P1

A silicon P-N junction diode is fabricated with the following parameters: $N_A = 10^{16}\text{cm}^{-3}, N_D = 10^{15}\text{cm}^{-3}$. The intrinsic carrier concentration is $n_i = 1.5 * 10^{10}\text{cm}^{-3}$ at 300K, and the electron and hole mobility are $\mu_n = 1350\text{cm}^2/V, \mu_p = 480\text{cm}^2/(V \cdot s)$ respectively. Junction cross area is 0.01cm^2; the electron lifetime in the p-region is $\tau_n = 1\mu s$, the hole lifetime in the n-region is $\tau_p = 2\mu s$.

1. Calculate the diffusion coefficient for electron and hole (based on Einstein's relation)
2. calculate the building voltage across the depletion region
3. calculate the current at biases including: $-0.1V, 0.3V, 0.7V$

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1. For electrons,

$$D_n = \mu_n \frac{kT}{q} = 1350\text{cm}^2/V \cdot s * 25.85\text{mV} = \boxed{34.898\text{cm}^2/s.} \tag{1}$$

   For holes,

$$D_p = \mu_p \frac{kT}{q} = 480\text{cm}^2/V \cdot s * 25.85\text{mV} = \boxed{12.408\text{cm}^2/s.} \tag{2}$$

2. $$V_{\text{bi}} = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) = 25.85\text{mV} \ln\left(\frac{10^{16} 10^{15}}{(1.5 * 10^{10})^2}\right) \boxed{= 0.644V.} \tag{3}$$

3. recall

$$\begin{gathered} I = I_s\left(\exp\left(\frac{V_a}{V_T}\right) - 1\right), \\ \text{where } I_s = Aqn_i^2\left(\frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D}\right), \\ \text{and } L_n = \sqrt{D_n \tau_n}, \quad L_p = \sqrt{D_p \tau_p}. \end{gathered} \tag{4}$$

So,

$$\begin{aligned} L_n &= \sqrt{34.898\text{cm}^2/s * 1\mu s} = 5.907 * 10^{-3} \text{ cm}, \\ L_p &= \sqrt{12.408\text{cm}^2/s * 2\mu s} = 4.981 * 10^{-3} \text{ cm}, \end{aligned} \tag{5}$$

$$\begin{aligned} \Rightarrow I_s = {} & 0.01\text{cm}^2 * 1.6 * 10^{-19} C * (1.5 * 10^{10}\text{cm}^{-3})^2 \\ & \left(\frac{34.898\text{cm}^2/s}{5.907 * 10^{-3}\text{cm} * 10^{16}\text{cm}^{-3}} + \frac{12.408\text{cm}^2}{4.981 * 10^{-3} \text{ cm} * 10^{15}\text{cm}^{-3}}\right) \\ = {} & 1.11 * 10^{-12} A. \end{aligned} \tag{6}$$

From which we can find the current given the bias voltage.

$$\begin{aligned} I(-0.1V) &= 1.11 * 10^{-12}\left(\exp\left(-\frac{0.1}{0.02585}\right) - 1\right) = \boxed{-1.09 * 10^{-12} A} \\ I(0.3V) &= 1.11 * 10^{-12}\left(\exp\left(\frac{0.3}{0.02585}\right) - 1\right) = \boxed{1.22 * 10^{-7} A} \\ I(0.7V) &= 1.11 * 10^{-12}\left(\exp\left(\frac{0.7}{0.02585}\right) - 1\right) = \boxed{0.645A}. \end{aligned} \tag{7}$$