PN Junction Supplements

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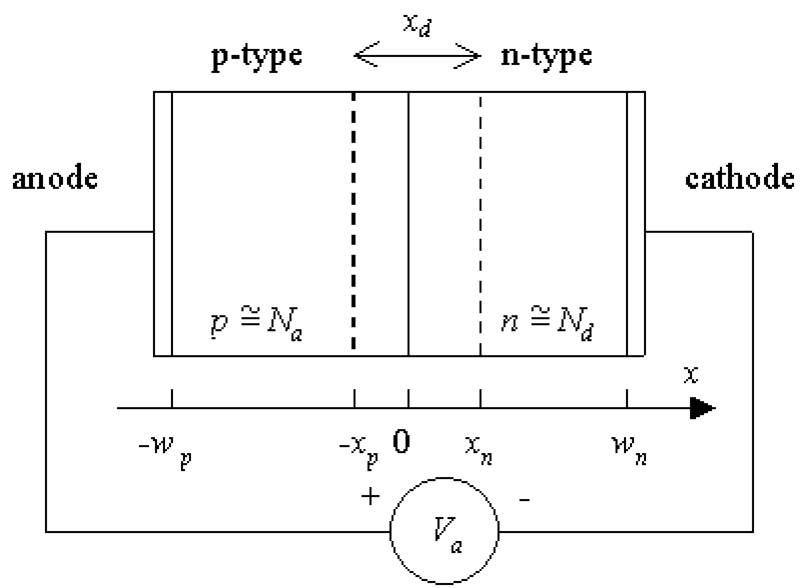
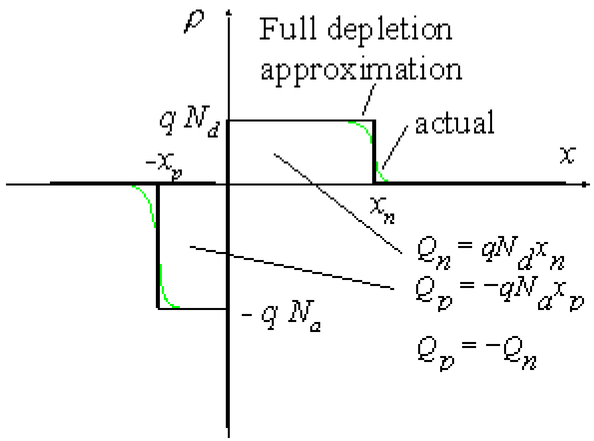
Cross Section of a PN Junction



- **Assumptions**
  - The doped regions are uniformly doped.
  - The transition between the two regions is abrupt.

Charge Density Profile



- $\rho = q(p - n + N_d^+ + N_a^-) \approx q(N_d^+ + N_a^-)$
- $\rho(x) = 0 \; (x < -x_p \; or \; x > x_n)$
- $\rho(x) = -qN_a \; (-x_p < x < 0)$
- $\rho(x) = +qN_d \; (0 < x < x_n)$

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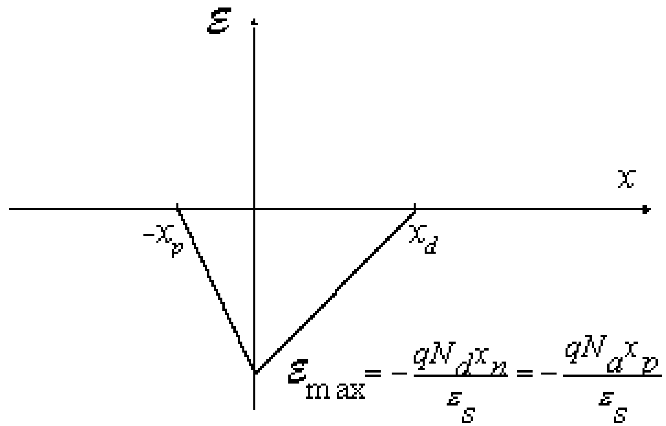
Electric Field



- $\frac{dE}{dx} = \frac{\rho(x)}{\epsilon_s}$: **Gauss's law**
- $E(x) = 0 \left(x < -x_p \text{ or } x > x_n\right)$
- $E(x) = -\frac{qN_a(x+x_p)}{\epsilon_s} \ (-x_p < x < 0)$
- $E(x) = +\frac{qN_d(x-x_n)}{\epsilon_s} \ (0 < x < x_n)$
- $N_a x_p = N_d x_n$

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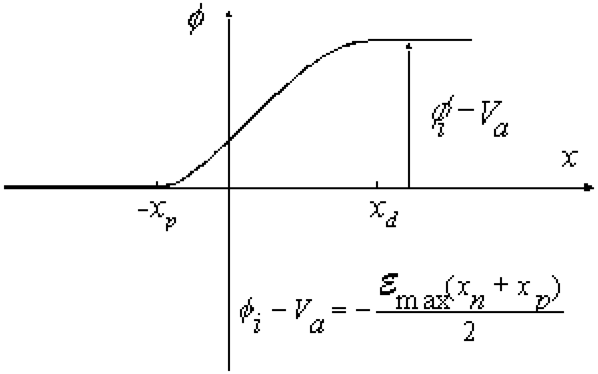
Built In Potential



- $\phi_1 - V_a = \frac{qN_d x_n^2}{2\varepsilon_s} + \frac{qN_a x_p^2}{2\varepsilon_s}$

Depletion Region Width

- $x_d = x_n + x_p$
- $N_a x_p = N_d x_n$
- $\phi_1 - V_a = \frac{qN_d x_n^2}{2\varepsilon_s} + \frac{qN_a x_p^2}{2\varepsilon_s}$
- $x_d = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)(\phi_1 - V_a)}$
- $x_n = \sqrt{\frac{2\varepsilon_s}{q}\frac{N_a}{N_d}\frac{1}{N_a + N_d}(\phi_1 - V_a)}$
- $x_p = \sqrt{\frac{2\varepsilon_s}{q}\frac{N_d}{N_a}\frac{1}{N_a + N_d}(\phi_1 - V_a)}$

Junction Capacitance

- $C(V_a) = \left|\frac{dQ(V_a)}{dV_a}\right|$
- $\rho(x) = +qN_d \, (0 < x < x_n)$
- $x_n = \sqrt{\frac{2\varepsilon_s}{q}\frac{N_a}{N_d}\frac{1}{N_a+N_d}(\phi_1 - V_a)}$
- $C_j = \sqrt{\frac{q\varepsilon_s}{2(\phi_1-V_a)}\frac{N_a N_d}{N_a+N_d}} = \frac{\varepsilon_s}{x_d}$ **: voltage dependent**
- $C_{j0} = \sqrt{\frac{q\varepsilon_s}{2\phi_1}\frac{N_a N_d}{N_a+N_d}}$ **: zero bias capacitance**
- $C_j = \frac{C_{j0}}{\sqrt{1-\frac{V_a}{\phi_1}}}$

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References

- **B. Van Zeghbroeck, 2011 (http://ecee.colorado.edu/~bart/book/book/chapter4/ch4_3.htm#4_3_3)**