# Physics of Semiconductor Devices

# p-n junction (depletion width)

---

### Problem

A silicon p-n diode has a doping of $N_D = 8*10^{15}\frac{1}{cm^3}$ and $N_A = 2*10^{16}\frac{1}{cm^3}$. What are the depletion width in the n-region, the depletion width in the p-region, and the built-in potential at $300K$? Use the depletion approximation.

For Si: $n_i = 1.5 * 10^{10}\frac{1}{cm^3}$, $\epsilon_r = 11.9$.

Attention: The parameters are changing everytime. These results are calculated with the above mentioned values.

**Useful physical constants:**

| | |
|---|---|
| Boltzmann constant: | $k_B = 1.38 * 10^{-23}\ \frac{J}{K}$ |
| Elementary charge: | $e = 1.602 * 10^{-19}\ As$ |
| Vacuum permittivity: | $\epsilon_0 = 8.854 * 10^{-12}\ \frac{As}{Vm}$ |

**Useful formulas:**

Permittivity:

$$\epsilon = \epsilon_0 * \epsilon_r \tag{1}$$

Built-in voltage, contact potential:

$$V_{bi} = \frac{k_B * T}{e} * ln(\frac{N_D * N_A}{n_i^2}) \tag{2}$$

Depletion width (no external bias):

$$W = \sqrt{\frac{2 * \epsilon * (N_D + N_A) * V_{bi}}{e * N_D * N_A}} \tag{3}$$

Depletion width in the p-region:

$$W_p = \frac{N_D * W}{N_D + N_A} \tag{4}$$

Depletion width in the n-region:

$$W_n = \frac{N_A * W}{N_A + N_D} \tag{5}$$

**Solution:**

Note: To get the correct SI-units:

$$N_D = 8 * 10^{15} \frac{1}{cm^3} = 8.10^{21} \frac{1}{m^3}$$

$$N_A = 2 * 10^{16} \frac{1}{cm^3} = 2 * 10^{22} \frac{1}{m^3}$$

Built-in voltage, contact potential:

$$V_{bi} = \frac{k_B * T}{e} * ln(\frac{N_D * N_a}{n_i^2}) = \frac{1.38 * 10^{-23} * 300}{1.602 * 10^{-19}} * ln(\frac{8.10^{21} * 2 * 10^{22}}{(1.5 * 10^{10})^2}) = \underline{0.7052V} \tag{6}$$

Depletion width (no external bias):

$$W = \sqrt{\frac{2 * \epsilon * (N_D + N_A) * V_{bi}}{e * N_D * N_A}} = \sqrt{\frac{2 * 11.9 * 8.854 * 10^{-12} * (8.10^{21} + 2 * 10^{22}) * 0.7052}{1.602 * 10^{-19} * 8.10^{21} * 2 * 10^{22}}} = 4.029 * 10^{-7} m \tag{7}$$

Depletion width in the p-region:

$$W_p = \frac{N_D * W}{N_D + N_A} = \frac{8.10^{21} * 4.029 * 10^{-7}}{8.10^{21} + 2 * 10^{22}} = \underline{1.151 * 10^{-7} m} \tag{8}$$

Depletion width in the n-region:

$$W_n = \frac{N_A * W}{N_A + N_D} = \frac{2 * 10^{22} * 4.029 * 10^{-7}}{2 * 10^{22} + 8.10^{21}} = \underline{2.8779 * 10^{-7} m} \tag{9}$$

**Control:**

1. $N_A > N_D \Longrightarrow W_n > W_p$
2. $W = W_n + W_p = 2.8779 * 10^{-7} + 1.151 * 10^{-7} = 4.0289 * 10^{-7} m$