From *Semiconductor Physics and Devices: Basic Principles* (4th Edition), Donald A. Neamen, McGraw Hill, 2012, ISBN 978-0-07-352958-5.

Forward biased pn diode

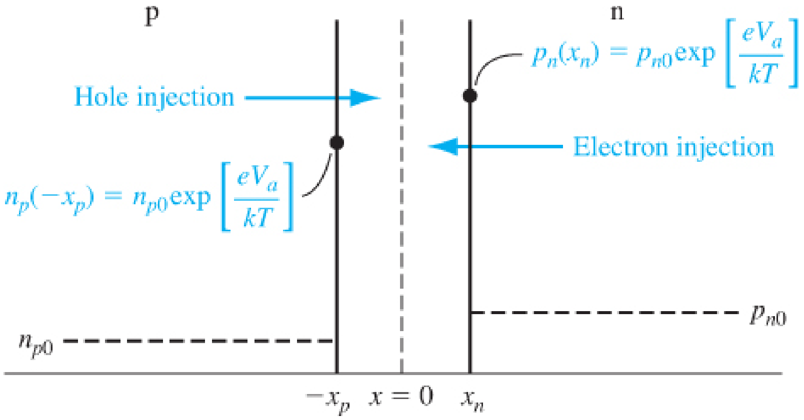

Figure 8.4 | Excess minority carrier concentrations at the space charge edges generated by the forward-bias voltage.

- At 300 K, $k_B T/e = 0.025852$ V.
- Therefore, once $V_a > 0.025852$ V, both $n_p(-x_p)$ and $p_n(x_n)$ increase rapidly.
- Conversely, if $V_a < 0$ (reverse bias), both $n_p(-x_p)$ and $p_n(x_n)$ decrease rapidly below n_{p0} and p_{n0} respectively (i.e., effectively zero).

Example- Let's revisit our germanium pn junction at 300 K where $N_a = 8 \times 10^{15}$ cm^{-3} (p region) and $N_d = 10^{16}$ cm^{-3} (n region). Calculate the excess minority carrier concentrations at the edges of the depletion layer/space charge region when a forward bias voltage of 0.2 V is applied.

From Table B.4, $n_i = 2.4 \times 10^{13}$ cm^{-3}

p region-

majority carrier concentration is $p_{p0} = N_a = 8 \times 10^{15}$ cm^{-3}

minority carrier concentration is $n_{p0} = n_i^2/N_a = (2.4\times10^{13})^2/8\times10^{15} = 7.2 \times 10^{10}$ cm^{-3}

n region-

majority carrier concentration is $n_{n0} = N_d = 10^{16}$ cm^{-3}

minority carrier concentration is $p_{n0} = n_i^2/N_d = (2.4\times10^{13})^2/10^{16} = 5.76 \times 10^{10}$ cm^{-3}

$$n_p(-x_p) = n_{p0}\, e^{eV_a/k_BT} = 7.2\times10^{10}\, e^{0.2/0.025852} \quad \Rightarrow \quad \underline{\mathbf{n_p(-x_p) = 1.649 \times 10^{14}\ cm^{-3}}} \ll N_a$$

$$p_n(x_n) = p_{n0}\, e^{eV_a/k_BT} = 5.76\times10^{10}\, e^{0.2/0.025852} \quad \Rightarrow \quad \underline{\mathbf{p_n(x_n) = 1.319 \times 10^{14}\ cm^{-3}}} \ll N_d$$

Low level injection assumption is OK.