Problem Solutions

Chapter Three: Diodes

P3.1. Consider a p-n junction diode with negligible series resistance. The voltage drop is 0.7 V with a forward current of 5 mA. Determine the reverse saturation current for the case of

a. a unity emission coefficient; and

b. an emission coefficient of 1.3.

Solution.

a. With N = 1,

$$I_S = I\exp\left(-\frac{V}{NkT/q}\right) = (0.005A)\exp\left(-\frac{0.7V}{26mV}\right) = 1.01\times10^{-14}A$$

b. With N = 1.3,

$$I_S = I\exp\left(-\frac{V}{NkT/q}\right) = (0.005A)\exp\left(-\frac{0.7V}{(1.3)(26mV)}\right) = 5.1\times10^{-12}A$$

P3.2. Consider diodes with unity emission coefficients and negligible series resistance. Determine the reverse saturation current for

a. a p-n junction which exhibits a voltage drop of 0.7 V at a forward current of 1 mA; and

b. a Schottky diode which exhibits a voltage drop of 0.3 V at a forward current of 1 mA.

Solution.

a. For the p-n junction, assuming room temperature and a unity emission coefficient,

$$I_S = \left(10^{-3}\,A\right)\exp\left(-\,0.7V/0.026V\right) = 2.0\times10^{-15}\,A$$

b. For the Schottky diode, assuming room temperature and a unity emission coefficient,

$$I_S = \left(10^{-3}\,A\right)\exp\left(-\,0.3V/0.026V\right) = 9.7\times10^{-9}\,A$$

P3.3. Suppose a diode has a unity emission coefficient. Determine the change in the forward bias voltage which will cause a ten-fold increase in the forward current.

Solution. Using the diode equation,

$$10 = \frac{I_S e^{qV_2/kT}}{I_S e^{qV_1/kT}}.$$

Solving,

$$\Delta V = V_2 - V_1 = \frac{kT}{q}\ln(10) = 60mV.$$

P3.4. Consider a Si p$^+$-n junction at 300 K with $N_a = 10^{18}$ cm^{-3} and $N_d = 10^{16}$ cm^{-3}. The junction area is 10^{-5} cm^2. Determine

a. the built-in potential;

b. the zero-bias depletion width; and

c. the zero-bias depletion capacitance.

Solution.

a. The built-in potential is

$$V_{bi} = \frac{kT}{q}\ln\left[\frac{\left(10^{18}\,cm^{-3}\right)\left(10^{16}\,cm^{-3}\right)}{\left(1.45\times10^{10}\,cm^{-3}\right)^2}\right] = 0.82V$$

b. The zero-bias depletion width is

$$W = \sqrt{\frac{2(11.9)(8.85\times10^{-14}\,F/cm)(0.82V)}{(1.602\times10^{-19}\,C)(10^{16}\,cm^{-3})}} = 0.33\mu m.$$

c. The zero-bias depletion capacitance is

$$C_0 = \frac{(11.9)(8.85\times10^{-14}\,F/cm)(10^{-5}\,cm^2)}{0.33\times10^{-4}\,cm} = 0.32pF.$$

P3.5. Consider a Si p^+-n junction at 300 K with $N_a = 2 \times 10^{18}$ cm^{-3} and $N_d = 10^{16}$ cm^{-3}. The junction area is $3.2\times10^{-6}\,cm^2$. Determine and plot $1/C^2$ versus the reverse bias voltage.

Solution. The built-in potential is

$$V_{bi} = \frac{kT}{q}\ln\left[\frac{(10^{18}\,cm^{-3})(10^{16}\,cm^{-3})}{(1.45\times10^{10}\,cm^{-3})^2}\right] = 0.82V.$$

The depletion width with a reverse bias V_r is given by

$$W = \sqrt{\frac{2(11.9)(8.85\times10^{-14}\,F/cm)(0.82V+V_r)}{(1.602\times10^{-19}\,C)(10^{16}\,cm^{-3})}} = 0.33\mu m\sqrt{1+V_r/0.82V}.$$

The depletion capacitance with a reverse bias V_r is given by

$$C = \frac{\varepsilon A}{W} = \frac{(11.9)(8.85\times10^{-14}\,F/cm)(3.2\times10^{-6}\,cm^2)}{0.33\times10^{-4}\,cm\sqrt{1+V_r/0.82V}} = \frac{0.102pF}{\sqrt{1+V_r/0.82V}}.$$

The results are plotted in Figure 3.20.

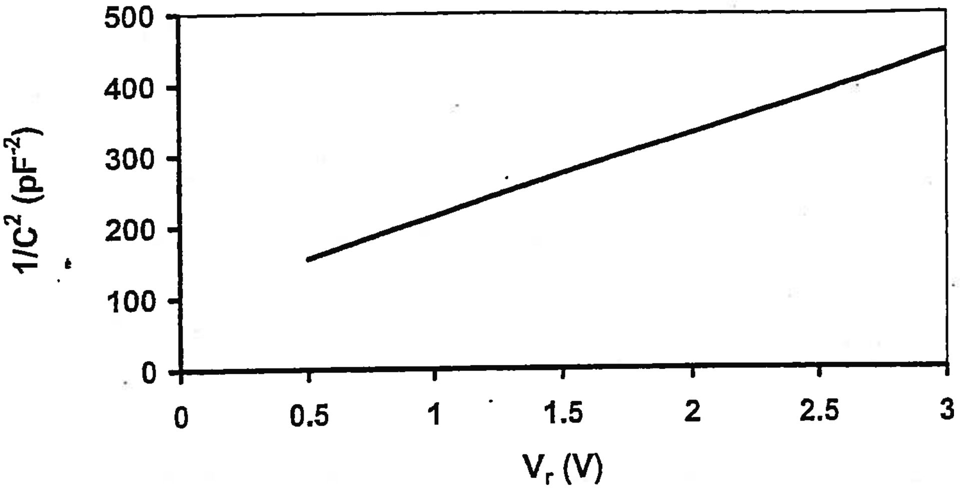

Figure 3.20.

P3.6. Consider the p-n junction shown in Figure 3.19. T = 300K.

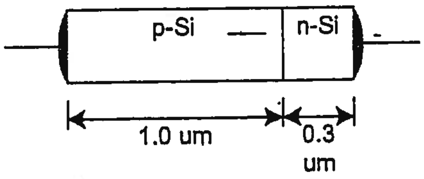

Figure 3.19.

The material parameters are given in Table 3.3, and the junction area is 10^{-5} cm^2.

Table 3.3.

p-Si	n-Si
$N_a = 10^{15} cm^{-3}$	$N_d = 10^{18} cm^{-3}$
$D_n = 25 cm^2 s^{-1}$	$D_p = 8 cm^2 s^{-1}$
$\tau_n = 20 ns$	$\tau_p = 3 ns$

a. Determine the reverse saturation current.

b. Determine the bias voltage at a forward current of 1 mA, assuming the emission coefficient is unity.

Solution. This is an n^+-p junction, so the conduction will be dominated by the injection of electrons into the quasi neutral p-type region. The diffusivity for electrons on the p-type side is given to be $D_{np} = 25 cm^2 s^{-1}$. Therefore the minority carrier diffusion length is

$$L_{np} = \sqrt{D_{np}\tau_{np}} = \sqrt{(25cm^2 s^{-1})(20ns)} = 7.1\mu m.$$

Therefore $L_{np} >> W_B$ and this is a short base diode.

a. The reverse saturation current is given by

$$I_S \approx \frac{qAD_n n_i^2}{N_a W_B}$$

$$= \frac{(1.6\times10^{-19}C)(10^{-5}cm^2)(25cm^2V^{-1}s^{-1})(1.45\times10^{10}cm^{-3})^2}{(10^{15}cm^{-3})(10^{-4}cm)} = 8.4\times10^{-14}A$$

b. The bias voltage which will result in 1 mA of forward current is

$$V = \frac{kT}{q}\ln\left(\frac{I}{I_S}\right) = 0.026V\ln\left(\frac{10^{-3}A}{8.4\times10^{-14}A}\right) = 0.60V$$