Section 24
Bipolar Junction Transistor - Fundamentals

24.3 Currents in BJTs

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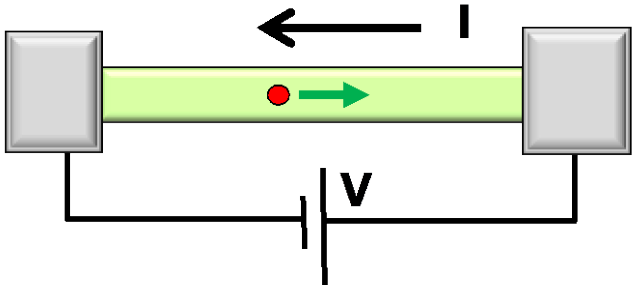
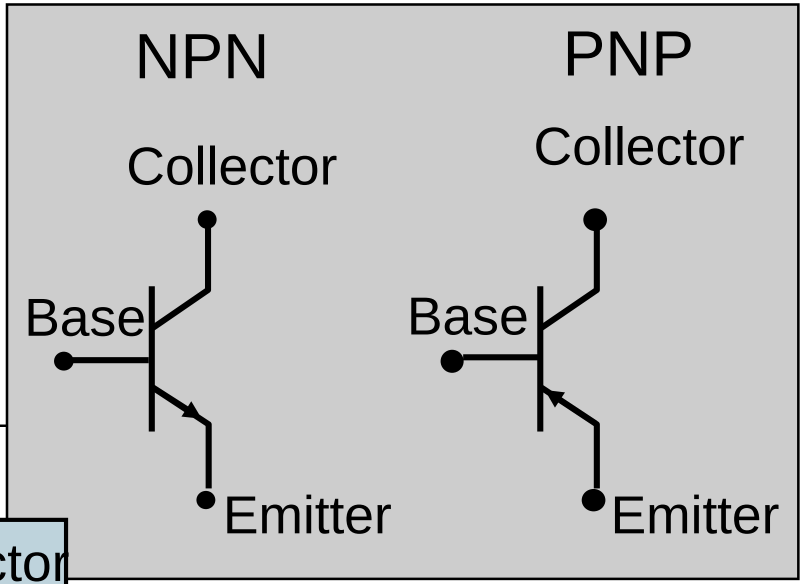


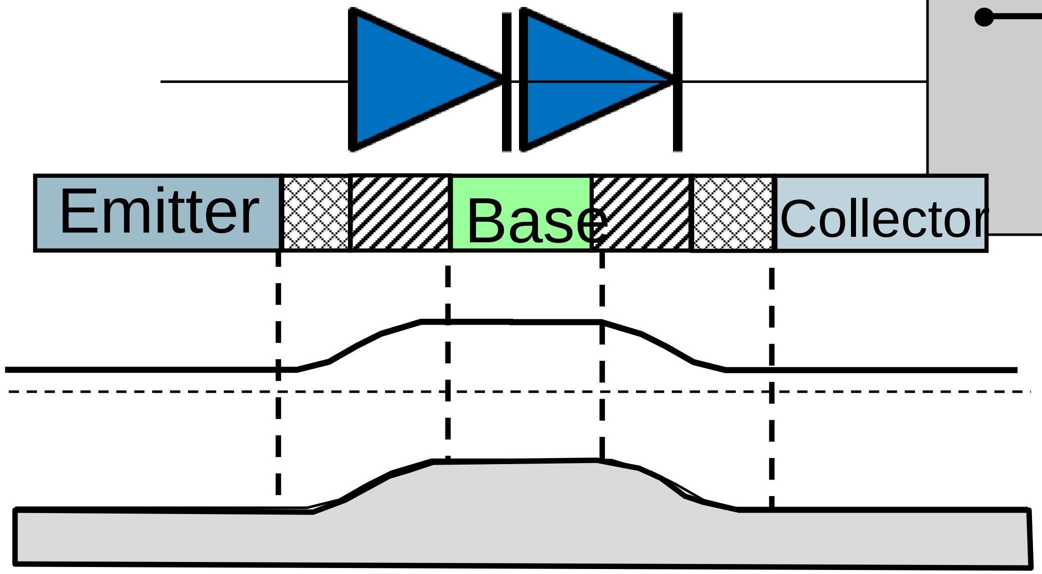
$I = G \times V$

$= q \times n \times v \times A$

charge density velocity area

status





Band Diagram with Bias

$$\nabla \bullet D = q\left(p - n + N_D^+ - N_A^-\right)$$

Non-equilibrium

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_N - r_N + g_N$$

$$\mathbf{J}_N = qn\mu_N E + qD_N \nabla n$$

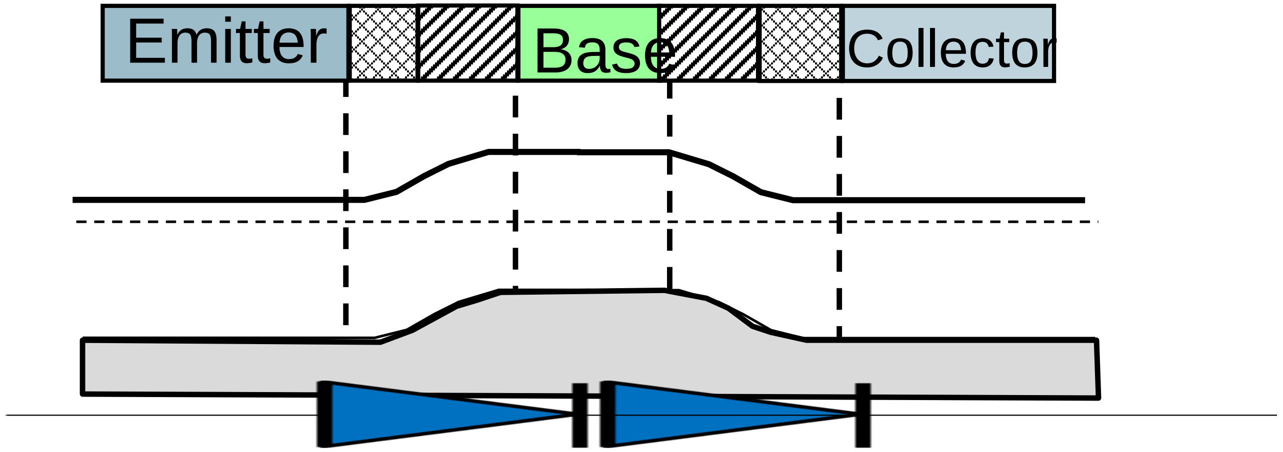
$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_P - r_P + g_P$$

$$\mathbf{J}_P = qp\mu_P E - qD_P \nabla p$$

DC dn/dt=0

Small signal dn/dt ~ jωtn

Transient --- Charge control model



Electrostatics in Equilibrium

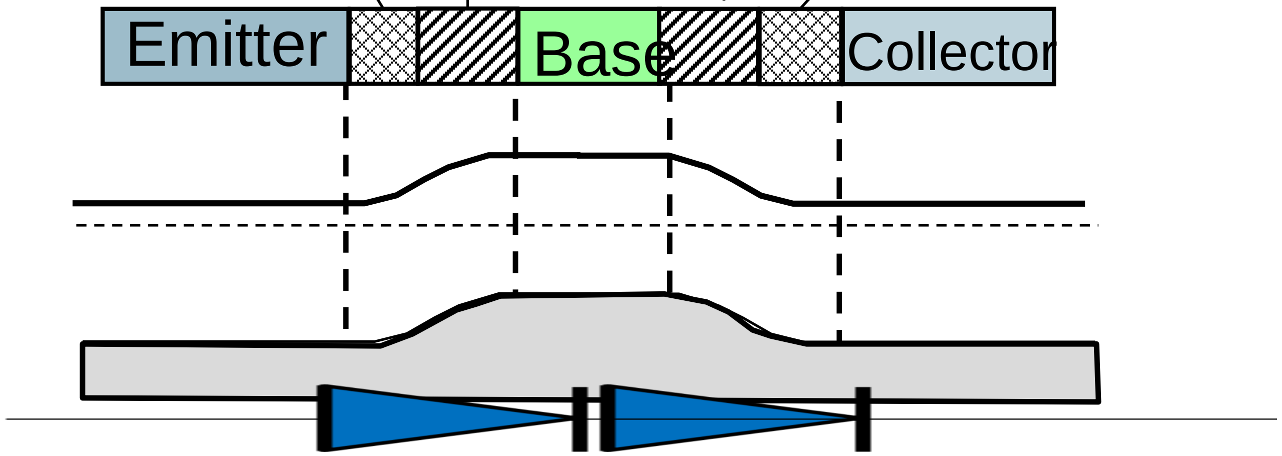
Two back to back p-n junctions

$$x_{p,BE} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_E}{N_B\left(N_E+N_B\right)}V_{bi}}$$

$$x_{p,BC} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_C}{N_B\left(N_C+N_B\right)}V_{bi}}$$

$$x_{n,E} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_B}{N_E\left(N_B+N_E\right)}V_{bi}}$$

$$x_{n,C} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_B}{N_C\left(N_C+N_B\right)}V_{bi}}$$



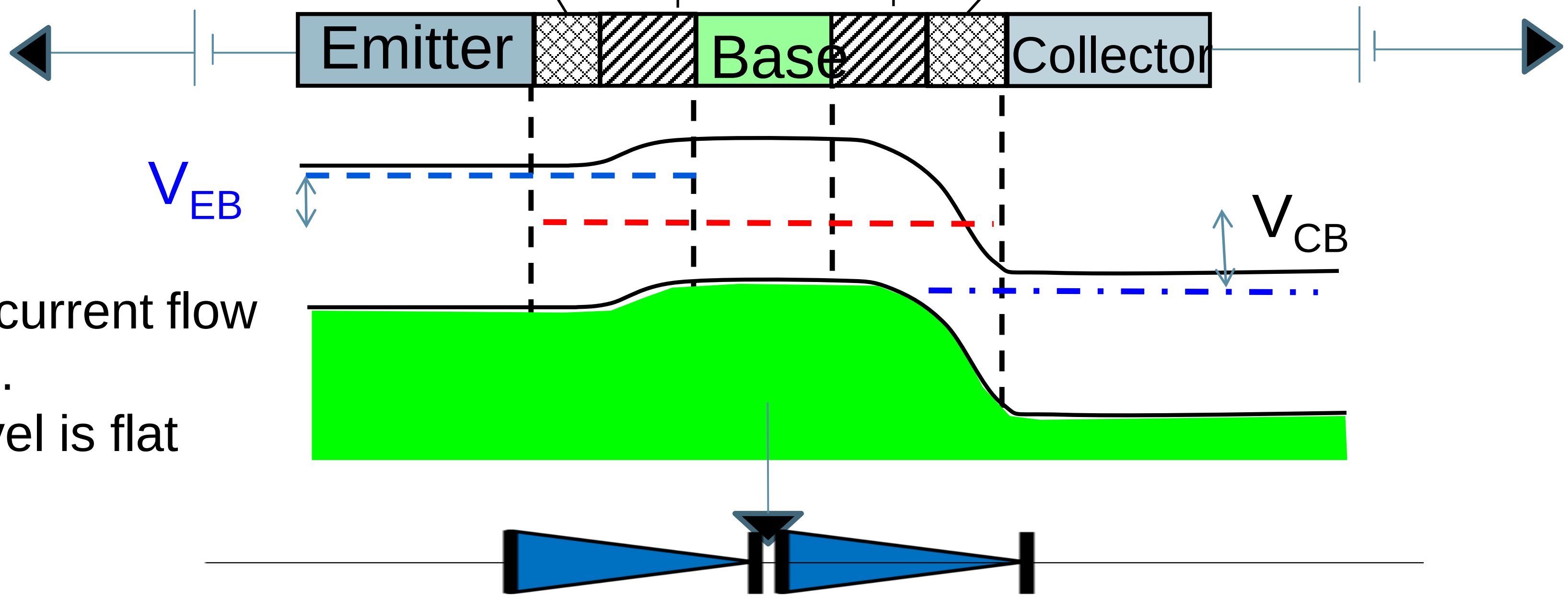
Electrostatics in Equilibrium

$$x_{p,BE} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_E}{N_B\left(N_E+N_B\right)}\left(V_{bi}-V_{EB}\right)}$$

$$x_{p,BC} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_C}{N_B\left(N_C+N_B\right)}\left(V_{bi}-V_{CB}\right)}$$

$$x_{n,E} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_B}{N_E\left(N_B+N_E\right)}\left(V_{bi}-V_{EB}\right)}$$

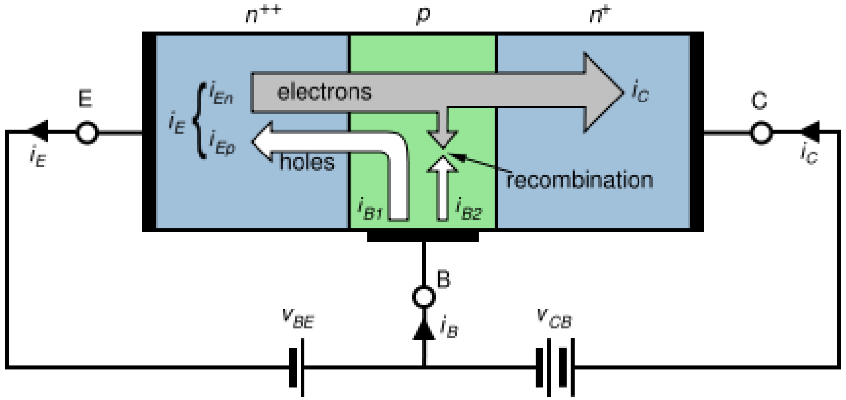
$$x_{n,C} = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_B}{N_C\left(N_C+N_B\right)}\left(V_{bi}-V_{CB}\right)}$$

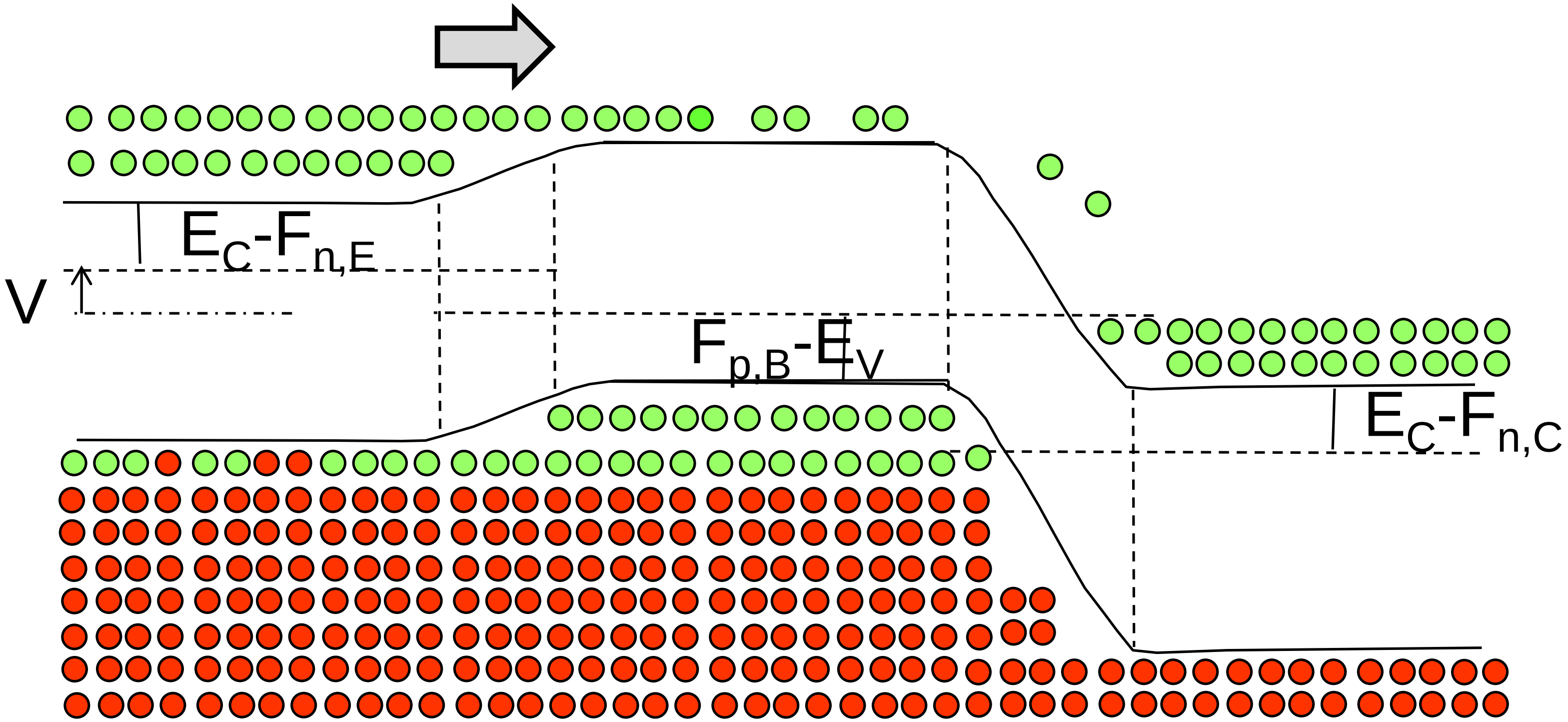


Assume current flow is small…
Fermi level is flat

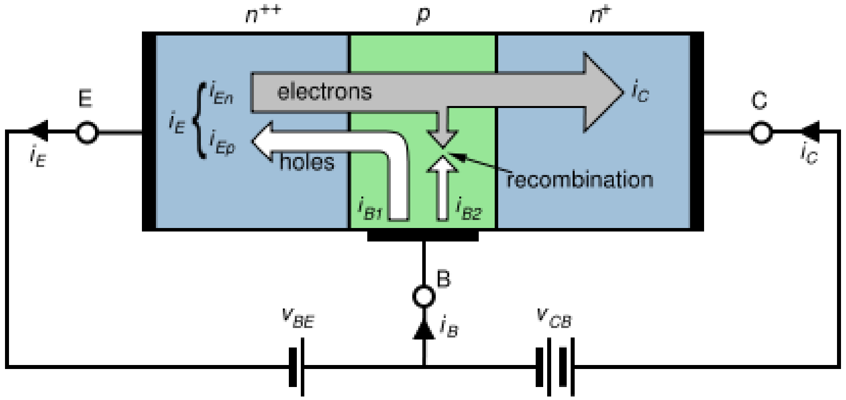
Current flow with Bias

Input small amount of holes results in large amount of electron output





Current flow with Bias



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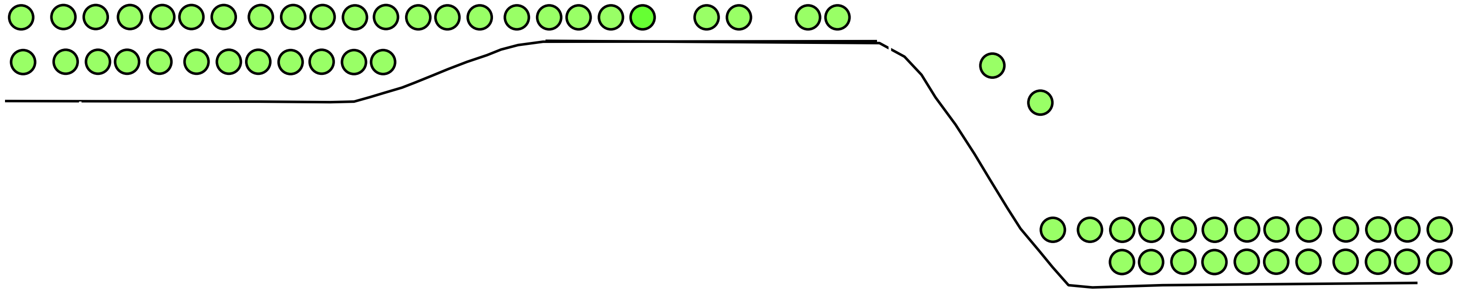
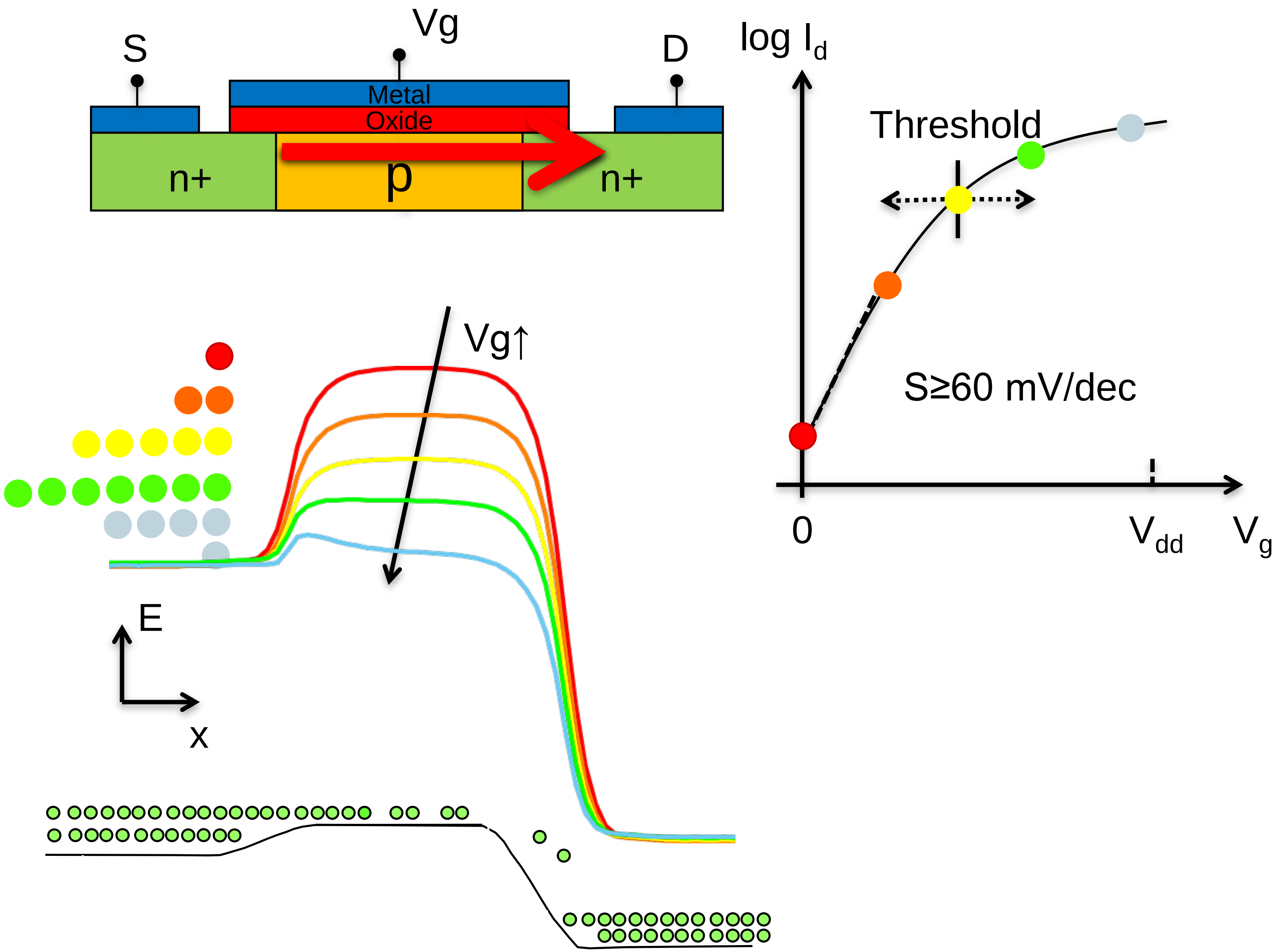


Modern MOSFET - "Fundamental" Limit looks similar to BJT



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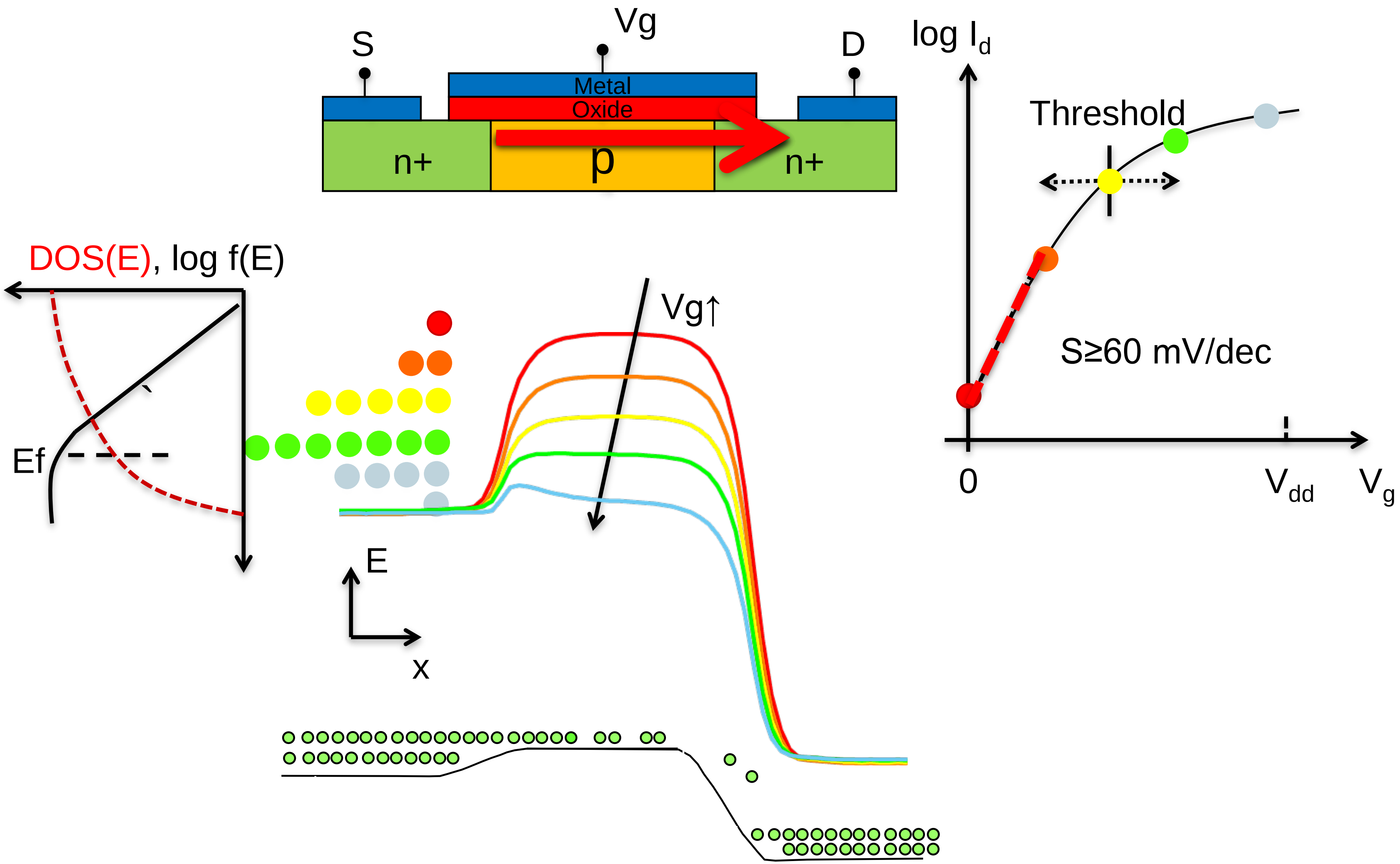
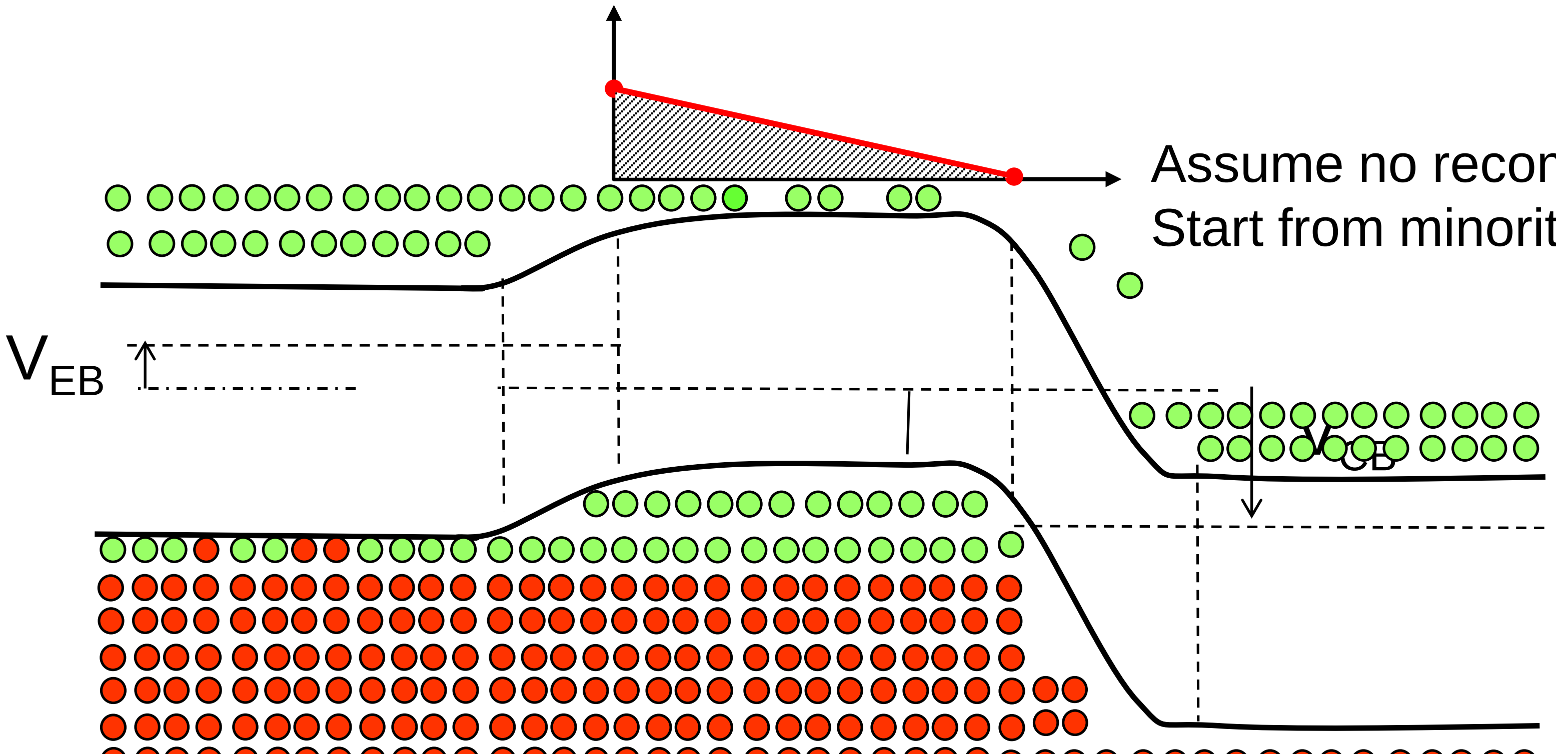


Carrier Distribution in Base



Assume no recombination.
Start from minority carrier

Carrier Distribution in Base

$$\Delta n(x) = Ax + B = C\left(1 - \frac{x}{W_B}\right) + D\left(\frac{x}{W_B}\right)$$

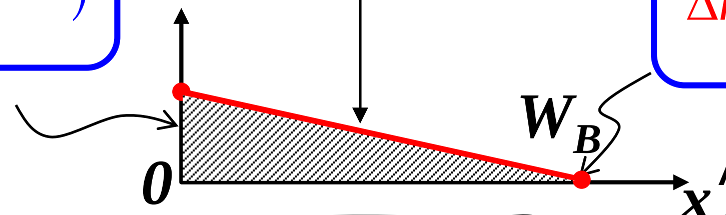
C

D

$$\Delta n(x) = \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)\left(1 - \frac{x}{W_B}\right) + \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BC}\beta} - 1\right)\left(\frac{x}{W_B}\right)$$

$$\Delta n(0^+) = \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$

$$\Delta n(x = W_B) = \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BC}\beta} - 1\right)$$



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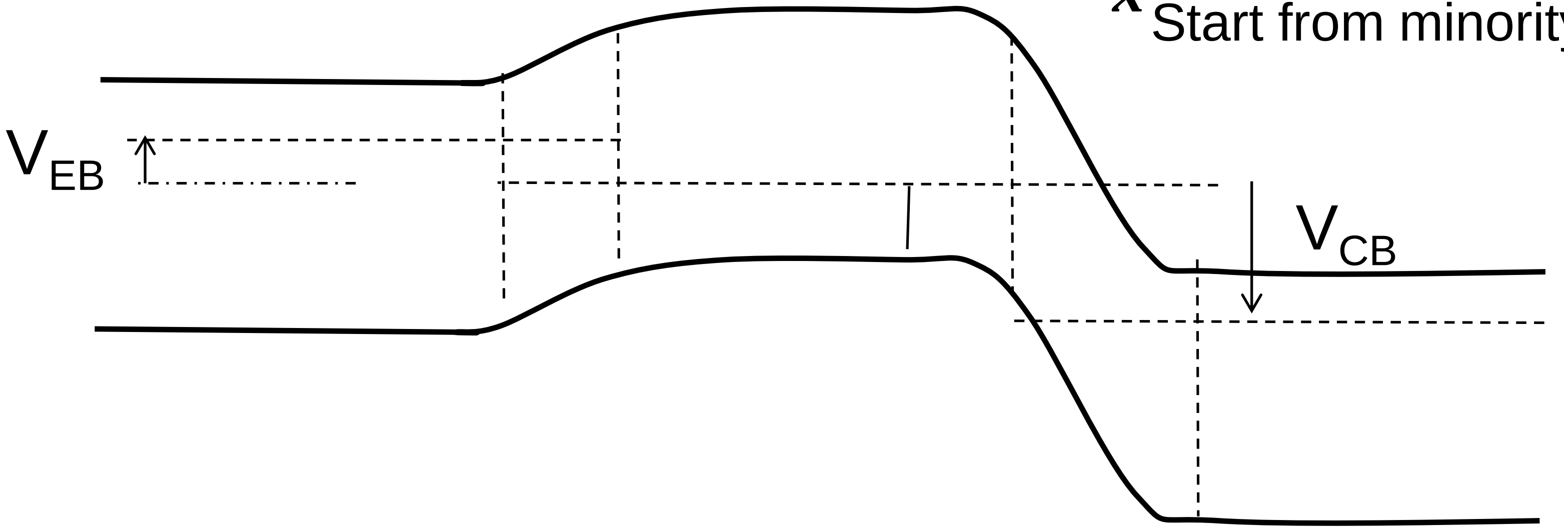
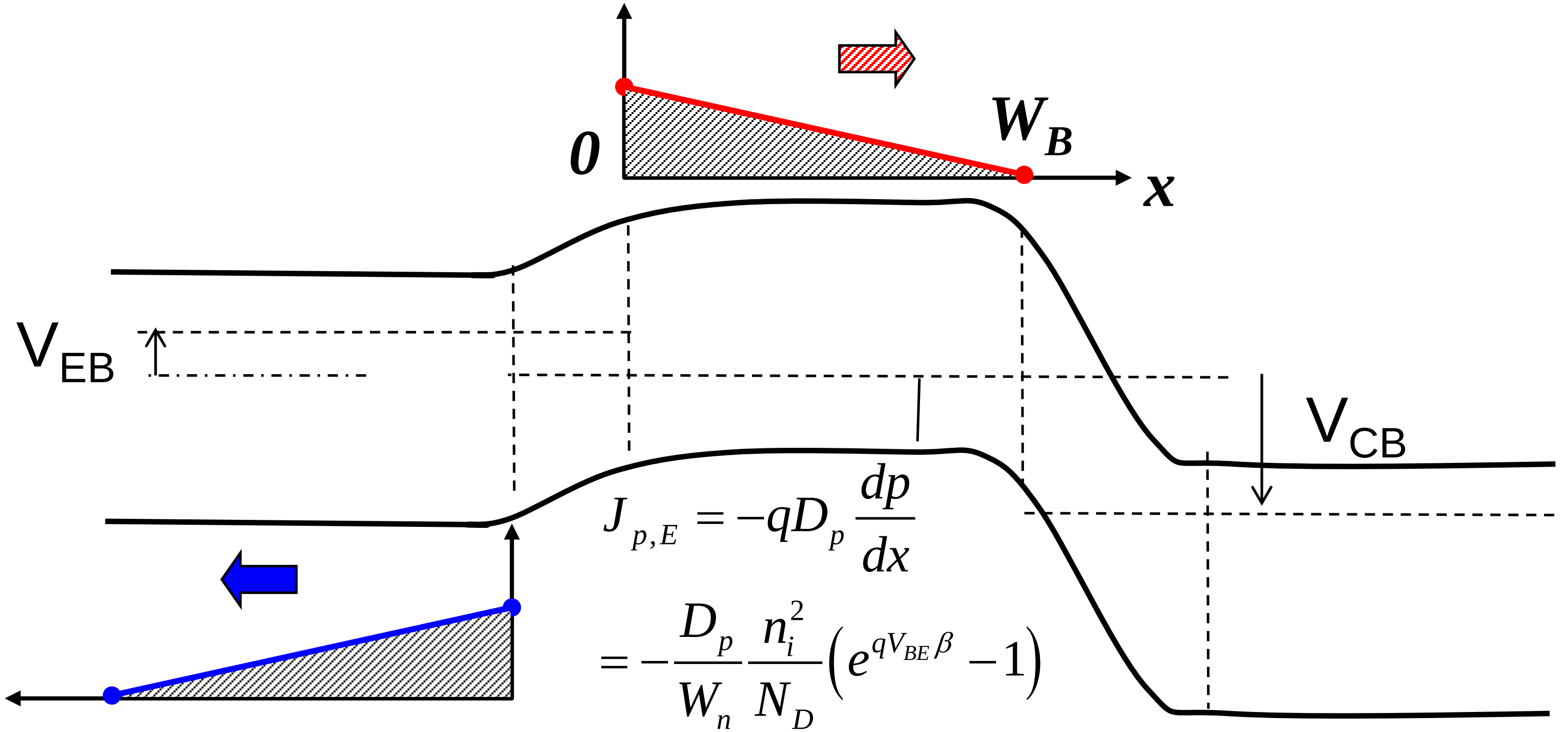


Collector and Emitter Electron Current

$$\Delta n(x) = \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)\left(1 - \frac{x}{W_B}\right) + \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BC}\beta} - 1\right)\left(\frac{x}{W_B}\right)$$

$$J_{n,C} = qD_n \left.\frac{dn}{dx}\right|_{W_B}$$

$$J_{n,C} = -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right) + \frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BC}\beta} - 1\right)$$



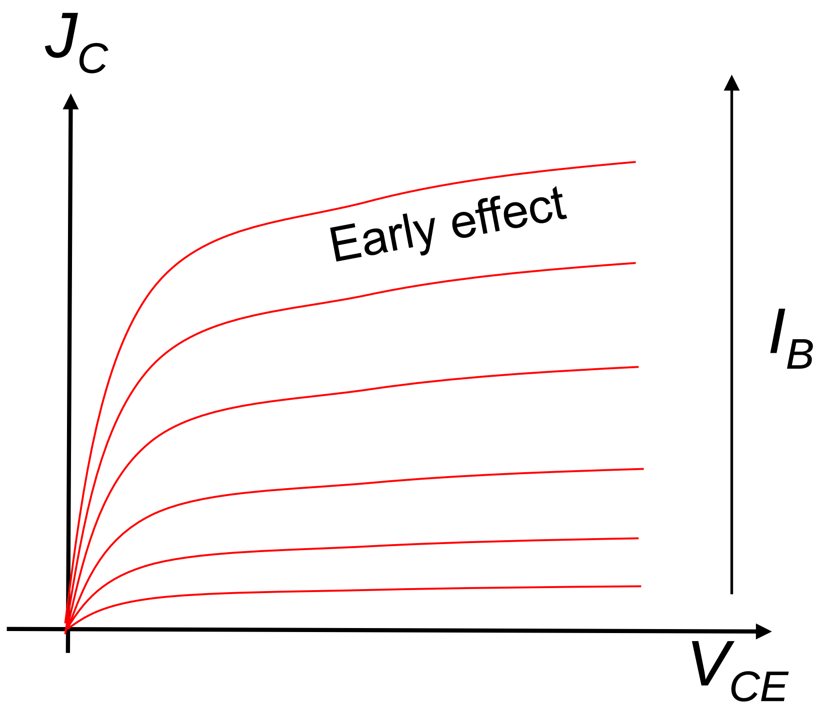
$$J_{p,E} = -qD_p \frac{dp}{dx}$$

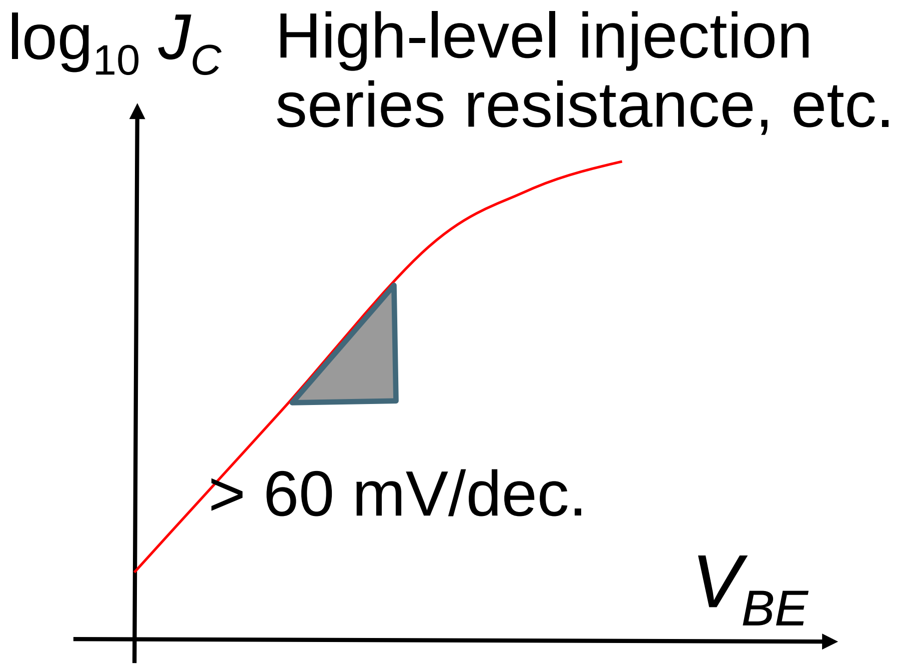
$$= -\frac{D_p}{W_n}\frac{n_i^2}{N_D}\left(e^{qV_{BE}\beta} - 1\right)$$

Current-Voltage Characteristics

Normal, Active Region
EB: Forward biased
BC: Reverse biased

$$J_{n,C} = -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right) + \frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BC}\beta} - 1\right)$$





W_B is not independent of bias
=> Early Effect

same physics of diode, rollover

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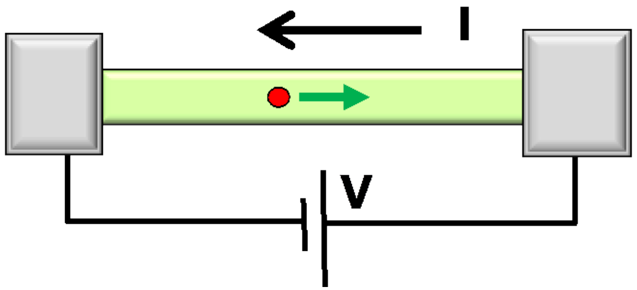
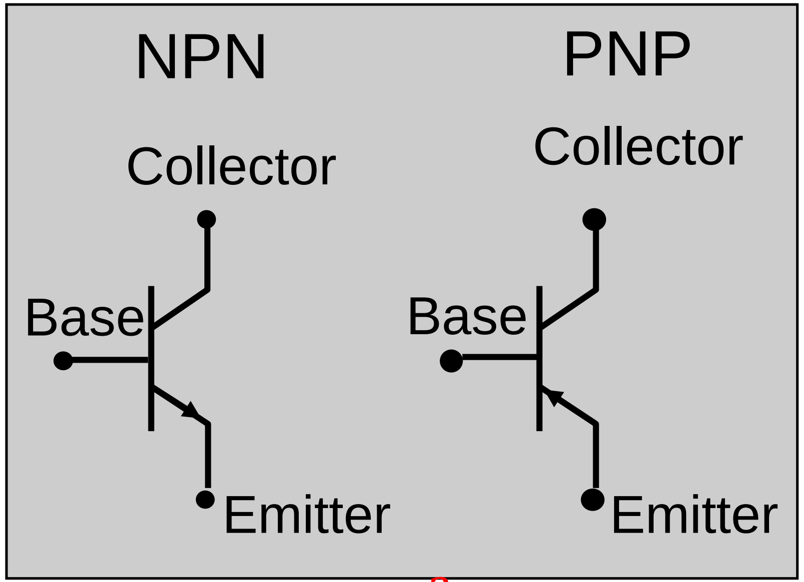


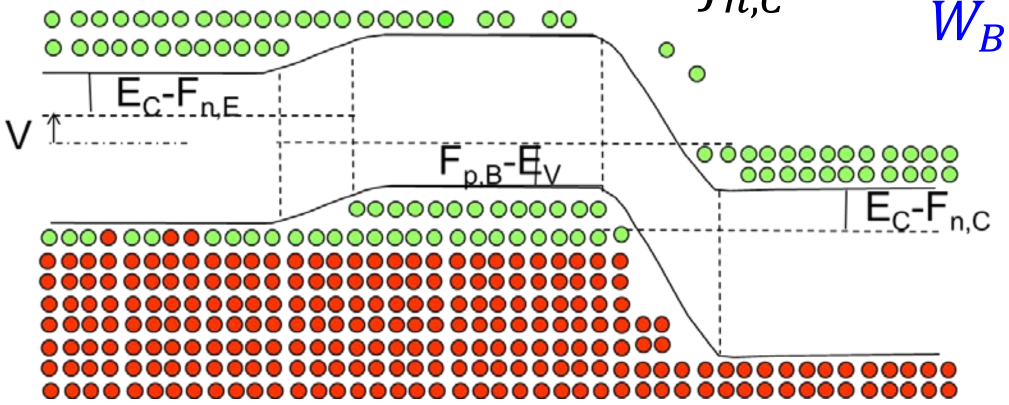
I = G x V
= q x n x v x A

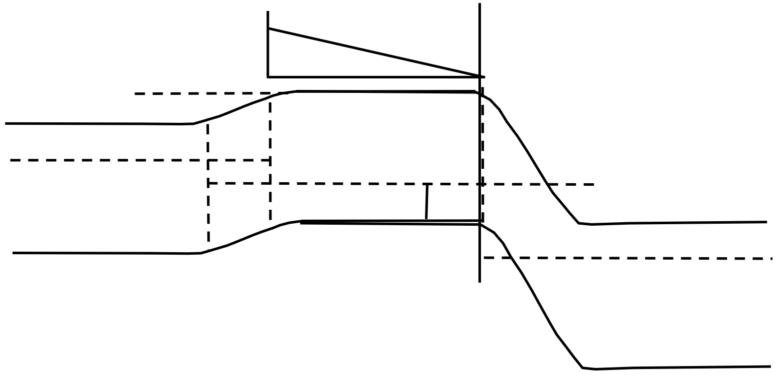
charge density velocity area

- 24.1 Introduction
- 24.2 Band Diagram in Equilibrium
- 24.3 Currents in BJTs ← status
- 24.4 Ebers Moll Model



$$J_{n,C} = -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta}-1\right) + \frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BC}\beta}-1\right)$$





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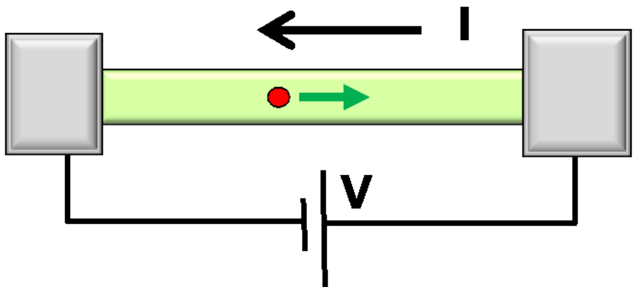

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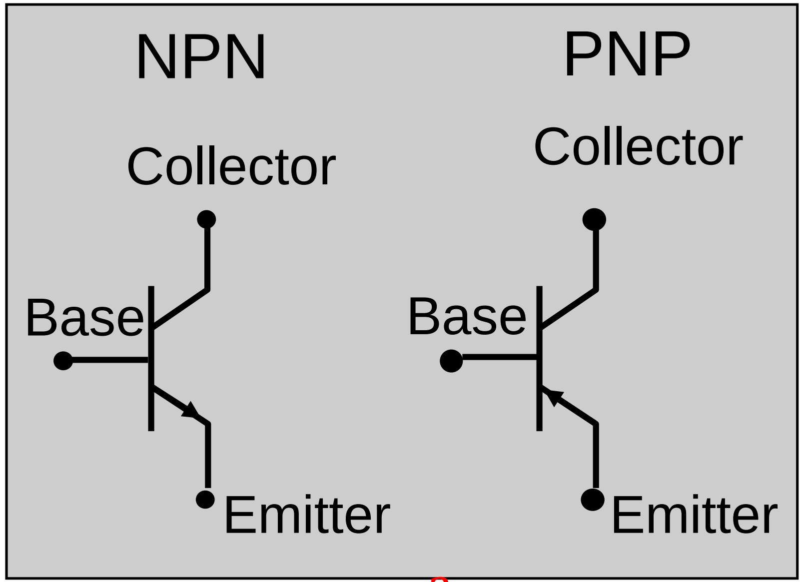

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