Examrace

Abrupt PN Junctions in the Depletion Approximation and Graph

In an abrupt pn junction, the doping changes abruptly from p to n. It is common to solve for the band bending, the local electric field, the carrier concentration profiles, and the local conductivity in the depletion approximation. In this approximation it is assumed that there is a depletion width W around the transition from p to n where the charge carrier densities are negligible. Outside of the depletion width, the charge carrier densities are equal to the doping concentrations. So, the semiconductor is electrically neutral outside of the depletion width. Using this depletion approximation, it is possible to calculate important properties of pn junctions. The charge density distribution for an abrupt junction is,

$$\rho(x) = \begin{cases} 0 & \text{for } x < x_p, \\ -\mathrm{eN}_A & \text{for } x_p < x < 0, \\ \mathrm{eN}_D & \text{for } 0 < x < x \\ 0 & \text{for } x_n < x \end{cases}$$

The charge density can be integrated to determine the electric field $E = \int \frac{\rho}{\in} \mathrm{dx}$,

$$\rho(x) = \begin{cases} 0 & \text{for } x < x_p, \\ -\frac{\mathrm{eN}_A}{\in}\left(x - x_p\right) & \text{for } x_p < x < 0, \\ \frac{\mathrm{eN}_D}{\in}(x - x_n) & \text{for } 0 < x < x_n \\ 0 & \text{for } x_n < x. \end{cases}$$

The electric field can be integrated to determine the electrostatic potential $\phi = -\int \mathrm{Edx}$,

$$\phi(x) = \begin{cases} \frac{\mathrm{eN}_A\, x_p^2}{2\in} & \text{for } x < x_p, \\ -\frac{\mathrm{eN}_A}{\in}\left(\frac{x^2}{2} - x_p x\right) & \text{for } x_p < x < 0, \\ \frac{\mathrm{eN}_D}{\in}\left(\frac{x^2}{2} - x_n x\right) & \text{for } 0 < x < x_n \\ \frac{\mathrm{eN}_D\, x_n^2}{\in} & \text{for } x_n < x. \end{cases}$$

The voltage across the junction is the difference in the electrostatic potential $V_{\mathrm{bi}} - V = \phi(x_n) - \phi\left(x_p\right)$,

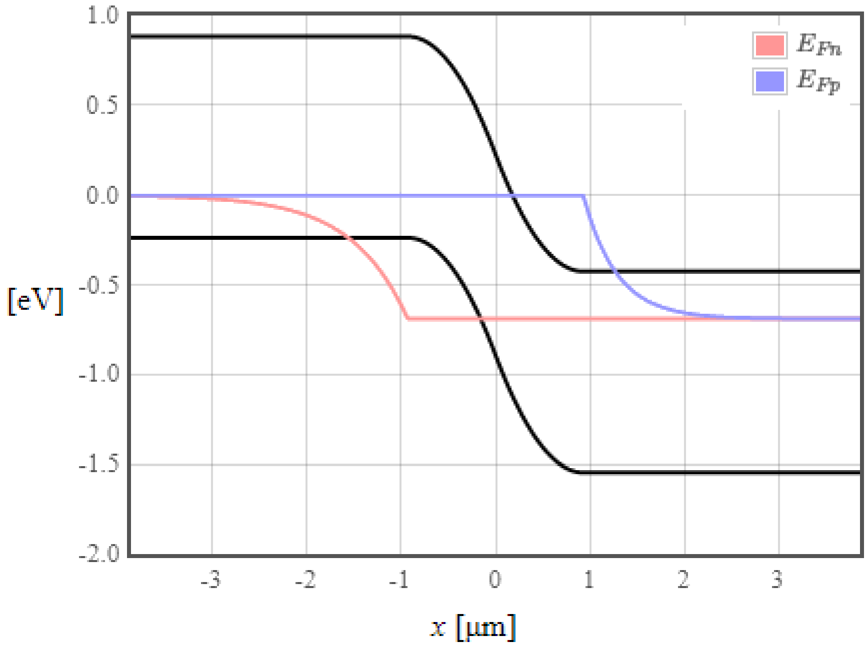
$$V_{\mathrm{bi}} - V = \frac{\mathrm{eN}_D\, x_n^2}{2 \in} + \frac{\mathrm{eN}_A\, x_p^2}{2 \in}$$

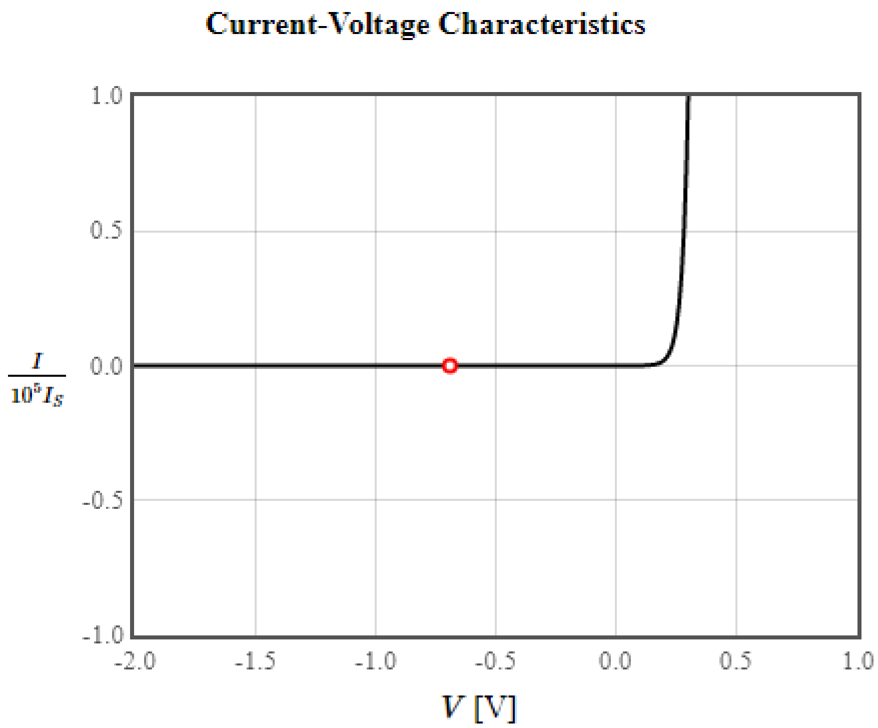
The depletion width $W = x_n - x_p$ can now be calculated using the charge neutrality $\left(N_A x_p = N_D x_n = N_A (W - x_n) = N_D \left(W - x_p\right)\right)$ and the expression for V_{bi} ,

$$V_{\text{bi}} = \frac{k_B T}{e} \ln \left(\frac{N_D N_A}{n_i^2}\right).$$

The depletion width is, $W = \sqrt{\frac{2 \in (N_D + N_A)(V_{\text{bi}} - V)}{\text{eN}_D \, N_A}}$

Band diagram





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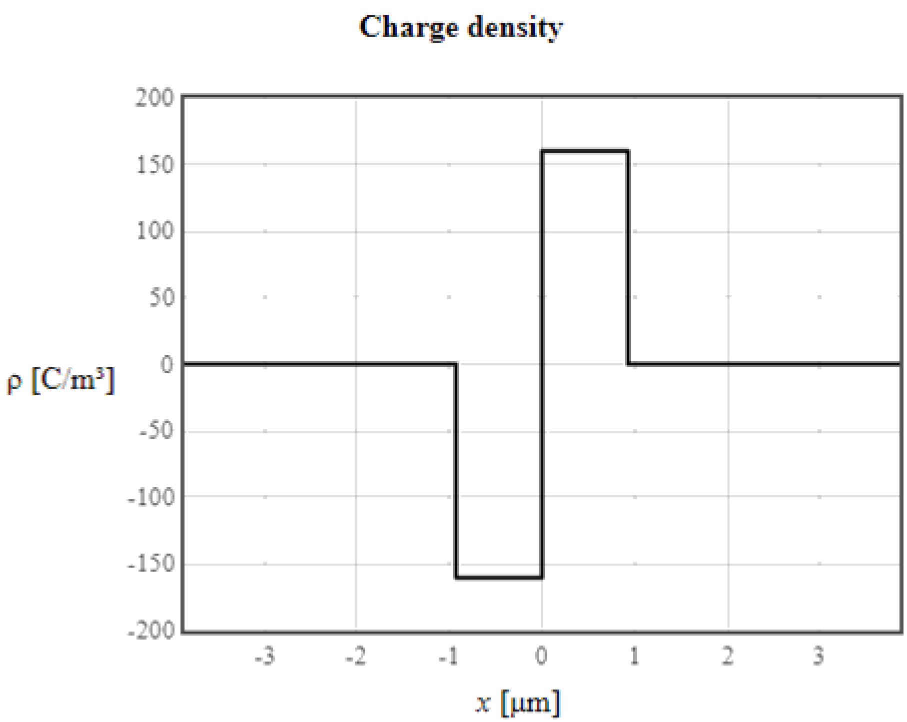
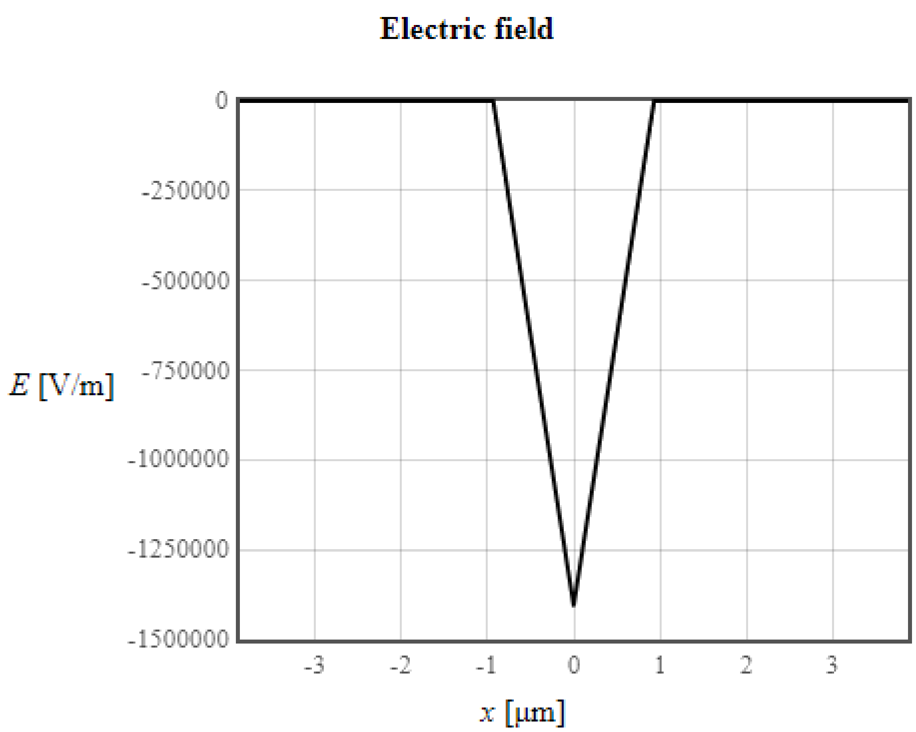
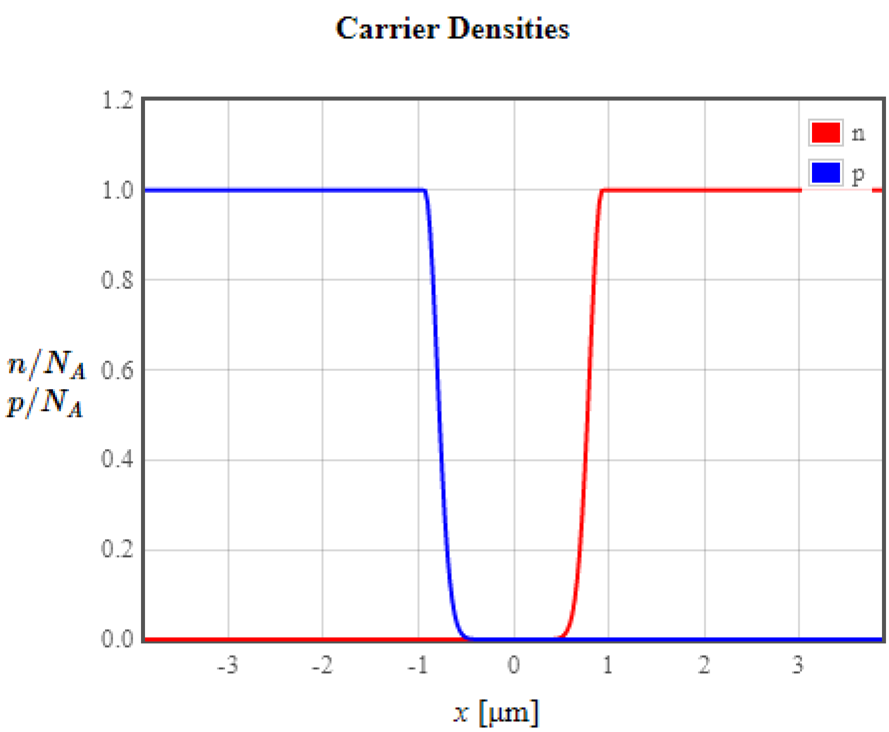
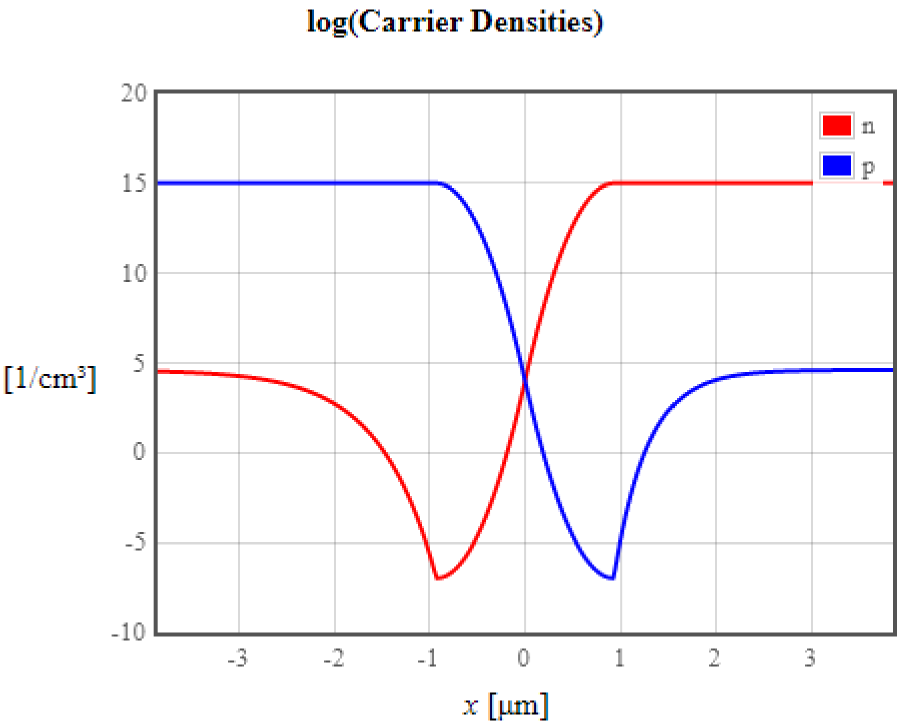
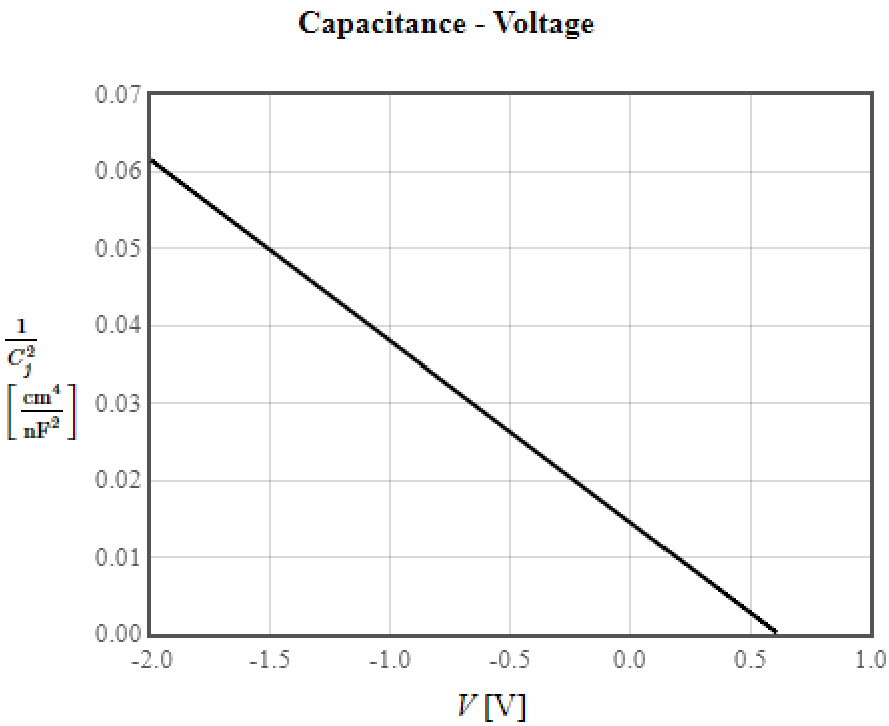
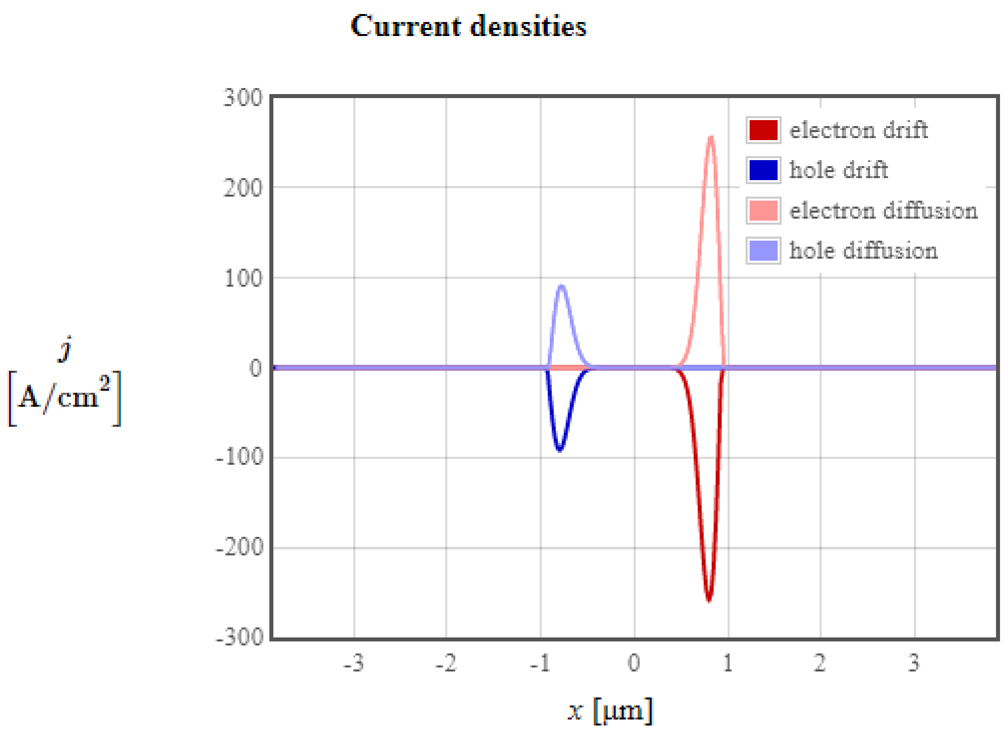

Charge density
200
150
100
50
0
-50
-100
-150
-200
ρ [C/m³]
-3
-2
-1
0
1
2
3
x [μm]


Electric field
0
-250000
-500000
-750000
-1000000
-1250000
-1500000
E [V/m]
-3
-2
-1
0
1
2
3
x [µm]


Carrier Densities
n
p
1.2
1.0
0.8
0.6
0.4
0.2
0.0
n/N_A
p/N_A
-3
-2
-1
0
1
2
3
x [μm]


log(Carrier Densities)
20
15
10
5
0
-5
-10
[1/cm³]
n
p
-3
-2
-1
0
1
2
3
x [µm]


Capacitance - Voltage
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
V [V]



$\vec{j}_{n,\mathrm{drift}} = \mathrm{ne}\,\mu_n \vec{E}$ $\vec{j}_{p,\mathrm{drift}} = \mathrm{pe}\,\mu_p \vec{E}$,

, and $\vec{j}_{p,\mathrm{diffusion}} = -\mathrm{eD}_p \frac{\mathrm{dp}}{\mathrm{dx}}$ $\vec{j}_{n,\mathrm{diffusion}} = \mathrm{eD}_n \frac{\mathrm{dn}}{\mathrm{dx}}$