

**8.39** Consider a p<sup>+</sup>n silicon diode at  $T = 300$  K. The diode is forward biased at a current of 1 mA. The hole lifetime in the n region is  $10^{-7}$  s. Neglecting the depletion capacitance, calculate the diode impedance at frequencies of 10 kHz, 100 kHz, 1 MHz, and 10 MHz.

➤ First, find the small-signal diffusion conductance  $g_d$  and capacitance  $C_d$ .

$$\text{Per (7.10), } V_t = \frac{k_B T}{e} = \frac{8.617333 \times 10^{-5} \text{ eV/K} (300 \text{ K})}{e} = 0.025852 \text{ V}$$

$$\text{Per (8.104), } g_d \approx \frac{I_{DQ}}{V_t} = \frac{1 \times 10^{-3}}{0.025852} \Rightarrow \underline{g_d = 0.038682 \text{ S.}}$$

$$\text{Per (8.105), } C_d = \frac{1}{2V_t} (I_{p0} \tau_{p0} + I_{n0} \tau_{n0}) \text{ where (8.94) } I_{p0} = \frac{eAD_p p_{n0}}{L_p} e^{V_0/V_t} \text{ and (8.97)}$$

$$I_{n0} = \frac{eAD_n n_{p0}}{L_n} e^{V_0/V_t}.$$

For a p<sup>+</sup>n diode,  $p_{p0} \cong N_a \gg n_{n0} \cong N_d$ . Using (4.43), this implies that  $p_{n0} = n_i^2 / n_{n0} \gg n_{p0} = n_i^2 / p_{p0}$ . In turn,  $I_{p0} \gg I_{n0}$  which means we can say  $I_{p0} \approx I_{DQ}$  and

$$C_d \approx \frac{I_{p0} \tau_{p0}}{2V_t} = \frac{I_{DQ} \tau_{p0}}{2V_t} = \frac{1 \times 10^{-3} (10^{-7})}{2(0.025852)} \Rightarrow \underline{C_d = 1.934 \times 10^{-9} \text{ F} = 1.934 \text{ nF.}}$$

The diode small-signal admittance is (8.103)  $Y = g_d + j\omega C_d$ . We can invert  $Y$  to get the diode impedance

$$Z = \frac{1}{g_d + j\omega C_d} = \frac{1}{0.038682 + j2\pi f (1.934 \times 10^{-9})}.$$

$$\text{@ 10 kHz, } Z = \frac{1}{0.038682 + j2\pi(10 \times 10^3)1.934 \times 10^{-9}} \Rightarrow \underline{Z_{10\text{kHz}} = 25.852 - j0.0812 \Omega.}$$

$$\text{@ 100 kHz, } Z = \frac{1}{0.038682 + j2\pi(100 \times 10^3)1.934 \times 10^{-9}} \Rightarrow \underline{Z_{100\text{kHz}} = 25.826 - j0.811 \Omega.}$$

$$\text{@ 1 MHz, } Z = \frac{1}{0.038682 + j2\pi(1 \times 10^6)1.934 \times 10^{-9}} \Rightarrow \underline{Z_{1\text{MHz}} = 23.530 - j7.392 \Omega.}$$

$$\text{@ 10 MHz, } Z = \frac{1}{0.038682 + j2\pi(10 \times 10^6)1.934 \times 10^{-9}} \Rightarrow \underline{Z_{10\text{MHz}} = 2.3786 - j7.472 \Omega.}$$