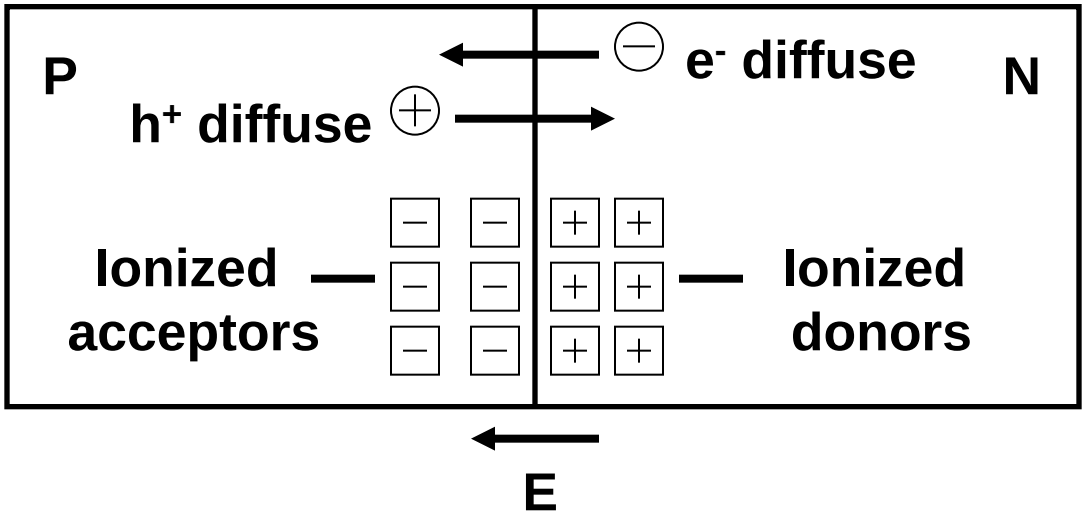
Diode Electrostatics Summary

EECS 320

Introduction to Semiconductor Devices

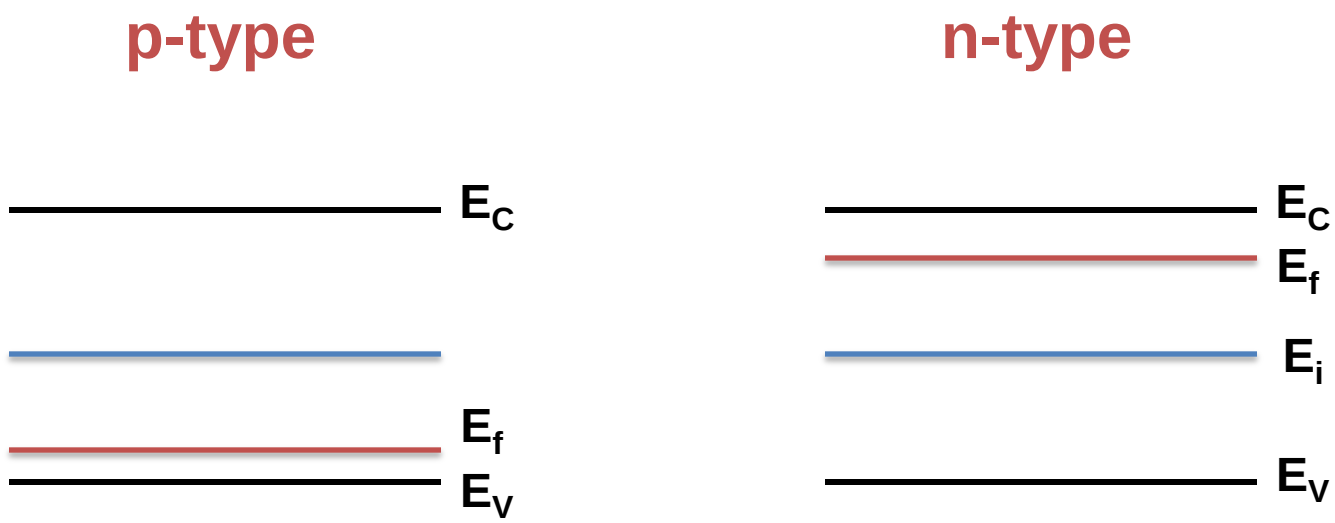
Joining P-type and N-type

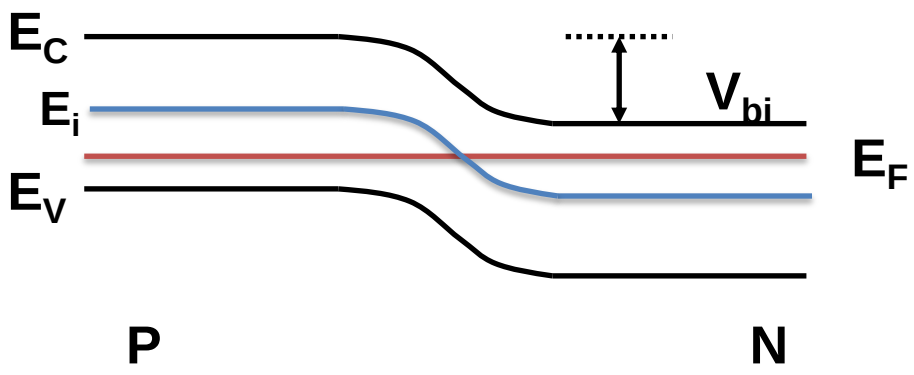
What happens when you join p-type and n-type material?

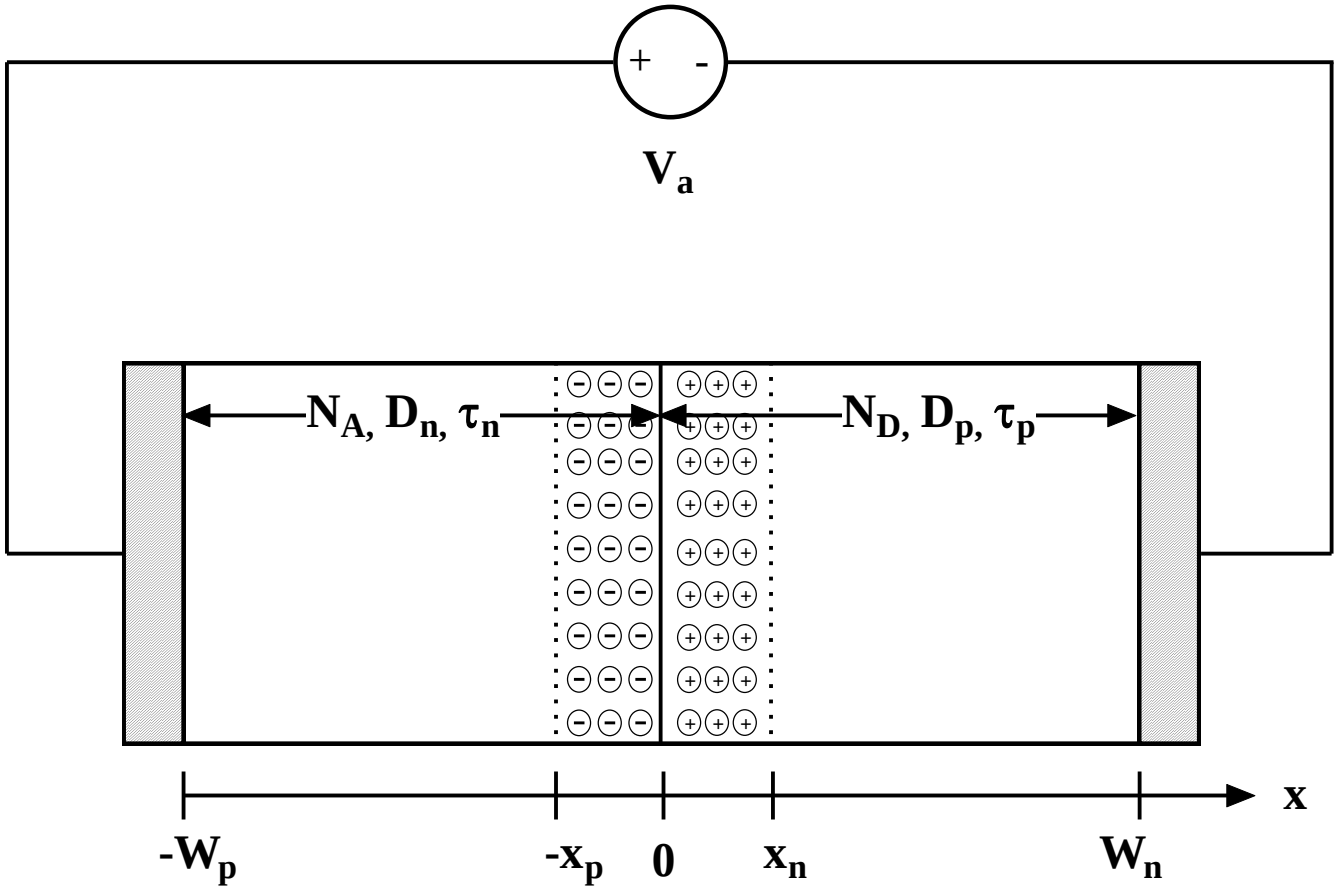


- Diffusion drives e's and h's to lower concentration regions
- Ionized dopants remain, creating an electric field
- Under equilibrium, diffusion and drift processes are balanced

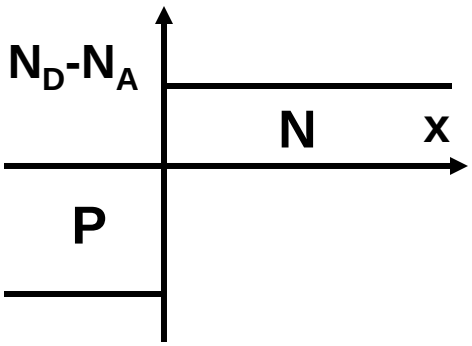
Equilibrium Energy Band Diagram

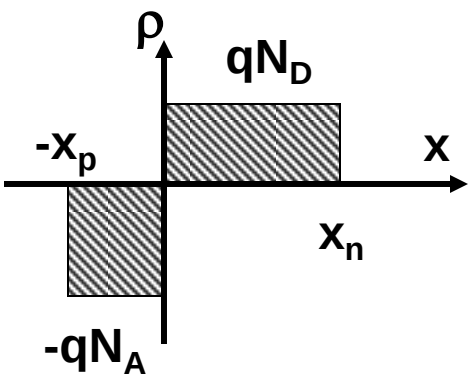


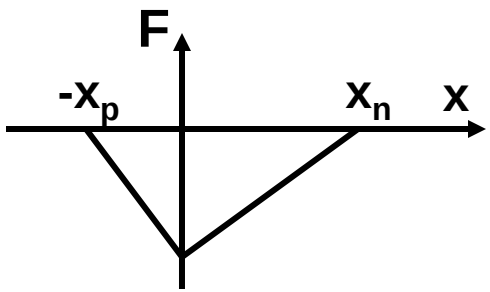



+
-
V_a
N_A, D_n, τ_n
N_D, D_p, τ_p
x
$-W_p$
$-x_p$
0
x_n
W_n

Electrostatics Summary







Electric Field In Depletion Region

- Electric Field

$$F(x) = -\frac{qN_A}{\varepsilon}(x + x_P) \qquad -x_P < x < 0$$

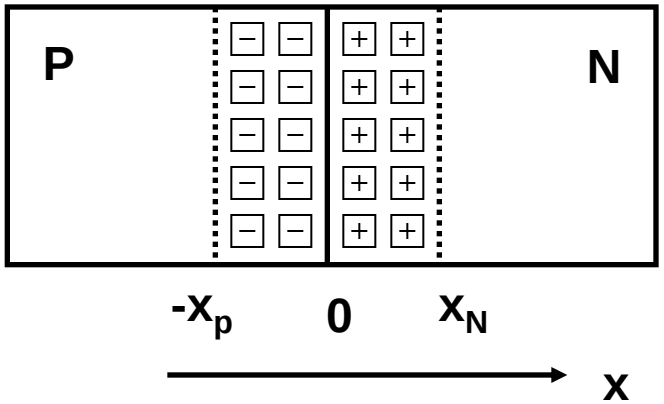
$$F(x) = -\frac{qN_D}{\varepsilon}(x_N - x) \qquad 0 < x < x_N$$

$$F(x) = 0 \quad \text{elsewhere}$$

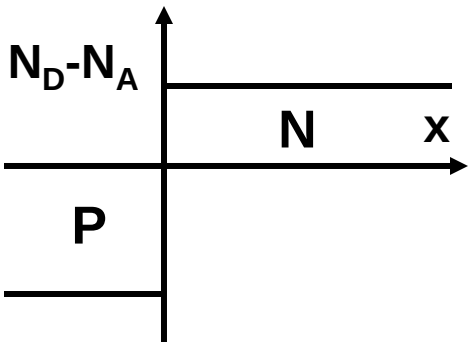
- At x=0, field must be continuous

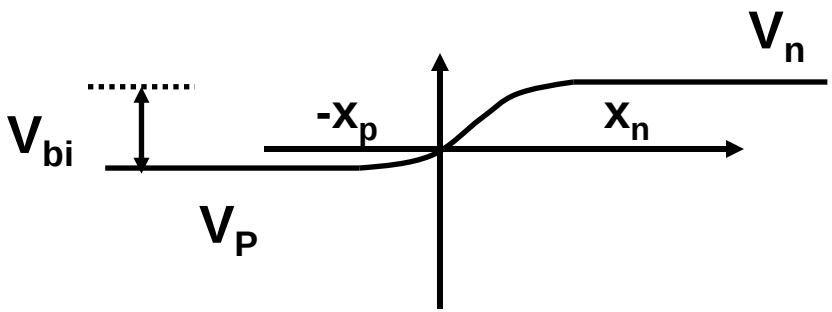
$$F(0) = -\frac{qN_D}{\varepsilon}(x_N) = -\frac{qN_A}{\varepsilon}(x_P)$$

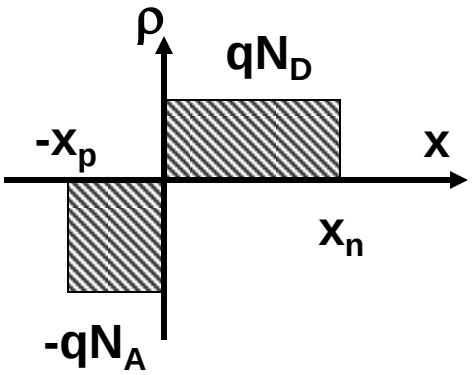
$$N_D x_N = N_A x_P$$

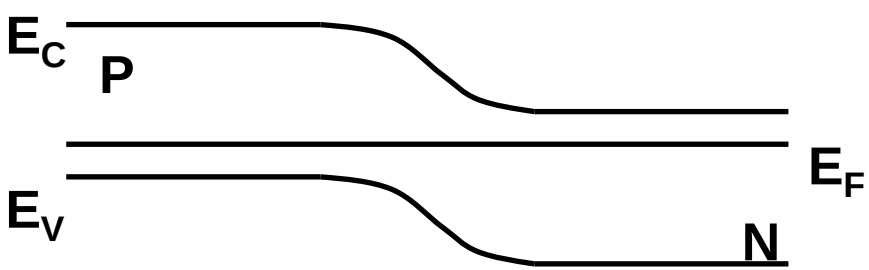


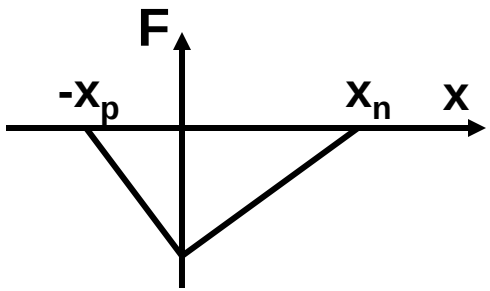
Electrostatics Summary











Built-In Potential In Depletion Region

- Electrostatic potential, integrate electric field

$$V(x) = V_P \qquad -\infty < x < -x_P$$

$$V(x) = \frac{qN_A}{2\varepsilon}(x + x_P)^2 + V_P \qquad -x_P < x < 0$$

$$V(x) = -\frac{qN_D}{2\varepsilon}(x_N - x)^2 + V_N \qquad 0 < x < x_N$$

$$V(x) = V_N \qquad x_N < x < \infty$$

$$V(x_N) - V(0) = \frac{qN_D}{2\varepsilon}(x_N)^2$$

$$V(0) - V(-x_P) = \frac{qN_A}{2\varepsilon}(x_P)^2$$

$$V(x_N) - V(-x_P) = \frac{qN_D x_N^{\ 2}}{2\varepsilon} + \frac{qN_A x_P^{\ 2}}{2\varepsilon}$$

$$\boxed{V_{bi} = \text{built in potential}}$$

Built-In Potential In Depletion Region

- Electrostatic potential, integrate electric field

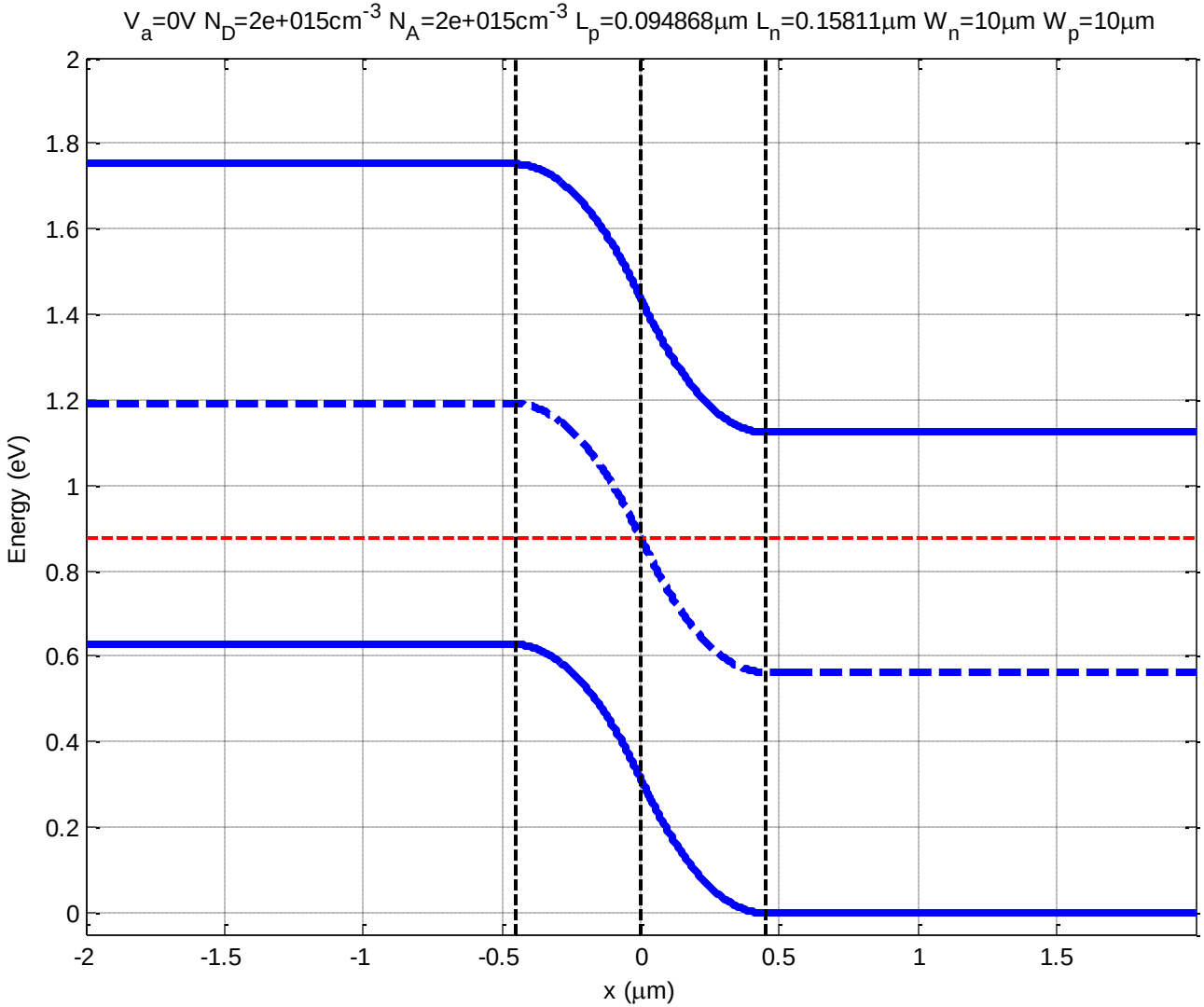
$$V_{bi} = V(x_N) - V(-x_P) = \frac{qN_D x_N^{\ 2}}{2\varepsilon} + \frac{qN_A x_P^{\ 2}}{2\varepsilon}$$

$$N_D x_N = N_A x_P \longrightarrow \text{charge neutrality}$$

$$x_P(V_{bi}) = \sqrt{\frac{2\varepsilon V_{bi}}{q}\left[\frac{N_D}{N_A(N_A + N_D)}\right]}$$

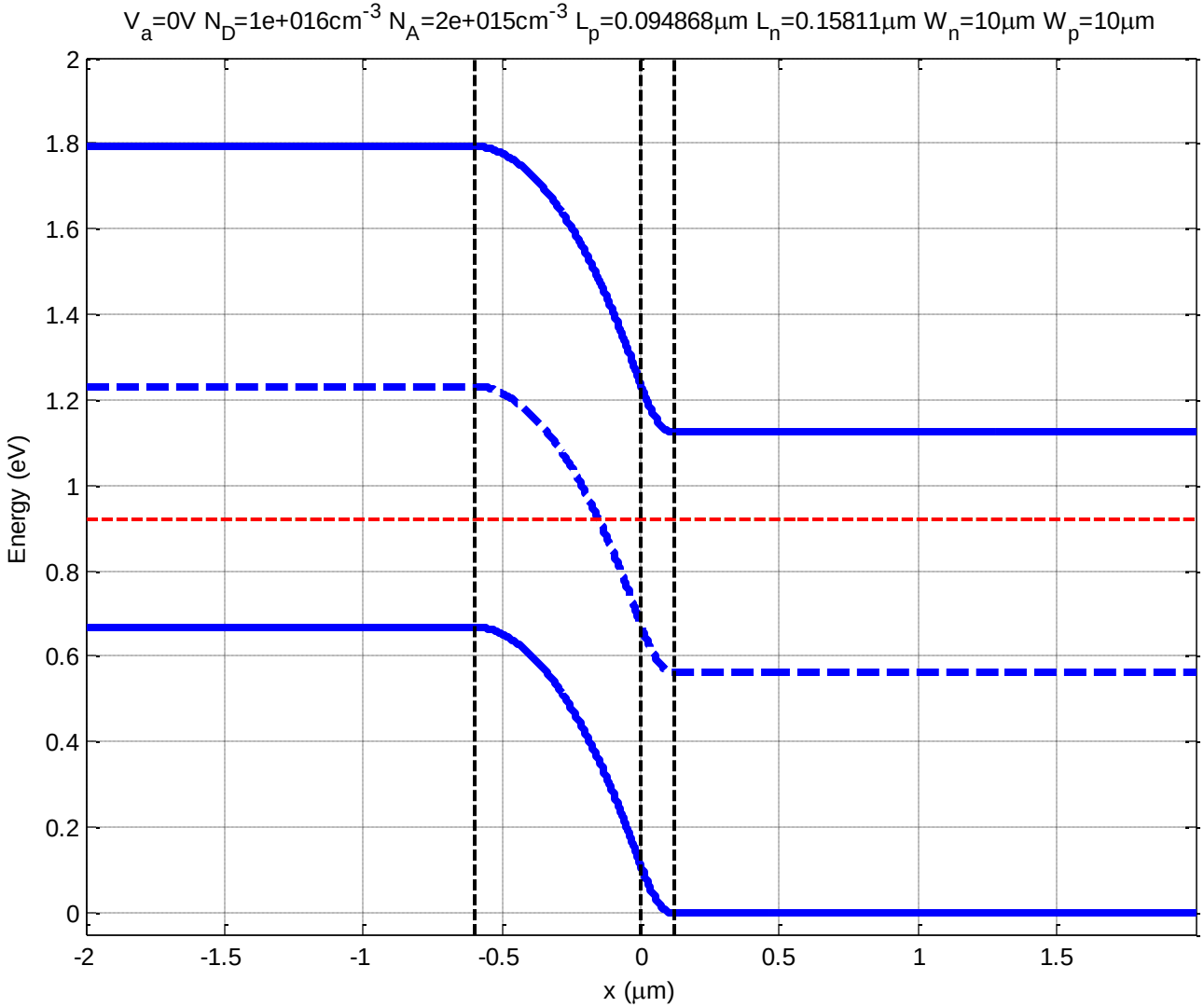
$$x_N(V_{bi}) = \sqrt{\frac{2\varepsilon V_{bi}}{q}\left[\frac{N_A}{N_D(N_A + N_D)}\right]}$$

$$\boxed{W(V_{bi}) = x_P(V_{bi}) + x_N(V_{bi}) = \sqrt{\frac{2\varepsilon V_{bi}}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)}}$$

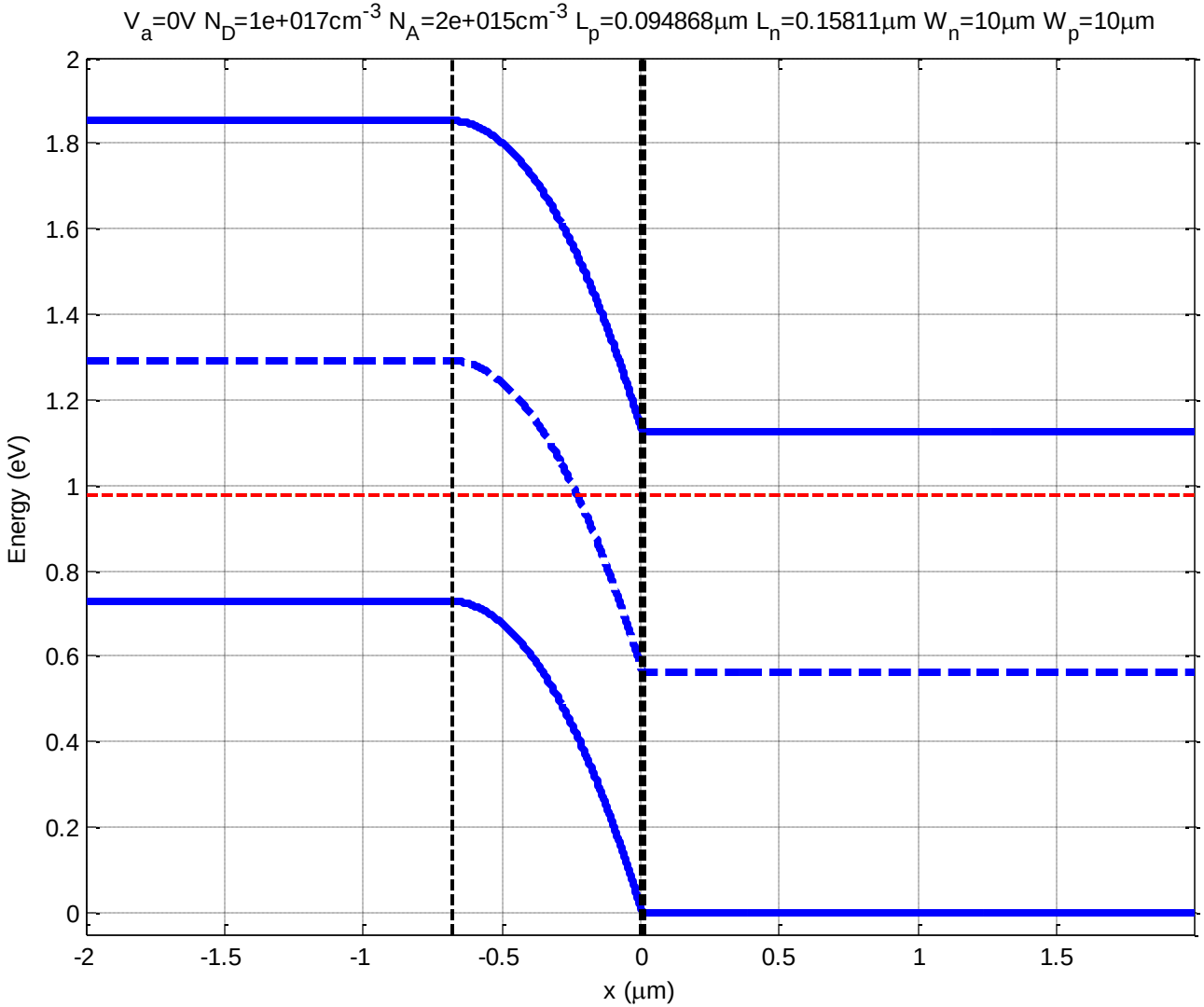


Na	$2x10^{15}cm^{-3}$
Nd	$2x10^{15}cm^{-3}$
Vbi	0.6274V
xn	0.45045μm
xp	0.45045μm
W	0.90090μm

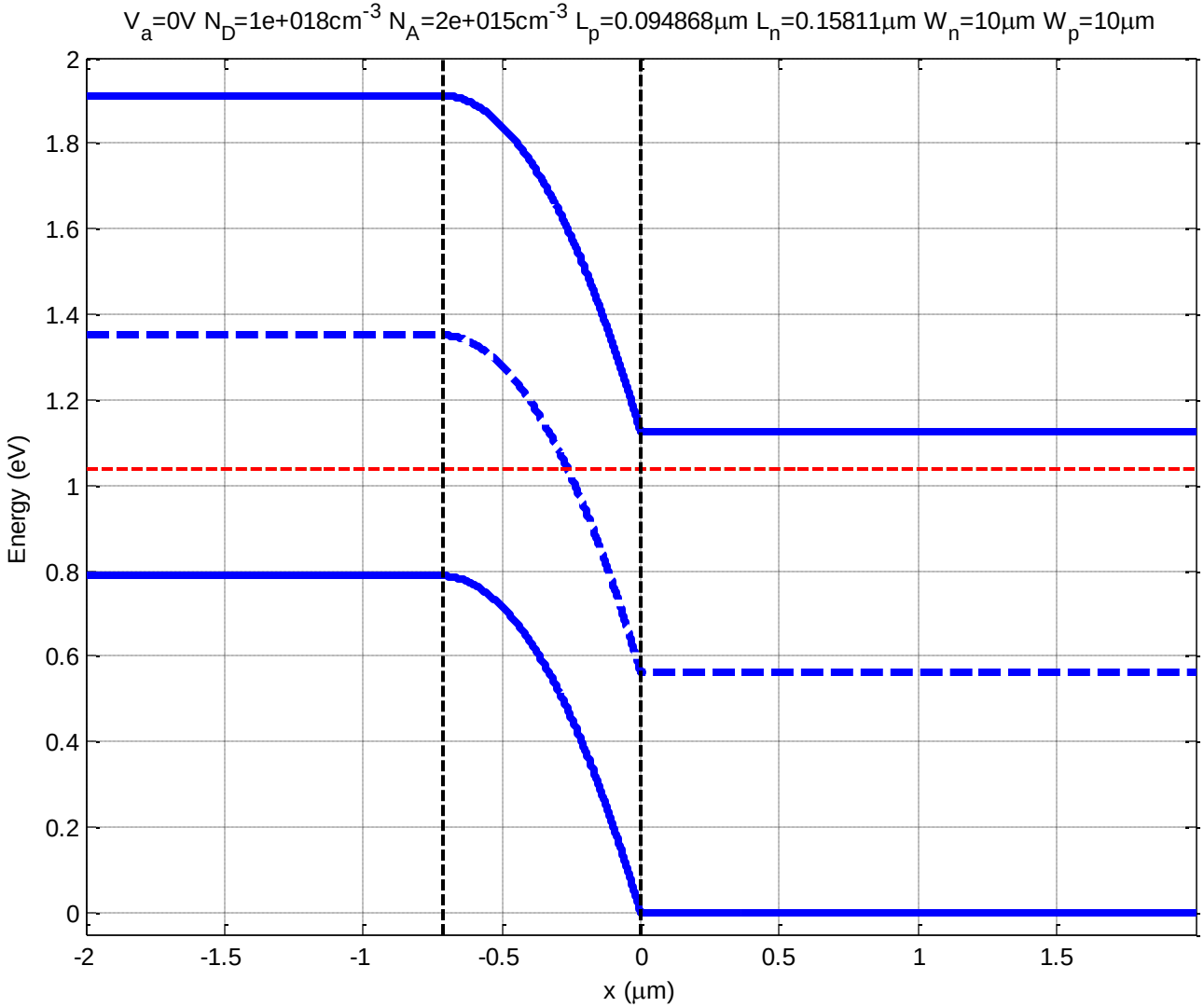
$$N_c = 2.86x10^{19} cm^{-3} \quad N_v = 3.10x10^{19} cm^{-3} \quad E_g = 1.1242eV \quad \varepsilon_{Si} = 11.7\varepsilon_0$$



Na	$2x10^{15}cm^{-3}$
Nd	$1x10^{16}cm^{-3}$
Vbi	0.6691V
xn	0.12010μm
xp	0.60050μm
W	0.72060μm



Na	$2x10^{15}cm^{-3}$
Nd	$1x10^{17}cm^{-3}$
Vbi	0.7286V
xn	0.01359µm
xp	0.67969µm
W	0.69328µm



Na	$2x10^{15}cm^{-3}$
Nd	$1x10^{18}cm^{-3}$
Vbi	0.7881V
xn	0.00143µm
xp	0.71323µm
W	0.71465µm