Section 25
Bipolar Junction Transistor – Design

25.4 Emitter Doping Design

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PURDUE UNIVERSITY

School of Electrical and Computer Engineering

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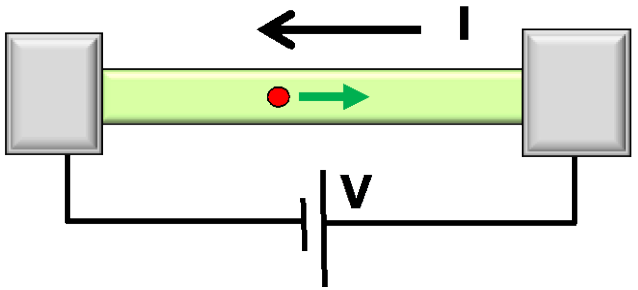
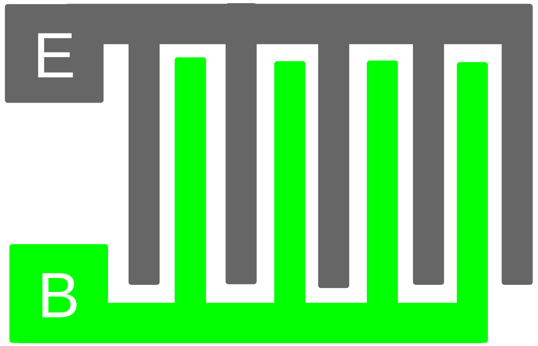


$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area



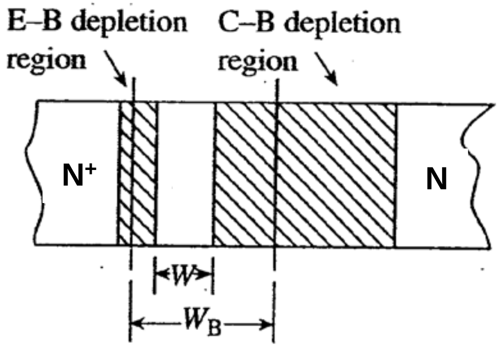
- 25.1 Current gain in BJTs
- 25.2 Base Doping Design
  - » Current Crowding – Non-Uniform Turn-On
  - » Punch-through
  - » Base Width Modulation
- 25.3 Collector Doping Design (Kirk Effect, Base Pushout)
- 25.4 Emitter Doping Design

status

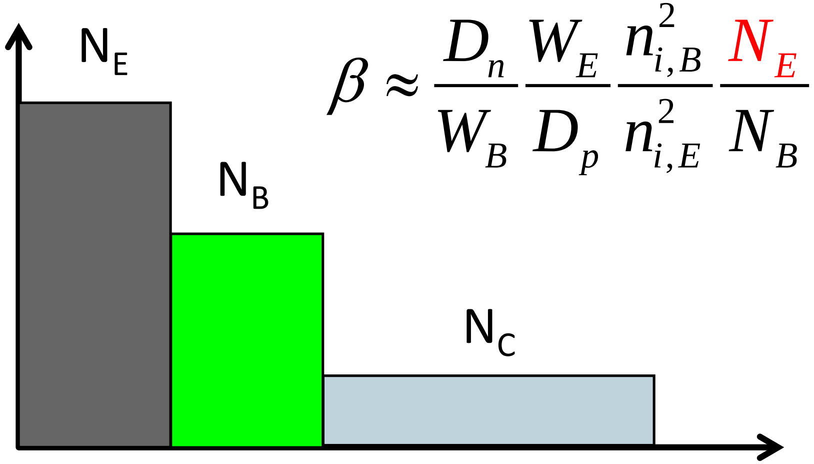
- 25.5
- 25.6

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

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



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



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

Perhaps High Doping in Emitter?

$$\beta \approx \frac{D_n}{W_B}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B} = \frac{D_n}{W_B}\frac{W_E}{D_p}\frac{N_C N_V e^{-E_{g,B}/kT}}{N_C N_V e^{-E_{g,E}/kT}}\frac{N_E}{N_B}$$

$$\beta \approx e^{-\Delta E_g/kT}\frac{N_E}{N_B}$$

Example increase doping by 40x:

$N_E from\ 10^{18}\ cm^{-3} to\ 4x10^{19}\ cm^{-3}$

$$\Delta E_G from\ 25meV\ to\ 150meV$$

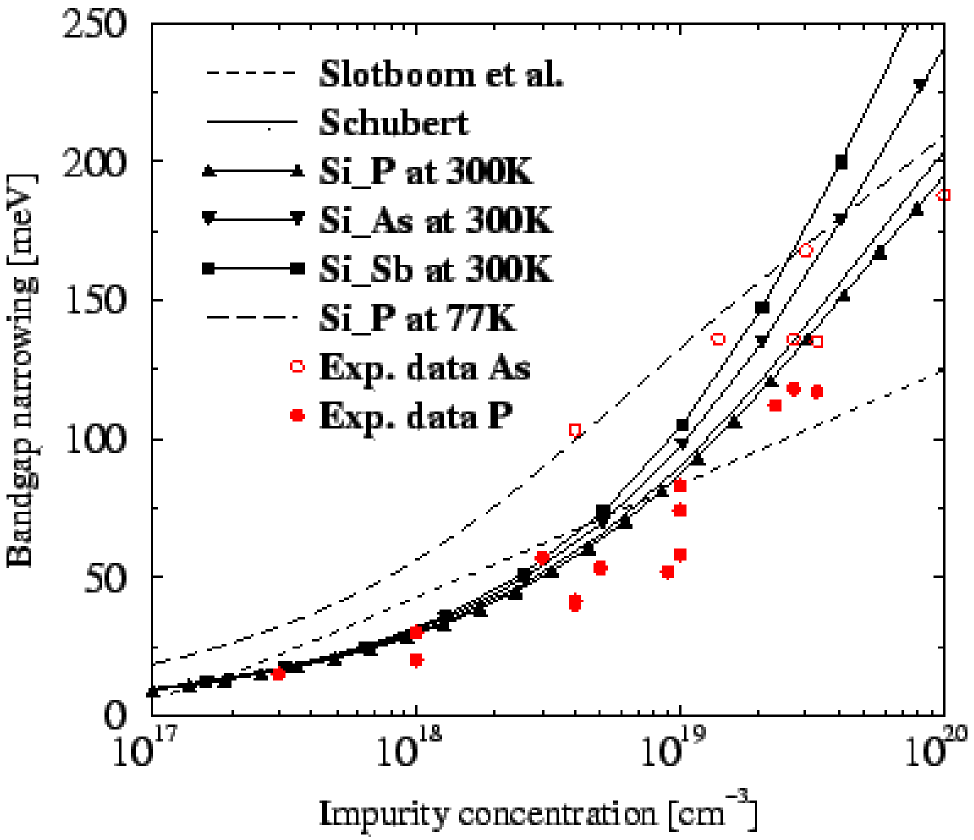
$$\Delta E_{G,net} = 125meV \sim 5k_BT$$

$$e^{-5} \sim 6.73\ 10^{-3}$$

$$\Delta\beta \sim 40x6.73\ 10^{-3} = 0.27$$

=> Reduction in gain

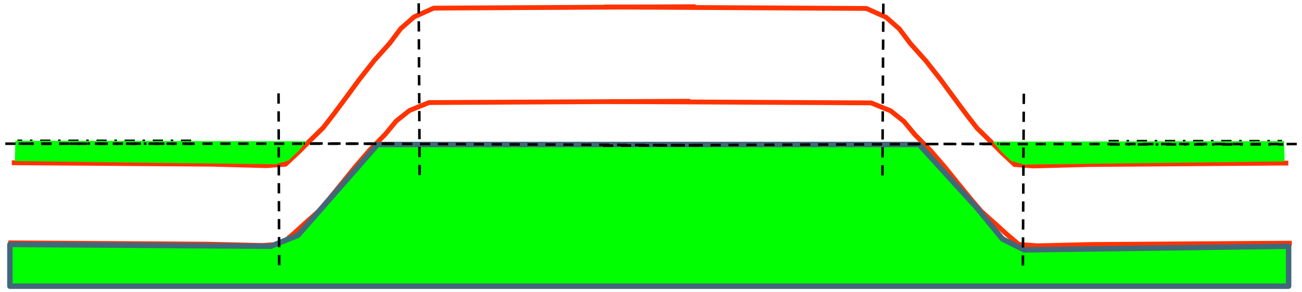
Very high doping can narrow the bandgap of a semiconductor!



J.-S. Park, A. Neugroschel, and F. Lindholm, ``Comments on Determination of Bandgap Narrowing from Activation Plots,'' IEEE Trans.Electron Devices, vol. 33, no. 7, pp. 1077-1078, 1986.

Perhaps High Doping in Emitter?

(Esaki-like) Tunneling cause loss of base control …



Doping for Gain

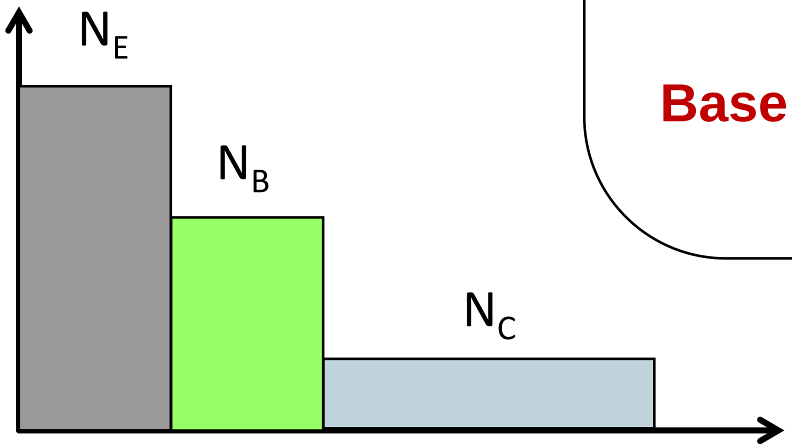
$$\beta_{dc} \approx \frac{D_n}{W_B}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}$$

Emitter doping: As high as possible without *band gap narrowing*

Base doping: As low as possible, without *current crowding, Early effect*

Collector doping: Lower than base doping *without Kirk Effect*

Base Width: As thin as possible without *punch through*



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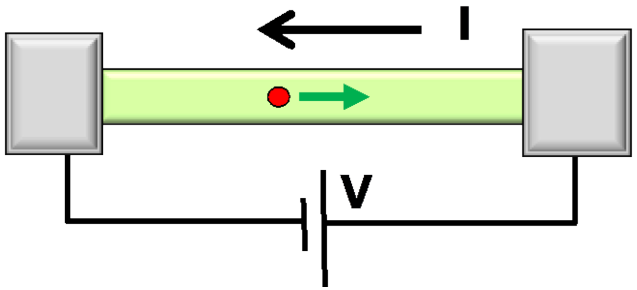

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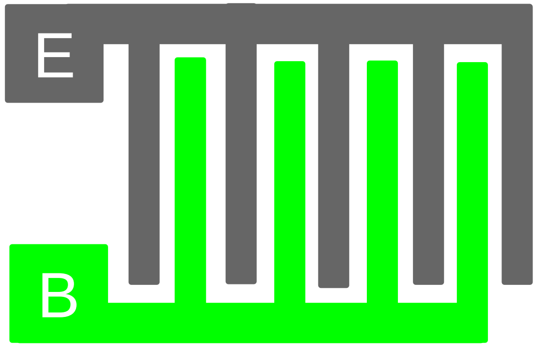

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- 25.6

status

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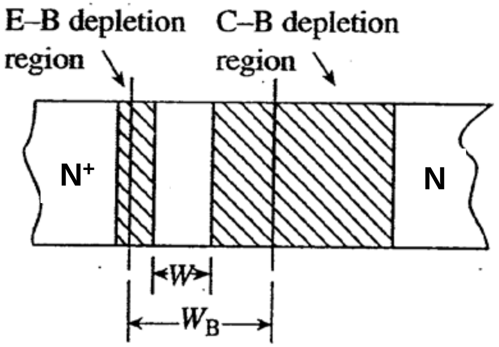
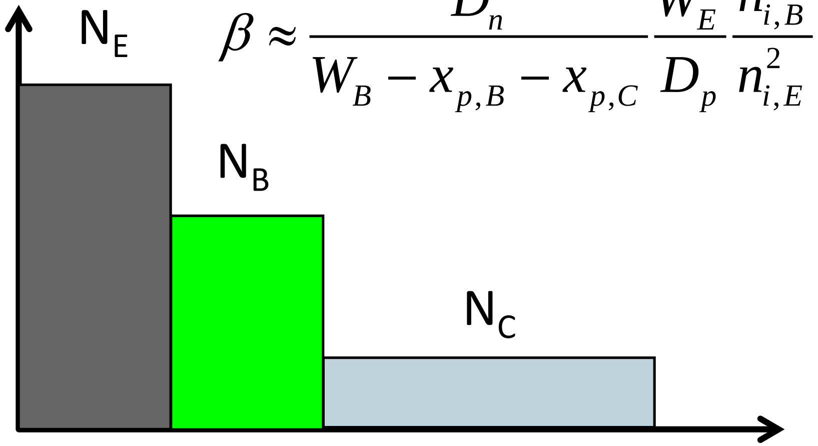


$$\beta \approx \frac{D_n}{W_B - x_{p,B} - x_{p,C}}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}$$



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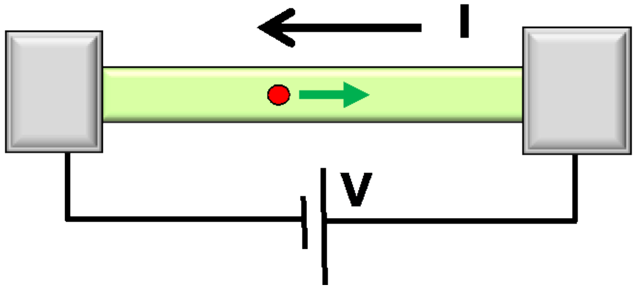

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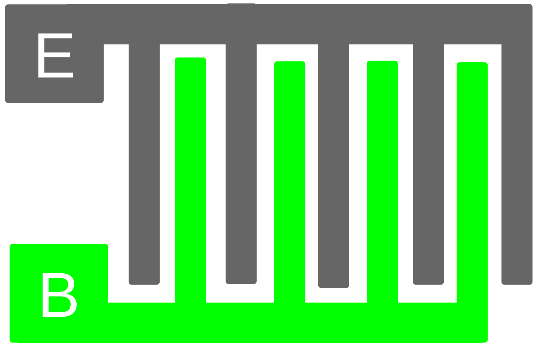

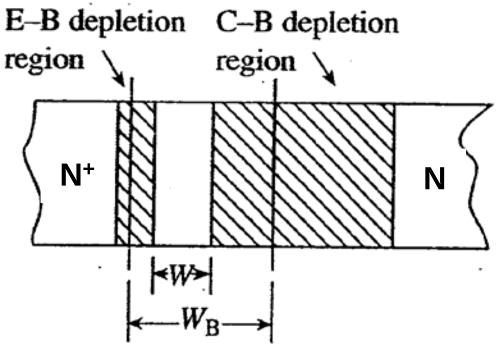

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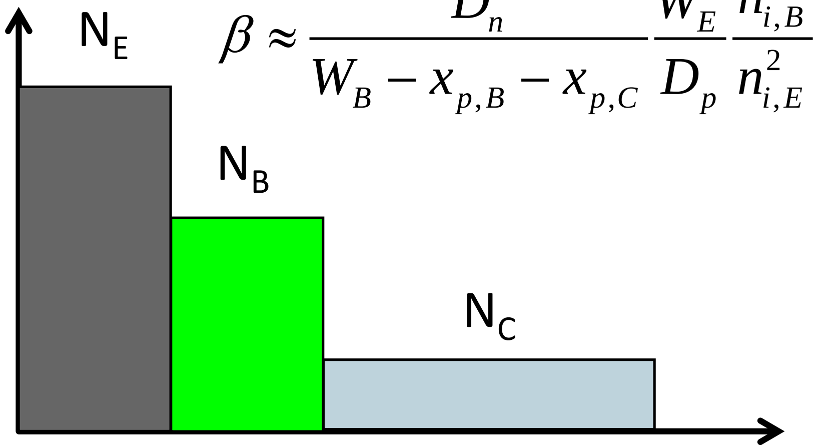

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