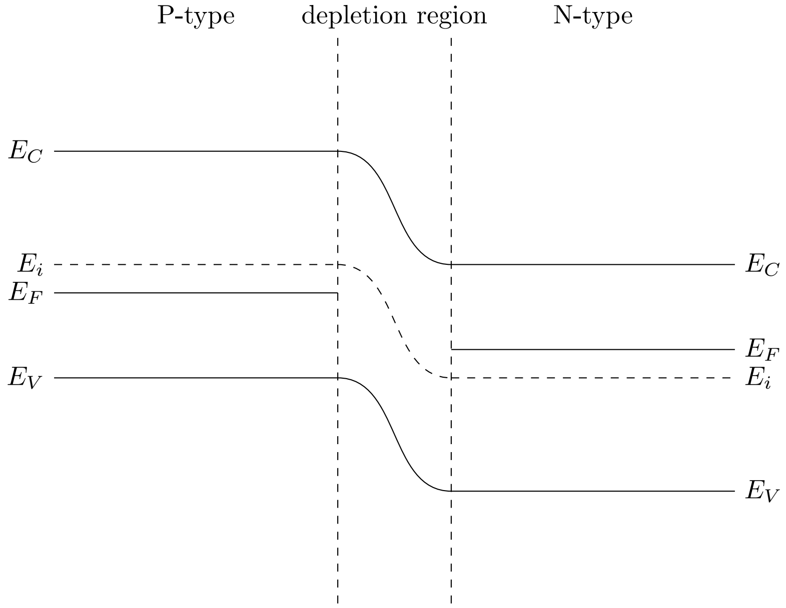
Therefore,

$$\begin{aligned}
W &= \sqrt{\frac{2\varepsilon\varepsilon_0(V_{\text{BI}}+V_a)}{q}\left(\frac{N_A+N_D}{N_AN_D}\right)} \\
30.6 &= \sqrt{\frac{(2)(11.8)\left(8.85\times 10^{-14}\right)(0.574+V_a)}{q}\left(\frac{51\times 10^{14}}{5\times 10^{29}}\right)}
\end{aligned}$$

Therefore, solving,

$$V_a = -0.566968\,\mathrm{V}$$

(4)



(5)

$$\begin{aligned} V_a &= -\frac{0.566968}{200} \\ &= 0.00283484 \end{aligned}$$

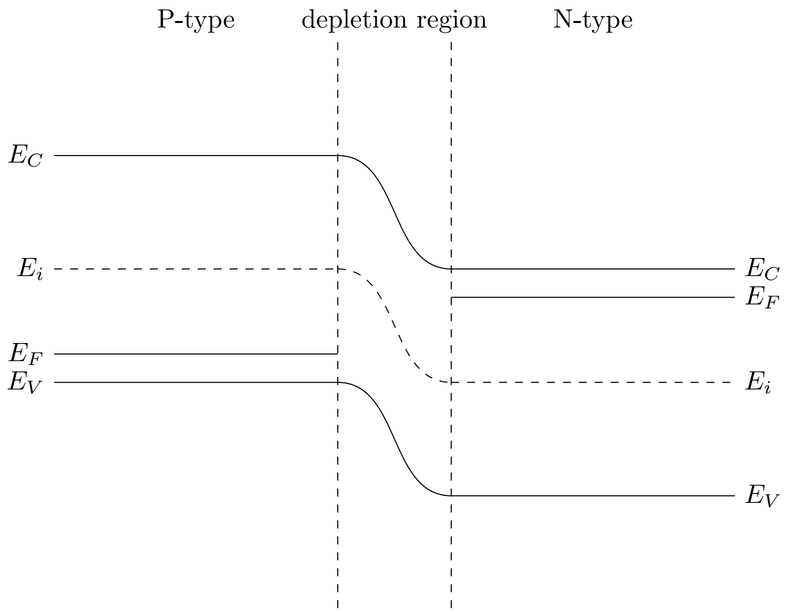
Therefore,

$$\begin{aligned} W &= \sqrt{\frac{2\varepsilon\varepsilon_0(V_{\mathrm{BI}} + V_a)}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)} \\ &= 0.000277136\mathrm{cm} \\ &= 2.77136\mathrm{\mu m} \end{aligned}$$

Therefore,

$$\begin{aligned} x_n &= W\frac{N_A}{N_A + N_D} \\ &= 2.71702\mathrm{\mu m} \end{aligned}$$

(6)



(7) The electric fields corresponding to the biases are as shown. The areas under the curves represent the corresponding voltages.