**Example 4.5** Consider an abrupt silicon p-n junction with $N_a = 10^{16}$ cm$^{-3}$ and $N_d = 4 \times 10^{16}$ cm$^{-3}$.

a. Calculate the diffusion capacitance of this at zero bias. Use $\mu_n = 1000$ cm$^2$/V-s, $\mu_p = 300$ cm$^2$/V-s, $w_p' = 1$ µm and $w_n' = 1$ mm. The minority carrier lifetime equals 0.1 ms. The diode area is $10^{-4}$ cm$^2$.

b. For the same diode, find the voltage for which the junction capacitance equals the diffusion capacitance.

Solution

a. The diffusion capacitance at zero volts equals

$$C_{d,0} = \frac{I_{s,p}\tau_p}{V_t} + \frac{I_{s,n}t_{r,n}}{V_t} = 1.73 \times 10^{-19} \text{ F}$$

using

$$I_{s,p} = q\frac{A\, p_{n0} D_p}{L_p} = 4.46 \times 10^{-17} \text{ A}$$

and

$$I_{s,n} = q\frac{A\, n_{p0} D_n}{w_p'} = 4.16 \times 10^{-16} \text{ A}$$

Where the "short" diode expression was used for the capacitance associated with the excess charge due to electrons in the *p*-type region. The "long" diode expression was used for the capacitance associated with the excess charge due to holes in the *n*-type region.

The diffusion constants and hole diffusion length equal:

$$D_n = \mu_n \times V_t = 25.8 \text{ cm}^2/\text{s}$$

$$D_p = \mu_p \times V_t = 7.75 \text{ cm}^2/\text{s}$$

$$L_p = \sqrt{D_p \tau_p} = 278 \text{ µm}$$

The electron transit time in the *p*-type region equals

$$t_{r,n} = \frac{w_p'^2}{2D_n} = 193 \text{ ps}$$

b. The voltage at which the junction capacitance equals the diffusion capacitance is obtained by solving

$$\frac{C_{j0}}{\sqrt{1 - \frac{V_a}{\phi_i}}} = C_{d,0}\mathrm{e}^{V_a/V_t}$$

yielding $V_a = 0.44$ V