Section 25
Bipolar Junction Transistor – Design

25.6 Short base transport

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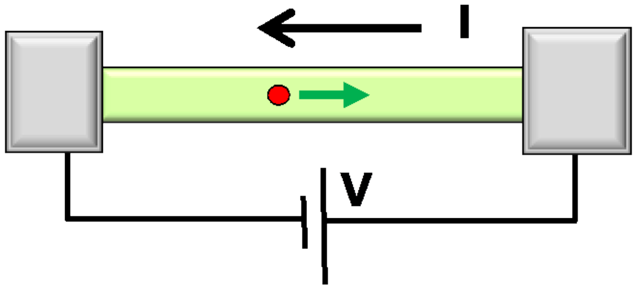
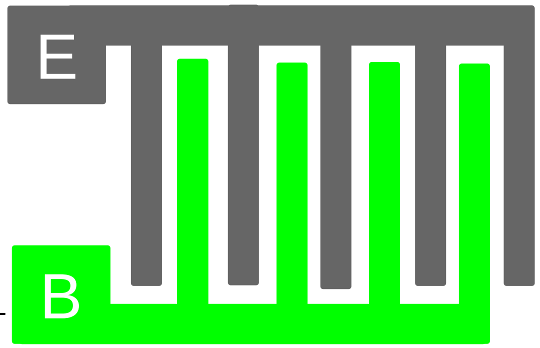


I = G x V

= q x n x v x A

charge density velocity area



- 25.1 Current gain in BJTs
- 25.2 Base Doping Design
  - » Current Crowding – Non-Uniform Turn-On
  - » Punch-through
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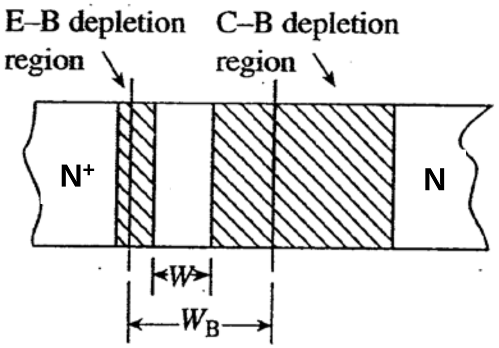
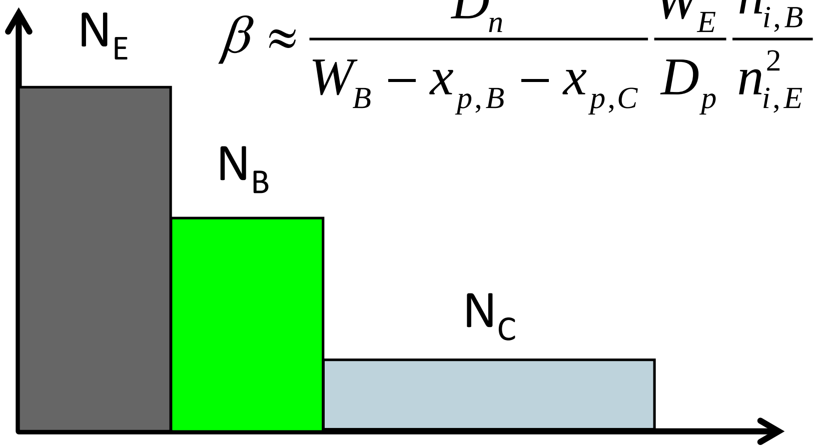
status

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

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



$$\beta \approx \frac{D_n}{W_B - x_{p,B} - x_{p,C}}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}$$

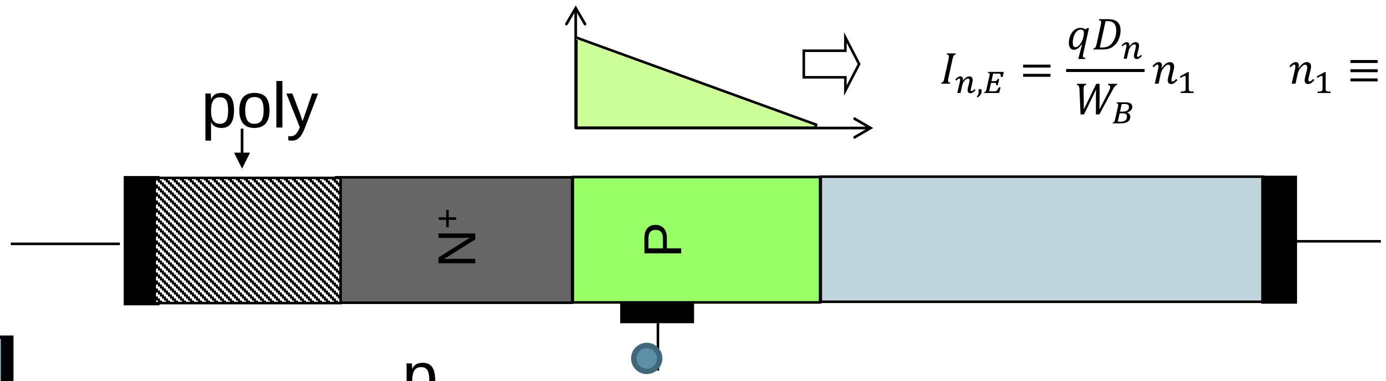


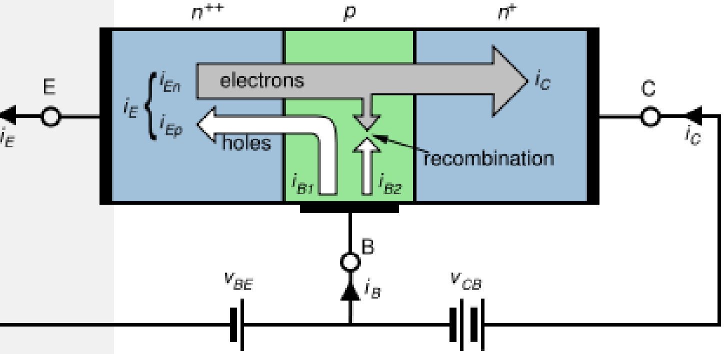
$$V_A = -\frac{qN_B W_B}{C_{CB}} \qquad C_{CB} = \frac{\kappa_s \varepsilon_0}{x_{n,C}+x_{p,B}}$$

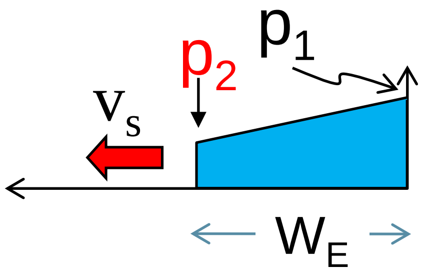
Poly-silicon Emitter + Graded Base

$$\frac{I_{B,poly}}{I_{B,Si}} = \frac{v_s}{\frac{D_p}{W_E} + v_s}$$

$$I_{n,E} = \frac{qD_n}{W_B} n_1 \qquad n_1 \equiv \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$





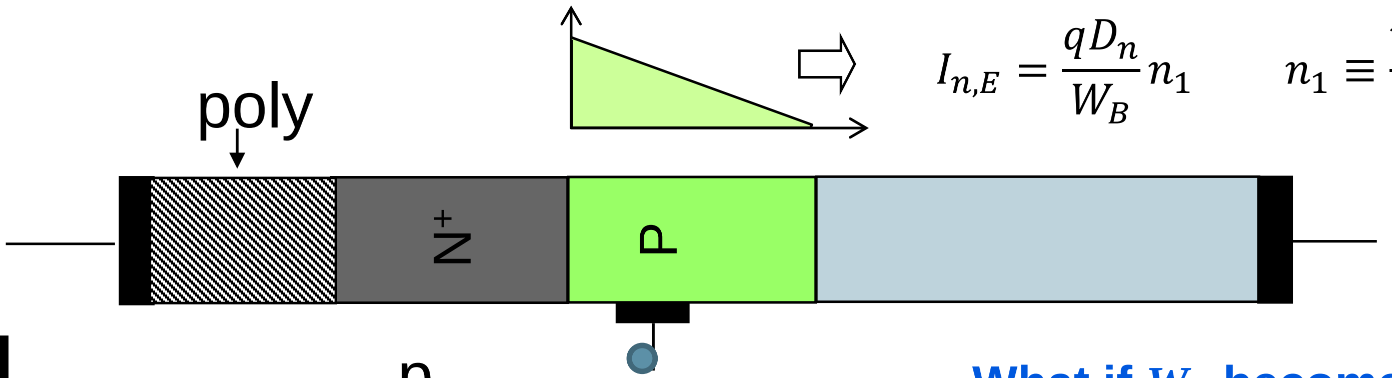


$$\beta_{poly} \sim \frac{D_n}{W_B} \frac{n_{i,B}^2}{n_{i,E}^2} \frac{N_E}{N_B} \times \frac{1}{v_s}$$

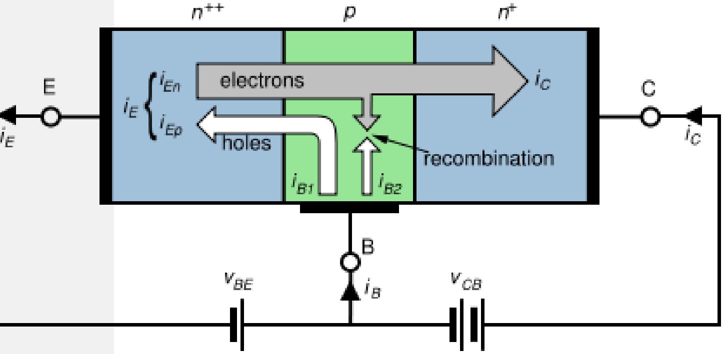
Graded Base transport

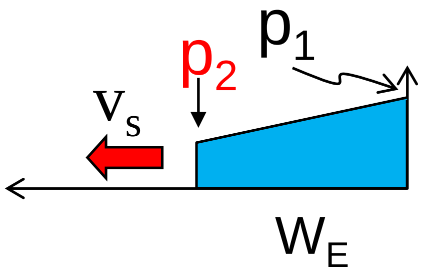
Poly-silicon Emitter + Graded Base

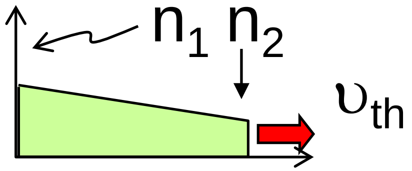
$$\frac{I_{B,poly}}{I_{B,Si}} = \frac{\upsilon_s}{\frac{D_p}{W_E}+\upsilon_s}$$



$$I_{n,E} = \frac{qD_n}{W_B} n_1 \qquad n_1 \equiv \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$







What if W_B becomes very short?

$$\frac{D_n}{W_B} = v_{diff} > v_{th}$$

$$n_2 > 0$$

$$I_{n,E} = -qD_n \frac{n_1 - n_2}{W_B} = -q\upsilon_{th} n_2$$

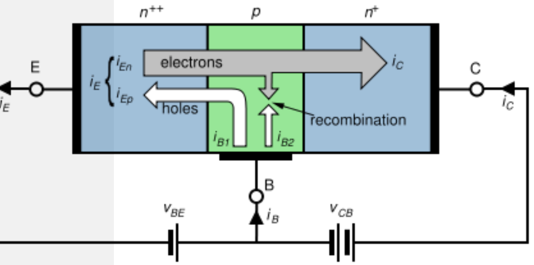
$$\frac{n_2}{n_1} = \frac{D_n/W_B}{D_n/W_B + \upsilon_{th}}$$

$$\frac{I_{n,E,ballistic}}{I_{n,E,si}} = \frac{\upsilon_{th}}{\frac{D_n}{W_B} + \upsilon_{th}}$$

Gain in short-base Poly-silicon Transistor

$$\frac{I_{n,E,ballistic}}{I_{n,E,si}} = \frac{\upsilon_{th}}{\frac{D_n}{W_B} + \upsilon_{th}}$$

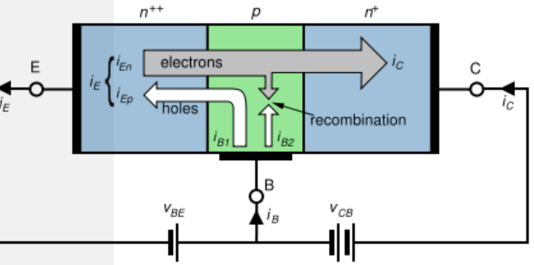
$$\frac{I_{B,poly}}{I_{B,Si}} = \frac{\upsilon_s}{\frac{D_p}{W_E} + \upsilon_s}$$



$$\beta_{poly,ballistic} = \frac{I_{C,ballistic}}{I_{B,poly}}$$

Gain in short-base Poly-silicon Transistor

$$\frac{I_{n,E,ballistic}}{I_{n,E,si}} = \frac{\upsilon_{th}}{\frac{D_n}{W_B} + \upsilon_{th}} \qquad \frac{I_{B,poly}}{I_{B,Si}} = \frac{\upsilon_s}{\frac{Dp}{W_E} + \upsilon_s}$$



$$\beta_{poly,ballistic} = \frac{I_{C,ballistic}}{I_{B,poly}} = \left[\frac{I_{C,ballistic}}{I_{C,si}}\right] \times \left[\frac{I_{C,si}}{I_{B,si}}\right] \times \left[\frac{I_{B,si}}{I_{B,poly}}\right]$$

$$\approx \left[\frac{\upsilon_{th}}{D_n/W_B + \upsilon_{th}}\right] \times \left[\frac{D_n}{W_B}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}\right] \times \left[\frac{D_p/W_E + \upsilon_s}{\upsilon_s}\right]$$

v_{th} Assume small Compared to diffusion velocity

$$\rightarrow \frac{n_{i,B}^2}{n_{i,E}^2} \times \frac{N_E}{N_B} \times \frac{\upsilon_{th}}{\upsilon_s}$$

v_s Assume small

Large devices, finite diffusion length => small diffusion velocity => thermal velocity is large => neglect diffusion velocity

Quasi-Ballistic transport in very short base limits the gain ...

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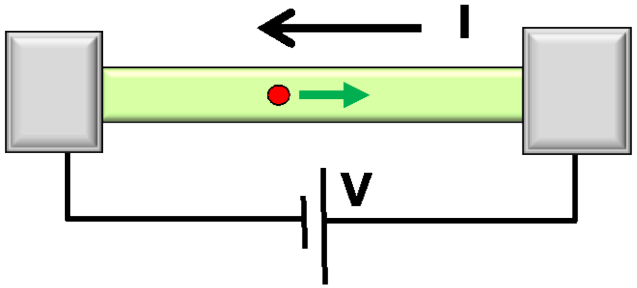

$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density (q, n) velocity (v) area (A)

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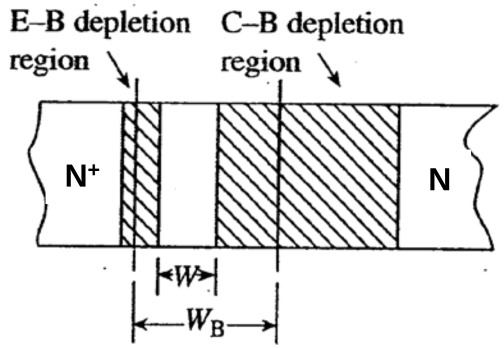

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