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

a. Calculate the diffusion capacitance of this diode at zero bias. Use μ_n = 1000 cm^2/V-s, μ_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

$$C_{d,0} = \frac{I_{s,p}\tau_p}{V_t} + \frac{I_{s,n}t_{r,n}}{V_t} = 1.73\times10^{-19}\ \text{F}$$

using

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

and

$$I_{s,n} = q\frac{A\,n_{p0}D_n}{w_p'} = 4.14 \text{ x } 10^{-14}\ \text{A}$$

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:

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

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

$$L_p = \sqrt{D_p\tau_p} = 278\ \mu\text{m}$$

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

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

with C_{j0} = 2.43 pF and ϕ_i = 0.71 V, yielding V_a = 215 mV